National Aeronautics and Space Administration

Educator Product	
Educators	Grades 5-8

EG-2004-10-302-ARC

Future Flight Design

Part II

Educator and Student Guides

Aircraft Design Problem

http:// futureflight.arc.nasa.gov

Future Flight Design Educator Guides
are available in electronic format through NASA Spacelink—one of NASA's electronic resources specifically developed for the educational community.

This publication and other educational products may be accessed at the following address:

http://spacelink.nasa.gov/products

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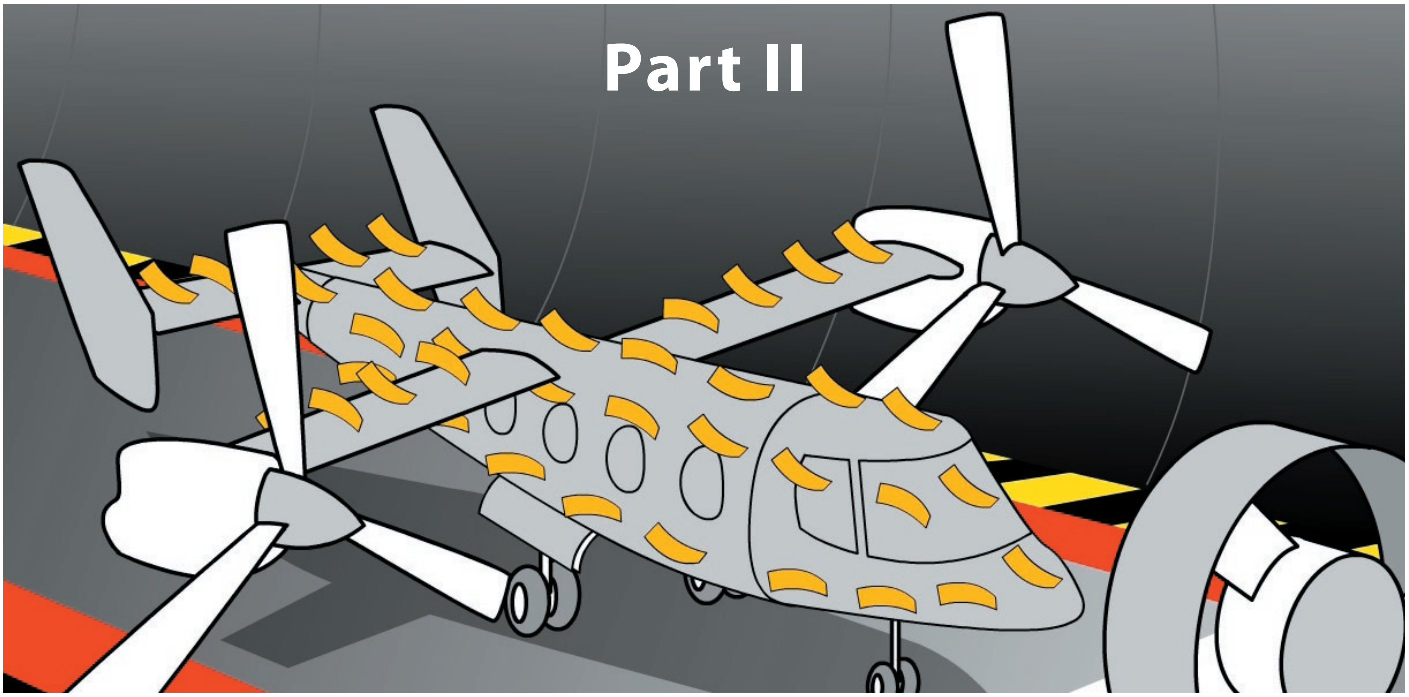


AIRCRAFT DESIGN PROBLEM

INTRODUCTION

The Future Flight Design Aircraft Design Problem Educator Guide has been developed by the National Aeronautics and Space Administration (NASA) for the purpose of increasing students' awareness of and interest in aeronautics, aviation and the many career opportunities that utilize science, math, and technology skills. The lessons are designed for educators to use with students in grades 5-8 in conjunction with the Future Flight Design multimedia activities on the Future Flight Design Web site (http://futureflight.arc.nasa.gov).

The Future Flight Design Aircraft Design Problem is designed to follow the Future Flight Design Air Transportation Problem-Based Learning (PBL) exercise. It is possible to take students through the Aircraft Design Problem without having completed the Air Transportation Problem; however, by first completing the Air Transportation PBL, students will gain a better understanding of the larger context of the Aircraft Design PBL. Designing new aircraft may be part of a possible solution to the Air Transportation PBL.

F Future Flight Design Overview

Future Flight Design is a web-based interactive, problem-based learning environment where students in grades 5–8 learn about forces of flight and design air transportation and aircraft systems of the future. Biographies highlight careers in aeronautics and aerospace engineering.

F Future Flight Design Overall Goal

Future Flight Design uses aeronautics and aviation content, problem-based learning, the engineering design process, and critical thinking skills to increase awareness of NASA careers and to educate students in grades 5-8 on the design of capacity solutions for a future air transportation system.

F Future Flight Design Part II Overall Objectives

- Students will use the process of engineering design to design an aircraft that might be a part of improving the air transportation system.
- Students will explain how their aircraft works as a system and will use the four forces of flight to explain how their aircraft flies.
- Students will identify at least one NASA occupation that best fits their interests and skills.

F Future Flight Design Structure

Future Flight Design is composed of two problems: Air Transportation PBL and Aircraft Design Problem. The Introduction Movie presents the overall problem of increasing airport delays due to a growing demand on the current system. This movie provides the overall purpose and motivation for the two problems. Each problem includes an Educator Guide, Student Log, and online resources. The Air Transportation PBL includes numerous movie clips and online articles to assist students in researching solutions to the problem. The Aircraft Design Problem includes interactive multimedia activities in which students simulate the design and testing of a new aircraft while exploring instructional animations in the online labs to better understand the results of their design choices. Occasional live, online challenges on NASA Quest will allow students the opportunity to connect with and receive feedback from NASA engineers working on the same problems.

PART II Future Flight Design: Aircraft Design Problem

In the Aircraft Design Problem, students select roles and a situation, and they follow the engineering design process to design an aircraft that fits their situation. This engineering design process is as follows:

Step 1: Define The Problem
Step 2: Generate Ideas
Step 3: Select a Solution
Step 4: Test and Refine the Solution
Step 5: Present the Results

As they go through this process making use of online interactive multimedia activities, they learn about forces and motion, systems, and engineering concepts such as criteria, constraints, and trade-offs. They also gain an awareness of numerous science, engineering, and technology careers. The problem concludes with students presenting their solutions and summaries of their learning at an Aircraft Design Conference.

I Information Resources

NASA's Airspace Systems Program is described at the following web site:

http://www.asc.nasa.gov/

An extensive list of resources is provided on the Future Flight Design web site:

http://futureflight.arc.nasa.gov/resources.html

For Educators Grades 5-8:

Title	Link	Description	Type
Exploring the Extreme	http://spacelink.nasa.gov/	This guide presents the basic science of aeronautics by emphasizing hands-on involvement, prediction, data collections and interpretation, teamwork, and problem solving.	Educator guide
Adventures in Aeronautics	http://avst.larc.nasa.gov/education.html	A storybook that teaches all about aeronautics at NASA. Available in English, Spanish and Chinese. A coloring book is also available	Storybook and Coloring book
Exploring Aeronautics	http://core.nasa.gov/	This CD-ROM offers an introduction to aeronautics, covers the fundamentals of flight, contains a historical time line, examines different types of aircraft and teaches students to use the tools of aeronautics used by researchers to test aircraft designs.	CD-ROM
Fold It and Fly It!	http://www.nasaexplores.com/	This activity demonstrates how an assembly line works, in the context of building aircraft.	Hands-on activity

Fractal Ownership	http://www.nasaexplores.com/	This activity teaches students how to use mathematics skills to solve fractions, in the context of owning your own jet.	Hands-on activity
Small Jets, Big Future	http://www.nasaexplores.com/	NASAExplores provides science articles about NASA programs written at various age levels. This article describes the future of personal aircraft. Supplemental activities are included.	Science article with supplemental activities
X-1 Paper Glider kit	http://spacelink.nasa.gov/	This NASA Educational Brief, featuring the X-1, investigates the basics of flight with a paper model of the first supersonic aircraft.	Paper model kit
Learning to Fly: the Wright Brother's Adventure	http://spacelink.nasa.gov/	This NASA educator guide has excellent background information about Wilbur and Orville Wright. The guide contains student activity pages and templates for building the 1900, 1901, and 1902 Gliders and the 1903 Flyer.	Educator guide

Education Standards

In addition to meeting the National Science Education Standards, International Technology Education Association, and International Society for Technology in Education standards, Future Flight Design Educator Guides are written to meet benchmarks found in the Benchmarks for Science Literacy produced by the American Association for the Advancement of Science (AAAS) as part of their science, math, and technology reform movement called Project 2061. The mission of Project 2061 is to "shape the future of education in America, a future in which all students [will] become literate in science, mathematics and technology by graduation from high school" (p. VII). "The Benchmarks for Science Literacy are statements of what all students should know or be able to do in science, mathematics and technology by the end of grades 2, 5, 8 and 12" (p. XI) and are based on extensive research of when and how it is developmentally appropriate to teach the concepts and skills described.

The tables below show the benchmarks and standards for the Aircraft Design Problem. The first portion of the table entry identifies which standards or benchmarks are referenced. "2061" is a reference to the Benchmarks for Science Literacy. "NSES" is a reference to the National Science Education Standards. "ITEA" is a reference to the International Technology Education Association national education standards. "ISTE" is a reference to the International Society for Technology in Education standards. The second portion of the table entry identifies the specific standard referenced. In the case of Project 2061, the standard is referenced, the grade range and then the number of the concept under this standard. We distinguish between "meeting" benchmarks or standards, "partially meeting" them and "addressing" them, to alert educators to concepts that are taught or partially taught for deep understanding in a lesson compared to topics or ideas that we might touch upon but do not really teach for deep understanding.

A Air Transportation Problem Objectives/Standards

Objectives	Standards
• Students will identify the criteria and constraints for a chosen problem and will design and refine a solution . • Students will give a presentation or poster in which they will: • identify the trade-offs they made in their solution • describe how their solution meets the criteria and constraints of their problem. • describe how the parts of their aircraft work together as a system. • describe how their aircraft flies using the four forces of flight.	Meets: ITEA (3-5) #9 C ITEA (6-8) #8 G ISTE 3, 5, 6 Partially Meets: ITEA (6-8) #18 G 2061 11A (6-8) #2, #3 NSES (5-8) #1.2, #1.3, #1.4, #1.5 Addresses: 2061 4F (3-5) #1 2061 4F (6-8) #3 NSES B (5-8) #2.3 ISTE 4

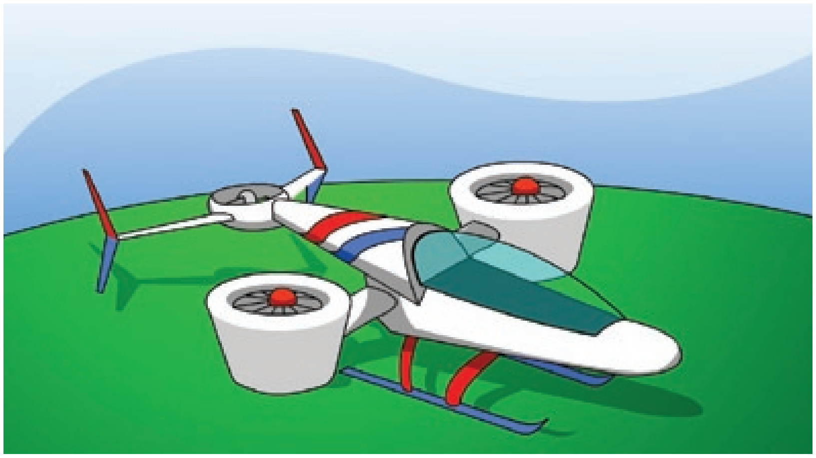
More information on the benchmarks and standards referenced can be found at the following Web addresses:

Standard/Benchmark Title	Web Address
American Association for the Advancement of Science: Project 2061	http://www.project2061.org/
National Science Education Standards (NSES)	http://www.nap.edu/readingroom/books/nses/html/
National Council of Teachers on Mathematics (NCTM)	http://standards.nctm.org/index.htm
International Society for Technology in Education (ISTE)	http://cnets.iste.org/
International Technology Education Association (ITEA)	http://www.iteawww.org/TAA/TAA.html

[1] Project 2061, American Association for the Advancement of Science. (1993). Benchmarks for Science Literacy. New York. Oxford University Press. (p. VII).

[2] Project 2061. (p. XI).

LESSON



Main Concept

The engineering design process involves defining a problem, generating ideas, selecting a solution, testing the solution(s), making the item, evaluating it and presenting the results.

Major Concepts

- Requirements for a design are made up of criteria and constraints.
- Criteria are standards or things that the design will need to be able to do.
- Constraints are limits to design.
- Defining the problem involves understanding the requirements and making a plan for solving the problem.
- Generating ideas involves brainstorming solutions, and creating basic and detailed designs.
- Selecting a solution involves choosing the solution that best meets the criteria and constraints.
- Testing and refining the solution involves performing numerous tests, making changes to the design, and testing again until they find the best solution to meet the criteria and constraints.
- In the final step of presenting the results, engineers present their solution to others for feedback to further improve their design and to see if their solution is accepted for use.
- Engineers can improve a system in one area, but by making this improvement, it can worsen the system's performance in another area. This is called a trade-off.
- Changes in speed or direction of motion are caused by forces.
- The greater the force is, the greater the change in motion will be.
- The more massive an object is, the less effect a given force will have.
- An unbalanced force acting on an object changes its speed or motion, or both.
- Thinking about things as systems means looking for how every part relates to others. Any system is usually connected to other systems both internally and externally.
- Transportation vehicles are made up of subsystems, such as structural, propulsion, suspension, guidance, control, and support systems that must function together for a system to work effectively.

Materials

- A class set of Aircraft Design Problem Student Design Logs
- 1 computer per group with Internet connection, Internet browser, and Flash plug-in installed*
- A printer connected to the computers
- A computer with Internet connection, Internet browser connected to a projector, or television (optional)
- Paper for paper airplane construction (optional)
- 5 paperclips per group (optional)
- 1 toothpick (broken into halves) for each group (optional)
- Poster paper or computers with presentation software for each group

System Requirements to Run Future Flight Design Interactive Multimedia

Platform	Browser
Windows 95 Windows 98 Windows Me	Internet Explorer 4.0 or later (Internet Explorer 5.0 or later is recommended), Netscape Navigator 4 or later, Netscape 7.0 or later (Netscape 6 is not recommended) JavaScript enabled
Windows NT Windows 2000 Windows XP or later	Internet Explorer 4.0 or later, Netscape Navigator 4 or later, Netscape 7.0 or later, with standard install defaults (Netscape 6 is not recommended) JavaScript enabled
Macintosh: 8.6 to 9.2	Netscape 4.5 or later (Netscape Communicator 4.7 or Netscape 7.0 are recommended), Netscape 7.0 or later, (Netscape 6 is not recommended) Microsoft Internet Explorer 5.0 or later JavaScript enabled
Macintosh OS X 10.1 or later	Netscape 7.0 or later (Netscape 6 is not recommended), Microsoft Internet Explorer 5.1 or later JavaScript enabled
Browser plug-ins	Flash Player 6 or higher QuickTime Player 6 or higher

P Preparation

- Prepare a class set of Student Design Logs.
- Download and install Flash Player 6 (or higher) plug-ins on computers. Test these at http://futureflight.arc.nasa.gov/welcome.html by clicking the link to the Introduction Movie.
- Prepare large area for the Aircraft Design Conference on the last day where students can either post their posters or give their presentations.

S Suggested Schedule

Day 1	Day 2	Day 3-4	Day 5	Day 6-7
Define the Problem	Generate Ideas: Aeronautics Lab	Generate Ideas: Lift, Fuselage, Propulsion Labs	Select a Solution/ Test and Refine the Solution	Present the Results

Day 1 (45–60 minutes)

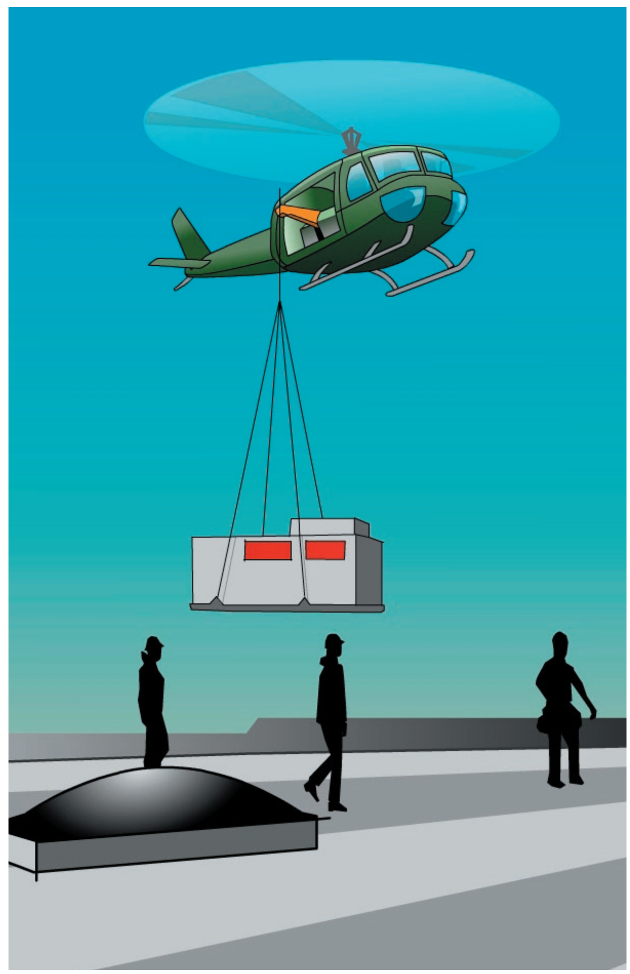
I Introduction

Read the introduction in the Student Design Log with students and go over the steps they will need to do to begin defining the problem.

STEP 1 Define the Problem

Tell students that the first step is to define the problem. They can read and discuss the following information about this step in their log:

In this phase, engineers understand the problem and outline the requirements that must be met. They then make a plan for solving the problem.



L Letter From NASA

- In their logs or on the Future Flight Design web site (http://futureflight.arc.nasa.gov/design.html), have students read the letter from NASA. Tell them that they will be helping NASA to solve this problem. To do this, they will follow the steps that engineers use to design new technologies.
- Ask students what steps they take to solve a problem. List student ideas on the board. Share with students the engineering design process they will be going through:
    1. Define The Problem
    2. Generate Ideas
    3. Select a Solution
    4. Test and Refine the Solution
    5. Present the Results
- Tell students that these steps are listed and described in their logs.

C Choose a Partner

- Have students choose partners and list their names in the log under Choose a Partner.
- Tell students that they will need to use their log throughout the process to take notes that will be used in their final design and final project.

D Discuss the Problem

- Have students watch the Introduction Movie on the Web site at http://futureflight.arc.nasa.gov/welcome.html. Ideally, they will do this in pairs or small groups at a computer, but if that is not possible, you could show it to the whole class using a projector or TV monitor connected to a computer.
- Using the information from the introduction movie and the letter from NASA, have groups discuss the problems of air travel and ground travel. Have groups list the problems in their logs under Discuss the Problem.
- Discuss systems. Tell students that as they go through the process of designing a new aircraft, they will be thinking about things as systems. Tell them that thinking about things as systems means looking for how every part relates to others. Any system is usually connected to other systems both internally and externally.

> ***Note:*** *If this is the first time students are introduced to systems, you may want to have them discuss other examples of systems and identify the various parts. These might include cars, electronics, human body, social systems, etc.*

☐ Question: How is an aircraft a system?
■ *Answer:* *It is made up of parts that work together that enable it to fly.*

☐ Question: What are some of the parts of an aircraft system?
■ *Answer:* *(Answers may vary but may include the body or cabin, wings or other lift system, engines or propulsion system, navigation system, communication system, etc.)*

Say: Transportation vehicles are made up of subsystems, such as structural, propulsion, suspension, guidance, control, and support systems, that must function together for a system to work effectively. (You may want to have students identify each of these sub-systems on different transportation vehicles.)

☐ Question: What would happen to the aircraft system if one part were broken?
■ *Answer:* *The aircraft might not be able to fly.*

☐ Question: What larger system is the aircraft a part of?
■ *Answer:* *It is a part of our air transportation system.*

☐ Question: What are the parts of the air transportation system?
■ *Answer:* *(Answers may include other aircraft, airports, people, air traffic control centers, runways, flight towers, etc.)*

☐ Question: How do the parts of the air transportation system work together?
■ *Answer:* *The air traffic controllers tell the aircraft when and where it's safe to fly. The aircraft use runways to take off and land, and these are located at airports where people and cargo depart and arrive as they travel on aircraft.*

Say: So, as you design your aircraft, think about the parts of the aircraft and how they work together to solve your given problem.

C Choose a Situation

Have students read and choose a situation from the three listed in their log or by clicking on item 2 "Problem Situation" at http://futureflight.arc.nasa.gov/design.html.

L List the Criteria and Constraints for Your Aircraft

Discuss or have students read about criteria and constraints under List the Criteria and Constraints for Your Aircraft.

Note: *You may want to have a class discussion about criteria and constraints and have students give examples. The following is an activity that you could do if you are introducing criteria and constraints for the first time:*

1. Introduce criteria and constraints
   - Tell the students that there are criteria and constraints for designing any aircraft.
   - Ask them to explain what they think it means to have criteria and constraints.
     - The students should understand that criteria are standards or requirements that the aircraft must include. Examples of criteria are that the aircraft must be a certain type (ex. passenger, military, private), must be efficient, and must be able to land gently.
     - Constraints are things that limit the design of the aircraft. Examples of constraints are money, time, maximum size, available materials, space to build or use, and human capabilities to use it.

2. Have students apply this concept.
   - Explain to students that before NASA will hire the students to design their new aircraft, they have given the class a task to complete. This will allow NASA to determine whether they are knowledgeable on aircraft design.
   - Write the following list of characteristics on the board. Explain that these are characteristics decided by the NASA scientists.

   Note: *Do not write "criteria" or "constraint" next to each characteristic. This information is only for you.*

     - The aircraft must be designed and constructed in three class periods. (constraint)
     - The aircraft must be a commercial aircraft that can carry large amounts of materials—at least five paper clips. Note to teacher: Each paper clip will represent a large box of materials. (criteria)
     - The aircraft must be able to fly 9 meters in a straight line without stopping. (criteria)
     - The aircraft must be able to hold at least two passengers (two toothpick halves). (criteria)
     - All parts of the aircraft must be made out of paper. The type of paper is left up to the students/teachers. No rubber bands, paper clips, etc. may be used. (constraint)
     - The aircraft may not be tested until stated by the supervisor (teacher). (constraint)

   - Ask the students to read the list of characteristics. Decide as a class, which characteristics are criteria and which are constraints.

- Once the students have categorized the characteristics, write the word "criteria" or "constraint" next to each one. Leave the characteristics on the board for students to refer to later.

Note: *If you have time, rewrite the characteristics so there are two lists—one list of criteria and one list of constraints.*

  - Have students brainstorm ideas in small groups and draw a design. Once the supervisor has approved their design, the students can begin constructing the airplane, being sure to keep the criteria and constraints in mind.
  - Once the students have completed their airplanes, pair up two groups of students. Have the two groups switch their airplanes and designs and evaluate each other's project.
  - In this evaluation process, the groups should focus on whether the airplane is constructed as it was designed, since this is what the supervisor approved. They should also check to make sure that each criteria is included, and that the airplane was built within the constraints specified. If the criteria are not included or if they have not stayed within the constraints, the supervisor should be notified. Note to teacher: Remind students about the constraint that the airplane cannot be tested until stated by the supervisor.
  - Once the groups have had time to evaluate another group's airplane, have the two groups share their evaluations with each other.

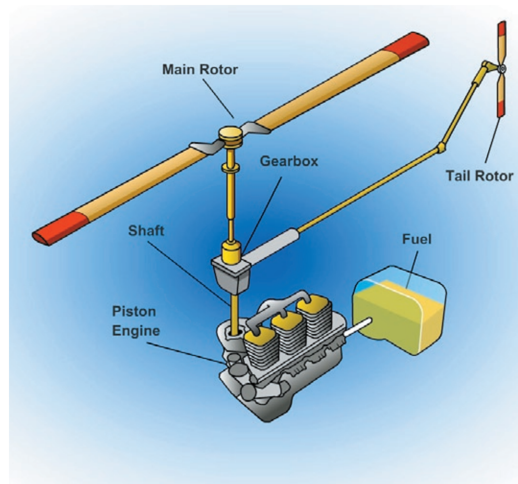
3. Have students use the letter from NASA and the description of their chosen situation to identify and list the criteria and constraints for their chosen problem.

Day 2 (50–70 minutes)

STEP 2 Generate Ideas

I Introduction to the Labs

Tell students that the second step is to generate ideas. They can read and discuss the following information about this step in their log:



In this phase, engineers brainstorm solutions and create a basic design followed by a detailed design of the aircraft.

- Tell students that in designing their aircraft, they will need to consider three types of systems: fuselage, lift, and propulsion. Have them read about these in their logs.
- Have students draw an aircraft they think will work for their situation and that has all three systems in their logs. Students should include descriptions, materials it is made of, the number of people it can carry, its dimensions, and where it gets its power.
  Drawings and ideas may vary and are not meant to be graded, but rather are meant as a reference for students to see how their ideas change as they go through the activity.
- Have students click on item 3 "Future Flight Design Center" on the Aircraft Design Problem page (http://futureflight.arc.nasa.gov/design.html) and work through the multimedia activities to learn about aircraft, design an aircraft, and test their aircraft. They can also go directly to the Future Flight Design Center Main Map by going to http//futureflight.arc.nasa.gov/map.html.

The Main Map interface will take students to the following sections:

- Aeronautics Lab
- Lift Lab
- Fuselage Lab
- Propulsion Lab
- Design Center
- Test Facilities (CFD, Wind Tunnel, and Flight Test)

- Have students go to the Aeronautics Lab first to understand how things fly.

A Aeronautics Lab

The Aeronautics lab teaches about the four forces involved in flight: weight, lift, thrust, and drag.

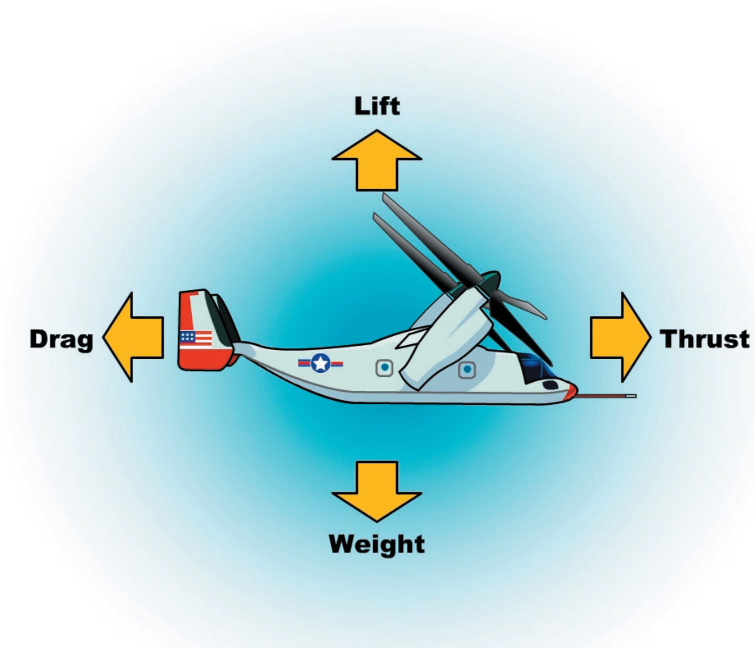
Before starting the lab

Have students discuss with their partners the following question in their log and record their answers.:

How can a heavy aircraft fly in the air?

As students go through the lab

- Have student partners discuss the questions in their log and take notes to help them design a successful aircraft for their given situation.
- After completing the Aeronautics lab, students can either explore the other labs to help get insight into good solutions for their situation, or they can design a solution in the Design Center. If their solutions are not accurate, they will be sent to appropriate sections of the labs to better understand relevant concepts.



Discussion points for this lab

The following discussion will reinforce what students observed in the Aeronautics Lab and will help introduce standards-based concepts of forces and motion:

☐ Question: We want an aircraft to move. How do we get an object to move?
■ *Answer: You can push it or pull it.*

Say: We call a push or pull a force.

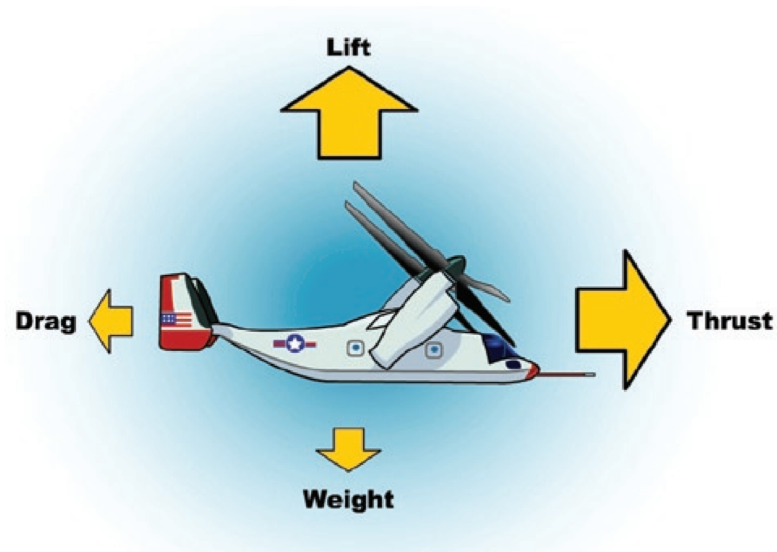
☐ Question: When an aircraft is sitting still on the ground, what forces are acting on it?
■ *Answer: Weight caused by gravity is pulling it to the ground. (Draw this on the board with an arrow pointing down.)*

☐ Question: If an aircraft is moving forward on the ground, what forces are acting on it?
■ *Answer: Weight is still pulling it down. Thrust is moving it forward. Drag, caused by air bumping into it, is pulling it back. (To the drawing, add arrows going forward for thrust and back for drag.)*

☐ Question: In order for the aircraft to begin to move forward, what must be true about these forces?
■ *Answer: Thrust has to be greater than drag. (Make the arrow for thrust bigger than the drag arrow to reinforce this.)*

Say: So, in order for an object to begin to move, the forces cannot be the same. One force has to be greater than the other(s). We say that they are unbalanced forces.

☐ Question: When an aircraft flies, what forces are acting on it?
■ *Answer: Weight is still pulling it down. Thrust is still moving it forward, and drag is still pulling it back. Lift is pushing it up. (Add an arrow pointing up for lift to the drawing.)*



☐ Question: What must be true in order for an aircraft to fly higher?
■ *Answer: Lift must be greater than weight and thrust must be greater than drag. (Make the arrow for lift bigger than the arrow for weight.)*

☐ Question: Once an aircraft reaches the altitude or height that the pilot wants to maintain and a speed she wants to maintain, how would you describe the forces acting on it?
■ *Answer: (Students may reply that lift is greater than weight and thrust is greater than drag, but guide them to conclude that unbalanced forces cause changes in movement. Once the motion is constant, the forces are balanced again. So, lift equals weight and thrust equals drag when an aircraft is moving at a constant speed and constant altitude.)*

☐ Question: Why is weight important when designing an aircraft?
■ *Answer: The more something weighs, the more lift will need to be created to get it off the ground.*

☐ Question: Something that weighs more has more mass. If we use the same force on two objects, one that is less massive and one that is more massive, what will occur? (It might be helpful to have two objects to demonstrate this. You could use an empty chair compared to a chair someone is sitting in, or an empty plastic container compared to a plastic container with water or some other substance in it.)
■ *Answer: he force will have less of an effect on the more massive object.*

☐ Question: Suppose you had two objects of the same mass and you applied a stronger force to one than the other. What would happen? (Again, you might want to demonstrate this with two empty chairs or two empty plastic containers.)
■ *Answer: The object that you give a greater force to will move further and/or faster.*

Say: So we can say that the greater a force is, the greater the change in motion will be.

Days 3–4 (90–120 minutes)

Note: *The following labs can be done in any order.*

L Lift Lab

Before starting the Lift Lab

Have students discuss with their partners the following questions and record their answers in their log.:

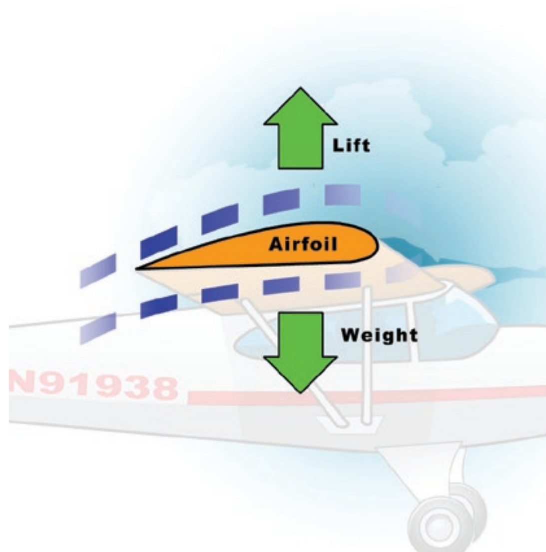
- What part of an aircraft do you think might lift it or move it up?
- For the situation you chose, what factors are important in the design of the lift system of your aircraft? (For example, how powerful does the lift system of your aircraft need to be? What kind of environment will it need to fly in? Is size an important factor?)

As students go through the lab

Have student partners discuss the questions in their log and take notes to help them design a successful aircraft for their given situation.

Discussion points for this lab

The following discussion will reinforce what students observed in the Lift Lab and will help reinforce standards-based concepts of forces and motion.



☐ Question: What causes the aircraft to lift off the ground in each situation?

■ *Answer: Air is being pushed down. (You might discuss with students that this is much like they would do while swimming. They push the water down, which propels them up.)*

☐ Question: When an aircraft is hovering, what forces are acting on it?

■ *Answer: Weight is pulling the aircraft down, and lift is pulling it up. (Draw this on the board.)*

☐ Question: What must be true about these forces for the aircraft to be able to hover?

■ *Answer: The forces must be the same or balanced. (Make sure the arrows in the drawing are the same size.)*

☐ Question: What would allow the aircraft to move up or down?

■ *Answer: The forces would need to be unequal or unbalanced.*

- ☐ Question: Can an airplane hover?
- ■ *Answer: No, airplanes cannot hover. They need push air over the wings to create lift, so airplanes must always be moving forward while in flight.*

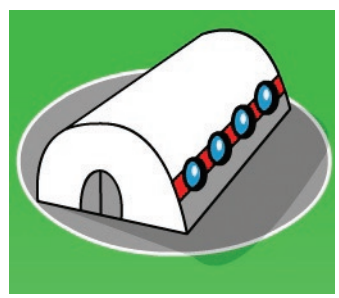
- ☐ Question: How will lift need to change for a large aircraft to take off? Why?
- ■ *Answer: Lift will need to be greater to overcome the weight of a larger aircraft.*

- ☐ Question: So, if you have a smaller aircraft and a larger aircraft and you apply the same amount of lift to each, what will happen?
- ■ *Answer: The smaller aircraft will fly higher and take off easier than the other.*

Say: So, the more massive an object is, the less effect a force will have on it.

- ☐ Question: How will the size or mass of your aircraft affect your choice of lift system?
- ■ *Answer: (Answers will vary depending on the problem students are working on. The long and medium distance situations require more people and cargo to be transported and, thus, will require longer and/or more blades. The short distance situation will require fewer and shorter blades to carry less people and cargo. You may want to discuss with those working on the short distance aircraft that they will need to tolerate the more noise of shorter and fewer blades to have blades short enough to fit between buildings, keep costs down, and minimize weight. You may want to discuss other NASA research that is being done to find other ways to reduce noise. At the following Web address, you will find an article about noise and other concerns that NASA is addressing through research http://futureflight.arc.nasa.gov/pbl/avia_envi.html. This article is from the Aviation Research page in the Air Transportation Problem section of the Future Flight Design Web site.)*

F Fuselage Lab



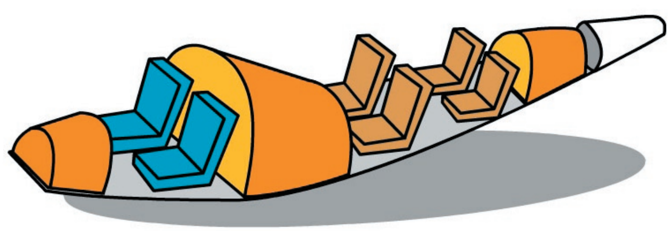
Before starting the Fuselage Lab

Have students discuss with their partners the following questions and record their answers in their log.

- Why do aircraft have different fuselages?
- For the situation you chose, what factors are important in the design of the fuselage of your aircraft? (For example, do you need a small or large cabin? Is cost a factor?)

As students go through the lab

Have student partners discuss the questions in their log and take notes to help them design a successful aircraft for their given situation.



Cabin

Discussion points for this lab

The following discussion will reinforce what students observed in the Fuselage Lab and will help reinforce standards-based concepts of forces and motion and systems.

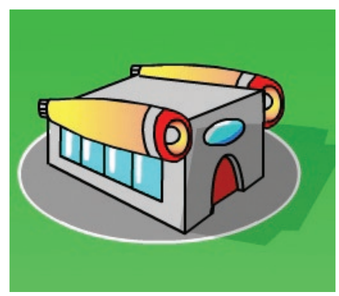
☐ Question: When looking at the fuselage of the aircraft, which forces do the size and shape of the fuselage affect?
■ *Answer: The size of the aircraft affects how much weight is pulling it to the ground and so how much lift is needed to get it off the ground. Its shape will affect how much air is running into it (how much drag is pulling it backwards) and so how much thrust is needed to move it forward.*

Say: Aircraft designers must pay attention to more than just the weight of an aircraft. They need to think about how the weight is distributed, which affects the aircraft's "balance."

Say: For any object, its center of gravity is the location where weight is balanced on all sides. This also applies to your body. You are most stable when your center of gravity, or point of best balance, is centered. If weight is added to one side of your center of gravity, you must work extra hard to keep your balance. The same is true on an aircraft. The weight of the aircraft's parts, passengers, cargo, and fuel must be arranged so the aircraft remains in balance. If it isn't, then the aircraft may not operate well, be hard to handle, or may not fly at all.

☐ Question: How do the parts of the fuselage work together as a system?
■ *Answer: The parts of the fuselage all must work together and form a shape that is as streamlined as possible. The cockpit has controls that control all parts of the aircraft. The tail cone has the wires that connect the cockpit to the empennage so that the direction of the aircraft can be controlled. All of these parts work together to carry people and cargo, which is the goal of the whole system.*

P Propulsion Lab



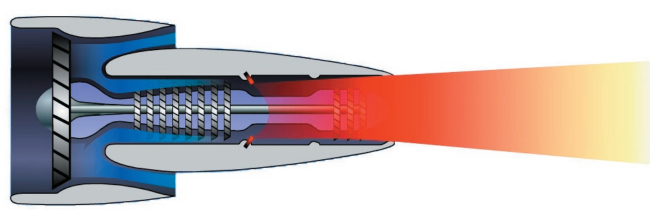
Before starting the Propulsion Lab

Have students discuss with their partners the following questions and record their answers in their log:

- What part of an aircraft do you think might propel it or move it forward?
- For the situation you chose, what factors are important in the design of the propulsion system of your aircraft? (For example, how powerful does the propulsion system of your aircraft need to be? Is cost a factor?)

As students go through the lab

Have student partners discuss the questions in their log and take notes to help them design a successful aircraft for their given situation.



Engine

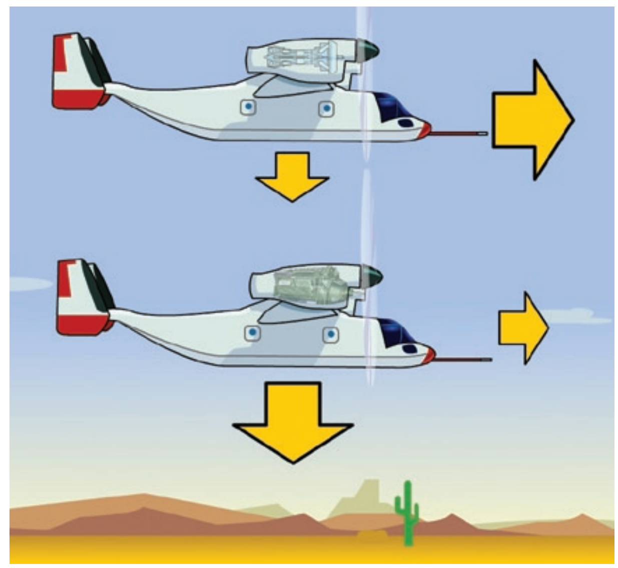
Discussion points for this lab

The following discussion will reinforce what students observed in the Propulsion Lab and will help reinforce standards-based concepts of forces and motion and systems.

- ☐ Question: What causes the aircraft to move forward (thrust)?
- ■ *Answer: Air is being pushed back. (You might discuss with students that this is much like they would do while swimming. They push the water back, which propels them forward.)*

- ☐ Question: Which forces are affected by the type of engine chosen for the aircraft and how?
- ■ *Answer: The power or strength of thrust is affected by the type of engine chosen. The weight is also affected.*

Have students draw the forces for an aircraft that has a piston engine, compared to an aircraft that is otherwise identical but has a turboshaft engine. (They should show that the piston engine has a smaller thrust arrow and larger weight arrow than the aircraft with the turboshaft engine.)



- ☐ Question: What are the parts of the turboshaft engine system and how do they work together to create thrust?
- ■ *Answer:*
  1. *Fans suck air inside the engine.*
  2. *Air is compressed in a chamber.*
  3. *Fuel mixed with the compressed air explodes when it is ignited with a spark.*
  4. *The blast is forced out the exhaust to propel the engine forward.*
  5. *The exhaust goes through fans.*
  6. *The fans are connected to a gearbox and shaft*
  7. *The shaft moves the rotor blades.*

- ☐ Question: How is this a system?
- ■ *Answer: It is made up of parts that work together.*

- ☐ Question: What would happen to the aircraft system if one part of the propulsion system were broken?
- ■ *Answer: If some part of it were broken, the propulsion system probably would not work, and the aircraft would not be able to create thrust.*

You may want to assure students that this is why aircraft are thoroughly examined before each flight to make sure everything is working fine. The aircraft also have safety precautions, like having more than one engine, so if one fails, they can still fly safely.

- ☐ Question: What other system is the propulsion system connected to?
- ■ *Answer: The engine is connected to the rotors that generate lift. (Modify the drawing on the board by adding an arrow for lift to show that propulsion affects lift.) The propulsion system is also connected to the fuselage, because it creates enough power to move the fuselage (and the rest of the aircraft) forward.*

Say: The power of an engine is also an important factor to consider. Most engines are measured in "horsepower." A "horsepower" is the amount of energy needed to move 550 pounds one foot in one second. You may have heard the term in reference to the power of different cars. A small car might have around 100 horsepower, while a race car can have 750 horsepower. Horsepower also applies to the power of an engine in an aircraft.

Day 5 (45–60 minutes)

STEP 3 Select a Solution

D Design Center

Tell students that the third step they will need to do is to select a solution. They can read and discuss the following information about this step in their log:

In this phase, engineers select the solution that best meets the criteria and constraints.

Before starting the Design Center, have students:

1. Review the criteria and constraints for their situation.
2. Look at their notes and drawings from the labs.
3. Discuss the following with their partner and write their answers in their logs.

What important factors will you look for when choosing the fuselage, engine and lift system of your aircraft?

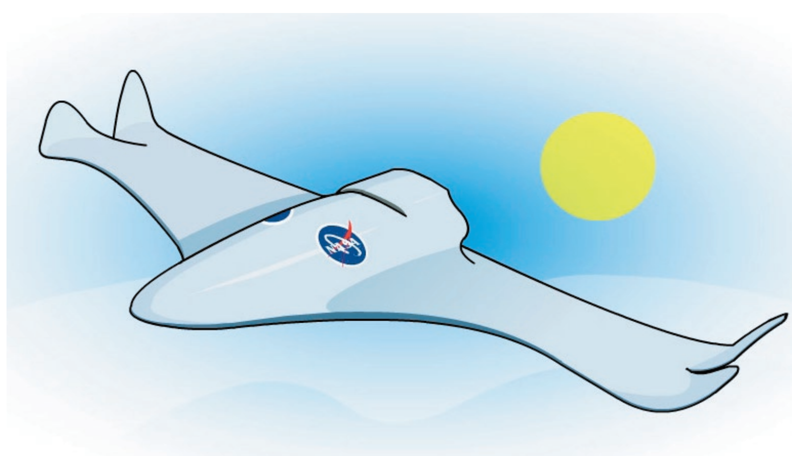
As students go through the Design Center, have teams discuss the questions and answer them in their logs.

STEP 4 Test and Refine the Solution

D Design Center: Testing/Results Area

Tell students that the fourth step they will need to do is to test and refine the solution. They can read and discuss the following information about this step in their log:

In this phase, engineers do a number of tests of their solution. Then they make changes and test again until they have their best solution to meet the criteria and constraints.



Have students submit their results in the Design Center and observe the feedback. They should record their results in their log.

Students will need to calculate their budget in their log. You may want to go over with them how to do this. You may also want to discuss the importance of cost effectiveness with the class.

- ☐ Question: What costs does an airline have to cover when operating an aircraft?
- ■ *Answer: The cost of the aircraft, maintenance, fuel, and the staff to fly it.*

- ☐ Question: Where does an airline get the money to pay for all of this?
- ■ *Answer: It gets its money from passengers.*

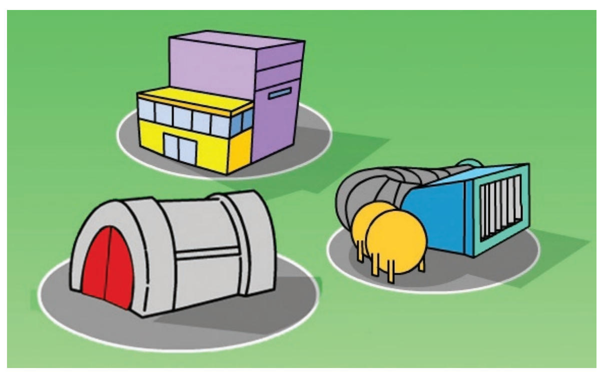
- ☐ Question: So, what happens if an aircraft is very expensive to buy or operate?
- ■ *Answer: The airfare goes up. Passengers may not be able to afford it, and airlines would not be able to attract passengers.*

- ☐ Question: How much would you be willing to pay to fly across town if it could save you time over ground transportation?
- ■ *Answer: Allow students to discuss their ideas about this. They will likely agree that they would not want to pay that much more than taking a taxi or other local transportation, so aircraft flying short distances must be much less expensive than an aircraft that goes longer distances. This is especially true with smaller aircraft that can't carry as many people.*

> ***Note:** For the short hop aircraft, you may want to reinforce this idea by asking students which combination resulted in the cheapest aircraft. They will probably notice that solutions using the piston engines are cheaper than ones using turboshaft. This is the only reason for using a piston engine over a turboshaft, because turboshaft engines are superior in other factors. The cost of turboshaft engines is coming down enough that soon even smaller aircraft can afford to use them, so that piston engines are not likely to be seen much in future aircraft.*

If students' solutions are not approved, have them look at the results and see what needs to be improved. They can visit the suggested labs or review their notes for the suggested labs and refine their design until they find a solution that works.

T Test Facilities (CFD, Wind Tunnel, and Flight Test Buildings)



Before starting the Test Facilities

- Have students discuss with their partner the following question and record their answers in their logs:
  List the steps you went through to design your solution.
- As students go through the Test Facilities, have teams discuss the questions and answer them in their logs.
- In the Flight Test section, be sure students click "Test my Aircraft" to see the flight test of their aircraft. This will only be possible if they found a successful solution in the Design Center. Also make sure students print their certificates as proof of their success or get their customized certificates from you, which can be downloaded at the Future Flight Design Teacher Page (http://futureflight.arc.nasa.gov/teacher.html) and filled out individually.

Day 6 –7 (90 –120 minutes)

STEP 5 Present the Results

I Introduction to Aircraft Design Conference

Tell students that the final step they will need to do is to present the results. They can read and discuss the following information about this step in their log:

In this phase, engineers present their solution to others for feedback in further improving their design and to see if their solution is accepted for use.

- Tell students that they will be attending a conference on future aircraft designs. Have them design a poster or presentation about their solution to share with others. They will need to be persuasive to try to convince their colleagues that their solution is the best one and should be recommended to NASA.
- Go over the presentation requirements and rubric in the Student Design Logs.

T The Aircraft Design Conference

- Have a mock conference in which students either present their posters as other students walk around and talk to them about it, or each team presents to the whole class.
- Have students look at each other's posters or presentations and have them consider the following questions, which can be part of a follow-up discussion:
  1. Did others come up with different solutions that also worked?
  2. How did these solutions compare with each other?
  3. What solutions will the class recommend to NASA?
  4. What were some of the trade-offs that people made?
  5. What were some of the challenges that they faced in engineering a new aircraft?
  6. What did they learn?
  7. What did they like about engineering?
  8. What careers interested them most? Why?
- Conduct a class discussion about the questions above.
- Use the rubric in the Student Design Log to assess student posters or presentations to make sure they've mastered the major concepts.

Multimedia Information

A Aeronautics Lab

The aeronautics lab covers the four forces of flight: weight, lift, thrust, and drag.

Aeronautics Lab: Weight

Weight is a measure of the force of gravity on a person's mass.

1. Objects that are the same size can have very different weights.
2. In aircraft design, the trade-off is between the strength of the materials and their weight. Whereas strong materials are desired for aircraft strength, if the materials are too heavy, the aircraft does not fly efficiently.

Common misconception: Students confuse mass with weight. Mass is measured in pounds or kilograms and is a quantity that does not change, no matter where you are. Weight is the force that acts on mass, and is measured in units such as Newtons. This lab does not address units of measure, but focuses on the concepts instead.

Aeronautics Lab: Lift

Lift is the upward force that causes an object to fly.

1. A variety of well-known objects produce lift using a special shape called an "airfoil."
2. An airfoil and the way it is tilted causes the air moving below it to push harder than the air above below it. This generates lift.

Aeronautics Lab: Thrust

Thrust is a force that moves an aircraft forward.

1. The following are examples of machines or mechanical devices that use a thrust force:
   - Cars and other vehicles
   - Power boats
   - Rockets
   - Balloon that is blown up, left untied, and released
2. The thrust force must be stronger than the opposing force if the purpose of the thrust force is to move something (which it usually is).
3. The force of friction affects the amount of thrust force you need. You need less force to overcome friction when you are moving on ice or in the air. More thrust is required when friction is to be overcome on the ground or if you are underwater.
4. The function of thrust in aircraft flight is to move the aircraft forward.

Aeronautics Lab: Drag

The force of resistance is called drag.

1. You feel drag when you stand against the wind, stick your hand out of the window of a moving car, or swim.
2. Drag opposes the motion of objects.
3. Too much drag can prevent an aircraft from flying. The shape of an object affects how much drag it creates.
4. Aircraft are designed to minimize the effects of drag.

Aeronautics Lab: Four Forces

1. For any type of aircraft, lift works opposite of weight, and thrust works opposite of drag.
2. When lift is greater than weight, the aircraft will gain altitude. When lift is less than weight, the aircraft will lose altitude.
3. When thrust is greater than drag, the aircraft's speed will increase. When drag is greater than thrust, the aircraft's speed will decrease.
4. Lift and thrust can work together. As an aircraft's speed increases, the wings move through more air, creating more lift. The opposite is true as the aircraft's speed decreases.

L Lift Lab

Lift Lab: Creating Lift

1. Students investigate the forces involved with ascent, descent, and hovering of a rotorcraft.
2. Different parts of an aircraft generate lift, depending on the motion of the aircraft. A helicopter uses its rotor blades for lift while in hover and forward flight; a tiltrotor uses its rotor blades for lift while in hover and uses its wings for lift while in forward flight.
3. When propellers or rotors turn on an aircraft, they create a force (called torque) that pushes the body of an aircraft in the opposite direction. One way to keep the aircraft from spinning is to add a tail rotor or another propeller that is rotating in the opposite direction.

Lift Lab: Rotor Size

1. The size of the rotor blades can affect the characteristics of an aircraft including downwash, fuel efficiency, noise, maneuverability, and carrying capacity.

Lift Lab: Number of Blades

1. The number of rotor blades can affect characteristics of an aircraft, such as noise and carrying capacity.

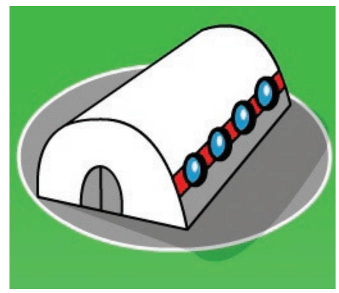
Lift Lab: Noise

1. In some places, it's important to have a quiet aircraft. In other places, it doesn't matter as much. Engineers make many trade-offs when designing an aircraft.
2. For instance, longer rotor blades are quieter, but they won't fit into small areas. Also, longer rotor blades cost more and add extra weight to the aircraft.
3. Adding more rotor blades can make the aircraft quieter, but the extra blades also cost more and create added weight.
4. Other factors affect the noise level of an aircraft, such as the power and size of the engines.

Lift Lab: Rescue Mission

1. Students are asked to choose the proper rotor system to rescue a stranded window washer from a high-rise building. The correct answer is long rotor blades—because they create less downwash and are more fuel efficient, so the aircraft can hover longer to make the rescue.

F Fuselage Lab



Fuselage Lab: Structure

1. A fuselage on an aircraft has many different parts including the cockpit, cabin, tail cone, and landing gear. Each part serves a different, but necessary purpose.

Fuselage Lab: Aerodynamics

1. The way a fuselage is shaped is very important. It must be streamlined to reduce drag so that it is efficient and safe.

Fuselage Lab: Materials

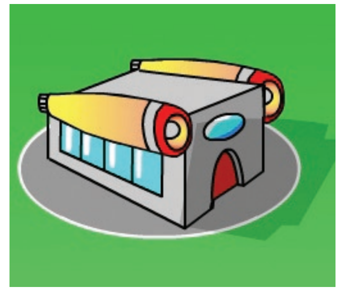
1. The materials that make up an aircraft are extremely important.
2. Lightweight materials can help with efficiency, but the material must also be very strong.
3. The types of materials that have been used for aircraft have changed over time.

Fuselage Lab: Capacity

1. The bigger the fuselage, the more the entire aircraft will weigh.
2. There's a trade-off between making something bigger to hold more cargo and passengers while ensuring it can lift off the ground and fly safely. Choosing the proper size fuselage for a particular job is not always very easy.

As with most other parts of the aircraft, the shape of the fuselage is normally determined by the function of the aircraft. The cockpit is where the pilots sit. On most commercial aircraft, the cockpit is in the front of the cabin. Aircraft have a wider fuselage to carry the maximum number of passengers. Fuel is usually stored in the wings or the fuselage.

P Propulsion Lab



Propulsion means to push forward or drive an object forward. A propulsion system is a machine that produces thrust to push an object forward.

Propulsion Lab: Thrust

1. The propulsion system provides the power to give an aircraft thrust.
2. Helicopters tilt their blades to move forwards, backwards, and sideways.
3. In a jet airplane, the exhaust from the engines moves the aircraft forward.
4. Tiltrotors use their rotor blades set vertically to take off and then tilt them forward to move through the air.

Propulsion Lab: Piston

There are several steps involved to make a piston engine work.

1. When the piston moves down into the cylinder, it sucks in air and fuel.
2. The piston moves back up to compress the air.
3. The spark plug ignites the fuel and air and causes an explosion.
4. The explosion forces the piston down and creates motion in the crankshaft.
5. When the crankshaft is connected to a shaft and gearbox, it can turn the blades of a helicopter.
6. Piston engines are heavier, less powerful, and more complicated than turboshaft engines.
7. Piston engines are inexpensive, so they are usually used in small aircraft.

Propulsion Lab: Turboshaft

There are several steps involved to make a turboshaft engine work.

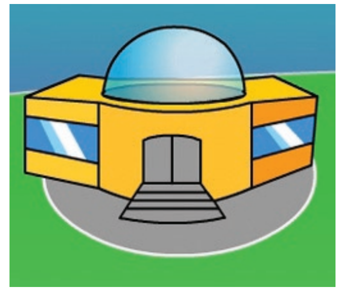
1. Fans are used to suck air inside the engine.
2. The air is put into a chamber, where it is compressed.
3. Fuel mixed with the compressed air explodes when it is ignited by a spark.
4. The blast from the explosion is forced out of the exhaust. The exhaust pushes the engine (and the rest of the aircraft) forward.
5. In a turboshaft engine, the exhaust is sent through a series of fans that are connected to a gearbox and shaft that turn the rotor blades.
6. Turboshaft engines are widely used because they are more powerful, simpler, and weigh less than piston engines.
7. Turboshaft engines are more expensive than piston engines.

Propulsion Lab: Selecting Engines

Students are presented with two scenarios asked to choose the proper engine for each job.

1. An aircraft is carrying two people to the other side of town for a meeting. Choose either a turboshaft or a piston engine. CORRECT ANSWER: Piston engine—because piston engines are much more affordable when carrying a small number of people across short distances.
2. An aircraft is transporting a heavy load 60 miles from Chicago to Milwaukee. Choose either a turboshaft or piston engine. CORRECT ANSWER: Turboshaft engine—because turboshaft engines are powerful enough to carry a heavy load across long distances.

D Design Center

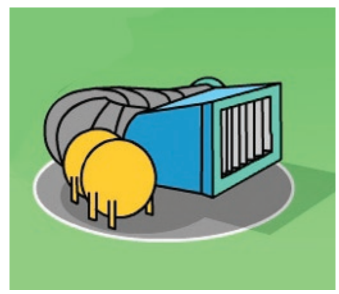


Students go to the Design Center after they have visited all the labs. They design and build an aircraft that can accommodate the design problem they chose at the beginning of the activity. They must consider the number of passengers and the distance the aircraft must travel. Students assemble aircraft from a pallet of fuselages, lift systems, and engines. They receive feedback and/or suggestions on their designs.

C CFD

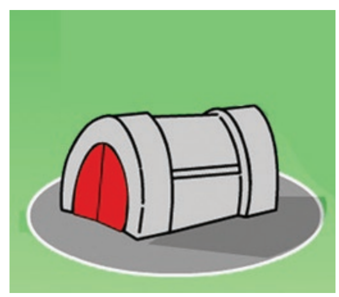
Students learn about computational fluid dynamics (CFD) and how scientists and engineers test concept aircraft on computers before they even begin building them.

W Wind Tunnel



A wind tunnel is another place to test an aircraft. Wind tunnels can test miniature aircraft and parts of aircraft. Some wind tunnels can even test full-scale models of an aircraft. An aircraft design must pass several types of wind tunnel and/or CFD tests before it is considered safe for a human to fly.

F Flight Test



After students pass the Design Center specifications and learn about testing their aircraft in CFD labs and wind tunnels, it's time to take their aircraft to the test area. Students learn about test pilots and what they do. Then the students can see their aircraft pass the final test.

C Career Cockpit

A variety of NASA people are featured. Different levels of experience and backgrounds are showcased via biographies and images.

N NASA Research

Current NASA research is highlighted in these articles.

Student Design Log

Contents of Student Design Log

The student design log contains:

- Practice worksheets
- Checks for concept and comprehension
- Graphic organizers for note taking and organization of thinking processes
- Scientific exploration guide sheets with emphasis on experimentation and journal writing
- Guide sheets reviewing the technology design process
- Guide sheets to document the students' own technology design process

Future Flight Design: Aircraft Design Problem Answer Key

STEP 1 Define the Problem

D Discuss the Problem

1. Click the "Introduction Movie" at http://futureflight.arc.nasa.gov/welcome.html, watch the animation, and study the letter from NASA. Discuss with your partner the problems with air travel and ground travel. Make a list of the problems.

Answers may include:

- *The amount of air traffic is increasing, which can cause delays.*
- *Crowded roads make it difficult to get to the airport.*
- *Current runways and air systems can't handle the growing number of people and cargo that need to be transported.*

L List the Criteria and Constraints for Your Aircraft

1. List the criteria and constraints that your aircraft must meet (see table next page).

We chose Situation number: ________

Criteria (standards or requirements)	Constraints (limits to design)
All • *able to fly* Short • *must travel 25 miles* • *must hold 3 people* Medium • *must travel 150 miles* • *must hold 9 people* Long • *must travel 500 miles* • *must hold 80 people*	All • *road traffic must not increase* Short • *must travel across town in half an hour* • *must fit between buildings* • *Cost must not exceed $4,425,000* Medium • *must travel quickly to not miss a day of school* • *Cost must not exceed $9,800,000* Long • *must make to the game on time even if there are airport delays* • *Cost must not exceed $76,000,000*

STEP 2 Generate Ideas

A Aeronautics Lab

Before going through the lab

1. How can a heavy aircraft fly in the air?

Student answers will vary and are not meant to be graded, but rather to help them to draw on prior knowledge.

Weight:

2. Why is weight important in designing an aircraft?

The heavier something is, the harder it will be to get off the ground.

3. In designing an aircraft, what could you do to help with the weight of the aircraft?

You can use lighter materials or make the aircraft smaller.

4. What trade-off(s) do engineers make when using lighter materials in an aircraft?

Using lighter materials lessens weight but might make the aircraft weaker or more expensive to build.

Lift:

5. What helps to create lift?

An airfoil and the way it is tilted help create lift.

6. How could you create lift in your aircraft design?

I can make sure my aircraft has airfoils either in the wings or in the rotors.

Thrust:

7. What are two ways that thrust is important to an aircraft?

Thrust moves an aircraft forward and moves air over the airfoils to create lift.

8. How can you create more thrust on your aircraft?

I can use larger engines, which will provide more power.

Drag:

9. What causes drag?

When air bounces off something, it causes a resistance called drag.

10. When designing an aircraft, how can you reduce drag?

An aircraft with less surface area can reduce drag. A blocky aircraft will have more drag than a streamlined one.

Four Forces:

11. When designing your aircraft, what must you make sure is true in order for your aircraft to take off and fly?

Lift must be greater than weight, and thrust must be greater than drag.

12. Systems have parts that work together. One part can affect another. What are some ways that the parts of an aircraft work together so that an aircraft can fly?

The engines create thrust that pushes airfoils through the air to create lift, so the engines must work together with the wings or rotors.

The shape of an aircraft works together with the lift and thrust systems to make it easier to fly.

The materials that the aircraft are made of work with the lift system to make it lighter and easier to fly.

Career Cockpit

13. Read the career fact sheets and trading cards in this section and learn more about careers related to aeronautics. What parts of the jobs described do you like best?

Answers will vary.

After going through the lab

14. Look at the drawing you made of a possible solution to your chosen situation. Modify the drawing of your aircraft with your knowledge of the four forces of flight. Redraw your new design below.

Answers will vary. Hopefully students will make modifications and notes such as making the fuselage more streamlined to decrease drag, using larger engines for the long haul situation to make sure thrust exceeds drag, and using lighter materials to reduce weight.

L Lift Lab

Before starting the Lift Lab

1. What part of an aircraft do you think might lift it or move it up?

2. For the situation you chose, what factors are important in the design of the lift system of your aircraft? (For example, how powerful does the lift system of your aircraft need to be? What kind of environment will it need to fly in? Is size an important factor?)

Student answers will vary and are not meant to be graded, but rather to help them to draw on prior knowledge.

Lift Lab: Creating Lift

3. In order for an aircraft to ascend or fly up, what must be true?

Lift must be greater than weight.

4. If an aircraft is hovering, what must be true?

Lift is equal to weight.

5. How can an aircraft lift off vertically (or straight up)?

An aircraft would need rotors to lift off vertically and lift must be greater than weight. An aircraft could also lift off vertically if the thrust source were pointed straight up—like on a rocket.

6. What's the difference between the systems that a helicopter uses to fly forward and the systems that a tiltrotor uses to fly forward?

Helicopters use rotors for both lift and thrust. Tiltrotors use wings for lift and rotors for thrust when flying forward.

7. What causes the aircraft to lift off the ground in each of these situations?

Air is being pushed in the opposite direction than the aircraft is moving.

8. Why is a tail rotor important?

When propellers or rotors turn an aircraft, they create a force that pushes the body of the aircraft in the opposite direction. One way to keep the aircraft from spinning is to add a tail rotor or another propeller that is rotating in the opposite direction.

Lift Lab: Rotor Size
In the tables below compare rotor blade size.

	Short Blades	Long Blades
Downwash	*More*	*Less*
Ability to Fit in Tight Spaces	*Fits*	*Doesn't fit*
Fuel Efficiency	*Less miles per gallon*	*More miles per gallon*
Noise	*Louder*	*Quieter*

	Short Blades	Long Blades	Very Long Blades
Cargo	*Less*	*More*	*Less*

10. What happened to the cargo capacity when very long rotor blades were used? Why?
The aircraft couldn't carry as much as the aircraft with long rotor blades, because the weight of the very long rotor blades also has to be lifted.

11. What size rotor blades do you think would be best to use in your aircraft? Why?
Long rotors should be used for long distances because they can carry more cargo with less downwash and better fuel efficiency.

Short rotors should be used for short and medium distance because they need to fly in tight places (between buildings of a city) and will be sufficient to carry a small number of passengers.

Lift Lab: Number of Blades
12. In the tables below compare the number of blades.

	Three Blades	Five Blades
Noise	*Louder*	*Quieter*
Weight	*Lighter*	*Heavier*

	Five Blades	Seven Blades	Nine Blades
Cargo	*Less*	*More*	*Less*

13. What happened to the cargo capacity when nine rotor blades were used? Why?
The aircraft couldn't carry as much as the aircraft with seven rotor blades, because the weight of the extra rotor blades also has to be lifted. More blades create more lift, which is good, but they also add more weight, which is bad. With too many blades (9 in this example), the weight penalty is greater than the lift benefit.

14. Do you think you should use few or many rotor blades in your aircraft? Why?
More blades should be used for medium and long distances because they can carry more cargo, more quietly. Using fewer rotors doesn't provide enough lift and creates a lot of noise, while using too many rotor blades adds to the weight of the aircraft and reduces its ability to lift cargo. Fewer rotors should be used for short distance because this will be sufficient to carry a small number of passengers without carrying the extra weight of extra blades that aren't needed.

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Lift Lab: Noise

15. What are some factors that affect how noisy an aircraft is?
Longer rotor blades can make an aircraft quieter. Adding more rotor blades can also make an aircraft quieter. However, the type of engine also affects noise levels. A large, powerful engine can contribute a lot of noise to the aircraft, in spite of the length or number of rotor blades.

16. List some trade-offs for making the rotor blades longer.
With longer blades, the trade-offs are having less downwash, better fuel efficiency, less noise, and increased cargo capacity (if the blades aren't too long), but longer blades are more expensive, weigh more, and prevent your aircraft from fitting in tight spaces.

17. List some trade-offs for adding more rotor blades to an aircraft.
By adding more rotor blades, the trade-offs are having better fuel efficiency, less noise, and increased cargo capacity (if there aren't too many blades), but adding more blades is more expensive and makes the aircraft weigh more.

Career Cockpit

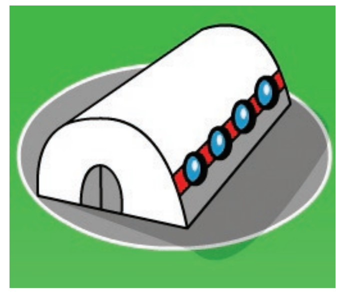
18. Read the career fact sheets and trading cards in this section and learn more about careers related to lift. What parts of the jobs described do you like best?
Answers will vary.

After going through the lab

19. Look at the drawing you made of a possible solution to your chosen situation. Draw and label the lift system that will meet the needs of your chosen situation based on what you've learned in this lab. Be sure to include notes on the size and number of rotors you will use, and explain how this lift system meets the criteria and constraints you listed for your situation.

Answers will vary. Students should conclude that they will need less rotors that are shorter for the Short Hop situation, because it needs to fit in tight areas but doesn't require as much lift, while the Medium Haul situation may require a medium number of shorter blades to carry a slightly larger capacity, and the Long Distance situation will require longer and more blades to create more lift to carry the weight, while increasing fuel efficiency, decreasing noise, and reducing downwash.

F Fuselage Lab



Before starting the Fuselage Lab

1. Why do aircraft have different fuselages?

2. For the situation you chose, what factors are important in the design of the fuselage of your aircraft? (For example, do you need a small or large cabin? Is cost a factor?)

Student answers will vary and are not meant to be graded, but rather to help them to draw on prior knowledge.

Fuselage Lab: Structure

3. What is the purpose or function of each part of the fuselage?

Cockpit

The cockpit is where the pilot sits to control and fly the aircraft.

Cabin

The cabin is used to transport people and cargo.

Tail cone

The tail cone has wiring and mechanical parts that connect the tail to the rest of the aircraft.

Empennage

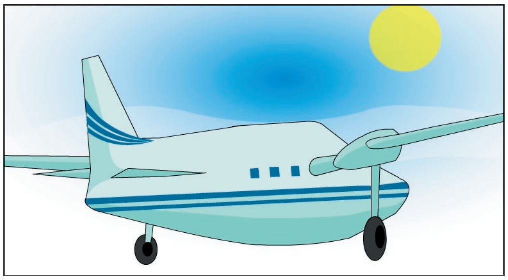
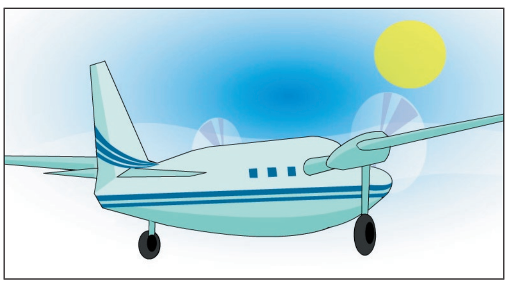
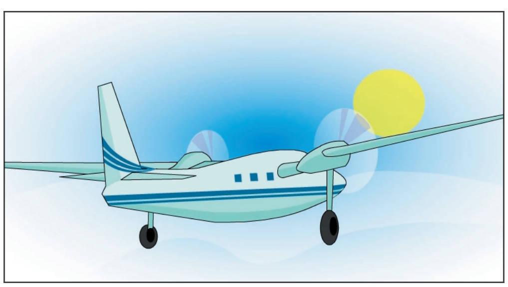
The empennage is the tail of the aircraft with parts that control the direction of the aircraft.

4. How do the parts of the fuselage (cockpit, cabin, tail cone, empennage) work together as a system? Write or draw your conclusions here.

The parts of the fuselage all must work together and form a shape that is as streamlined as possible. The cockpit has controls that control all parts of the aircraft. The tail cone has the wires that connect the cockpit to the empennage so that the direction of the aircraft can be controlled. All of these parts work together to carry people and cargo, which is the goal of the whole system.

Fuselage Lab: Aerodynamics

5. What observations can you make about each of the aircraft in this lab?

Aircraft	Flight Observations
Largest and blockiest 	*Very slow* *Had a hard time getting off the ground* *Used up almost all its fuel just to take off*
Medium sized, somewhat blocky 	*Somewhat slow* *Used a fair amount of fuel to take off*
Small, streamlined 	*Fast* *Used very little fuel to take off*

6. Based on the animations in this lab, what can you conclude about the shape of the fuselage and how it affects flight? Why?

The larger and blockier an aircraft, the slower it is and the less fuel efficient it is. This is because blockier aircraft have more air resistance (drag) that requires more thrust and lift to take off.

Fuselage Lab: Materials

7. In the table below compare different materials used over time.

	Linen/wood	Aluminum/steel	Composite
Strength	*Weak*	*Strong*	*Strong*
Cost	*Low*	*Low*	*Getting better*
Weight	*Light*	*Heavy*	*Light*

8. What material do you think would be best to use in your aircraft? Why?
Composite materials would be best, because they are strong, lightweight, and are becoming more affordable.

9. What trade-off(s) did engineers have to make in the past when selecting materials?
With linen and wood, they had to trade-off having low cost and lightweight materials that were weak. With aluminum and steel, they had to trade off having stronger, low-cost materials that were heavy.

Fuselage Lab: Capacity

10. How does the fuselage size affect the capacity and weight of an aircraft?
The larger the fuselage, the more it can carry. The larger the fuselage, the more it will weigh.

11. What trade-off(s) do you need to make when designing a fuselage?
The more capacity the fuselage has the heavier it will be, thus requiring more power and lift, making it less fuel efficient.

12. What are some things to think about when designing a fuselage for a specific task?
The cabin will need to be the right size for the chosen situation, neither too small nor too big. Also, the shape of the fuselage will need to be as streamlined as possible and made of materials that are strong, cheap and lightweight. (Designing for long distance travel means being especially conscious about using lightweight materials and a streamlined fuselage, since weight will be a larger concern for achieving successful flight

13. How will your fuselage affect the other parts of your aircraft?
Having a large fuselage will require the lift and propulsion systems to be more powerful.

Career Cockpit

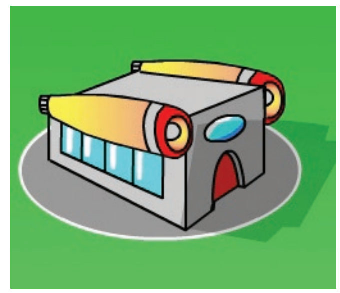
14. Read the career fact sheets and trading cards in this section and learn more about careers related to fuselages. What parts of the jobs described do you like best?
Answers will vary.

After going through the lab

15. Look at the drawing you made of a possible solution to your chosen situation. Draw and label the fuselage that will meet the needs of your chosen situation based on what you've learned in this lab. Be sure to include notes on the size, shape, and materials you will use, and explain how this fuselage meets the criteria and constraints you listed for your situation.

Answers will vary. Students' fuselages should be just the right size for the cargo and passengers in their situation — neither too big nor too small. Their fuselage shape should be streamlined to lessen drag and made of strong, light, inexpensive composite materials.

P Propulsion Lab



Before starting the Propulsion Lab

1. What part of an aircraft do you think might propel or move it forward?

2. For the situation you chose, what factors are important in the design of the propulsion system of your aircraft? (For example, how powerful does the propulsion system of your aircraft need to be? Is cost a factor?)

Student answers will vary and are not meant to be graded, but rather to help them to draw on prior knowledge.

Propulsion Lab: Thrust

3. What are different ways that an aircraft can be thrust or moved forward?

An aircraft can be thrust forward by its exhaust from the engines, or by tilting its propellers or blades forward.

4. What causes the aircraft to move forward in each of these situations?

Air is being pushed back.

Propulsion Lab: Engines

5. Choose one engine system and list the parts of the propulsion system, including the parts the engine interacts with to make the aircraft move forward.

Piston Engine: piston, cylinder, spark plug, crankshaft, shaft, gearbox, rotor blades.
Turboshaft Engine: fans, chamber, gearbox, shaft, rotor blades

6. Draw and explain how these parts work together as a system to propel an aircraft forward.

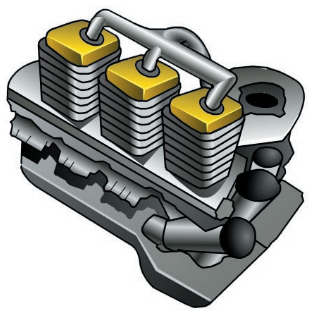
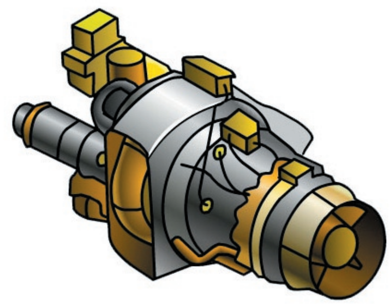
Piston Engine:

1. *A piston moves down into the cylinder and sucks in air and fuel.*
2. *The cylinder moves back up and compresses the air.*
3. *The spark plug ignites the fuel and air and causes an explosion.*
4. *The explosion forces the piston down and creates motion in the crankshaft.*
5. *When the crankshaft in the piston engine is connected to another shaft and a gearbox, it can be used to turn the rotor blades of a helicopter.*

Turboshaft Engine:

1. *Fans suck air inside the engine.*
2. *Air is compressed in a chamber.*
3. *Fuel mixed with the compressed air explodes when ignited with a spark.*
4. *The blast is forced out the exhaust to propel the engine forward.*
5. *The exhaust goes through fans.*
6. *The fans are connected to a gearbox and shaft.*
7. *The shaft moves the rotor blades.*

7. In the table below compare the two engines.

	Piston Engine 	**Turboshaft Engine** 
Weight	*Heavy*	*Lighter*
Power	*Less powerful*	*More powerful*
Cost	*Inexpensive*	*Very expensive*
Other Notes	*Used in small aircraft because of cost*	*Simpler system, so easier to fix*

8. Which engine do you think would be best to use in your aircraft? Why?

Turboshaft engines should be used for larger aircraft or aircraft that require more power to carry more cargo. They are lighter and more powerful, but must transport enough passengers or cargo to offset the cost of the engine.

Piston engines are used in smaller aircraft that are only carrying a few passengers, because these engines are less expensive and because the power is sufficient for small loads. (Note: The cost of turboshaft engines is coming down so that they may soon be used even in smaller aircraft.)

9. What trade-off(s) do you make when selecting an engine?
With piston engines, you trade off having low cost and with heavy, less powerful engines. With turboshaft engines, you trade off having a lighter, more powerful engine with a higher cost.

Career Cockpit

10. Read the career fact sheets and trading cards in this section and learn more about careers related to propulsion. What parts of the jobs described do you like best?
Answers will vary.

After going through the lab

11. Look at the drawing you made of a possible solution to your chosen situation. Draw and label the propulsion system that will meet the needs of your chosen situation based on what you've learned in this lab. Be sure to include notes on the type of engine you will use, and explain how this propulsion system meets the criteria and constraints you listed for your situation.
Answers will vary. Students' should note that a turboshaft engine has more power and thus is better for carrying larger loads, while a piston engine has sufficient power for smaller loads while being less expensive.

STEP 3 Select a Solution

D Design Center

Before starting the Design Center

1. What important factors will you look for when choosing the fuselage, lift system, and engine for your aircraft?
Student answers will vary and are not meant to be graded, but rather to help them to draw on prior knowledge.

Design Center: Assembly Area

2. As you go through the fuselages, lift systems, and engines you have to choose from, notice the statistical information associated with each part. Draw the combination that you think will work best for your aircraft solution.
Answers will vary.

3. How does this solution fit the criteria and constraints of your situation?
Turboshaft engines should be used for larger aircraft or aircraft that require more power to carry more cargo. They are lighter and more powerful, but must transport enough passengers or cargo to offset the cost of the engine. If budget allows, then turboshafts can be used for smaller aircraft as well.

Piston engines are used in smaller aircraft that are only carrying a few passengers, because these engines are relatively inexpensive and because the power is sufficient for small loads.

The fuselage should be chosen based on its ability to carry the number of passengers required in the situation. Students should not select a fuselage that is too big for the intended number of passengers, because it will add unnecessary weight, lowering fuel efficiency.

More blades should be used for medium and long distances because they can carry more cargo.

Fewer blades should be used for short distances because this will be sufficient to carry a small number of passengers without carrying the extra weight of blades that aren't needed.

Long rotor blades should be used for long distances because they can carry more cargo and have better fuel efficiency.

Short rotor blades should be used for short and medium distances because that is sufficient to carry a small number of passengers. For the short distance, the short rotor blades are also needed to fly in tight places—between buildings of a city.

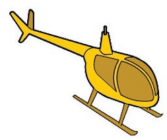
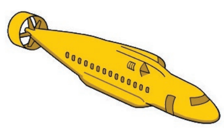
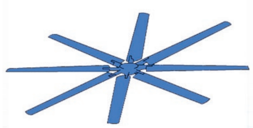
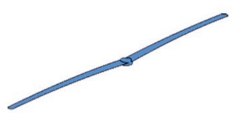
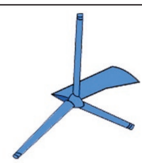
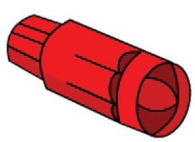
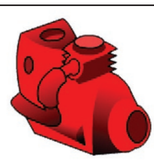
4. How will the parts you chose work together as a system that will solve your chosen situation?
Students should describe how the lift system they chose provides just enough lift to carry the amount of passengers that fit in the fuselage and how the engine provides just enough thrust to move the weight of this cargo.

STEP 4 Test and Refine the Solution

D Design Center: Testing/Results Area

1. After you build your aircraft, click the Submit button to get feedback on your design. What was the result of your test? Record how your test results compare to the expected criteria and constraints.

Criteria and Constraints	Test Result
Capacity	*Answers will vary*
Range	*Answers will vary*
Can it fit in between buildings? (short hop only)	*Answers will vary*
Does it fly?	*Answers will vary*
Does it fit within your budget constraint?	*Answers will vary*

Part		Cost
Fuselage 1		$5,500,000
Fuselage 2		$110,000
Fuselage 3		$50,000,000
Lift 1		$25,000,000
Lift 2		$110,000
Lift 3		$4,000,000
Engine 1		$150,000
Engine 2		$100,000
Engine 3		$25,000

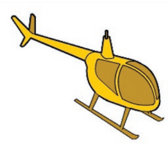
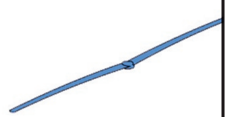
> ***Note:*** *The budget is something students will need to calculate in their student log. The Design Center will not provide feedback on this. A table is provided for this purpose. All solutions that work will fit within the budget, but some solutions are cheaper than others. You might want to discuss the value of having a cheaper aircraft. Discuss that airlines must charge more to passengers, if there are less of them to cover the cost of the aircraft, the fuel and cost to fly the aircraft, so the cost needs to be lower for smaller aircraft than for larger aircraft.*

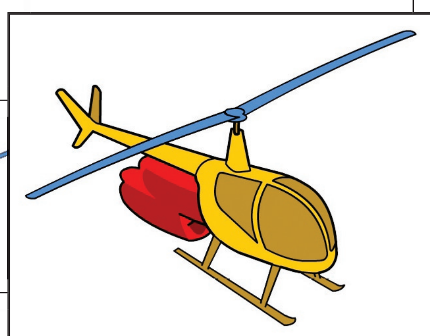
Total Budget

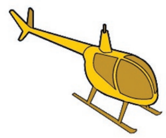
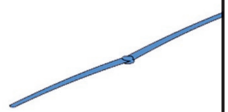
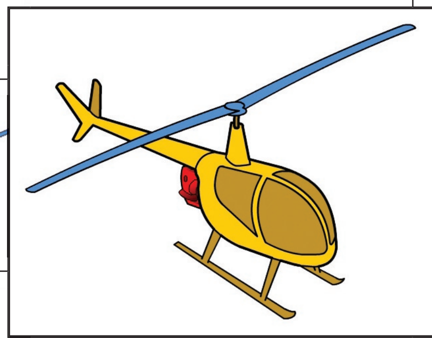
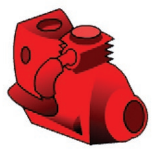
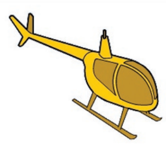
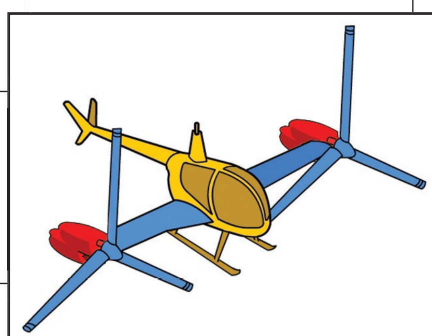
Be sure to include the cost of two or three engines for aircraft that require that many. Any aircraft using Fuselage 3 requires three engines. Any aircraft using Lift 3 requires two engines, regardless of the fuselage. All other combinations require only one engine.

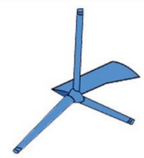
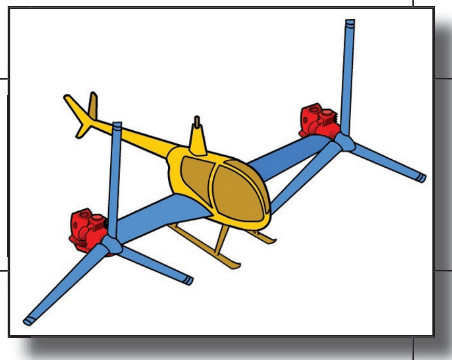
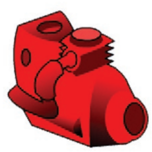
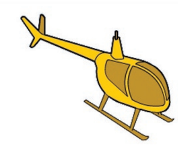
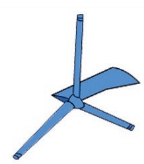
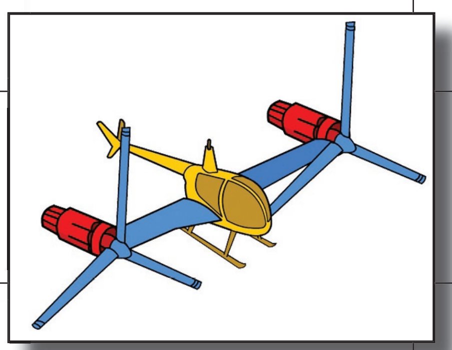
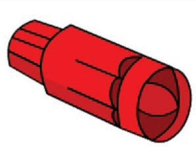
The following combinations will work for each situation:

Short Hop

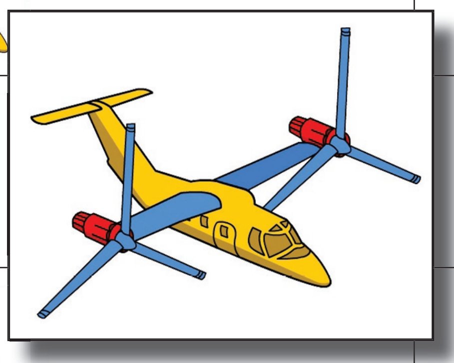
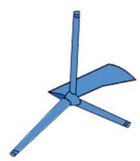
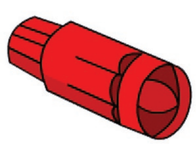
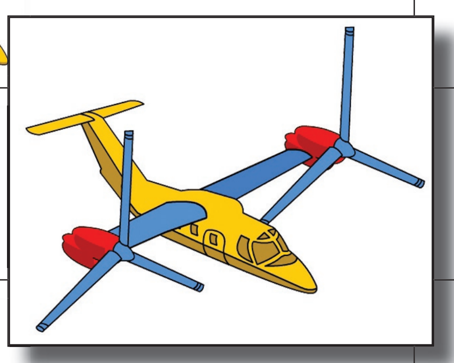
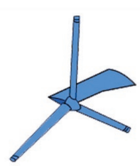
Part	No.	Cost per Item	Quantity	Total Cost
Fuselage 	2	$110,000	1	$110,000
Lift 	2	$110,000	1	$110,000
Engine 	2	$100,000	1	$100,000
Total Cost				$320,000

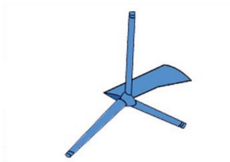
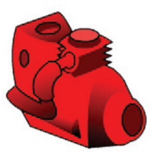


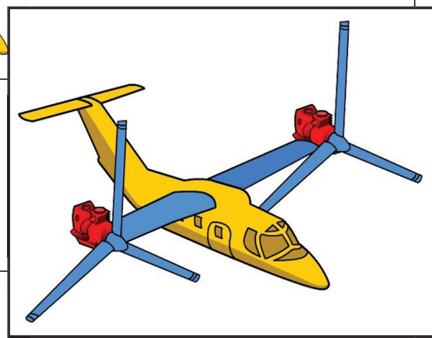
Fuselage 	2	$110,000	1	$110,000
Lift  	2	$110,000	1	$110,000
Engine 	3	$25,000	1	$25,000
Total Cost				$245,000
Fuselage 	2	$110,000	1	$110,000
Lift  	3	$4,000,000	1	$4,000,000
Engine 	2	$100,000	1	$100,000
Total Cost				$4,310,000

Fuselage 	2	$110,000	1	$110,000
Lift  	3	$4,000,000	1	$4,000,000
Engine 	3	$25,000	1	$50,000
Total Cost				$4,160,000
Fuselage 	2	$110,000	1	$110,000
Lift  	3	$4,000,000	1	$4,000,000
Engine 	1	$150,000	2	$300,000
Total Cost				$4,410,000

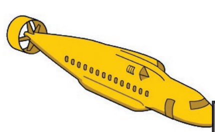
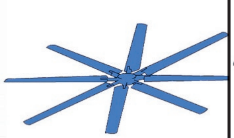
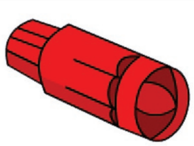
Medium Haul

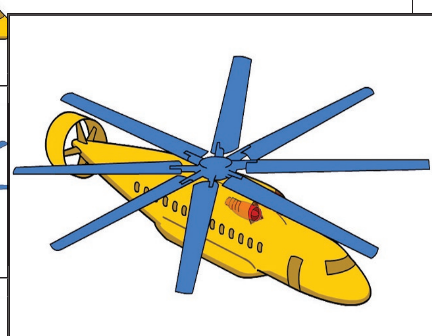
Part	No.	Cost per Item	Quantity	Total Cost
Fuselage  	1	$5,500,000	1	$5,500,000
Lift 	3	$4,000,000	1	$4,000,000
Engine 	1	$150,000	2	$300,000
Total Cost				$9,800,000
Fuselage  	1	$5,500,000	1	$5,500,000
Lift 	3	$4,000,000	1	$4,000,000
Engine 	2	$100,000	2	$200,000
Total Cost				$9,700,000

Fuselage 	1	$5,500,000	1	$5,500,000
Lift 	3	$4,000,000	1	$4,000,000
Engine 	3	$25,000	2	$50,000
Total Cost				$9,550,000



Long Haul

Part	No.	Cost per Item	Quantity	Total Cost
Fuselage 	3	$50,000,000	1	$50,000,000
Lift 	1	$25,000,000	1	$25,000,000
Engine 	1	$150,000	3	$450,000
Total Cost				$75,450,000

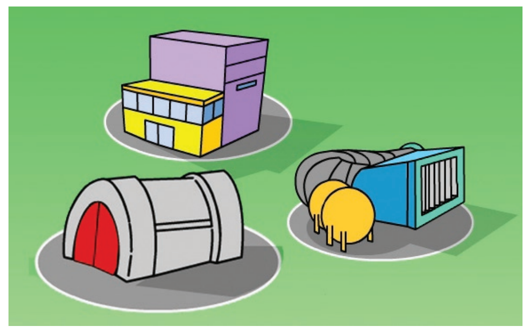


3. Did your design pass this phase of testing?
Students should record whether their solution passed or not and should describe whether it met the expected requirements in each area.

Career Cockpit:
4. Read the career fact sheets and trading cards in this section and learn more about careers related to aircraft design. What parts of the jobs described do you like best?
Answers will vary.

T Test Facilities (CFD, Wind Tunnel, and Flight Test Buildings)

Before starting the Test Facilities
1. List the steps you went through to design your solution.
    1. *Define the problem. (Choose a situation, discuss the problem, and list the criteria and constraints.)*
    2. *Generate ideas, (Explore labs and take notes on how each system works, trade-offs, and types of systems that are best in different situations.)*
    3. *Select a solution. (Select a fuselage, lift system, and engine for the situation.)*
    4. *Test and refine. (Submit the design and look at test results to see if it matched expected requirements. If not, go back to the labs, refine the design, and resubmit the new design.)*



While going through the Test Facilities/Career Cockpit
2. What are some of the techniques that NASA engineers use to test and refine aircraft?
Engineers use Computational Fluid Dynamics (CFD) to test their designs in computers. They also use wind tunnels to test models and do flight tests with full-size models. After each test, they refine their design.

3. How is the process that you used to design an aircraft similar to the process NASA engineers use?
Just like NASA engineers, we defined a problem by listing the criteria and constraints, we designed a solution, tested it, and refined it.

4. How is the process that you used to design an aircraft different from the process that NASA engineers use?
NASA engineers design, test, and refine solutions over and over using computers, wind tunnels, and flight tests before they come up with a final solution. It can take them months or years to complete this process and they usually work with a large team. We were able to go through this process with our partner in a few days using a Web site.

5. How does it feel to have successfully designed a new aircraft?
Answers will vary.

Career Cockpit:
6. Read the career fact sheets and trading cards in each flight test section and learn more about careers related to CFD, wind tunnel testing, and flight testing. What parts of the jobs described do you like best?
Answers will vary.

Educational Standards List

Benchmarks for Science Literacy (2061)

4. The Physical Setting

   F. Motion, Grades 3-5

   #1: Changes in speed or direction of motion are caused by forces. The greater the force is, the greater the change in motion will be. The more massive an object is, the less effect a given force will have.

   F. Motion, Grades 6-8

   #3: An unbalanced force acting on an object changes its speed or direction of motion or both.

11. Common Themes

   A. Systems, Grades 6-8

   #2 Thinking about things as systems means looking for how every part relates to others. The output from one part of a system (which can include material, energy, or information) can become the input to other parts. Such feedback can serve to control what goes on in the system as a whole.

   #3 Any system is usually connected to other systems, both internally and externally. Thus a system may be thought of as containing subsystems and as being a subsystem of a larger system.

National Science Education Standards (NSES)

B. Physical Science

   Grades 5-8

   2. Motions and forces

   #2.3 If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

E. Science and Technology,

   Grades 5-8

#1.2 Design a solution or a product.

#1.3 Implement a proposed design.

#1.4 Evaluate completed technological designs or products.

#1.5 Communicate the process of technological design.

Grades 5-8 Abilities of Technological Design

   #2 Design a solution or product. Students should make and compare different proposals in the light of the criteria they have selected. They must consider constraints—such as cost, time, trade-offs, and materials needed—and communicate ideas with drawings and simple models.

International Technology Education Association (ITEA)

Standard 8: Students will develop an understanding of the attributes of design.
Grades 6-8: Requirements for a design are made up of criteria and constraints.
Standard 9: Students will develop an understanding of engineering design.
Grades 3-5: The engineering design process involves defining a problem, generating ideas, selecting a solution, testing the solution(s), making the item, evaluating it and presenting the results.

The Designed World
Standard 18: Students will develop an understanding of and be able to select and use transportation technologies.
Grades 6-8: Transportation vehicles are made up of subsystems, such as structural, propulsion, suspension, guidance, control and support that must function together for a system to work effectively.

International Society for Technology in Education (ISTE)

Technology Foundation Standards for Students

3. Technology productivity tools
   - Students use technology tools to enhance learning, increase productivity and promote creativity.
   - Students use productivity tools to collaborate in constructing technology-enhanced models, prepare publications and produce other creative works.
4. Technology communications tools
   - Students use telecommunications to collaborate, publish and interact with peers, experts and other audiences.
   - Students use a variety of media and formats to communicate information and ideas effectively to multiple audiences.
5. Technology research tools
   - Students use technology to locate, evaluate and collect information from a variety of sources.
   - Students use technology tools to process data and report results.
   - Students evaluate and select new information resources and technological innovations based on the appropriateness for specific tasks.
6. Technology problem-solving and decision making tools
   - Students use technology resources for solving problems and making informed decisions.
   - Students employ technology in the development of strategies for solving problems in the real world.