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# Age Levels:

* High School / Physical Science / Computer Integrated Manufacturing

# Total Time Required:

### One to Two Weeks

# Prepared by:

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# Unit Objectives:

Students will be able to:

* Identify the basic forces involved in flight
* Design a modification for an ornithopter
* Design a wing to produce the most lift

# Science Standards and Standards for Technology Literacy:

## Science Standards:

* **ICP.3.2** Construct force diagrams and combine forces to determine the equivalent single net force acting on the object when more than one force is acting on the object.
* **ICP.3.5** Qualitatively describe and quantitatively determine the magnitude and direction of forces from observing the motion of an object of known mass.

## Standards for Technology Literacy:

* **Core Standard 2:** Students integrate effective communication skills to solve a problem.
* **Core Standard 3:** Students apply and adapt the design process to develop a working drawing to be used in the completion of a product.

# Recommended Instructor Preparation

The following are all great areas to gain some background understanding of the content in this unit.

Main Articles / Videos / Websites

* [Flight of the Bumblebee](https://www.sciencenews.org/article/flight-bumblebee) - ScienceNews + Google Document
* [Aerodynamic evaluation of four butterfly species](http://micro.seas.harvard.edu/papers/IROS2012_Kovac.pdf) - For use with Lesson #1
* [How a fly Flies](https://www.ted.com/talks/michael_dickinson_how_a_fly_flies#t-168978) - Michael Dickinson (15 min)
* [Robotic Insects](https://www.youtube.com/watch?v=olqaMw8bIb8) - Robert Wood National Geography Live! (15min)
* [How Bees Fly](http://www.livescience.com/33075-how-bees-fly.html) - livescience.com
* [Slo-mo Bee](https://www.youtube.com/watch?v=yRE2rMIXvyU) - 15 seconds
* [Slow Motion Flight and Facts](https://www.youtube.com/watch?v=IbS5KHzC-Y0)
* [Dragonfly Flight](https://www.youtube.com/watch?v=oxrLYv0QXa4) - Smarter Every Day. At 2 min he talks about what makes wasps fly.
* Purdue Bio-Robotics Lab
* Harvard Robotics Lab

Lesson Plan #1: Why Can’t Bumblebees Fly?

# Lesson Focus:

This lesson will introduce the main ideas, the design brief, and a starting place for students to investigate the forces of lift on insect wings.

# Age Levels:

### High School / Physical Science / Computer Integrated Manufacturing

# Total Time Required:

* Two 55 minute Class Periods

# Lesson Objectives:

Students will be able to:

* Explain what the basic forces affecting the flight of a butterfly
* Design a way to scientifically test and experiment with wing design and lift

# Equipment and Materials

| **Tools and Materials** | **Quantity Needed** |
| --- | --- |
| Butterfly Wing Designs | 4 Wing Templates per group + 1 Student Designed Wing |
| Popsicle Wing Stands | A range of angles per group |
| Basic Fans | One per group / every other group |
| Digital Anemometer | One per class |

## Special Notes on Materials:

# This lesson takes many materials from a [Butterfly Wings: Using Nature to Learn About Flight](https://www.sciencebuddies.org/science-fair-projects/project-ideas/Aero_p049/aerodynamics-hydrodynamics/butterfly-wings-using-nature-to-learn-about-flight#summary) and the instructor should read through this assignment.

Lesson Procedures:

Day 1: Intro, Design Brief, and Setup the Experiment.

1. Begin with ScienceNews article “[BumbleBees Can’t Fly](https://docs.google.com/document/d/19yCwU9fbA9aw7thRO1v-BXJEeEhjbrfs70e4_ezA2w8)”
2. Place students in groups for to discuss the article and their answers.
   1. ***Why did the engineer assume that the bumblebee could not fly?***
3. Introduce the [**Design Brief**](https://docs.google.com/document/d/1KSsQ0IGoV8bKlIVoNwRAEw6robBYeFIAmu4TSPFmYAg/edit) to the students.
4. As a class we will define lift, and I will introduce students to a free body diagram and the students will be able to use the [Butterfly Glide Reading](https://docs.google.com/document/d/1IemmdfjE8s0R0HaM31lPEV7o1QYOpM8bmfS7xyXoJvU/edit) as a resource.
5. After defining lift and we will begin the experimental procedure for lift based on butterfly glide.
6. Students will cut out the three designs and then also draw up their own butterfly wing design.
   1. When designing the wing, each member will make one sketch in their engineering notebook and then they will decide which one will give the greatest lift. Each group will take pictures of each student created design.
7. Depending on time remaining, we will introduce the method of testing the wing designs.
   1. ***Have you ever held your hand out the window of a moving car, or in front of a strong fan? How does rotating your hand affect the lift force that you feel (pretend your hand is a wing)?***
   2. ***What are the four forces that act on a flying object? Which ones cancel each other out?***
   3. ***How do you think changing angle of attack changes lift and drag?***
   4. ***What angle of attack do you think real butterflies use when they glide during flight?***
   5. ***What are possible variables that we are testing?***
   6. ***What are we measuring?***
   7. ***What are the controls?***

**Day 2 – Completing the Experiment**

1. On the second day we will actually test the wing designs with the bases. Prior to actually testing the designs, each student will make their own ranking prediction of the 5 designs and record this in their engineering notebook.
2. Students will create a data table in their engineering notebook and will record the data for the table.
3. Students will need to graph one wing design in their notebook.
4. They will then create a table in Google Slides and will enter their data and then create a graph of the data as well.

***Below is an example of what they should have in their notebooks.***

Experimental Procedure for Butterfly Lift

**Variables:**

Fan speed, angle, wing type, lift force, weight.

Angles to test: 0, 15, 30, 45, 60, 75, 90.

Teacher Created Supplies (Wing Supports, 0, 15, 30, 45, 60, 75, 90)

Student Materials (5 wing designs, 4 Given and one student created)

Data Table (Copied into Engineer’s Notebook) :

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Lift Force | | | | |
| Angle of Attack | Wing A | Wing B | Wing C | Wing D | Wing E (student designed) |
| 0 |  |  |  |  |  |
| 15 |  |  |  |  |  |
| 30 |  |  |  |  |  |
| 45 |  |  |  |  |  |
| 60 |  |  |  |  |  |
| 75 |  |  |  |  |  |
| 90 |  |  |  |  |  |

# Student Resources:

n/a

# Student Worksheets:

* Why Bumblebees Can’t Fly Article [Add links from dropbox?]
* Design Brief [Add links from dropbox?]
* Butterfly Reading [Add links from dropbox?]

Lesson Plan#2: Digging Deeper and Uncovering Flapping Wings

# Lesson Focus:

This lesson will introduce the main ideas, the design brief, and a starting place for students to investigate the forces of lift on insect wings.

# Total Time Required:

* Two to Three 55 minute Class Periods

# Lesson Objectives:

Students will be able to:

* Explain what the basic forces affecting the flight of a butterfly
* Design a way to scientifically test and experiment with wing design and lift

# Equipment and Materials

| **Tools and Materials** | **Quantity Needed** |
| --- | --- |
| Computers with Graphing Software |  |
| Laser Cut template for Ornithopters  (or 3-d Printed ones) | 2 per group |
| Large Tissue Paper for Wings | 2 per group |

## Special Notes on Materials:

Depending on what type of ornithopters you have will determine the length of this lesson. I had my students build them from scratch using balsa wood, paper clips, brass rods, etc and that was a HUGE mistake as it took several weeks to build. There are a couple of 3-d printed ornithopters out there (Thingiverse) but I am not sure how effective they are. If you can use a laser and cut out a template similar to the [Gryphon ornithopters](http://birdkit.com/models.gryphon.html) sold by birdkit.org would be the best solution. There are also plenty of [resources](http://birdkit.com/resources.school.html) found there as well. If they build them from a laser cut kit, they will probably work better but will take longer. If from a 3d printer, they may not work as well, but should be shorter time. If they build them from scratch, be prepared for the worst.

Lesson Procedures:

**Day One** [or more depending on ornithopters, see note above]

1. I will explain to students how to use Google Sheets to organize data and create graphs.
2. After graphing the whole set of data we will discuss the results.
   1. ***Which angle has the greatest lift? Does everyone agree?***
   2. ***Which wing design of the 4 had the greatest lift? Did anyone have a wing design that gave a greater lift than the teacher given designs?***
3. Students will then find calculate the surface area of each wing design using square cm graph paper. One person in each group will find the area for one design. Students will then have to make a claim about how surface area affects lift using data to substantiate their claim.
   1. ***Is there any relationship between surface area and lift?***
   2. ***Would this wing design lift a bumblebee? What about our drone? Was the engineer correct on the fact that bumblebees cannot fly? What is missing in this experimental design?***
4. After we realize that the fixed wing design does not work well to describe the motion of a bumble bee or a drone then I will show part of the Smarter Every Day “Dragonfly flight” video.
5. After the video I will introduce to students the ornithopter and toy plane models. We will show how the toy plane flies using the rubber band engine and then we will look at the design of the ornithopter.
6. Students will also be introduced to the 21st Century Rubrics
7. I will give each student group a 3D printed ornithopter and each group will have to design the wings. As before, each student will have to create their own design for the ornithopter in their engineering notebook.
   1. What did we learn from the butterfly glide lab and how will that affect your designs?

**DAY TWO**

On the second day of this lesson, students will create their design and we will have a flying competition. Each group will try to make their ornithopter fly as long as possible given the same number of twists with the rubber band.

1. Looking at each design each student designed, the groups will have to pick one design that they think will work the best based on what they have understood before.
2. Students will have time to build the ornithopters and some time to do several test flights. With about 15 minutes left in class, we will have them test out their designs one at a time. Prior to flying, each group will explain why they choose their design and what they believe are the benefits of their designs. Students will get two flights apiece.
3. After the launches and the mini-competition we will discuss as a class why the winner design was the best.
4. At the very end of class we will determine if these ornithopter designs are similar enough to actual insect designs that we would want to use for our 3-d printed bumble bee drone. If so, why? If not, what is the problem with these designs / or our assumptions on insect flight?

# Student Resources:

* [Dragonfly Wings](https://www.youtube.com/watch?v=oxrLYv0QXa4)
* [How to Build an Ornithopter](https://www.youtube.com/watch?v=NvFmh8MMyfI)

# Student Worksheets:

* Collaboration Rubric [Add links from dropbox?]
* Creativity and Innovation Rubrics [Add links from dropbox?]
* Critical Thinking Rubric [Add links from dropbox?]

Lesson Plan#3: How can we use biomimicry to design better drone wings?

# Lesson Focus:

This lesson will introduce the introduce biomimicry and will have the students begin to look at the basic types of insect flight.

# Total Time Required:

* 55 minute Class Period

# Lesson Objectives:

Students will be able to:

* Explain the two basic types of insect flight.

# Equipment and Materials

| **Tools and Materials** | **Quantity Needed** |
| --- | --- |
| Engineering Notebooks | One Per student |

## Special Notes on Materials:

If you have access to an entomologist it would be very beneficial to have them come in as an outside expert. We had the pleasure of having Dr. Holland from Purdue come and talk with us.

Lesson Procedures:

1. A couple of days ago we watched a part of the Smarter Every Day video on Dragonflies. In it he talked about the basic differences between wasps and dragonfly flight. Does anyone remember what the difference between the types of flight were? One of the things that Destin does in his videos is that he often goes and finds experts in the field of study that he can interview and learn more from. In science and in engineering it is important to learn from experts in their fields. Today we get to learn from one of those experts who will explain a little more about insect flight.
2. Introduce Dr. Jeff Holland, Purdue University (Entomologist)
   1. Undergrad and Graduate work at Carlton University in Ottawa.
   2. Post-doctoral work at Windsor University.
   3. Teaching and Researching at Purdue for 12 years.
   4. His interests include bugs, maps, and math.
3. Dr. Holland will show insect samples, explain the two main types of flight, explain about the different Orders of insects, and talk about various other interesting insect flight ideas.
   1. What is Biomimicry
   2. Two Main types of insect flight
      1. Direct Flight Mechanism (older evolvement)
         1. Damselflies, Dragonflies, Mayflies
      2. Indirect Flight Mechanism (new evolvement)
         1. Dobsonfly, Beetles, flies, bees
   3. Introduction to the Orders of Insects
   4. Interesting Insect Flight / Behaviors
4. If there is time left, have students get back into their groups and begin to design a wing shape that they would like to use for their final design. Each student should have their own design and then as a group they can finalize and choose one design.

# Student Resources:

* If you don’t have access to an outside expert, it would be time to enlist students to do online research.

# Student Worksheets:

n/a

Lesson Plan#4: Designing Wings

# Lesson Focus:

This lesson will have students design wings using parametric modeling software and then having them 3-d print these designs. Afterwards we will test each design.

# Total Time Required:

* Several 55 minute Class Periods

# Lesson Objectives:

Students will be able to:

* Explain how modeling software works and put it to use.
* Explain how a 3-d printer works
* Test their wing designs

# Equipment and Materials

| **Tools and Materials** | **Quantity Needed** |
| --- | --- |
| Computers with 3-d Modeling | One per group |
| 3-d Printers | One per class |
| Digital Anemometer | One per class |
| Ornithopter Rig | One per class |

## Special Notes on Materials:

If you have access to a laser cutter, it might be nice to have the students design their wings and have them cut out of the same material. This may help to balance out the more effective designs, based on keeping the material the same thickness and density throughout. You could also have them recreate a whole new ornithopter based off flying off of these wings.

Ornithopter Rig – When we tested this in our class we took a basic ornithopter and had students attach their 3-d printed wing to it and then we measured the wind speed as measured by an anemometer.

Lesson Procedures:

1. If groups have not already finalized a design based on their previous brainstorming they need to do so now. Groups will take their brainstorming ideas from the previous lessons and make a model of it on the software.
2. After gaining approval from the teacher, they will go and begin printing their file. If there are not enough printers then some sort of queue will be set up.
3. After each group gets their designs printed or cut out, then they need to figure out how they will add them to the ornithopter design rig.
4. After each group has their wing ready, the class will go through and test their designs. Basically the wings will be added to the ornithopter, the rubber band will be wound up and they will then use the anemometer to measure the wind speed produced by each wing design.
5. The students will then fill out group evaluations and rate their partners on the different 21st Century rubrics.

# Student Resources:

n/a

# Student Worksheets:

* Collaboration Rubric [Add links from dropbox?]
* Creativity and Innovation Rubrics [Add links from dropbox?]
* Critical Thinking Rubric [Add links from dropbox?]



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