TEAM PROJECT REPORT

Bio-Inspired Airfoil Design: A Research Experience and Classroom Implementation Plan

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For
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Research Experiences for Middle and High School Teachers"

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Abstract

The project and research studies the characteristics and design of the brown bat (*eptesicus fuscus*) to enhance the fabrication of an airfoil to further investigations of unmanned aerial vehicles (UAV) with the intention to further the study of bio-inspired micro-UVA.

Goal and Objectives

The goal of this project is to study the flight of the brown bat (eptesicus fuscus) and to use this knowledge to design an airfoil that can change position for optimal maneuverability for an Unmanned Aerial Vehicle (UAV). To achieve this goal, the objectives are:

- Learn the fundamentals of flight (lift, thrust, drag, camber, chord, Reynolds number, Mach, etc..).
- Use flight simulators, software and IPad 2 to design and test airfoils.
- Design and build an airfoil and test in the wind tunnel.
- Determine possible uses of bio-inspired airfoil designs for UAVs.

Research Tasks

Researching bio-inspired flight included literature search, studying the four principles of flight, Reynolds number, Bernoulli's principle, Mach, lift coefficient, an explanation of the genetic algorithm. Following basic formulas are used in the design of the airfoil:

Lift equation: $L = 1/2\ \rho V^2 S C_l$, where ρ = density, V = velocity, S = area, and C_l = lift coefficient,

Lift coefficient: $C_l = L/1/2\rho V^2 S$,

Mach Number: $M = V/a$, where a = speed of sound,

Reynolds Number: $R_e = \rho Vc/\rho$, where c = chord and *v* = kinematic viscosity, and

Bernoulli's Principle: $P_t = P_s + ½\ \rho V^2$, where P_t = total pressure and P_s = static pressure.

Not only was the terminology studied but the concept of tensegrity and how it may influence flight of UAV or kites was also studied. Flight was experienced by using the Real Flight Simulator and by flying kites and RC helicopters. A discussion of the importance of an airfoil that can morph can provide better safety for search and rescue teams by having a UAV that can experience various hazards but remain in flight. The Aeromorph, XFOIL and FOILSIM III computer programs were used to test various airfoil designs before actually making a model. The model airfoil was then put into the wind tunnel to test for lift and drag. Knowing the lift and drag data then the efficiency of the airfoil was calculated and graphed. In summary, the research tasks were:

1. Outlining and understanding the scientific design terminology to be used.
2. Outlining and understanding the mathematics-genetic algorithm to be used.
3. Conducting simulation studies to test various airfoil designs.
4. Make model airfoils.
5. Test the model airfoils and evaluate their performance.

Methodologies Used

The study of bio-inspired flight began with the understanding of the principles of flight, such as lift, drag, thrust and weight. In order to understand these terms and concepts many diagrams were drawn (see **Figure 1** on page 4) for the math equations to be used, such as, Reynolds number and lift coefficient. Many articles and books were read to give added information to support the instruction and research. Once the basics had been covered the concept of flight whether by an animal or a man-made machine was discussed with use of the flight simulator. The *UAV RealFlight* and the use of a remote control helicopter helped the understanding of the principles by demonstrating the thrill of flight. Using the iPad 2 to draw various airfoil shapes one can see that the flow of pressure or fluid flow around the airfoil can vary depending on the shape (camber percentage or thickness), as shown in **Figure 2** on page 4. To connect the shape of an airfoil to that of a bird or bat wings the genetic algorithm was demonstrated by using the *AeroMorph* and *XFoil* software. The goal is to develop the most efficient airfoil that is similar to that of a flying animal so that it can have better maneuverability. Perhaps, this new airfoil can be used to better allow UAV to fly more successfully in search and rescue missions. After generating the most efficient airfoil based on an existing airfoil and modifying the wing through a fitness mode the template of the airfoil was used to make a model airfoil (shown in **Figures 3, 4** and **5** on page 4) which was then tested in the wind tunnel.

The wind tunnel testing involved the airfoil being tested at angles of negative 21 degrees to positive 21 degrees, changing the angle every six degrees as well as taking data at 5 m/s intervals from 0 m/s to 35 m/s. The data collected for lift and drag was inserted into an Excel spread sheet and then graphed. The graphs consisted of (1) lift versus angle of attack, (2) drag versus angle of attack, (3) efficiency versus angle of attack, and (4) efficiency versus lift. Three of the four graphs seemed to offer visual data that represented a proportionate relationship between the variables graphed, however the efficiency versus lift graph looked very unusual, which is shown in **Figure 6** on page 5. As can be seen the comparison of the efficiency (= lift/drag) versus lift did not have a clean pattern because the data for the x-axis is constantly changing, unlike that of the other graphs with the comparison to the angle of attack (plotted on

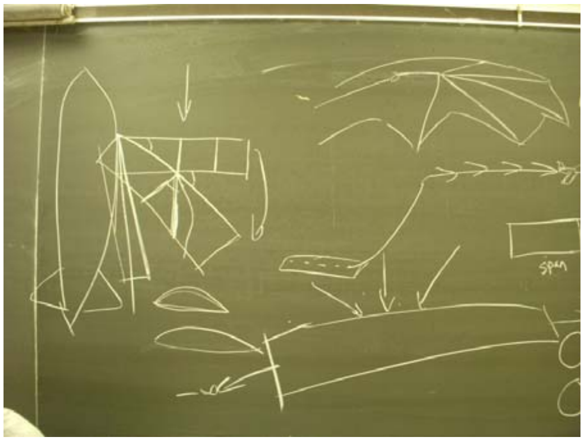

Figure 1. Drawings Showing the Comparison of the Bat Wing to that of Airplanes Ability to Sweep and to the Dynamics of a Supersonic Wing

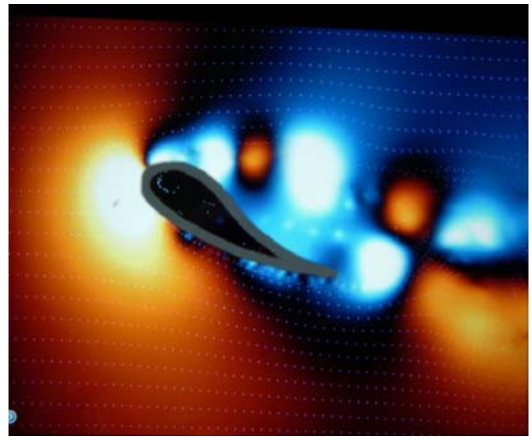

Figure 2. Wind Tunnel Simulator on the iPad2, Showing the Pressure Exerted on an Airfoil (Red is the high pressure and blue low pressure) - Low Pressure is Beginning to Wrap Around the Tail of the Airfoil which may Cause Stall

Figure 3. Working on the Template for the Cutting of the Airfoil

Figure 4. Using the Hot-Wire to Cut the Airfoil Out of Foam Insulation

Figure 5. The Airfoil After the Epoxy Resin was Applied and the Airfoil was Sanded (from the side view one can see the camber of the airfoil)

x-axis) are fixed numbers. However, the graph obtained for lift versus angle of attack, which is shown in **Figure 7**, shows a nice pattern of an increase of lift as the angle of attack increased as well as the velocity. The slight downturn on the positive side of the graph represents the beginning of stall.

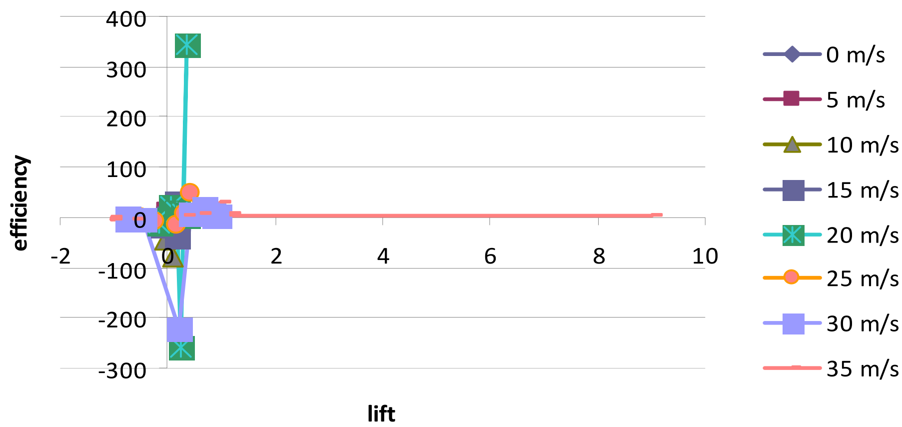

Figure 6. Efficiency Versus Lift Plot

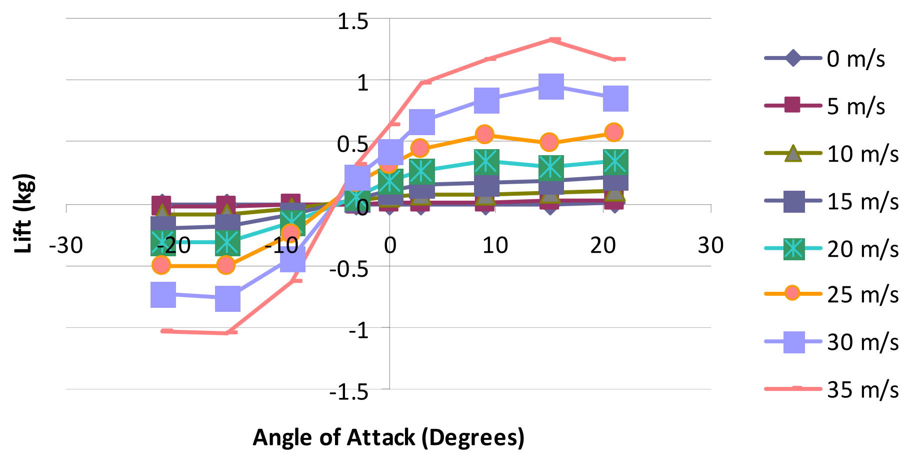

Figure 7. Lift Versus Angle of Attack Plot

<u>Training Received</u>

As mentioned earlier many simulators were used to help the participants to visualize and participate in the process of developing flight. While the flight concepts were being discussed the participants were able to use the flight simulator, RealFlight, and a remote control helicopter to actively experience the concepts. The Graduate Student Mentor was very helpful in giving the reasons as to why the aircraft can take flight and sustain flight based on what the participants were learning. The knowledge gained by using the simulators was then used to fly a kite and discuss the reasoning behind this very early means of flying and how this tied in to the earliest explorations in flight.

Designing the airfoil involved the use of the iPad 2 as a means of demonstrating the concept of lift and drag. Various shapes and sizes of an airfoil were drawn on the iPad 2 and the participants were able to see the change of pressure (see **Figure 2** on page 4). The iPad 2 would be a great tool to use in the classroom because it is easy to work with, is visual, and the students can touch the screen, therefore allowing the tactile learners to explore. After the Genetic Algorithm basics were covered the use of the software, *AeroMorp*h, to generate an optimal airfoil was used. Several math equations were needed to perform this task, such as finding the lift coefficient, Reynolds number, and Mach number. The book, *Fundamentals of Flight*, 2nd Edition by R. S. Scherell (Publisher: Prentice Hall, Inc., Upper Saddle River, New Jersey, 1989) proved beneficial information to the participants. The needed data to solve these mathematics equations are included in this text. After the optimal airfoil was generated, then the use of hot-wire was used to cut out the model of an airfoil from a foam board pressure (see **Figures 3** and **4** on page 4). The constructed airfoil was sanded and a coating of epoxy resin was applied on its surface, as shown in **Figure 20** on page 4. The testing in the wind tunnel involved attaching the airfoil in the chamber (see **Figure 6** below) and then setting to zero the lift and drag on the wind tunnel digital readout (see **Figure 7** below) assembly that sends the data to the computer to be put into an Excel program. Each time an angle of attack was tested the airfoil had to be moved to the angle and then the computer program had to be reset with the angle of attack and the increments of velocity tested. When the sound of the wind tunnel leveled out the log data button was clicked, the velocity was increased until 35 m/s was reached, and then the reverse was recorded back to 0 m/s. One must remember to reset the lift and drag digits to zero before every testing. Once all data was collected in the Excel program, graphs were generated and analyzed. The wind tunnel proved useful allowing for the visualization and documentation of the data needed to support or refute the airfoil design prepared by the participants.

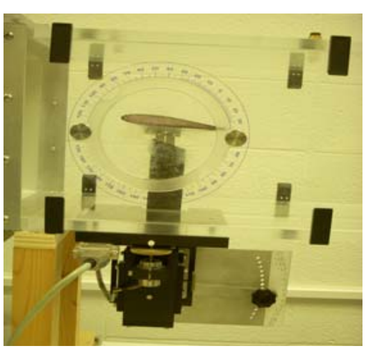

Figure 6. The Airfoil in the Wind Tunnel at a Positive Angle of Attack

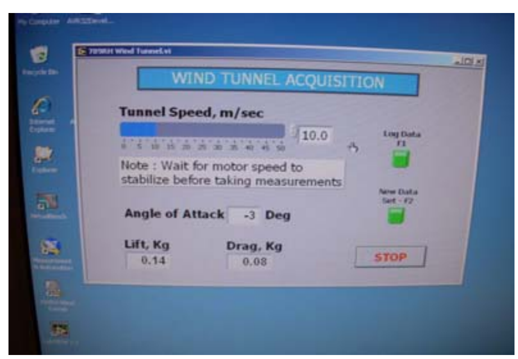

Figure 7. Wind Tunnel Data Collection for 3° Angle of Attack with Velocity of 10 m/s

Research Findings

Research led to many discoveries such as the four components of flight: lift, drag, thrust and weight were discussed and understood. In order to design an airfoil these components needed to be discovered so that the remaining of the research could then be built upon. Because the research is in Bio-Inspired Flight the use of the Genetic Algorithm was of utmost importance. The Genetic Algorithm is something that can be used in our daily lives but on a different scale. It is the approximate solution to problems through the use of natural selection (evolution). A Genetic Algorithm maintains a population of candidate solutions for the problem at hand, and makes it evolve by iteratively applying a set of stochastic operators, such as selection, recombination and mutation. This process continues until optimal population (threshold) is achieved. The selection is the survival of the fittest leading to the best population. The information presented in the text, *The Simple Science of Flight from Insects to Jumbo Jets* by Henk Tennekes (Publisher: MIT Press, Cambridge, Massachusetts, 2009), gives supporting evidence that unless a bird can adapt to wind speed, weight etc. it will not be able to complete its flight and may perish. Sahara grasshoppers have ended up in England or unfortunately have drowned in the Atlantic Ocean. Many birds have adapted over the years to build up their strength in order to maintain flight for longer distances. Because bird's wings can move independent of themselves and airplane wings are static the knowledge of how to design the optimal wing using the genetic algorithm will help to insure a safe and more efficient flight for aircraft.

Another goal of developing a new wing is to be able to maneuver the wing to meet the demands on the wing due to environmental stresses, such as wind speed, the avoidance of objects or attack. The bat is a good example of being able to change the form of its wing, thereby changing its camber. According to *Bats, Biology and Behavior* by John D. Altringham (Publisher: Oxford University Press, Oxford, England, 2001), one example of how a bat's anatomy is helpful in allowing the bat to morph or change its wing is that bats are always changing direction and this is possible by making subtle movement of the wings or tail membranes. The capability of the bat's wing to fold allows the bat to retract one wing to avoid collision or to change direction.

The use of tensegrity may help with the manufacture of a wing that is able to morph. According to Richard Buckminster Fuller (excerpt from *Synergetics*, p. 372, Publisher: Macmillan Publishing Company, New York, New York, 1982), "The word 'tensegrity' is an invention: a contraction of 'tensional integrity.' Tensegrity describes a structural-relationship principle in which structural shape is guaranteed by the finitely closed, comprehensively continuous, tensional behaviors of the system and not by the discontinuous and exclusively local compression member behaviors. Tensegrity provides the ability to yield increasingly without ultimately breaking or coming asunder." The body has its own tensegrity system at work. The use of the limbs of the human body and being able to move them at will is very similar. The bones would be the structure to be moved while the ligaments and muscles would be the cables which allow movement and attachment. The bat's anatomy has this capability for movement.

The use of an airfoil that can change shape and allow for greater agility can be very helpful for MAVs or UAVs for search and rescue missions. The ability to send in a small aircraft with a camera to send back data will allow for the safety of the rescue team and the adapted airfoil would enable the MAV/UAV to maneuver through tight places and go where man may not be able to venture safely.

In summary following was learned from this research:

1. Four components of flight are: lift, drag, thrust and weight
2. Genetic Algorithm is the approximate solution to problems through the use of natural selection (evolution). The process includes in each generation the current population, selection (mutation or recombination), ranking of new possibilities repeated until the optimal population (threshold) is achieved. The selection is the survival of the fittest leading to the best population.
3. Airplane wings are static while birds/insect wings can morph (change shape).
4. Bats are able to morph (change camber, sweep and fold) their wings.
5. Unmanned Aerial Vehicles (UAV) is used to assist in the safety, search and rescue and collecting data related to natural disasters etc.
6. According to Richard Buckminster Fuller (excerpt from *Synergetics*, p. 372, Publisher: Macmillan Publishing Company, New York, New York, 1982): "The word 'tensegrity' is an invention: a contraction of 'tensional integrity.' Tensegrity describes a structural-relationship principle in which structural shape is guaranteed by the finitely closed, comprehensively continuous, tensional behaviors of the system and not by the discontinuous and exclusively local compression member behaviors. Tensegrity provides the ability to yield increasingly without ultimately breaking or coming asunder."

Classroom Implementation Plan

The Bio-Inspired Airfoil Design lesson is a part of a flight unit. The lessons can build upon one another and do not have to follow a particular order. This lesson is estimated to take five days to complete. The target audience (class) for this research is students ages 13 to 14 year olds, 8^{th} grade. To inspire and excite the students the setting of the classroom should invite the students to want to know more. The classroom should be decorated to resemble that of the interior of an airplane. Greet each student at the door and give out boarding passes with seating assignments. By giving the boarding pass with the seating assignment the teacher can change the groupings based on a heterogeneous grouping to allow for varied abilities to work together.

Once seated the rules of the flight (classroom rules) should be given, similar to that of a flight attendant explaining the rules on an airplane. Students should be given the lesson pre-test and then introduced to the lesson by reviewing with the students the genetics they have previously studied and the concept of survival of the fittest and natural selection. Explain the Genetic Algorithm by relating it to the making of the best shopping list of snacks for the classroom and the breeding of chickens to produce the most eggs. The teacher may want to use the smartboard to draw the options. Students will have fun playing the genetic algorithm card game in small groups to see how going through many generations of selection of the best traits will lead to the best offspring. Since this lesson is in addition to other lessons about flight some material may be review for the student, the teacher should be sure to review terminology if needed.

The teacher should show many pictures of flying animals and discussion should take place about the how these animals are able to fly and pay particular attention to the sings. Show the anatomy of a bat and how a bat flies. Relate flight of an aircraft with that of a bat and discuss the purpose of the study is to design a wing (airfoil) that can morph and have better maneuverability. Show the students the viewing of the United Streaming video, *Inquiring Minds: Things with Wings*, to help visualize these concepts. Discuss the components of flight, drag, lift, thrust and weight by showing an airfoil and labeling these terms as well as discussing their importance (this could be review depending on the order in which lessons are taught).

Using the iPad2 show the students many airfoil shapes and discuss how the flow and pressure shown can influence the efficiency of the airfoil. Using the Aeromorph software (software use is dependent upon operational ability) demonstrates to the students how the Genetic Algorithm can be used to design the optimal airfoil. Students will use the FOILSIM III simulator from the NASA website to work on their own airfoil design. After taking data the students will summarize their findings in writing as well as design on paper their airfoil. Students will design an airfoil and make a model that will be cut out and labeled. As a culminating activity students will play the review game from the NASA website answering various questions about flight and having fun by “flying” around the world in the game to reach their final destination. Many of these activities are hands-on and minds-on activities. According to the article, “What happened to science education?” in the *Astronomy* journal by B. Andrews (p. 44-47, August issue, 2011) teachers need to instill in their students the desire to explore and learn. Science happens every day and students need to see the relationship of science with every day luxuries that the students enjoy. Without science many inventions that are so important in their lives would not exist. Based on many of these activities it is hoped that the students will see that science is fun and they will develop a desire to question and then to explore. The "what if" question should be a part of the common language of the science teacher and to persuade the students to always ask "what if" and to seek out new and exciting ways to improve our lives. When the lesson is complete the students will take the Post-test.

As an extension the students may be taken to the National Museum of the United States Air Force in Dayton, Ohio. The students can then see the actual aircraft and wings (airfoils) that have evolved over the decades to better meet the demands of flight. This fieldtrip can incorporate other curricular areas such as Language Arts (writing descriptive paragraphs), Social Studies (WWI and WWII), art (drawing of an aircraft) as well as mathematics (measurement the use of various formulas of flight). Taking the student out of the classroom and allowing them to see that science is all around and how beneficial science is to their daily life is of importance. It is hoped that by seeing science in action many students will strive to become scientist and become the future of science.

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www.grc.nasa/WWW/k-12/airplane/ (retrieved 7-19-2011)

APPENDIX: LESSON PLAN

1A. Lesson Name: Genetic Algorithm/Airfoil design
Teachers Names: Veronica Dean and Sherry Kembre
Subject: Physical Science
Grade level: 8^{th}
Duration: 5 day lesson

1B. Analyze Learners:

Overview & Purpose (Engineering theme):

A Applying key flight engineering concepts to the creation of a model.
C Aerospace engineering, mechanical engineering, meteorology, material engineer, computer engineer, computer software design,
S Safety of flight, consumer cost,

2. Education Standards Addressed

Ohio Standards:

Science and Technology

B. Design a solution or product taking into account needs and constraints (e.g., cost, time, trade-offs, properties of materials, safety and aesthetics).

3. Design and build a product or create a solution to a problem given more than two constraints (e.g., limits of cost and time for design and production, supply of materials and environmental effects).

4. Evaluate the overall effectiveness of a product design or solution.

Scientific Inquiry

B. Analyze and interpret data from scientific investigations using appropriate mathematical skills in order to draw valid conclusions.

3. Read, construct and interpret data in various forms produced by self and others in both written and oral form (e.g., tables, charts, maps, graphs, diagrams and symbols).

Scientific Ways of Knowing

C. Give examples of how thinking scientifically is helpful in daily life.

2. Explain why it is important to examine data objectively and not let bias affect observations.

3. Goal

To engage students with the concepts genetic algorithm and airfoil design.

Objectives: Students will be able to:

- predict by genetic algorithm method to help generate an efficient airfoil design.
- identify the key parts of an airfoil/flight.
- create a model of an airfoil.
- identify forces acting upon an airfoil.
- compare flight of an airplane to that of a bat.

STEM components: science, engineering and technology

4. Misconceptions

- The motion of an object is always in the direction of the net force applied to the object.
- A force is always needed to keep an object moving with a constant speed.

5. Materials needed

- iPad 2 Computers
- FoilSim III www.grc.nasa/WWW/k-12/airplane/foil3.html
- Game www.grc.nasa/WWW/k-12/airplane/ (Aeromorph U.C. software Cody Lafountain
- 10 decks of playing cards

6. Instructional strategies

Direct instruction, demonstration, hands on lesson, inquiry lesson, student presentation, activity.

7. Technology

- iPad 2 computers
- Wind tunnel
- Smoke tunnel

8. Learner Participation

Teacher pieces: Facilitator of material, simulators and wind/smoke tunnels.

Student pieces:

- Use of computer and simulators.
- Create a model airfoil.

Days 1:

- Give students the pre-test (10 min.)

- Review genetics' material covered in previous classes. (5 min.)

- Relate the Genetic Algorithm to their lives through the making of a list. (10 min.)

- If needed discuss the breeding of chickens, show on board, to get the best chickens for egg production. (10 min.)

- Introduce the Genetic Algorithm card game, see handout, in small groups.

Day 2:

- Review how to play the GA card game (10 min.)

- Students will play the GA card game (20 min.)

- Review the day's activity by relating it to natural selection and breeding. (10 min.)

- Show various pictures of flying animals. Ask, "What is unique about these animals that would allow them to fly?" "Are the wings of these animals similar to that of an aircraft?" "How are they different?" "How do these wings benefit the animal compared to an airplane?" Discuss with the students the anatomy of the bird and bat. Show picture of the bat wing anatomy and a bat in flight. Explain how the ultimate goal is to be able to have wings like a bat so that the aircraft can have better maneuverability. (10 min.) Continue discussion to day 3 if needed.

Day 3:

- Continue discussion from day 2 if needed. Show the United Streaming video, "Inquiring Minds: Things with wings" (15 minutes)

- Students should write down what is unique about animals with wings and discuss in a group their list. Have the students list what an airplane would need in order to fly like a bird. (10 min.).

- Review the components of flight by using the sample airfoils to show lift, drag, thrust, camber, chord, and weight.

- Using the iPad 2 Wind Tunnel and a document projector show the students various airfoil shapes and the pressure and airflow of an airfoil. (10 min.)

Day 4:

- Aeromorph software demonstration by teacher: (20 min.) Using the smartboard to show the students the Aeromorph software.

- Review the Genetic Algorithm with the students and using the software demonstrate for the students the Aeromorph software. See teacher instructions handout.

- Enter data into the software and generate new generations of airfoil.

- Ask "Which combination will result in the best efficiency?" Students should see the different graphs, but pay close attention to the efficiency graph. Ask, "Which one reaches the highest in number for efficiency?

- This can also be continued to optimize the airfoil to get the best combination out of the 20 generations. Remember to discuss the genetic algorithm with this method.

- Ask, "Why do we want to have the most efficient airfoil for our airplane/UAV?" record responses on the board.

- After having discussed the Aeromorph software students should work with the computers to use the FOILSIM III simulator from NASA. www.grc.nasa/WWW/k-12/airplane/foil3.html (25 min.)See student's worksheet packet. Students are to record data from their testing of the thickness, lift, drag, Reynolds number, l/d ratio and are to draw the graph of each as well as the airfoil shape.

- If time repeat the process by having the camber constant at 0 and then the student adjusts the thickness 4 different times and record the same data as mentioned above.

Day 5:

- Give students time to finish their design of their airfoil on paper. In small groups student should share their design and discuss their reasoning for their design. (20 min.) **Extension:** With the help of parents students can make a stencil of their airfoil and cut out a model of the airfoil using insulation foam and a hot wire. Students should then label the model. Another possible extension is to tour the National Museum of the United States Air Force in Dayton.

- Culminating activity-Students should play the review game at www.grc.nasa/WWW/k-12/airplane

- Once at the site the students should click on Kid's Page then click on Fun & Games then click on The Plane Game and play the game. The sound should be turned off. (10 min.)

- Post-test (10 min.) Give students back the original test and have them write their new answer on the back. This is so they can see how their knowledge has increased.

9. Evaluate (Assessment)

1. Pre-assessment

2. Participation

3. Airfoil model

4. Post-assessment

10. Essential/Review Questions

1. What does it mean to cooperate with others?

2. How is the flight of an airplane similar to that a bat?

3. What are the four components of flight?

4. How will the flight of an airfoil with a large camber number compare to one with a zero camber number?

11. Pre/Post test Questions

1. Draw and airfoil and label the four components of flight.
2. How does the flight of an airfoil with a large camber percentage (40%) compare to 0% camber?
3. How is the flying of an airplane similar/different to that of a bat?
4. How does the Genetic Algorithm relate to everyday tasks?

12. Reflection

We predict that the students will enjoy playing the card game and working with the computer software.

Safety concerns:

- Ergonomics-students should have proper posture and hand positioning for working with the computers.

- Safety glasses

APPENDIX TO LESSON

PLAN: Genetic Algorithm Card Game

Purpose:

To achieve the highest score by adding the remaining cards in hand after 3 generations of breeding. Highest score has the best genetic offspring.

Material:

2 decks of cards (population). One for dealing and one with the cards 9-Ace used for selective breeding (exchange).

Card Values:

Number cards = face value
Ace=1 Jack = 11 Queen = 12 King = 13

Directions:

Players may choose to play as cooperative teams, or as individuals. Teams may decide not to continue at any time.

(Teams)

Divide into teams of no more than 4-5 players.

Dealer deals one card to each player on the team. Team works together while holding one each.

(Individual)

Players work alone with a group of cards. Dealer deals each player 5 cards at random.

Round 1 (1st generation)

At this point, each competing team or individual has a population of cards.

Players are to (rank) the cards and decide which card they would like to discard and randomly choose a card from the dealer (mutation).

(Teams)

The teams decide as a group which card to discard. The player holding the discarded card chooses a random card from the complete mutation deck held by the dealer.

(Individual)

Each player chooses which card to discard, then selects a new card from the mutation deck.

Round 2 (2nd generation)

Players decide (eliminate) which card to discard and which two good cards they would like to use to repopulate (selective breeding). Dealer presents the recombination deck (contains only 9-King and Ace).

(Teams)

Player holding the discarded card chooses a card from the recombination deck.

(Individual)

Each player chooses which card to discard, then selects a new card from the recombination deck.

Round 3 (3rd generation)

Individual/team can choose to repeat rounds 1 or 2. (repopulate and threshold) Repeat until no individual/team wish to continue.

Finish:

Individual/team is to add the value of the remaining cards in hand. Individual/team with the highest number has produced the best genetic offspring.

Teacher Directed Demonstration of the AeroMorph Software

After reviewing the Genetic Algorithm demonstrate using the smartboard the software for designing and testing an airfoil.

Choose from one of the following airfoils the data to be recorded in the following fields of the software.

	Piper J3 Cub		Cessna 172
Airfoil	USA35B		NACA2412
Cruise Speed	121 km/hr		226km/hr
Altitude	3500 m		4100 m
Weight	550 kg		1111 kg
Wing Area	16.58 m^2		16.2 m^2
Span	10.74m		7.32 m
Chord	1.54 m		1.49 m
Reynolds's #	2 641 459.56		45.3660429 x 10^5
Mach	0.103038107		0.19395
Lift coefficient	0.673613208		0.424867167

1. Select either USA35B or NACA2412
2. Type in the type of airfoil in Input Filename
3. Click on Load Airfoil
4. Click on Optimize Shape
5. Enter the Reynolds #, Mach #, Lift Coefficient for the aircraft from the chart above.
6. Enter the sweep as 1-45 degrees and the thickness -1 to 1.
7. Click on optimize
8. This runs through the Xfoil-virtual wind tunnel
9. Name the airfoil shape and save in Save Airfoil
10. Put your filename in input filename box and load in your airfoil named
11. Compare to original airfoil click generate run
12. Type in Reynolds # and Mach number select compare to original airfoil
13. Click generate run
14. See results comparing the two airfoils.
15. View the efficiency graph, lower right hand corner, the line with the highest value is the better airfoil for your flight conditions.

Ask students:

Which airfoil is the better airfoil in terms of efficiency?

Why do we want an airfoil that gives greater lift?

How is this process related to natural selection of animals?

Further testing option:

If you would like to design another airfoil use the following website to find the data necessary to calculate using the following formulas.

http://www.engineeringtoolbox.com/international-standard-atmosphere-d_985.html

16. Collect the following data: density, speed of sound, kinematic viscosity and complete the table.

17. Calculate for the Reynold's #, Mach, and Lift Coefficient

Re = VC / kinematic viscosity (velocity * chord / kinematic viscosity)

Mach = v / a velocity (velocity / speed of sound)

C_l (Lift Coefficient) = L / ½ density (rho symbol) * v^2 * s

Lift (Force= mass * acceleration) = weight (mass * gravity) /

½ * density * velocity^2 * area

Gravity constant=9.8 m/s^2

Take the airfoil and the numbers

() input

Generating the GA thru Xfoil software

FoilSim III Activity

Name___________________________Period______________________

Using the website www.grc.nasa/WWW/k-12/airplane/foil3.html to test the camber and thickness of various airfoils.

1. Click on Flight.
2. Enter 162 for the speed and 32400 for the altitude.
3. Click on Size.
4. Enter 10 for the chord length and 60 for the span.
5. Click on Shape.
6. Enter 2 for the angle and 0 for the camber.
7. You are to choose 4 different thicknesses for your airfoil to test. Enter all data in the chart below.
8. After entering the thickness then click on select plot and then click on lift vs. angle. Record the data below.

Trial 1: Angle **2** Thickness **0** S peed **162 mph** Altitude **32,400 feet** Chord **10 %c** Span **60**

Airfoil	Camber %	Lift lbs	Drag lbs	Reynolds#	L/D ratio
A	0				
B	40				
C					
D					

After each testing for a thickness draw the airfoil, label (thrust, lift, drag, weight, chord, mean camber line) as well as draw and label each graph.

Airfoil	Lift versus angle graph-label	Draw and label the airfoil
A		
B		

C		
D		

9. Repeat steps above and enter all data the same except thickness will be 10, see below:

Trial 2: Angle 2 Camber 0 Speed 162 mph Altitude 32,400 feet Chord 10 %c Span 60

Airfoil	Thickness %crd	Lift lbs	Drag lbs	Reynolds#	L/D ratio
A	5				
B	15				
C					
D					

After each testing for a thickness draw the airfoil, label (thrust, lift, drag, weight, chord, mean camber line) as well as draw and label each graph.

Airfoil	Lift versus angle graph-label	Draw and label the airfoil
A		

B		
C		
D		

How does the graph change from a Camber of 0% to a thickness of 40%? Explain.

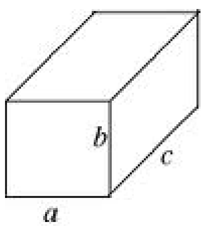
How does the graph change from a camber of -13.56 % to a camber of 15.52%? Explain.

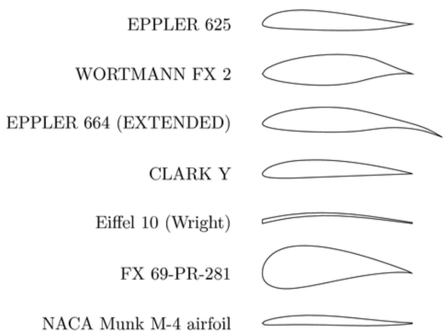
Which camber of an airfoil has the best lift to angle ratio? What does this mean?

Which thickness of an airfoil has the best lift to angle ratio? What does this mean?

Draw your ideal airfoil, the width should be no more than 8 inches and the length no more than 3 inches.

A=3 inch section (side view) C=8 inch section (front view).





mathsfirst.massey.ac.nz texample.net

Drawing:

Pre-Post Test Genetic Algorithm/Airfoil design

Name_____________________________Period _____________________

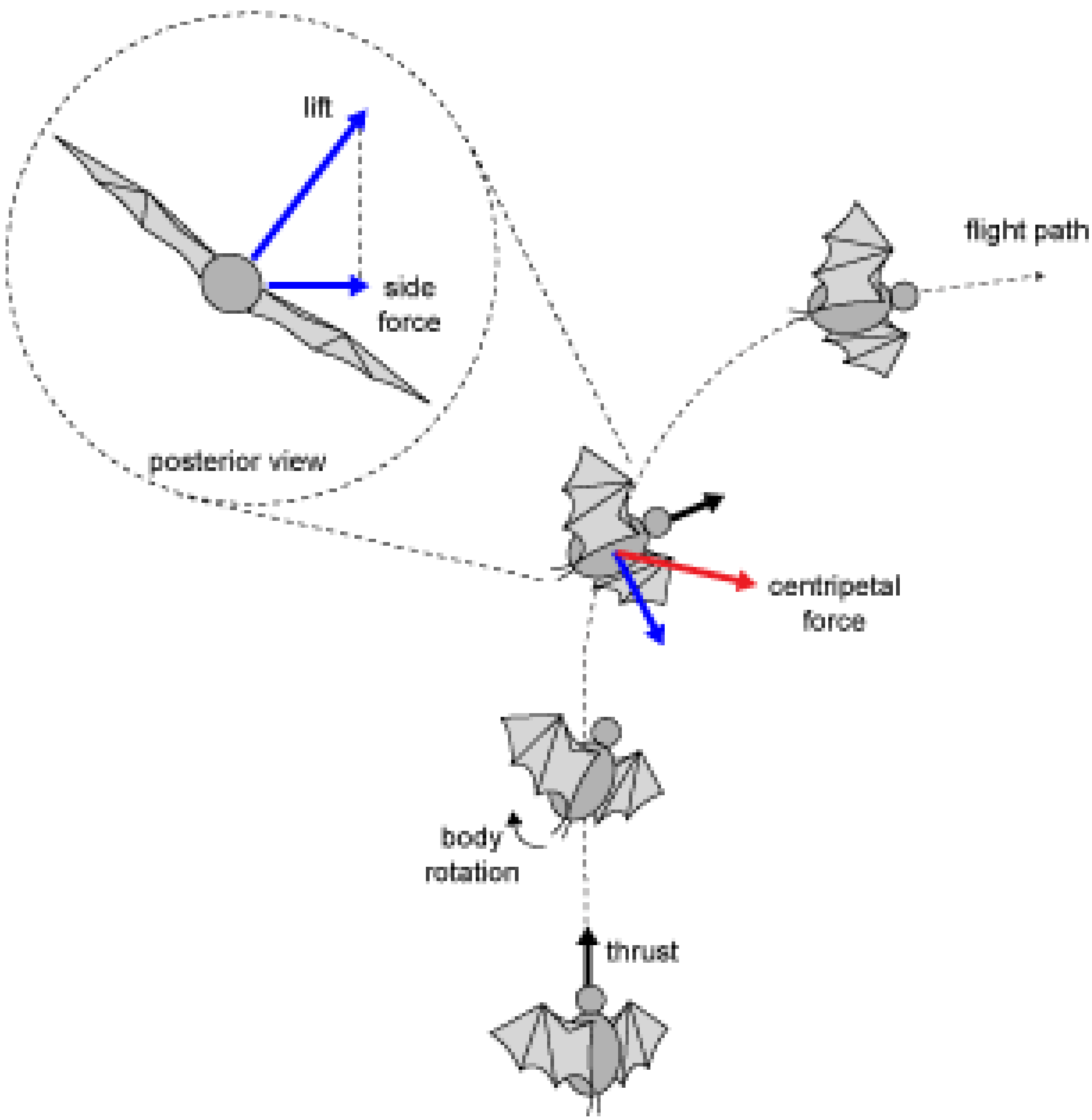
1. Draw and airfoil and label the four components of flight. (4 points)

2. How will the flight of an airfoil with a large camber percentage (40%) compared to 0% camber? (2 points)

3. How is the flying of an airplane similar/different to that of a bat? (2 points)

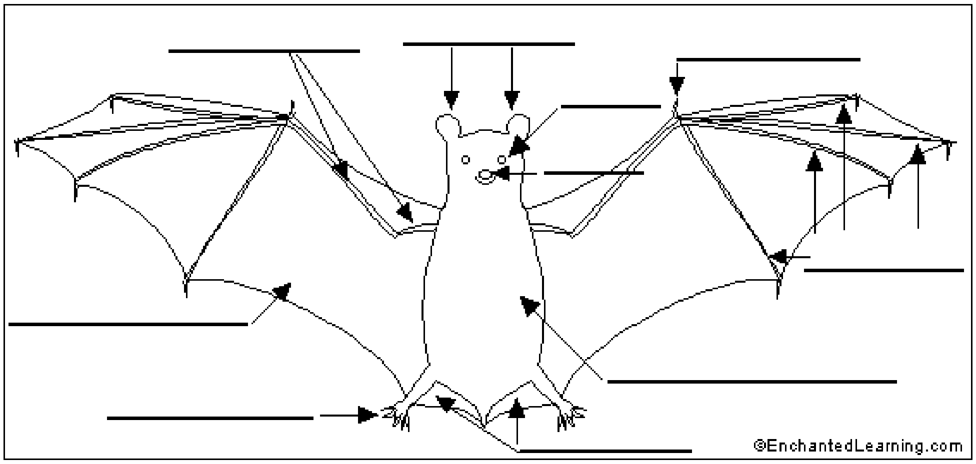
4. How does the genetic algorithm relate to everyday tasks? (2 points)

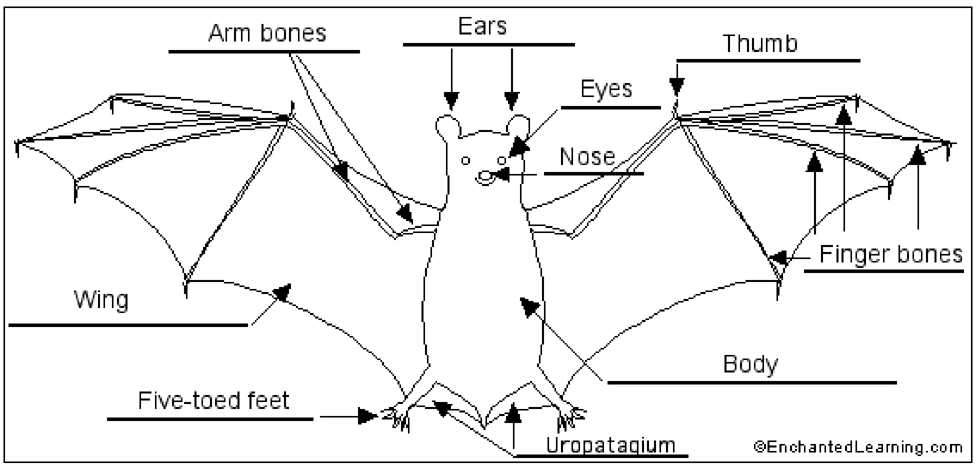
FLIGHT OF THE BAT

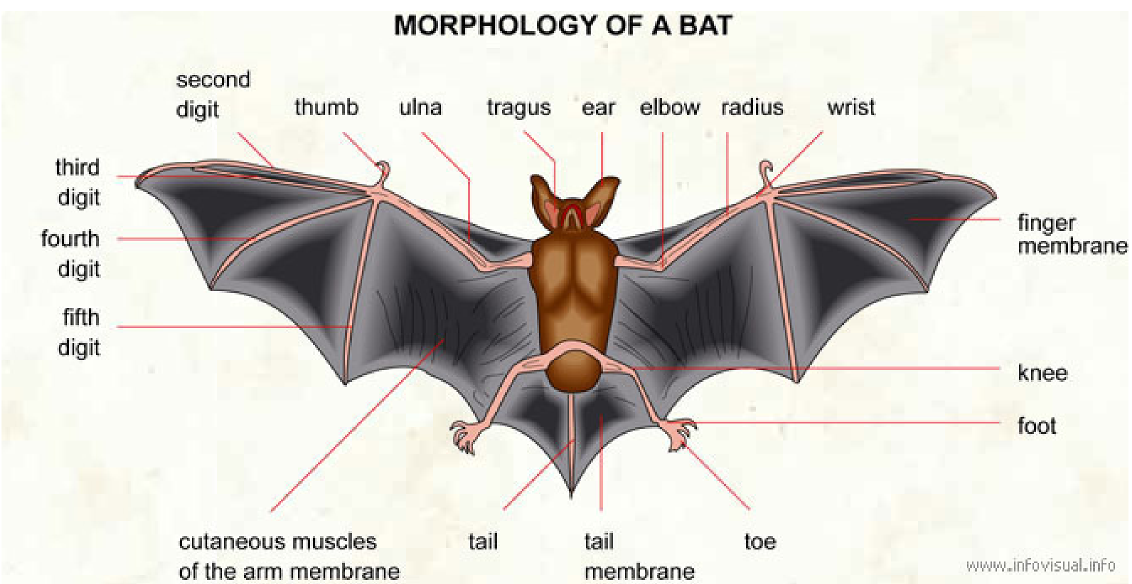


From: http://home.uchicago.edu/~jiriarte/images/turning.png

ANATOMY OF THE BAT







From: http://www.batproofny.com/images/batMorphology.jpg