For grade Level(s)  Middle School grades 6-8  
High School grades 9/10 and 11/12  

Suggested Time  MESA period: 3-5 weeks of daily 50 min. sessions  
MESA afterschool: 4 total sessions of 60-90 min periods  
MESA Saturday: 2 Saturdays for a total of 8 hours  

Purpose  The purpose of this unit is to reinforce or introduce the engineering design process to MESA students, while introducing them to the principle of flight and aircraft design. Students will be prepared to build and fly a model aircraft that will sustain a long flight time in MESA Day competition.  

Objectives  At the end of the unit students will;  
- Know the parts of the design cycle and relate them to aircraft design and construction  
- Critically analyze the design and construction in relation to the flight mission  
- Solve problems related to flight, lift and drag  
- Solve problems related to balance and torque  
- Solve problems related to angles  
- Understand the practical applications of the design process for students and engineers.  

Standards Addressed  
Common Core and NGSS  
Common Core Mathematics  
Ratios and Proportional Relationships 6. RP  
3. Use ratio and rate reasoning to solve real-world and mathematical problems, e.g. by reasoning about tables of equivalent ratios, tape diagrams, or equations.  
3c.Find a percent of a quantity as a rate per 100 (e.g., 30% of a quantity means 30/100 times the quantity); solve problems involving finding the whole given a part and the percentage.  

Grade 6  
Expressions and Equations 6. EE  
6. Use variables to represent numbers and write expressions and when solving real-world or mathematical problems;
understand that a variable can represent an unknown number, or, depending on the purpose at hand, any number in a specified set.

**Grade 6**

Geometry 6.G
Solve real-world and mathematical problems involving area, surface area, and volume.

**Grade 7**

Ratios and Proportional Relationship 7. Rp
Analyze proportional relationships and use them to solve real-world and mathematical problems.

Expressions and Equations 7.EE
2. Understand that rewriting an expression in different forms in a problem context can shed light on the problem and how the quantities are related. For example, \( a + 0.05a = 1.05a \) means that “increase of 5%” is the same as “multiply by 1.05”

4. Use variables to represent quantities in a real-world or mathematical problem. And construct simple equations and inequalities solve problems by reasoning about the quantities

Geometry 7.G
1. Solve problems involving scale drawing of geometric figures, including computing actual lengths and areas from a scale drawing at a different scale.

6. Solve real-world and mathematical problems involving area. Volume, surface area of two and three-dimensional objects composed of triangles, quadrilateral, polygons, cubes, and right prism.

**Grade 8**

Expressions and Equations 8.EE
1. Know and apply the properties of integer exponents to generate equivalent numerical expressions. For example;
\[ 3^{(2^{-5})} = 3^{-3} = 1/3^3 = 1/27. \]

Statistics and probability 8. SP
Investigate patterns of association in bivariate data
1. Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering outlies, positive or negative associations, linear or non-linear associations.
2. Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear relationship, informally fit a straight line, and points to the straight line

Higher Common Core Mathematics
Algebra 1- A1
Quantities N- Q
Reason quantitatively and use units to solve problems.
1- Use units as a way to understand problems and t
  guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

Seeing Structure in Expressions in A-SSE
Write expressions in equivalent forms to solve problems.
3-Choose and produce an equivalent form of an expression t reveal and explain properties of the quantity represented by the expression.

Statistics and Probability
Interpreting Categorical and Quantitative Data S-ID
1-Represent data with plots on the real number line (dot plots, histograms, and box plots.)

Make geometric constructions. G-CO
12-Make geometric constructions using a variety of tools and methods (compass, and straight edge, sting,
reflective device, paper folding, dynamic geometric software, etc.).

Geometric Measurement and Dimension G-GMD
4-Identify the shapes of two-dimensional cross-sections of three-dimensional objects, and identify three-dimensional objects by rotations of two-dimensional objects.

Modeling with Geometry G-MG
3-Apply geometric methods to solve design problems (e.g. designing an object or structure to satisfy physical constraints or minimize cost, working with typographical grid systems based on ratios.)

Next Generation Science Standards
Physical Science PS

MS-PS2-2- Plan an investigation to provide evidence that the change in an object’s motion depends on the sum of the forces on the object and on the mass of the object. [Clarification Statement: Emphasis is and on balanced (Newton’s first law) and unbalanced forces in a system, qualitative comparisons of forces, mass and changes in motion (Newton’s second law) frame of reference and specification of units.

HS-PS2-1-Analyze data to support the claim that newton’s second law of motion describes the mathematical relations among the net force on a macroscopic object, its mass, and its acceleration. Analyzing data using tools, technologies, and/ or models to make valid and reliable scientific claims or determine an optimal design solution.

Engineering Design

MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific...
principles and potential impacts on people and the natural environment that may limit potential solutions.

MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well the meet the criteria and constrains of the problem.

MS-ETS-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

HS-ETS1-2 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Assessment

Students will be evaluated through the following methods;
- Assessment work sheets
- Oral presentations with rubrics
- Lab reports with rubrics
- Project testing and evaluation

Additional Resources

www.physicsclassroom.com
www.grc.nasa.gov/WWW/k-12/airplane/short.html
www.modelaircraft.org/education/edpacket.aspx

Background

The first evidence of man wanting to fly was a coin from about 3500 BC depicting a man flying on an eagle’s back. About 1000 BC, the Chinese invented kites which carried men to scout troops. The first step to modern aeronautical engineering was Leonardo da Vinci’s designs about 1500. In 1799 Sir George Cayley invented the concept of fixed wing aircraft and followed that by building and flying a successful model glider. In 1903 the Wright brothers flew the first heavier than air, manned, engine powered airplane. Since then aircraft development, design and manufacturing has progressed rapidly. Long distance travel is now dominated by commercial aircraft.
are still problems to be solved—fuel economy, safety, passenger comfort, crew fatigue, take-off and landing reliability, manufacturing costs and plane longevity. For example, the addition of winglets on the wing tips significantly reduced drag and, therefore, saved much fuel.

**Benefit to Society**

Aircraft is now the major form of long distance travel. It is used for people, cargo, scientific experiments, hurricane watching, hospital, news watch, mail, firefighting, traffic watching, and the military. The next generation (there’s always a new innovation that advances the aircraft status) is the use of pilotless aircraft. With that change came the need for safety assurances, new flying space regulations, privacy protection and less pollution. Today’s commercial aircraft, i.e. Boeing and Airbus, are less reliant on pilots during long flights and are more fuel efficient. The passengers generally are more comfortable and the fatality rate is low. These trips are quick, clean, relatively inexpensive, allowing more time at the flight terminus. A trip from LA to NY takes about 5-8 hours while a train requires 3+ days.

**Engineering Design Process/ Module Content**

Engineers have to create solutions to a problem. The solution must fit into the given constraints the problem. In the MESA program, we learn to engineer solutions that can relate to real work problems. The use of the engineering design process contextualizes this problem solving approach for students.

This unit is organized around the steps in the engineering cycle. Define the problem, investigate, plan, create, evaluate and then start the process all over again until a valid competition ready project is created. The unit begins with an introductory activity that leads to students into the challenge to be addressed.
Organization of the Module Content

Introduction
- Build a foam plate glider (FPG-9) as an ice breaker. (www.modelaircraft.org/education/fpg-9aspx)

Define the Problem
- Read the specification closely to define the requirements including constraints to be met when your product, process, or system is designed. For example: wingspan limit?, propeller size?, material? And etc.

Investigate
- Research glider/propeller model aircraft on the web or other sources. The NASA web site contains much of the aircraft science and math that is applicable to this program. (http://www.grc.nasa.gov/WWW/k-12/airplane/short.html) This site is a clickable index. Pick your subject and a click shows the Power Point and description. (NASA Aerodynamics Index is attached)
- Review the reverent mathematics and science with students (the complexity and depth science background and is at the instructor’s discretion).
  - Newton’s three laws of motion, torque, forces and torque, and equilibrium.
  - Area, volume, acceleration, ratios, and geometry
  - Identify how aircraft is constructed and what are the key parts and how does an aircraft fly? Thrust, lift, drag etc.
- Introduce MESA students to the engineering design cycle.
- There are many online resources to do this including, the teach engineering resource (http://www.teachengineering.org/engrdesign/process.php) and the science buddies website (http://www.sciencebuddies.org/engineering-design-process/engineering-design-process-steps-shtml). And the NASA web site (http://www.nasa.gov/audience/foreducators/plantgrowth/reference/Eng_Design_5-12.html)
- Have the students create their own design notebooks. MESA students will use the journal to document the information gathering process they engaged in and any relevant information that will prepare them for designing and building their competition ready package. The logbook can also follow throughout the different stages of the project. Regular entries into notebook/journal are an essential part of this unit/project. (http://www.sciencebuddies.org/blog/2010/01/labnotebooks.php)
Planning and Brainstorming

At this point the students should get experience building a small glider (~7 inch wingspan). A huge variety of plans can be found by “googling” “plans for balsawood gliders”. The airplane building students can also search “rubber powered flying model airplanes”. A few examples include:
http://www.amaflightschool.org/diy
http://www.4p8.com/eric.brasseur/glider2.html
http://www.theplanpage.com/months/2406/recordhlg.html
http://www.rubber-power.com/make-it.htm

After building and testing their small models, the team brainstorms the possible designs for the competition glider/airplane. They pick the best two or three ideas, and Design and build their Prototypes. Design means they draw the construction plans.

Prototype and Testing

After designing the prototype(s) must be built and tested. Good detailed records must be kept so the same mistakes are not continually repeated. Testing conditions need to be changed (wing locations, wing design, dihedral angles, aspect ratio, center of gravity, trim and etc.) Several tries at each condition are needed since one test is not adequate for data reliability. Not only is the design and construction important but the launch technique also needs to be developed and tested.

Analysis

After the prototype testing, the results are analyzed and the group selects the best potential design for their competition model. Using data tables from the notebook with all the information such as wing span, location of center of gravity, glider weight, angle of launch, and flying time and plotting the key information on graphs will enable clear visuals on how the glider/plane performed. Then modify the design to correct the defects that prevent them from their reaching their goal. The engineering cycle is now repeated until the glider/plane achieves the flying time goal repeatedly and consistently. The designs and construction must be regularly checked against the MESA specifications so the product doesn’t drift into reject range.
http://www.mesa.ucop.edu/mesa_day_rules.html.
**Compete**

If the final model meets the teams goals and the MESA specifications and does so repeatedly then it is ready for competition. If a drawing is required make sure it is complete in every detail.

**Pacing Guide**

Although Advisors can structure their lessons as they see fit, below is the suggested pacing guide for this module.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>APPROXIMATE TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td></td>
</tr>
<tr>
<td>Foam Plate Glider (FPG-9)</td>
<td>1-2 class periods</td>
</tr>
<tr>
<td>Discuss how to control the glider and answer the work sheet in the packet.</td>
<td></td>
</tr>
<tr>
<td><strong>Define the problem</strong></td>
<td></td>
</tr>
<tr>
<td>Read the MESA rules and discuss what are the goals and the constrictions. Summarize in the journal.</td>
<td>1 class period</td>
</tr>
<tr>
<td><strong>Investigation</strong></td>
<td></td>
</tr>
<tr>
<td>Research gliders or rubber powered model airplanes on line. After the students identify potential plans have them build a small (~7 inch wingspan) glider to get a feel for working with balsa and flying. Followup with the physics and math of flying, designing, and building the aircraft. Investigation reflection in log. The students answer quizzes available in the NASA lessons.</td>
<td>5-8 45 min. class periods</td>
</tr>
<tr>
<td><strong>Planning and Brainstorming</strong></td>
<td></td>
</tr>
<tr>
<td>Overview of the Engineering Cycle and math. Students brainstorm ideas (in logs) and select</td>
<td>3-4 class periods</td>
</tr>
</tbody>
</table>
most probable routes to aircraft meeting specs.
Draw preliminary design selections.

**Prototypes**
The first prototype(s) are built and tested. 3-5 periods
Several variables need to be evaluated such as aspect ratio, weight, launch conditions, and etc. Repeat tests to establish data reliability.
Enter data directly into logs.

**Analysis**
Analyze the prototype results and select the competition design, build and fly it repeatedly and make the final trim adjustments until it is competition ready.

**Compete.** *GOOD LUCK!* 
Here is a list of all the topics available from the Beginner's Guide to Aerodynamics (BGA) site. Clicking on the title will deliver a page with a slide and a scientific explanation of the contents. Click on the word "Animated" for the animated version of selected pages. If the number and variety of pages seems too intimidating, consider taking one of our Guided Tours through the web site.

Another method for reaching students, teachers and lifelong learners is the use of Distance Learning. While preparing presentations for students, many Power Point files have been developed for the Digital Learning Network using information from the BGA. Another group of Power Point presentations has been prepared concerning the exploration of space. Students and teachers are encouraged to copy the Power Point files to their own computers and to modify them as desired for their own presentations. We have also created a home page for all of our movies featuring Wilbur and Orville Wright.

* Animation files can be large (average 350K bytes)
** Java Applet

### STUDENT ACTIVITIES
- NASA Glenn History and Missions Activities
- FoilSim Activities
- Basic Aerodynamics Activities
- Aerospace Lesson Plans
- Cross-Word Puzzle Activity
- Airplane Gallery

### SCIENCE FUNDAMENTALS
- Three Phases of Matter
- Newton's Laws of Motion ..Movie
- Newton's First Law - Inertia
- Newton's Second Law - Force
- Newton's Third Law - Action & Reaction
- Torques (Moments)
- Forces and Torques
- Equilibrium - 2 Forces
- Equilibrium - 3 Forces
- Equilibrium - 2 Torques

### MATH FUNDAMENTALS
- Functions
- Rectangular and Polar Coordinates
- Area
- Volume
- Displacement, Velocity, Acceleration
- Angular Displacement, Velocity, Acceleration
- Scalars and Vectors
- Comparing Two Scalars - Ratio

### AIRPLANE PARTS
- Airplane Parts Definitions
- Fuselage
- Turbine Engines
- Wing Geometry Definitions ..Interactive**
- Winglets
- Elevator ..Movie ..Interactive**
- Aileron ..Movie ..Interactive**
- Rudder ..Movie ..Interactive**
- Spoilers ..Interactive**
- Flaps and Slats ..Interactive**
- Stabilator ..Interactive**
- Pitot-Static Tube - Speedometer

### AIRCRAFT FORCES
- Four Forces on an Airplane ..Movie
- What is Weight? ..Movie
- What is Lift? ..Movie
- What is Drag? ..Movie
- What is Thrust? ..Movie
- Lift to Drag Ratio
- Thrust to Weight Ratio
- Excess Thrust (Drag - Thrust)
- Forces in a Climb
- Vectored Thrust
- Airplane Cruise - Balanced Forces
- Trimmed Aircraft
- Momentum Effects
- Density Effects ..Interactive**
- Velocity Effects ..Interactive**

### AERODYNAMICS
- Aerodynamic Forces
Comparing Two Vectors
Vector Addition
Vector Components
Trigonometry
Sine-Cosine-Tangent
Ratios in Triangles
Pythagorean Theorem

**ANALYSIS**
Conservation of Mass
Conservation of Momentum
Conservation of Energy
Euler Equations
Bernoulli's Equation
Navier-Stokes Equations
Lift of Rotating Cylinder
Ideal Lift on Spinning Ball
Ideal Flow Around Spinning Ball
Conformal Mapping

**STATIC GASES**
Animated Gas Lab
Gas Properties Definitions
Equation of State (Ideal Gas)
Specific Heats - cp and cv
Boyle's Law
Charles and Gay-Lussac's Law
Specific Volume
Kinetic Theory of Gases

**THE ATMOSPHERE**
Interactive Atmosphere Simulator
The Atmosphere
Air Properties Definitions
Air Pressure
Air Temperature
Air Density
Air Viscosity
Earth Model - Imperial Units
Earth Model - Metric Units
Mars Model - Imperial Units
Mars Model - Metric Units
Relative Velocity - Ground Reference
Relative Velocity - Aircraft Reference
Cross Winds
Updrafts and Downdrafts
Lightning Strike

**SPEED REGIMES**
SoundWave Interactive Simulator

**DYNA**
Dynamic Pressure
Center of Pressure - cp
Aerodynamic Center
Similarity Parameters
Reynolds Number
Boundary Layer
Mass Flow Rate
Definition of Streamlines

**THRUST**
Beginner's Guide to Propulsion
EngineSim Interactive Simulator
Thrust Equation

**HEIGHT**
Determining Aircraft Weight
Center of Gravity - cg
Aircraft Center of Gravity - cg
Weight Equation

**LIFT**
FoilSim III Interactive Simulator
Bernoulli and Newton
Objects with Lift
Lift from Flow Turning
Shed Vorticity
Equal Transit Theory
Skipping Stone Theory
Half Venturi Theory
Factors That Affect Lift
Size Effects on Lift
Inclination Effects on Lift
Downwash Effects on Lift
Lift Equation
Lift Coefficient

**DRAG**
Factors That Affect Drag
Shape Effects on Drag
Drag on a Sphere
Size Effects on Drag
Inclination Effects on Drag
Drag Measurement
Induced Drag Coefficient
Drag Equation
Drag Coefficient

**GLIDERS**
Giders
Paper Airplanes

12
Compressible Aerodynamics
Mach Number..Interactive**
Speed of Sound..Interactive**
Subsonic
Transonic
Supersonic
High Supersonic
Hypersonic
Re-Entry
Mach Calculator

Fun with Gliders
Space Shuttle as a Glider
Three Forces on a Glider
Glide Angle
Vector Balance of Forces - Glider
Glider Trajectory Problem

MODEL ROCKETS
Beginner's Guide to Model Rockets
RocketModeler Interactive Simulator

KITES
Beginner's Guide to Kites
KiteModeler Interactive Simulator

WIND TUNNELS
Beginner's Guide to Wind Tunnels
TunnelSim Interactive Simulator

SPORTS
Baseball Home Page
HitModeler Interactive Simulator
HitModeler Weather Interactive Simulator
CurveBall Student Interactive Simulator
CurveBall Expert Interactive Simulator
Soccer Home Page
SoccerNASA Interactive Simulator

MISCELLANEOUS
Wright Brothers Aircraft
Let's be Specific
Venus Airfoil