JavaScript Web Technologies in Aeronautics

Chima A. Ugonna

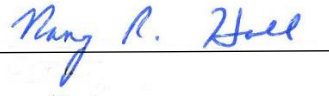
NASA Glenn Research Center

Major: Computer Science

2018 Spring Session

Date: 26 APR 18

This final report has been reviewed and approved by Mentor to ensure information is accurate and does **not** contain sensitive data.

Signature  MSI/ April 26, 2018

Mentor Name & Org Code/Date

Chima A. Ugonna[1] and Nancy R Hall[2]

The Beginner's Guide to Aeronautics is a popular website owned by NASA Glenn Research Center, containing various simulators and activities on Aeronautics topics. However, many of these simulators were made with outdated Java applets, thus causing problems when running the simulators on modern browsers such as Chrome. Stricter security settings may also prevent the applets from running. As such, it was concluded that one way to approach this issue would be to replace the applets with JavaScript versions of the simulators. The website as a whole is in need of numerous updates. During this session, several efforts were made in order to make these updates. Such efforts include updating information on various pages and creating a new template for the website's most popular simulator, FoilSim, as well as for the homepage of the website. The development of this project involved the use of tools such as HTML, CSS, JavaScript and different JavaScript libraries. This project did not require the assistance of outside frontend frameworks, and instead used JavaScript directly. The goal of modernizing the website is a continuous process, but the need to prioritize updates is being taken into consideration.

Nomenclature

L = lift of an airfoil wing
L' = lift per unit span
D = drag of an airfoil wing
Cl = coefficient of lift
Cd = coefficient of drag
V = free stream velocity
ρ = density
A = area
s = spin of cylinder or ball
R = radius
Γ = circulation
α = angle of attack of airfoil
β = angle between x-axis and line from x-intercept and shape center point

I. Introduction

The Beginner's Guide to Aeronautics (BGA) is Glenn Research Center's most popular website, getting up to tens of thousands of views daily (Ref 1). The website contains numerous interactive simulators and activities for the purpose of educational use for Aeronautics topics. The website was developed in the early 1990's by NASA employee and Aerospace Engineer Thomas J. Benson. He was inspired by the interactivity of his son's video games and feedback he received from teachers. The BGA is made up of thousands of webpages, and the various topics are divided into twelve categories: aerodynamics, Wright airplanes, propulsion, baseball, soccer, kites, rockets, water rockets, wind tunnels, compressible aerodynamics, hypersonics, and the kid's page.

[1] USRA intern, NASA Glenn Research Center, MSI0, Illinois Institute of Technology
[2] Aerospace engineer, NASA Glenn Research Center, MSI0

The website is included in the Glenn Web Improvement Project, or GWIP, an effort to make better templates and layouts for GRC's websites. The task is a collaborative effort between organizations Code V, M, K, and CE/CP. The website is in constant need of updates, each page having its own share of issues. During this session, particular interest was focused on the updating of the interactive simulators present on the website.

A. Development Process

The interactive simulators on the website were originally made by Thomas Benson as Java applets. There are around a hundred pages on the BGA that contain a Java applet. The issue is that today, Java applets are not as well supported on modern browsers, so they may not work the way they are supposed to. However, there are ways to get around these issues. It is important to note that the Java applets can still be run on Java Runtime Environments. This means that if one were to install a program containing a JRE, such as NetBeans or Eclipse, they should be able to run the applet from there and view the simulator without any problems. This method has been tested and is confirmed to work. The website now provides links to tutorials on how to run Java applets on NetBeans or Eclipse, if the user would prefer that method.

B. Converting to JavaScript

The main method proposed to solve this problem was to replace the Java applets with JavaScript web applications that simulate the same topic. Previous interns working on this project helped to confirm that this is indeed possible. JavaScript, with the help of HTML and CSS, is capable of recreating the simulators, both in calculations and interactivity. JavaScript performs the calculations and functionalities while HTML and CSS control the graphics and appearance of the application. To make it even easier, different JavaScript libraries were also used. First, jQuery is a JavaScript library used to simplify HTML and allows for quicker access to the different elements on a page. Another library used is p5.js, used for drawing interactive graphics on a webpage. For other graphics such as charts and graphs, Plotly.js was used. Other tools used to enhance the appearance of the Graphical User Interface are CSS Flexbox and Bootstrap. CSS Flexbox allows for a more flexible layout for creating responsive elements while Bootstrap creates things like headers, footers, and navigation bars.

II. FoilSim

As stated previously, FoilSim (Fig. 1) is the most popular interactive simulator on the website. For that reason, a large portion of the project focused on updating this simulator. The previous Fall 2017 intern, Patrick Perez, created a new page template for FoilSim (Ref 1). It was in this template that Perez used p5.js to replicate a simplistic version of the graphic in the FoilSim applet, as shown in Figure 2. The template also made use of navigation bars in place of dropdown lists and buttons, but still used a combination of those, buttons, and sliders.

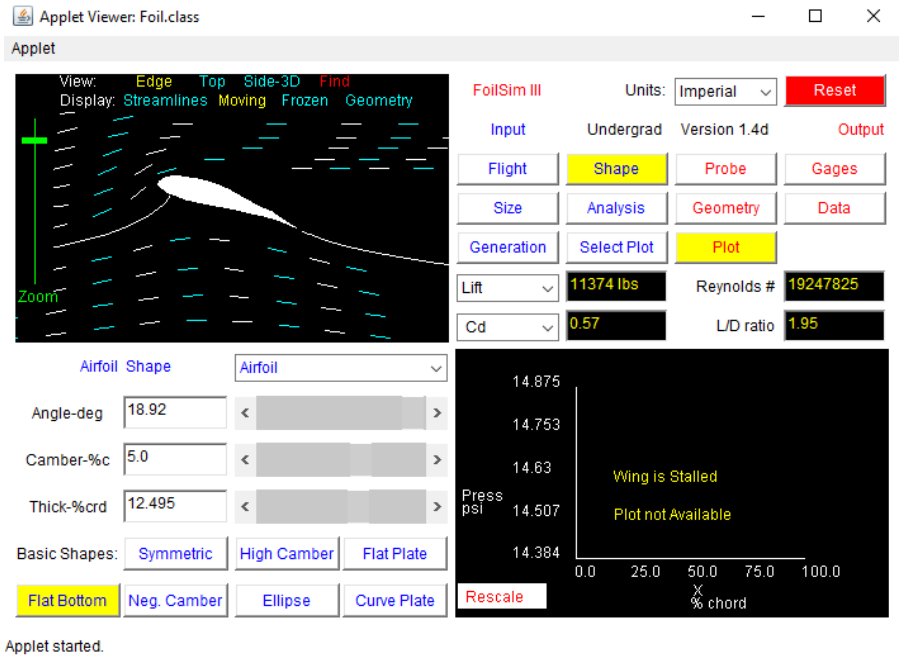


Figure 1: Original Java applet Foil.java (FoilSim)

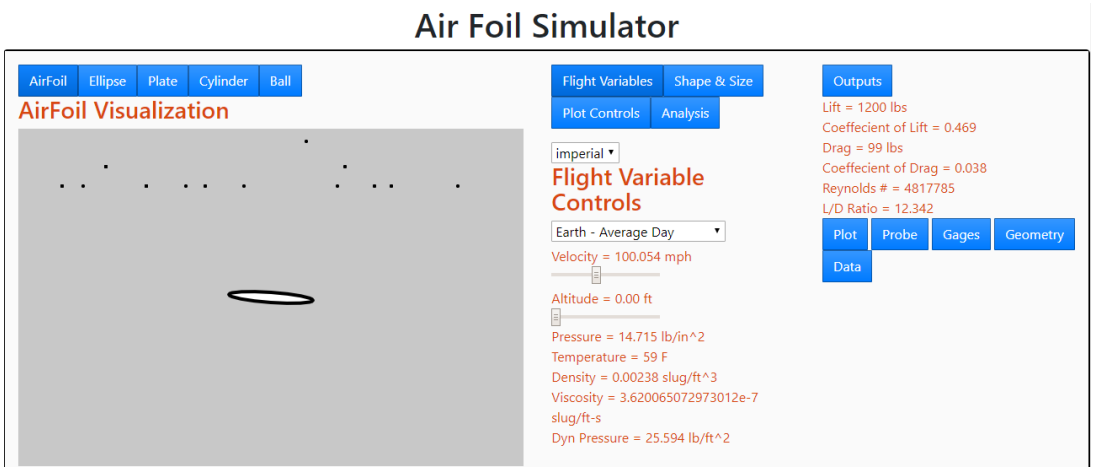


Figure 2: New template for FoilSim using HTML and JavaScript

A. Background

The purpose of FoilSim is to show the visualization and calculations for the lift and drag of an airfoil wing. In order to do this, there are several variables you can set via sliders. These include velocity, altitude, angle, camber, thickness, chord, span, radius, spin, and area. You can also change other options, such as units of measurement, location, shape, and analysis buttons that affect calculations. Given all these different variables, the main goal is to be able to solve the equations for lift L and drag D, as follows:

$$L = Cl \frac{\rho V^2}{2} A \quad (1)$$

$$D = Cd \frac{\rho V^2}{2} A \quad (2)$$

The greatest difficulty with solving these equations is calculating Cl and Cd, the coefficient of lift and coefficient of drag. There is no uniform equation for finding these values. For this reason, other methods for obtaining the lift, drag, or their coefficients were attempted. For lift, another method would be to find the circulation Γ, which represents the strength of the vortex flow around the airfoil (Ref 2). The equation for circulation varies based on shape, but for an airfoil, ellipse, or plate it can be found as

$$\Gamma = 2R\sin(\alpha + \beta) \tag{3}$$

For a cylinder or ball, circulation is found as

$$\Gamma = \frac{4\pi^2 sR^2}{V} \tag{4}$$

Once you find circulation, you can calculate the generalized lift per unit span equation:

$$L' = \rho V\Gamma \tag{5}$$

The coefficient of drag has a particular relationship with another value called the Reynold's number. By following this relationship, shown in Fig. 3, you can set a value for Cd.

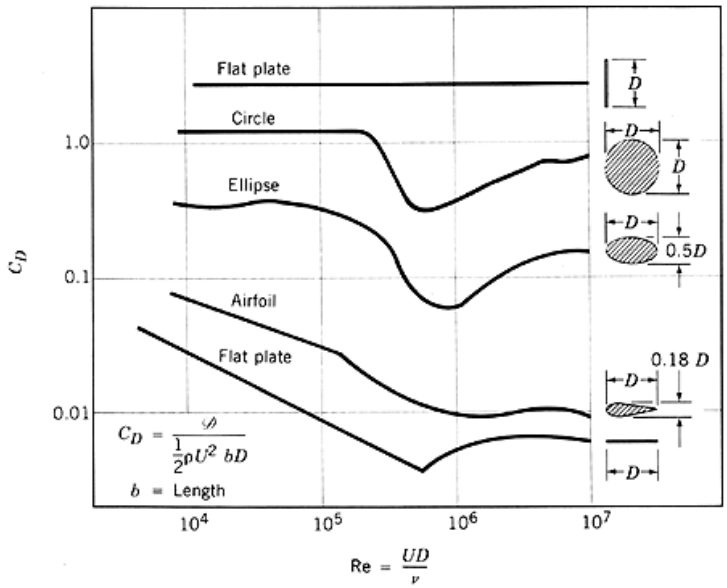


Figure 3: Cd vs Reynold's Number[3]

Both coefficients also have a constant relationship with an airfoil's angle of attack. No matter what the airfoil, the shape of these graphs, shown in Figures 4 and 5, is generally the same.

[3] http://www.dept.aoe.vt.edu/~jschetz/fluidnature/unit02/unit2c.html

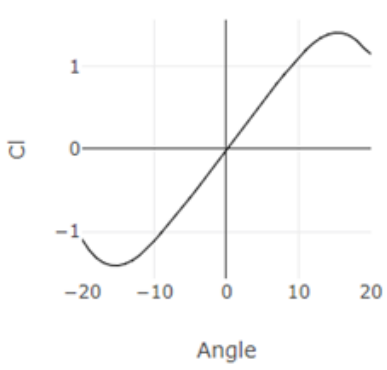


Figure 4: Cl vs Angle

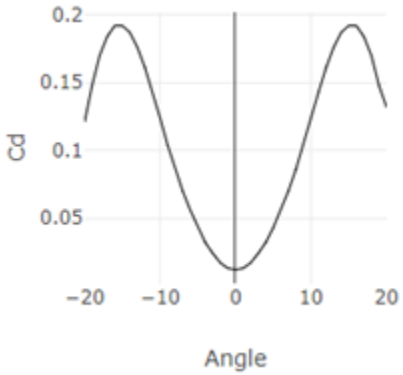


Figure 5: Cd vs Angle

By following these relationships, I was able to set values for the coefficients and use those corresponding values to find the lift and drag, based on the calculated Reynold's number and the set angle of attack. This was insufficient, however, due to the fact that the camber and thickness of the airfoil also affects the coefficients. So, it became necessary to find a way to include those variables into the equation as well.

B. Solution

The circulation method was attempted, but it was not returning the desired results. The original Java source code, Foil.java, does some very complex calculations without sufficient instructions, so it was difficult to follow its methods. It was suggested to me that the only way to accurately find the coefficients would be to manually set them, using a lookup table. What this means is that, given the current angle, camber and thickness values, the table would return what the coefficients would be at those values. So, in foilSimObjects.js, where all the attributes of a Foil object are created, I included the lookup table. In the original FoilSim applet, the angle and camber range from -20 to 20 while thickness ranges from 1 to 20. To have an entry in the table for each combination of those three would be up to 33,620 entries. Due to not having that kind of time, I shortened the lookup table to only include factors of 4 for the angle and factors of 2 for camber and thickness. The lookup table method has been working, and would just need the inclusion of other entries over time, until it has an entry for every possible combination of angle, camber, and thickness.

C. Remaining Issues

While much progress has been made on the new FoilSim GUI, it is still incomplete with many problems. One issue is that the outputs don't display correctly unless you first change one of the inputs under the Flight Variables tab, then change one of the inputs under the Shape and Size tab (excluding area). Another issue is that the coefficient of drag outputs correctly if you change only velocity/altitude or change only angle/camber/thickness. But when you change values in both sections, Cd does not output correctly. This is due to the fact that Cd's relationship to the Reynold's number and its relationship to angle, camber, and thickness are calculated separately.

The analysis buttons also have issues. The lift analysis buttons should either include stall at angles greater than 10 or less than -10, or for ideal flow set Cd and drag to zero. AR lift correction should control the effects of downwash while the induced drag button controls induced drag. These

conditions change the coefficient of lift and coefficient of drag through equations involving the aspect ratio. Thus, since the aspect ratio changes when the chord or span are changed, the chord and span also affect the output for the coefficients. Perhaps one solution to this would be to include the aspect ratio in the lookup table. Lastly, the Re # Correction button should alter Cd based on the Reynold's number.

Other things that still need to be implemented are how changing the shape changes the calculations, switching units, the effects of changing location, the analysis buttons for the drag of a ball, and changing the path of the particles as you change shape and size. Luckily, the plot, probe, gage, geometry, and data tabs all work as intended, thanks to Plotly.js. FoilSim still needs a lot of work, and as the website's most popular interactive simulator, it deserves to be put at high priority.

III. BGA Homepage

When not working on FoilSim, another task was to create a new homepage for the BGA. I completed this task using the same template that was made for the new FoilSim GUI (see Fig. 6). The current homepage is a lot of hyperlinks and a lot of scrolling. The twelve categories are listed in a single column, each with a list of subcategories that link to different simulators and activities for that topic. Under that is a long description of the website's history. My task was to create a more modern version of this page, which included making it easier to navigate and nicer to look at. Many of Glenn's websites are following a certain template for the GWIP, so I aimed to make the new homepage use a similar layout. This layout involved having each category displayed in responsive table cells that move and change size as the browser window changes size. The tables are preceded by a short introduction on how to navigate the page and a note about the outdated applets. Each category has a label that takes you to that topic's index when clicked, and the subcategories are shown in a dropdown list if you click on the category's picture.

The page also includes its own header and footer. The header has the option to view some of the categories grouped together, go to downloads, activities, or presentations offered on the website, or go to a page that has the site history and site updates. The footer has the address to GRC, links to NASA social media pages, the privacy notice page and document and media viewers.

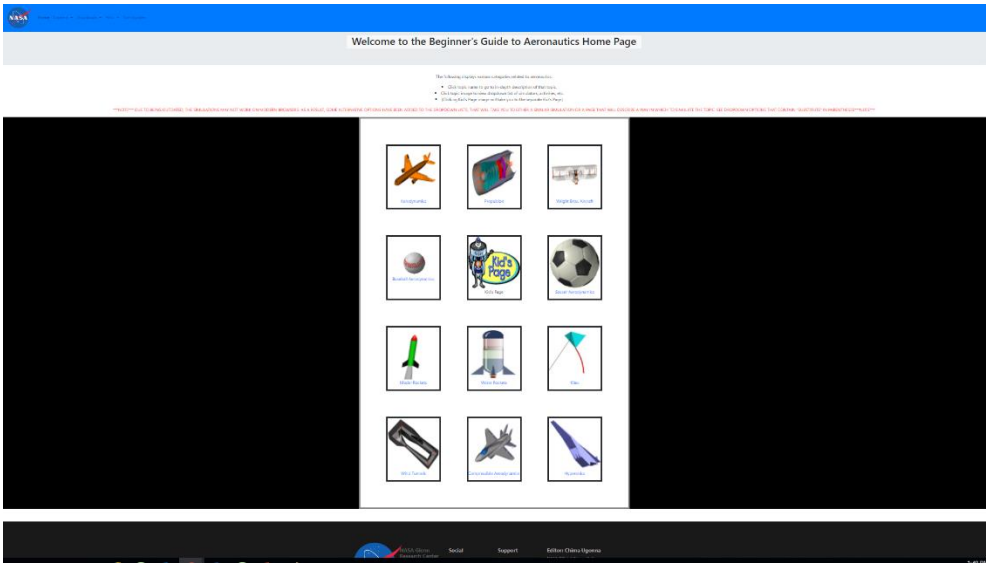


Figure 6: New BGA Homepage

Some of the category images were also updated in order to look better. You can view the new homepage by going to https://www.grc.nasa.gov/WWW/K-12/airplane/tempBGA/index.html.

IV. Other Simulators

Aside from FoilSim, there are dozens of other interactive simulators on the website. These simulators are in just as much need to be updated. When progress on FoilSim slowed down, I decided it might be more beneficial to start updating the other simulators that could be completed more quickly due to not using a graphic like FoilSim does. By the end of the internship, I managed to update up to eight other interactive simulators with JavaScript versions. It should be noted that, while the updated simulators all work correctly in Chrome, Internet Explorer, and Firefox, the CSS somewhat messes with the page only in Internet Explorer. So something to look into in the future is how to have the CSS apply differently to different browsers.

The simulators that have been updated thus far are included in a chart of all interactive simulators on the website, located in the appendix of this report. The process of recreating one of the simulators is as follows: Create an HTML file with the base content such as inputs, labels, and buttons. Then create a JavaScript file for making calculations and controlling different actions the same way they are done in the Java applet. Lastly, create a CSS file to manipulate the overall layout of the page content. This same process can be recycled between simulators for faster updates.

A. Alternate Simulators

For some of the simulators, I also managed to find already existing web applications that simulate the same topic, or something very similar. For those pages, I added a note that directs the user to an alternate simulator, to use until the one on the BGA website has been updated. The list of alternate simulators added can also be found in section B of the appendix.

V. Future Work

Because the Beginner's Guide to Aeronautics is such an old and outdated website, the main overarching goal of this project is to update and maintain the website wherever needed. This can include just changing the information on a page so it is more accurate, or fixing small errors on a page. The website is also littered with hyperlinks in order to connect all the pages, so it looks messy. If there is a better way to implement the navigation between pages, that might be something to consider.

Of course, updating the interactive simulators is a main goal of the project. Because there are so many on the website, we are tasked with the need to prioritize what parts of the website to update. This prioritization is being accomplished by examining a collection of emails from users to see which simulators are the most asked about, and by keeping track of a list of the most visited pages of the website. For example. FoilSim and then EngineSim are the two most popular interactive simulators based on page visits, while the Baseball simulators are some that have been getting asked about recently. Even if the more popular simulators are a priority, if several of the

smaller simulators can be updated in a shorter amount of time, then that can be another direction to take.

VI. Conclusion

At the beginning of this project, the task was focused on updating the FoilSim application. Using the layout provided by the previous intern, I was able to add several of the functionality requirements. However, due to insufficient data and knowledge related to calculating lift and drag, completing FoilSim became more difficult. The most successful solution was to make a lookup table that would return values for the coefficients of lift and drag at different values of angle, camber, and thickness. However, effects such as downwash, stall, and induced drag need to be taken into account in order for this solution to work completely. Several other simulators were updated in the meantime, on each page where the corresponding Java applet used to be. The homepage of the website was also redone, using the same new layout as the one made for FoilSim. The move from Java applets to JavaScript applications will ultimately help to modernize and maintain the website as a whole. Because of its popularity, it is important to continue to document the updates made to the website. We keep track of these updates via a Gitlab repository. Hopefully in time, there will be a uniform framework that all the pages on the website will follow to make updating and maintaining the website easier.

VII. Appendix

A. Tools and Libraries

1. Plain JavaScript: A programming language commonly used for creating web pages. The most recent documentation for JavaScript can be found at https://developer.mozilla.org/en-US/docs/Web/JavaScript
2. ECMAScript: A standard language specification that JavaScript uses. http://es6-features.org/#Constants
3. HTML5: The latest standard for HTML, a language used to create websites. https://developer.mozilla.org/en-US/docs/Web/Guide/HTML/HTML5
4. CSS: A language used to control the styling and layout of a webpage. https://developer.mozilla.org/en-US/docs/Web/CSS
5. CSS Flexbox: A CSS model to enhance the spacing and alignment of web page content. https://developer.mozilla.org/en-US/docs/Web/CSS/CSS_Flexible_Box_Layout/Basic_Concepts_of_Flexbox
6. CSS Grid: CSS model that adjusts the layout into organized columns and rows. https://developer.mozilla.org/en-US/docs/Web/CSS/CSS_Grid_Layout
7. Bootstrap: A library with embedded HTML and CSS templates, used to make responsive web pages. https://getbootstrap.com/
8. JQuery: A JavaScript library that simplifies interaction with HTML and makes manipulation of a web page easier. https://api.jquery.com/
9. P5.js: An extension of Processing that allows for better ways of drawing graphics onto a page. https://p5js.org/
10. Plotly.js: A JavaScript library that ues d3.js for making dynamic charts and graphs. https://plot.ly/javascript/

B. Alternate Simulators

1. Soundwave Sim (https://www.grc.nasa.gov/WWW/K-12/airplane/sndwave.html)
   Alternate Simulator:
   http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/doppler.htm
2. Engine Sim (https://www.grc.nasa.gov/WWW/K-12/airplane/ngnsim.html)
   Alternate Simulator: http://www.aerodynamics4students.com/propulsion/gas-turbine-analysis.php
3. HitModeler Sim (https://www.grc.nasa.gov/WWW/K-12/airplane/hitmod.html)
   Alternate Simulator:
   http://physics.wustl.edu/introphys/Fall/ExperimentPages/baseball/simulator.html
4. RocketModeler Sim (https://www.grc.nasa.gov/WWW/K-12/rocket/rktsim.html)
   Alternate Simulator: https://www.sciencelearn.org.nz/embeds/25-rocket-launch-simulation
5. KiteModeler Sim (https://www.grc.nasa.gov/WWW/K-12/airplane/kiteprog.html)
   Alternate Links: https://www.sciencefriday.com/educational-resources/kite-engineering/, http://www.aui.ma/sse-capstone-repository/pdf/spring-2017/Aerodynamic%20&%20structural%20analysis%20of%20a%20Kite-Wing,%20ICARUS.pdf
6. Wind Tunnel Sim (https://www.grc.nasa.gov/WWW/K-12/airplane/tunopen.html)
   Alternate Simulator: http://www.aerodynamics4students.com/wind-tunnel-simulation/
7. Oblique Shock Sim (https://www.grc.nasa.gov/WWW/K-12/airplane/shock.html)
   Alternate Simulator: http://www.aerodynamics4students.com/table9.php
8. Multiple Shock Sim (https://www.grc.nasa.gov/WWW/K-12/airplane/mshock.html)
   Alternate Simulator: http://www.aerodynamics4students.com/table5.php
9. Hypersonic Flow Calculator (https://www.grc.nasa.gov/WWW/BGH/ieisen.html)
   Alternate Simulator: http://www.dept.aoe.vt.edu/~devenpor/aoe3114/calc.html
10. ShockModeler Sim (https://www.grc.nasa.gov/WWW/BGH/mshock.html)
    Alternate Simulator:
    http://www.aerodynamics4students.com/table5.php?M1=30&ga=1.4&Compute=Compute
11. Wright 1903 Flyer (https://www.grc.nasa.gov/WWW/Wright/airplane/air1903.html)
    Alternate Simulator: https://airandspace.si.edu/exhibitions/wright-brothers/online/workshop/flyer_sim/index.html

C. List of Interactive Simulators on BGA

Title of Page	URL	Date Completed	Time Taken to Complete	Applet Used	Note Updated
1900 Aircraft Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/air1900.html				yes
1901 Aircraft Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/air1901.html				yes

1902 Aircraft Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/air1902.html				yes
1903 Aircraft Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/air1903.html				yes
1904 Aircraft Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/air1904.html				yes
1905 Aircraft Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/air1905.html				yes
Aileron Movie Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/alr.html				yes
Air Rocket Launch Interactive	https://www.grc.nasa.gov/WWW/K-12/rocket/rktslaunch.html				yes
Air Rockets Animated Interactive	https://www.grc.nasa.gov/WWW/K-12/rocket/rktstomp.html				yes
Air Viscosity Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/viscosity.html	4/16/2018	4 days	Similarity Parameter Calculator	yes
Airflow per Area Interactive	https://www.grc.nasa.gov/WWW/K-12/rocket/wcora.html	3/27/2018	3 days	Isentropic Flow Calculator	yes
Area Ratio A/A* Interactive	https://www.grc.nasa.gov/WWW/K-12/rocket/astar.html	3/27/2018	3 days	Isentropic Flow Calculator	yes
AtmosModeler Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/atmosi.html https://www.grc.nasa.gov/WWW/K-12/rocket/atmosi.html				yes
Ballistic Flight Calculator	https://www.grc.nasa.gov/WWW/K-12/airplane/fltcalc.html https://www.grc.nasa.gov/WWW/K-12/rocket/fltcalc.html	4/4/2018	2 days	Ballistic Flight Calculator	yes
Ballistic Flight Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/ballflght.html https://www.grc.nasa.gov/WWW/K-12/rocket/ballflght.html	4/4/2018	2 days	Ballistic Flight Calculator	yes
Booster Staging Interactive	https://www.grc.nasa.gov/WWW/K-12/rocket/rktstage.html				yes
Centered Expansion Fan Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/expans.html https://www.grc.nasa.gov/WWW/K-12/rocket/expans.html				yes
Compressible Airflow per Unit Area Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/wcora.html	3/27/2018	3 days	Isentropic Flow Calculator	yes

Compressible Area Ratio Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/astar.html	3/27/2018	3 days	Isentropic Flow Calculator	yes
Compressible Mass Flow Rate Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/mflchk.html	3/29/2018	2 days	Mass Flow Calculator	yes
Conformal Mapping Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/map.html				yes
Crossed Shocks Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/crosshock.html https://www.grc.nasa.gov/WWW/K-12/rocket/crosshock.html				yes (excluding hypersonic)
CurveBall Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/foil2b.html				yes
Density Effects Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/density.html				yes
Detached Shock Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/detach.html				yes (excluding hypersonic)
Determine Maximum Altitude Interactive	https://www.grc.nasa.gov/WWW/K-12/rocket/rkthowhi.html	3/30/2018	1 day	Altitude Calculator	yes
DropSim Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/dropsim.html				yes
Effects of Inclination on Lift Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/incline.html				yes
Effects of Shape on Lift Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/shape.html				yes
Effects of Velocity on Lift Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/vel.html				yes
Elevator Movie Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/elv.html				yes
Elevators Interactive Movie	https://www.grc.nasa.gov/WWW/Wright/airplane/elv.html				yes
Engine Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/eng03.html				yes
EngineSim Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/ngnsim.html				yes
Equal Transit Theory Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/wrong1.html				yes
Flaps and Slats Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/flap.html				yes
Flight with Drag Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/flteqs.html https://www.grc.nasa.gov/WWW/K-12/rocket/flteqs.html	4/4/2018	2 days	Ballistic Flight Calculator	yes

FoilSim Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/foil3.html				yes
Gimbaled Thrust Animated Interactive	https://www.grc.nasa.gov/WWW/K-12/rocket/gimbaled.html				yes
Half Venturi Theory Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/wrong3.html				yes
HitModeler Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/hitmod.html				yes
HitModeler Weather Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/hitmodw.html				yes
Hypersonic Flow Calculator Interactive	https://www.grc.nasa.gov/WWW/BGH/ieisen.html				Don't have access
Hypersonic Shock Interactive Simulator	https://www.grc.nasa.gov/WWW/BGH/shock.html				Don't have access
Ideal Flow Around Spinning Ball Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/bball.html				yes
Ideal Lift of Spinning Ball Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/beach.html				yes
Inclination Effects on Lift Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/incline.html				yes
Interactive Model Design Program	https://www.grc.nasa.gov/WWW/K-12/airplane/tunmodd.html				yes
Interactive Nozzle	https://www.grc.nasa.gov/WWW/K-12/airplane/ienzl.html				yes
Interactive Performance Predictions	https://www.grc.nasa.gov/WWW/Wright/replica/upredict.html				yes
Interactive Performance Predictions	https://www.grc.nasa.gov/WWW/Wright/airplane/discint.html				yes
Interactive TBCC Simulator	https://www.grc.nasa.gov/WWW/BGH/tbcc.html				Don't have access
Interactive Tunnel Test Program	https://www.grc.nasa.gov/WWW/K-12/airplane/tunwtest.html				yes
Interactive Wind Tunnel	https://www.grc.nasa.gov/WWW/Wright/airplane/tunnlint.html				yes
Isentropic Flow Calculator	https://www.grc.nasa.gov/WWW/K-12/airplane/ieisen.html https://www.grc.nasa.gov/WWW/K-12/rocket/ieisen.html	3/27/2018	3 days	Isentropic Flow Calculator	yes
Isentropic Flow Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/isentrop.html https://www.grc.nasa.gov/WWW/K-12/rocket/isentrop.html	3/27/2018	3 days	Isentropic Flow Calculator	yes

Kite Modeler Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/kiteprog.html				yes
Lift from Flow Turning Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/right2.html				yes
Lift of Rotating Cylinder Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/cyl.html				yes
Mach Angle Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/machang.html https://www.grc.nasa.gov/WWW/K-12/rocket/machang.html	3/27/2018	3 days	Isentropic Flow Calculator	yes
Mach Number Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/mach.html https://www.grc.nasa.gov/WWW/K-12/rocket/mach.html	3/22/2018	4 days	Mach/Speed of Sound Calculator	yes
Modern Lift Equation Interactive	https://www.grc.nasa.gov/WWW/Wright/airplane/lifteq.html				yes
Multiple Shock Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/mshock.html				yes
Normal Shocks Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/normal.html https://www.grc.nasa.gov/WWW/BGH/normal.html				yes (excluding hypersonic)
Objects with Lift Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/lift2.html				yes
Oblique Shocks Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/oblique.html https://www.grc.nasa.gov/WWW/BGH/oblique.html				yes
Oblique Shock Wave Interactive	https://www.grc.nasa.gov/WWW/BGH/shock.html				yes (excluding hypersonic)
Prandtl-Meyer Angle Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/pranmyer.html https://www.grc.nasa.gov/WWW/BGH/pranmyer.html	3/27/2018	3 days	Isentropic Flow Calculator	yes
Pythagorean Theorem Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/pythag.html https://www.grc.nasa.gov/WWW/K-12/rocket/pythag.html	3/29/2018	4 hours	Pythagorean Theorem Interactive	yes
RangeGames Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/ngnsimr.html				yes
Real Gas Effects Interactive	https://www.grc.nasa.gov/WWW/BGH/realgas.html				Don't have access
Reflected Shock Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/reflects.html https://www.grc.nasa.gov/WW				yes (excluding hypersonic)

	W/K-12/rocket/reflects.html https://www.grc.nasa.gov/WWW/BGH/reflects.html				
Reynold's Number Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/reynolds.html https://www.grc.nasa.gov/WWW/BGH/reynolds.html	4/16/2018	4 days	Similarity Parameter Calculator	yes
RocketModeler Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/rocket/rktsim.html				yes
RocketNozzle Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/rocket/ienzl.html				yes
Rudder Movie Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/rud.html				yes
Rudders Interactive Movie	https://www.grc.nasa.gov/WWW/Wright/airplane/rud.html				yes
Shape Effects on Lift Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/shape.html				yes
ShockModeler Interactive Simulator	https://www.grc.nasa.gov/WWW/BGH/mshock.html				Don't have access
Similarity Parameters Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/airsim.html	4/16/2018	4 days	Similarity Parameter Calculator	yes
Size Effects of Lift Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/size.html				yes
Skipping Stone Theory Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/wrong2.html				yes
SoccerNASA Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/soccercode.html				yes
Soundwave Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/sndwave.html				yes
Specific Heats Interactive	https://www.grc.nasa.gov/WWW/BGH/realspec.html				Don't have access
Speed of Sound Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/sound.html https://www.grc.nasa.gov/WWW/K-12/rocket/sound.html	3/22/2018	4 days	Mach/Speed of Sound Calculator	yes
Spoilers Movie Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/spoil.html				yes
Stabilator Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/stablator.html				yes
Stagnation Temperature Interactive	https://www.grc.nasa.gov/WWW/BGH/stagtmp.html				Don't have access

Supersonic Cone Flow Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/coneflow.html				yes
Supersonic Wedge Flow Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/wdgflow.html				yes
SupersonicFlow Sim Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/supsim.html				yes
Terminal Velocity Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/termv.html https://www.grc.nasa.gov/WWW/K-12/rocket/termvr.html	4/3/2018	2 days	Terminal Velocity Calculator	yes
Thrust Equations Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/rktthsum.html				yes
TunnelSim Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/tunopen.html				yes
TunnelSys Interactive Simulator	https://www.grc.nasa.gov/WWW/K-12/airplane/tunsys.html				yes
Velocity Effects Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/vel.html				yes
Wing Geometry Definitions Interactive	https://www.grc.nasa.gov/WWW/K-12/airplane/geom.html				yes
Wright 1901 Interactive Simulator	https://www.grc.nasa.gov/WWW/Wright/airplane/tunnlint.html				yes

VIII. Acknowledgements

I would like to thank Herb Schilling, Calvin Robinson, and the other employees of the Graphics and Visualization Lab for their assistance with some of the project's technical issues. I would also like to thank Richard Kurak, Tim Reckart, Michael Howard, and of course my mentor, Nancy Hall, for their guidance on the direction of my project. Also thanks to David Friedlander for his input on the Aerodynamics calculations.

IX. References

[1] Perez, Patrick D., "JavaScript Web Technologies in Aeronautics", NASA Glenn Research Center, MSI0, Cleveland, OH, 2017.

[2] Benson, Thomas J., "Interactive Educational Tool for Classical Airfoil Theory", NASA Glenn Research Center, Cleveland OH, 1996.