ME 497R: Mentored Projects

Spring Term Report

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# Introduction

This report serves as a summary of the work that I completed during spring term 2018. This introduction includes a summary of the concepts that I covered, and concludes with an introduction of a term project concerning a simple optimization problem using the skills that I gained across the term.

### Learning about GIT

Before this term I had no experience with repositories. This term I learned about the basic structure of repositories, remote repositories and what their uses are. Repositories are like snapshots of a directory. They store a previous version of the files within a directory. This allows you to return to older versions of a file, have multiple versions of the same file all going at once, or work on the same file as someone else, without interfering with each other. I learned the most relevant skills to use GIT to access files from a remote repository, pull them to my repository, commit them within my repository, and push them to a remote repository. I also learned the skills requisite to learn more about those commands, and any other command that projects I work on may require.

### Re-Learning Python

Prior to this term I had partially completed an online tutorial about Python. To be properly prepared to assist in research, I spent time reviewing what I knew about Python, by finishing the Codecademy course on Python, and learning more about relevant functions, libraries and syntax. I learned that Python is an interpreted language, meaning that its code is compiled as it is executed. Consequently, the code is easier to use for data analysis and other simple projects. Unfortunately, interpreted coding languages are slower than compiled languages. I also learned about the two different active versions of Python; that there are minor differences in syntax and Python 2 will lose support after two years.

### Learning Julia

Prior to this term I had no experience with the programming language Julia. I learned about some of the basic aspects of Julia. I learned that Julia is a Just-In-Time (JIT) compiled language. This means that part of the program is compiled at the time of computing, rather than being completely compiled prior to execution. JIT complied languages allow for some of the speed of a compiled language, and some of the flexibility of an interpreted language. One interesting aspect of Julia is the fact that it allows for distributed computing. This means that if coded properly, when it is compiled and executed by a super computing cluster, the main job will be divided up into portions to be completed by different nodes in the cluster, allowing it to be significantly faster than code in contemporary numerical analysis languages like python. Having not been able to locate a suitable tutorial to complete for Julia, I followed some examples online. After completing these examples, I returned to several assignments from a numerical methods class I took this last winter, and completed them in Julia. I expect to further my understanding of Julia as I continue to develop my research skills, both in my understanding of how to use distributed computing and the language itself.

### Learning about Xfoil

I learned about the basic functions of Xfoil. Xfoil is a program developed by Mark Drela at MIT in the 1980’s to calculate the pressure distribution on an airfoil. These pressure distributions are useful to us because they are used to calculate useful information such as the coefficient of lift, drag and moment. Xfoil considers a whole series of inputs for subsonic airfoils, which allows us to make more accurate calculations on possible airfoils. Xfoil is interesting because it is written in Fortran, one of the oldest still active computing languages. Because Xfoil is in Fortran, I learned about wrappers such as PyXlight, which allow a user to interact with Xfoil from Python.

### Learning about the Windows and Linux operating systems

Prior to this term I had no experience with Linux. While preparing to complete my basic optimization project, I realized that PyXlight would only run in an Unix environment, which meant learning how to use Linux. I researched which version of Linux to install, and proceeded to install Xfoil. Ubuntu however, did not have the requisite packages to build the program. I spent a lot of time trying to figure out how to build the requisite packages, which included establishing connections in the BYU Linux club and with several experienced computer science undergraduate students. I then learned how to install, and troubleshoot the requisite IDEs for Julia and Python on both my Linux and Windows machine. I expect to increase my knowledge of operating systems through experience as I continue into the world of academic computing.

### Learning Basic Aerodynamics

Prior to this term, I did not have very much experience with aerodynamics. I had heard of several terms, and interacted with some basic statics questions that deal with aerodynamics. I was assigned the textbook *Fundamentals of Aerodynamics* by John Anderson to gain a basic understanding of aerodynamics. While I did not cover the amount of material that initially planned to cover, I did learn some basic terminology and concepts to help me better understand aerodynamics, and get me started into research. Some of the rudimentary concepts that I was introduced to include: coefficients of lift, drag and moment, Reynolds numbers, Mach numbers, the chord, camber, and angle of attack.

### Learning about NACA Parameters

In preparation for my mini airfoil optimization design project, I did a cursory review of parameters from the National Advisory Committee of Aeronautics (NACA). I learned that four-digit NACA numbers represent 3 parameters: maximum camber, maximum camber location, and maximum thickness. All three parameters are measured in percent of chord length to neglect airfoil size and focus on shape in theoretical calculations. The maximum camber is the difference between the maximum distance from the chord to the mean camber line, and the distance to the leading edge along the chord. The maximum camber location is the location of the maximum camber measured from the leading edge. The maximum thickness is the largest measurement from the top of the airfoil to the bottom of the airfoil, perpendicular to the chord. These three parameters are used to precisely generate cross-sections of an airfoil. The shape of the airfoil, along with the Reynolds number, angle of attack and Mach number determine the pressure distribution on the airfoil. The NACA parameters help us design the unvarying part of an airfoil. When designing an airfoil, you tend to hold the varying parameters constant while you change the NACA parameters.

### Airfoil Design Project

The airfoil design project is designed to allow me to apply several of the techniques that I learned throughout the term. The goal of the project is to find a set of four-digit NACA parameters that allow for a certain Lift/Drag ratio under a certain range of Reynolds numbers (1e4, 1e5), at a certain angle of attack (5 degrees), and Mach number (0.0).

# Methods

I coded several simple programs in Python to loop through a range of possible combinations of NACA parameters and used the PyXlight wrapper to determine the coefficient of lift and coefficient of drag. I do not fully understand how Xfoil calculates these coefficients, however I know that it uses pressure distribution to come up with these numbers. I then divided the coefficients by each other to find the ratio of lift to drag.

Where and are the coefficients of lift and drag respectively, L is the Lift, D is the Drag, is the dynamic pressure and S is the reference area.

After calculating the ratios, I analyzed the datasets to determine any trends and the maximum lift – drag ratio. To determine any trends, I selected data that held one parameter constant and plotted in 3D, then I held two parameters constant and plotted in 2D. I used the native max function in python to find the largest lift – drag ratio.

# Results

The following figures represent a small range of data that I considered. Each figure represents the variance in one of the NACA parameters. The code ran for both Reynolds numbers, however, because the graphs were so similar, in an interest of space, I have only shown the data for Re = 1e5. The vertical axis in all plots represents the ratio of lift to drag.

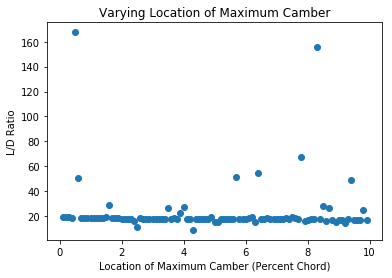
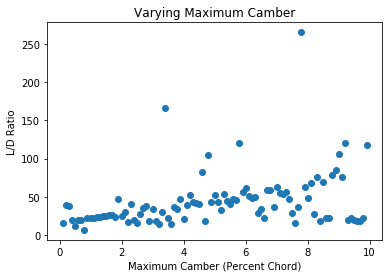


Figure 2:

Figure 1 :

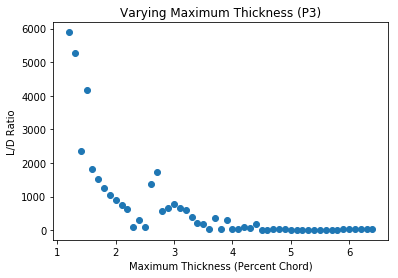
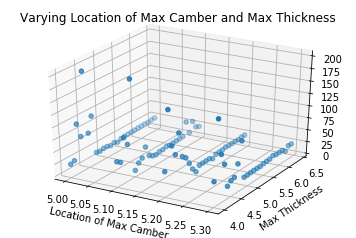
 

Figure 4:

Figure 3 :

Figure 1 depicts change in the first NACA parameter, maximum camber, while the other two parameters are held constant. As the maximum camber increases a general increase in the lift – drag ratio can be observed. It is also important to note that most of the data is not closely grouped, only in a small region near one percent chord.

Figure 2 depicts change in the location of the maximum camber. It is slightly difficult to note in the figure, however a slight decline in the lift – drag ratio can be noted as the location of the maximum camber gets further away from the leading edge. The data in this set is mostly grouped together.

Figure 3 depicts variation in the maximum thickness. Data near zero was not defined. The data points before 4.5 maximum thickness is more varied, while after 4.5 percent chord the lift – drag ratio stabilizes.

Figure 4 is special because it utilizes a 3-dimensional plot to show the relationship between the location of max camber and the max thickness. This combination of data was chosen to be graphed because the relationships found in the 2-dimensional plots are shown most clearly. The decline in the lift – drag ratio can clearly be seen as the max camber increases in distance from the leading edge.

The shown data is only a select portion all the data I calculated. The table below shows the ranges which I searched to locate the maximum lift – drag ratio.

|  |  |  |
| --- | --- | --- |
| Parameter | Minimum Value | Maximum Value |
| P1 – Maximum Chord | 0.1 | 3 |
| P2 – Location of Max Chord | 5.0 | 10 |
| P3 – Maximum Thickness | 3.0 | 6.5 |

The maximum lift – drag ratio was 114 and 1157 for 1e4 and 1e5 respectively. Their NACA parameters are shown below. An approximation of the airfoils that achieved that lift – drag ratio within the given design requirements are also shown below.

|  |  |  |
| --- | --- | --- |
| C:\Users\AdamC\AppData\Local\Microsoft\Windows\INetCache\Content.Word\1e4 airfoil.png | Reynolds Number | 1 e4 |
| Maximum Camber | 0.4 |
| Location of Max Camber | 7.6 |
| Maximum Thickness | 4.0 |
| Lift – Drag Ratio | 114.0 |

|  |  |  |
| --- | --- | --- |
| C:\Users\AdamC\AppData\Local\Microsoft\Windows\INetCache\Content.Word\1e5 airfoil.png | Reynolds Number | 1 e5 |
| Maximum Camber | 0.1 |
| Location of Max Camber | 6.6 |
| Maximum Thickness | 3.0 |
| Lift – Drag Ratio | 1156.8 |

# Discussion

In the proceeding paragraphs I will discuss the implications of each graph, weaknesses of this project and consider some possible improvements.

### Figure 1

The increase in the lift – drag ratio with the increase of camber makes sense, because as the camber increases in the positive direction, the air traveling over the wing must travel farther. This increased distance of travel creates a deficit of pressure on the upper edge of the wing, thereby increasing lift. This also would not drastically increase the surface area normal to the flow of air, limiting the increase of drag. The large instability of the data suggests that airfoil is largely unstable, except for the small region where the data points are more condensed. This would probably present itself in the form of shuddering, large leaps and drops and hard impacts on the wing.

### Figure 2

The relatively stability of the data with relation to the location of the maximum camber suggests that this parameter does not play as significant of a role in determination of the lift and drag coefficients. This seems particularly suspicious because it does not coincide with findings by Daniel Maynes in his Masters’ project. His findings state the first little part a ballistic object determine the majority of the drag. Proper citation cannot be given because the cited information is from word of mouth and is not available to civilians. The general decrease in the lift – drag ratio suggest that the further back the maximum camber is located, the less benefit it gives to the airfoil.

### Figure 3

As the maximum thickness approaches zero, the drag would go to infinity. This explains why the values near zero were undefined. It is important to note two things: that the values near zero are scattered suggesting that those values are unstable, which would not make a suitable airfoil. Second, as the airfoil got thinner and thinner, that it would not be able to withstand the material stresses exerted on the wing during flight.

### Figure 4

The relationship shown on this plot is simple, however displays an important piece of information. There seems to be interplay between the parameters. This makes logical sense, because camber is defined by the thickness function.

### Areas of Weakness

The chosen airfoils are within the maximum thickness range that is of questionable structural integrity. These airfoils are most likely unrealistic, and some research or consideration to the stresses made on the wing is requisite. On top of that weakness, this study does not consider a large enough set of data, with a fine enough step size. It does not provide an accurate display all of the possible trends present.

### Possible Improvements

The foremost improvement that could be made to this study is an inclusion of stress on the wing to make any optimized airfoils more realistic. This would bring the study back within the realm of engineering, instead of theory. On top of that, more time could be spent to refine the step size of the calculations, and expand the range of data considered. This would allow for more accurate observations of trends and data.

Improvements could also be made to the analysis on the data; another form of data analytics would improve this study. A program that included dot size or color to add a fourth dimension to the three-dimensional plots would allow for a visualization of the data. This might display the interaction between the parameters. Regression analysis might be possible by defining one of the parameters in terms of another. This analysis might be too complicated to implement in all of the different possible combinations of parameters. It might be of worth to try a fast Fourier transform to discern if there are any notable nodes or patterns within the data.

### Conclusion

Despite this projects’ shortcomings, it provided a rudimentary introduction to optimization of airfoils, and an excellent opportunity to implement some of the skills I have been learning. This project displayed this large variance possible in theoretical data calculated by Xfoil, and the need for more advanced data analysis tools. It demonstrated the interplay between the shape of an airfoil, lift and drag. It also helped further understanding of how NACA parameters determine the shape of an airfoil.