Revisiting the Calculations of the Aerodynamic Lift Generated over the Fuselage of the Lockheed *Constellation*

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ABSTRACT

The Lockheed *Constellation*, first flown in 1943 and retired in the early 1960's, was one of only several commercial aircraft to have a fuselage which created an amount of lift greater than other fuselages at that time. This was stated in several publications on this aircraft, along with Aerodynamic and Fluid Mechanics courses, and is said to be attributed to its radical shape (Pace, 1998). Therefore, it was seen to be an interesting idea to use the combined knowledge of design and analysis of the team members to investigate this phenomenon. To do this, SolidWorks will be used both to model and analyze two types of fuselages: the *Constellation* and a typical symmetrical fuselage in terms of the aerodynamic forces produced at different flight conditions. In addition, a new fuselage will be designed based on the *Constellation* with the intent of being used in the current aircraft market. Since the writing of this paper, the flow simulations on both fuselages have been completed and it has been seen that, in terms of aerodynamic forces, the *Constellation* does in fact have a higher lift-to-drag ratio when compared to a symmetrical fuselage.

Keywords: Aerodynamics, Flow Simulation, Aircraft Design, SolidWorks

1. INTRODUCTION

On January 9th, 1943, the Lockheed Constellation, also known informally as the "Connie", made its first flight into aviation history. The initial production had the Constellation powered by four Wright R-3350 radial engines (en.wikipedia.org). These engines contained unusually long propeller blades, which required a long front nose gear. To avoid this situation, the designers changed the mean camber line of the fuselage in two areas: it was first lowered in the forward section, and then curved downward in the aft section. The forward lowering allowed for the nose-gear to be just long enough for the clearance, while the downward curvature ended up decreasing the drag over the aft section of the fuselage (Pace, 1998). From this "fix", the basic design of the fuselage was made.

Outside of the original tests performed by Lockheed engineers during the initial phases of the design, there have been no analyses undertaken to calculate either the drag or lift over the fuselage of the Constellation. The reason why no one has done this can be explained by the simple fact that there was no real problem with this. Being that this was a good thing, there was no real need to find these values and publish them either in technical or educational publications.

1.1 Project Objectives

The objectives set out by the group for this project are as follows:

1. Design both Constellation fuselage and symmetrical fuselage in SolidWorks.
2. Simulate the flow over both Fuselages at various flight speeds and angles of attack.
3. Compare the results of the two fuselages in terms of aerodynamic forces.
4. Attempt to optimize the *Constellation* fuselage to increase its aerodynamic Performance.

First and foremost, both the *Constellation's* fuselage and the standard symmetrical fuselage needed to be modeled in 3D before the application of the flow analysis portion of the project. The next step will be to run the flow analyses on each fuselage at different wind speeds and angles of attack. The purpose of these analyses is to find the coefficients of lift and drag of the fuselages. From these values, the lift-to-drag ratios can be determined. As of now, one flow analysis has been completed for a wind speed of 40 m/s and 0° AOA (Angle of Attack). This was used as a test of the SolidWorks Flow Simulation add-in. With all these values, the two fuselages will be compared to see if the *Constellation's* fuselage truly generates a higher lift-to-drag ratio. Finally, if it does create a higher ratio, an "in-between" fuselage design will be attempted. The purpose of this is to see if a fuselage of this type can function under current aircraft standards.

2. 3-D CAD MODELING

The first objective of the project has been completed. To model the fuselage in SolidWorks, a blueprint, shown in Figure 1, was needed for the dimensions of the fuselage. A tracing technique, which is available in SolidWorks, was used to create each cross-section of the fuselage. These several cross-sections are then connected together to create the longitudinal continuous solid model of the fuselage. A multi-view of the fuselage is shown in Figure 2.
In addition, an initial test flow-simulation has been completed in an effort to identify the major parameters that will affect the analysis; also, to familiarize the group with the use the Flow Simulation package. It was this test flow which allowed the group to revise the model of the *Constellation* to what it is now. Initially, the first model made did not contain an empennage section. When the initial flow simulation was performed, it was seen that the blunt end created a large amount of drag. Therefore, the model was revised to include a small fin at the end, which is pointed out on Figure 2 with red arrows. This fin allowed the air flowing over the fuselage to reattach more smoothly than the blunt end.
In addition to the *Constellation* fuselage, the symmetrical fuselage has also been completed. As a base, the Boeing 737-700 was chosen due to its fuselage's symmetrical cross-section and similar length to the *Constellation*. The same process which was used to model the *Constellation* was used again for the 737-700 fuselage. A multi-view of the fuselage is shown in Figure 3.

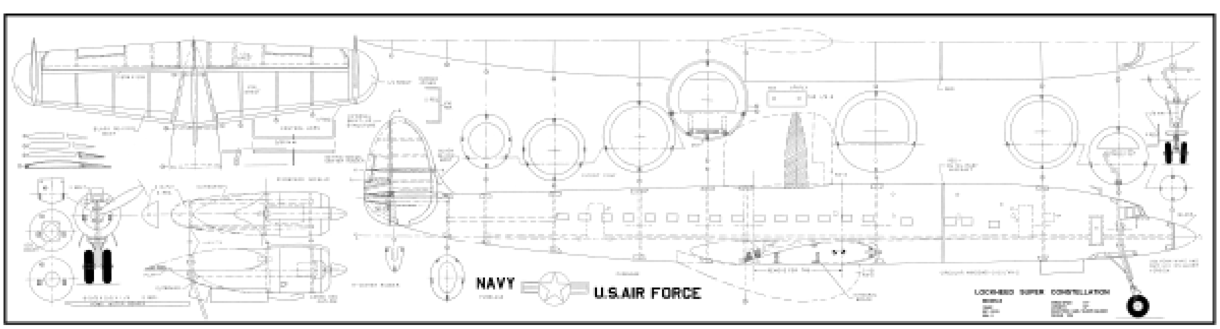

Figure 1: Blueprints of Lockheed *Constellation*.

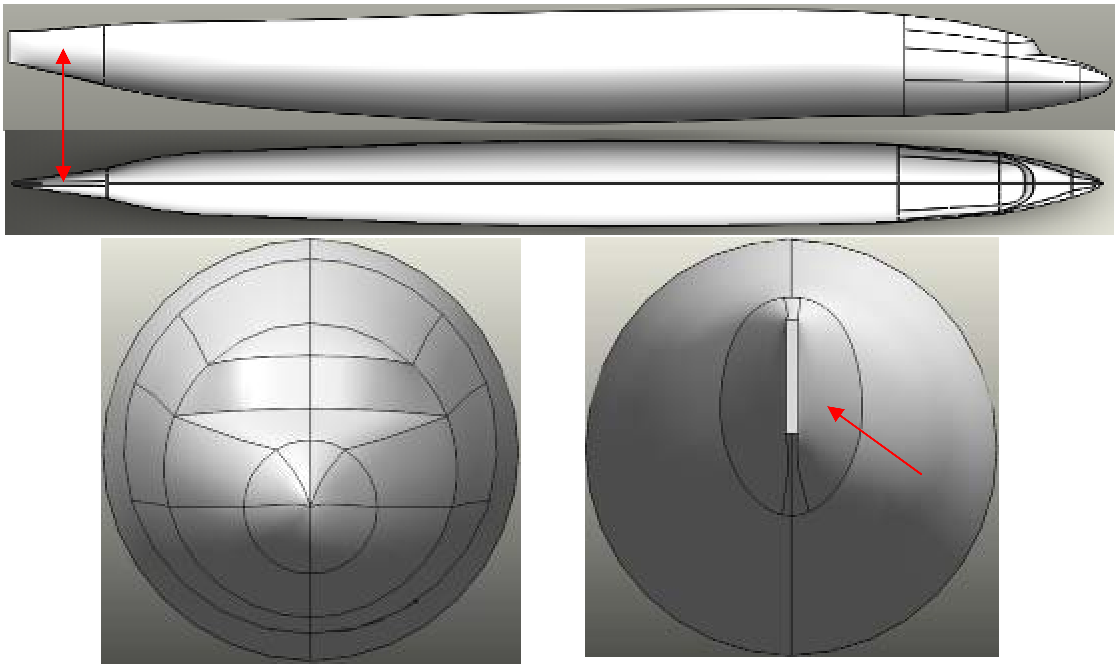

Figure 2: Side, Top, Front, and Rear views (top to bottom, left to right) of the *Constellation* fuselage modeled in SolidWorks.

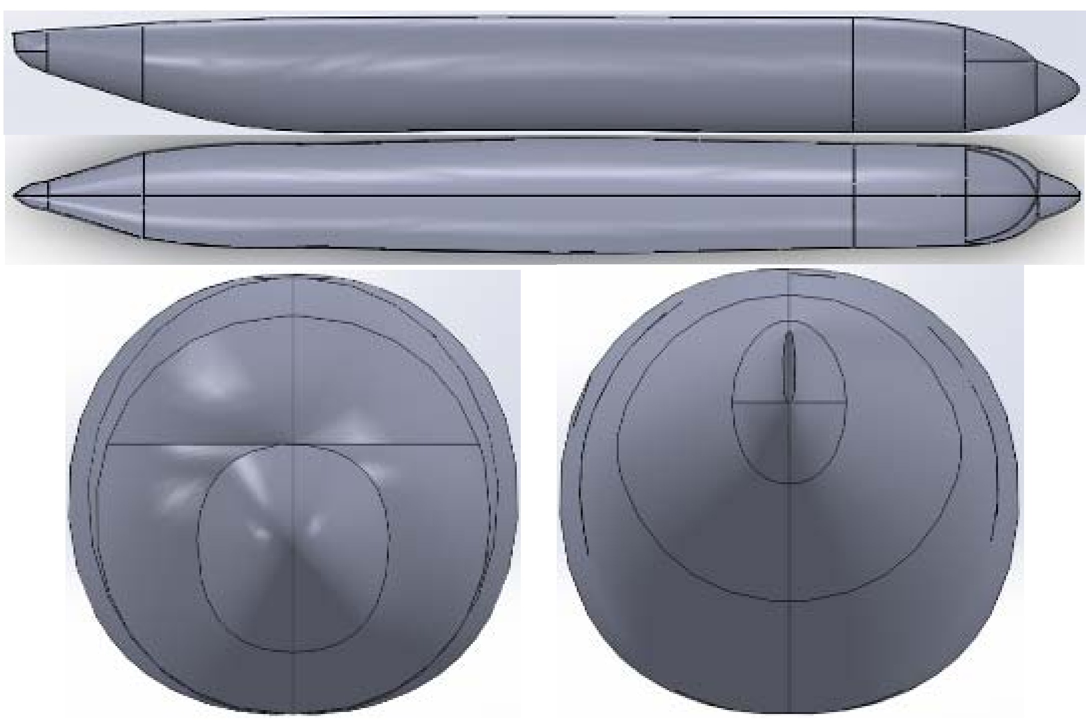

Figure 3: Side, Top, Front, and Rear views (top to bottom, left to right) of the Boeing 737-700 fuselage modeled in SolidWorks.

3. FLOW SIMULATION ANALYSIS

After completing the modeling of the fuselages, the second objective was started. As previously stated, each fuselage would be simulated at varying wind speeds and angles of attack. In an effort to make the results easier to compare, it was decided to keep the flow speed at 134-m/s, or 300-mph. This was the cruise speed of the *Constellation*. It was also decided to limit the range of angles of attack to a range from 0° to 10°.

There are a plethora of factors which must be taken into account when using the Flow Simulation add-in of SolidWorks. Some of these important factors that are essential to understand and to produce the right simulation are mesh configuration, boundary conditions, and the dimensions of the flow domain. Initially, the flow domain is automatically calculated by SolidWorks, which is where the simulation actually takes place. The flow domain encompasses an area around the fuselage which needed to be large enough to include all the volume where the flow is affected by the solid object. To enhance the accuracy of the solutions, the mesh generated around the flow domain was focused around the fuselage itself. This also allowed SolidWorks to cut back on the computer resources needed for the simulation.

Once the project team familiarized themselves with the Flow Simulation package, the various simulations were performed. In addition to solving for lift and drag coefficients, SolidWorks allowed other aerodynamic properties to be found. These included lift force, drag force, velocity profile, and pressure profile. All these values allowed the team to understand more fully what was happening to each fuselage during the simulation. However, the most important results were the lift and drag coefficients. The velocity and pressure profiles for both fuselages at 4° angle of attack are shown in Figures 4 through 7, respectively. The results for the lift-to-drag values are given in Figure 8.

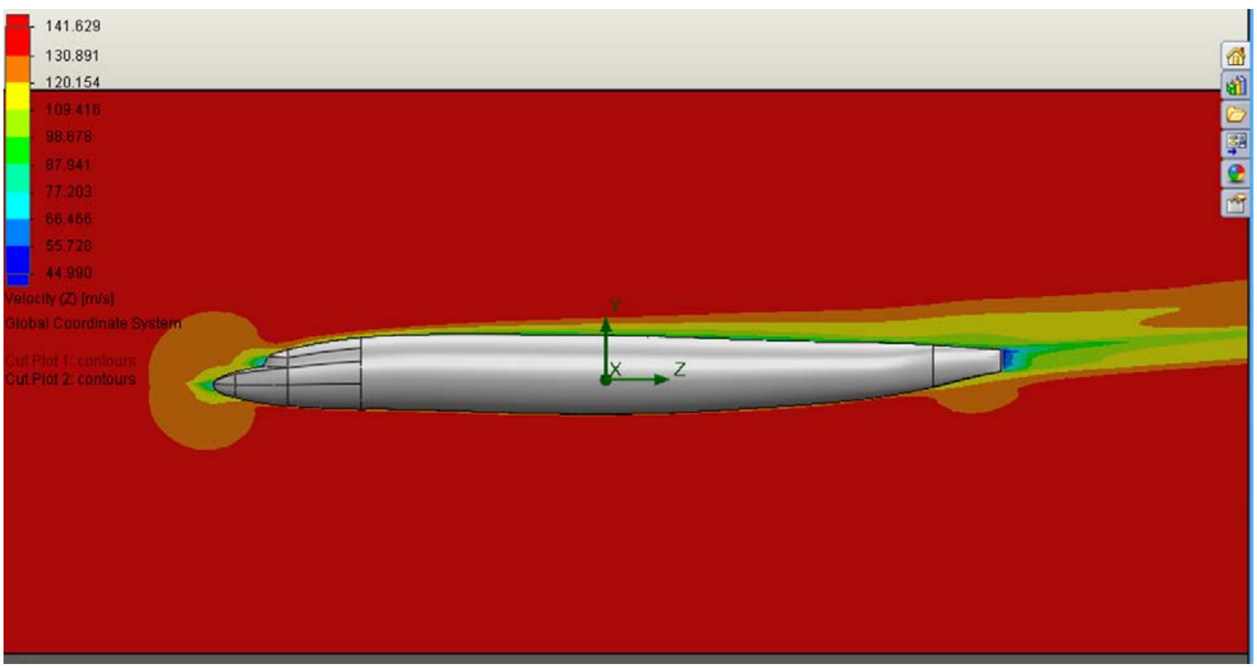

Figure 4: Velocity profile of *Constellation* at 4° Angle of Attack.

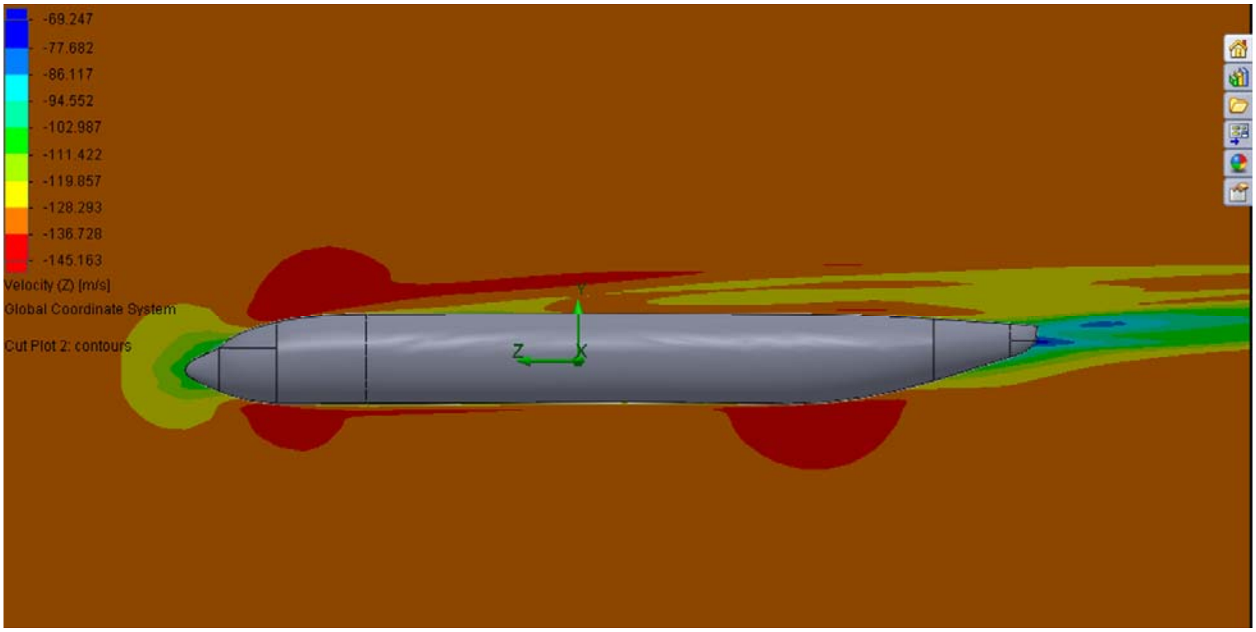

Figure 5: Velocity profile of Boeing 737-700 at 4° Angle of Attack.

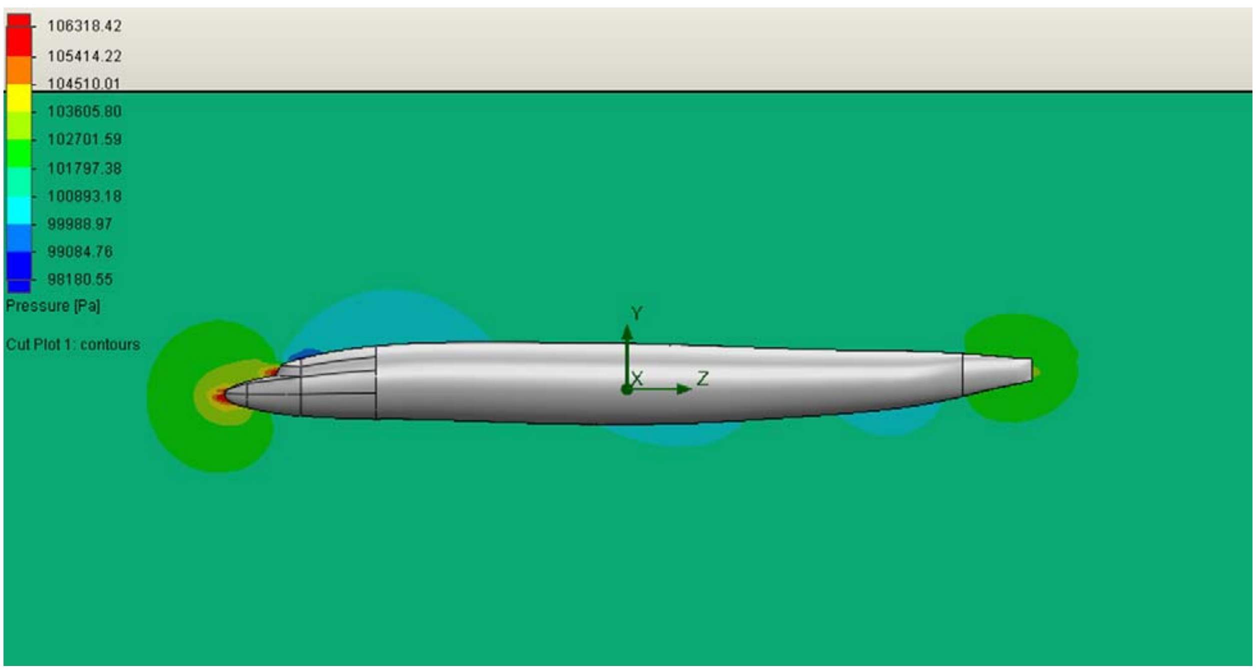

Figure 6: Pressure profile of *Constellation* at 4° Angle of Attack.

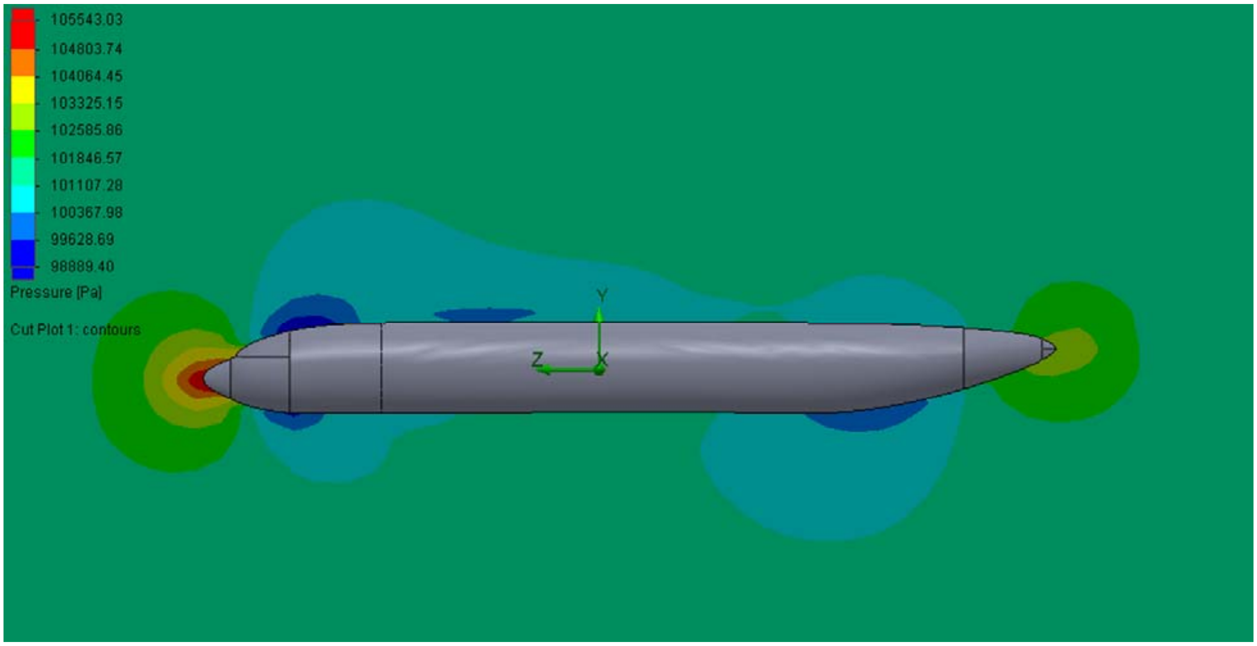

Figure 7: Pressure profile of Boeing 737-700 at 4° Angle of Attack.

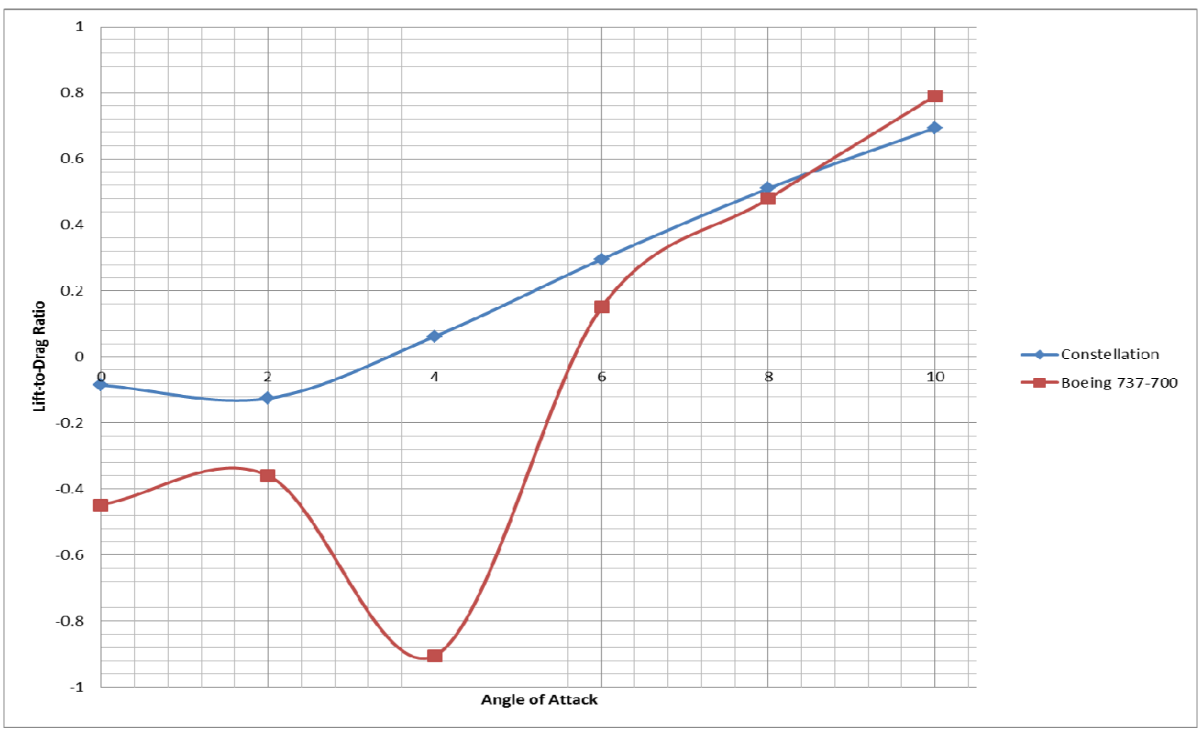

Figure 8: Graph of Lift-to-Drag ratio vs. Angle of Attack results for *Constellation* and Boeing 737-700.

It can be seen from the profiles shown in Figures 4 and 6 that the geometry of the *Constellation* leads to better airflow over the fuselage, and therefore a higher pressure-differential, thus creating more lift. Due to the symmetrical flow, there is less drag created when compared to the velocity profile of the Boing 737-700, as seen in Figure 5. Also, the erratic velocity profile of the Boeing 737-700 leads to an increase in the drag at the given angle of attack. This is shown in more detail in Figure 8. The graph shown in Figure 8 also illustrates that, at angles of attack less than roughly 8°, the *Constellation* does in fact have a higher lift-to-drag ratio. This also means that the geometrical design of the *Constellation* is not optimal for high angle of attack flights. However, due to the nature of civilian commercial flight, a high angle of attack is not seen outside of certain maneuvers, such as takeoff (Raymer, 2006). Therefore, it can be concluded that the *Constellation* fuselage does in fact produce a higher lift-to-drag ratio when compared to a symmetrical fuselage.

Although Figure 8 illustrates the aerodynamic performance of both fuselages, it also gives insight into how the geometry of the aircraft affects certain parameters of the flight performance. The major parameter, which is seen in the figure, is the idea of *critical angle of attack* or *stall angle of attack*. In aerodynamics, the *critical angle of attack* is the angle of attack where the lift generated is at the lowest and the drag generated is at the highest. In terms of flight, it is essential that this angle be avoided to prevent the aircraft from stalling. To do this, aircraft designers place the wings and other surfaces at certain angles of attack relative to the centerline of the fuselage, thus moving the *critical angle of attack* to a different angle (Raymer, 2006). With this knowledge in mind, it can be seen form Figure 8 that the fuselage of the Boeing 737-700 has a *critical angle of attack* of roughly 4°. On the other hand, it can be seen that the fuselage of the *Constellation* does not have an obvious *critical angle of attack*. However, this does not mean that it does not have one; the simplest explanation it that the *critical angle of attack* occurs at an angle outside of the angles tested in this project.

4. FUTURE WORK

With the results of the flow simulations proving that the *Constellation* fuselage is optimal in terms of lift-to-drag ratio, the final objective of the project can now be started. To optimize the results found in the simulations, the team decided to attempt to design a new fuselage which would combine the aerodynamics of the *Constellation* with the carrying-capacity of the Boeing 737-700. To accomplish this, it was decided to trade an increased lift-to-drag ratio for more fuselage volume. Therefore, it can be assumed that, once finished, the new fuselage will produce a lift-to-drag ratio somewhere in-between the *Constellation* and the 737-700.

The design of the new fuselage will be accomplished by using SolidWorks and the same techniques utilized in the creation of the original fuselages. However, without a blueprint or other sketch to trace, the design will require more of both time and patience to be achieved.

5. CONCLUSION

Moreover, it can be seen that, although outdated, the *Constellation* fuselage still has some precedence in today’s world of jets and rockets. However, finding and proving this precedence has been difficult. It took the project team roughly three weeks to find a blueprint of the *Constellation* which was accurate enough to be traced into SolidWorks. The process of actually modeling the fuselage took two weeks due to the errors encountered when extruding the solid model from the surfaces initially made. In addition to these difficulties, the project team did not know initially how to use the Flow Simulation package of SolidWorks. Therefore, time had to be allocated for the team to review the steps necessary to complete a flow simulation. This caused the project to be delayed several weeks, in addition to the weeks needed for the modeling phase. However, the project has been moving quickly and the final fuselage design is expected to be completed on time. Once the design of this new fuselage is completed, and the analyses on it are completed as well, the project will be considered finished.

This project consists of two major benefits: the first is the benefit to the airline and aircraft industry, and the second is the benefit to engineering education. By designing a new fuselage, the airline and aircraft industry will be able to utilize a fuselage that will have a high lift-to-drag ratio. Therefore, the entire aircraft can actually be smaller, i.e. the wings can be smaller, thus reducing the weight and allowing more passengers or cargo to be transported. In addition, completing this project allows undergraduate students in Aerodynamic or Fluid Mechanics courses to learn, in an easy and simply way, how to find the lift and drag generated by an aircraft fuselage by utilizing certain engineering programs, such as SolidWorks. By taking the work performed in this project and rewriting it in a step-by-step fashion, students can be able to not only study wings, but the fuselage as well. If students in aerodynamic programs are introduced early on in their career to advanced techniques to solving problems, such as the one presented here, they will be more prepared when solving these problems both in their graduate studies and in the aviation field.

Although the solutions found in this project were the main output of the work done, the work itself is the main focus of this project. The solutions were simply used to validate the work done and the assumptions made. Therefore, the technique used to solve the initial problem set forth by the group, not the solutions found, can be applied to new engineering problems faced by students in the future. Unlike other projects and papers which present a solution to be applied, the work performed in this project is the main goal. As previously stated, when the project is finished, the technique used here can be summarized and rewritten to be used by engineering students in undergraduate programs.

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