The Aerodynamic Effects of Dimples on the Fuselage of an Aircraft

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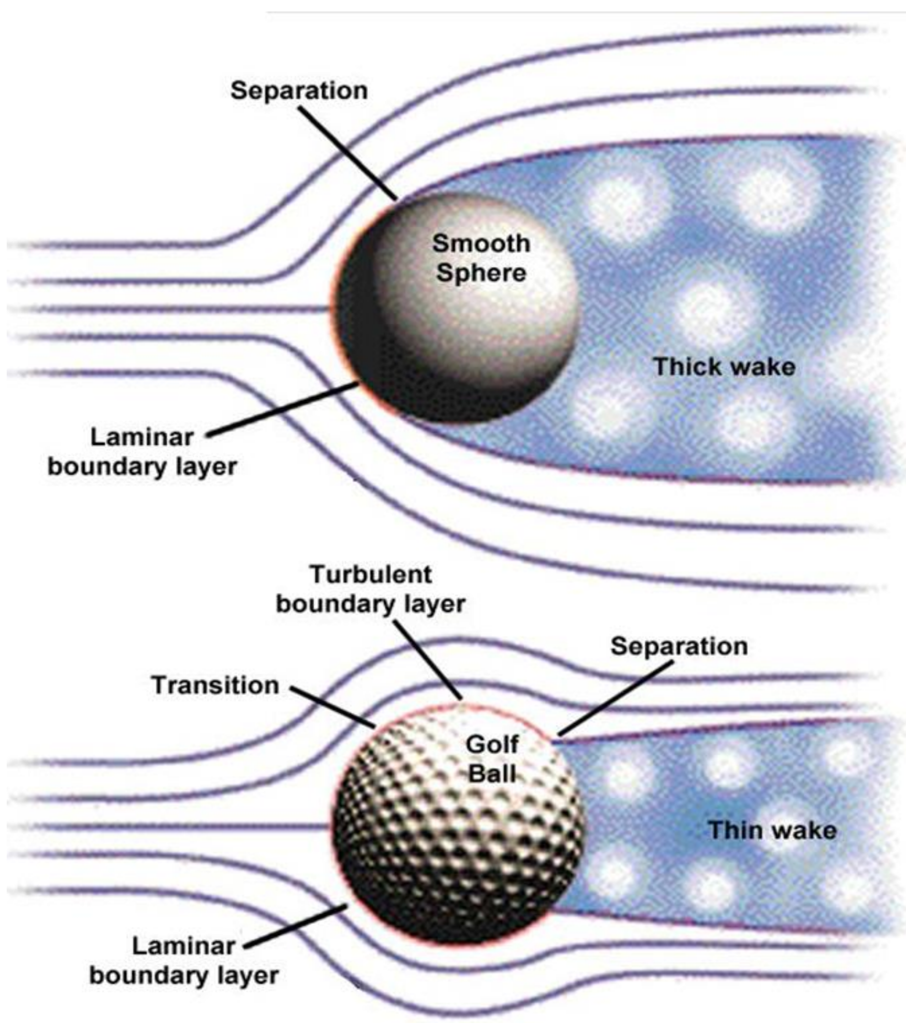
Kellogg Honors College Capstone Project

Introduction

Modern society is characterized by its mobility and connectivity, and one of the facilitators of these trends is modern aviation. Not only do aircraft provide transportation to millions of people across the world, but they are also used in transporting valuable goods, contributing significantly to the world economy. However, aircraft suffer from parasitic drag, which directly contributes to reduced fuel efficiency and increased operating costs. The purpose of this study was to analyze the aerodynamic effects of dimples on the fuselage of an aircraft in an effort to reduce the parasitic drag.

Due to its size, the fuselage generates a considerable amount of skin friction drag, a form of parasite drag, and contributes significantly to the overall drag of the aircraft, therefore reducing its efficiency. Previous studies have shown that dimples can reduce the overall drag of a body substantially; however, there have been no applications of dimples to a fuselage.



Literature Review

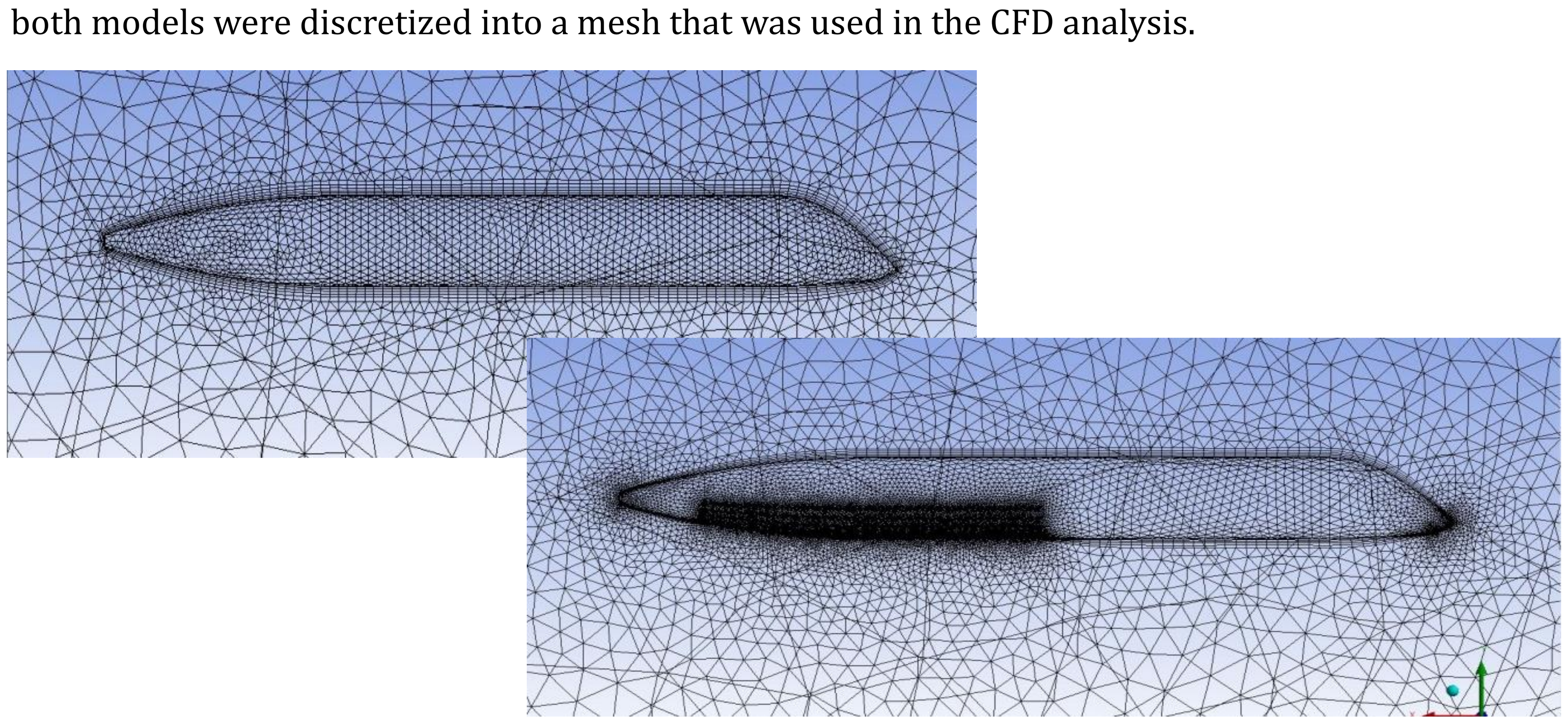
In a 2012 study by Deepanshu Srivastav titled "Flow Control over Airfoils using Different Shaped Dimples," it was shown that an airfoil with inward dimples had a smaller coefficient of drag than a conventional airfoil (Srivastav, 2012). However, Srivastav only analyzed a small section of the wing with only one dimple.

More recently, a group of aerospace engineering students at Cal Poly Pomona expanded upon Srivstav's research, theoretically and experimentally studying a model wing with a linear dimpling pattern along the leading edge. Titled "Passive Flow Control on an Airfoil by Use of Various Dimples," the students, under the mentorship of Dr. Ali Ahmadi, discovered that the dimples increased the stall angle by 2 degrees and resulted in a drag reduction of 30% at a Reynolds number of 300,000; 20% at Re of 500,000, and 10% at 700,000 (Abdou et al, 2013). Another discovery was that variations in the diameter of the dimple, be it 1% or 2% of the chord, had no noticeable effect. Additionally, it was discovered that the coefficient of lift was also reduced at all speeds (Abdou et al, 2013). Although the reduction in the coefficient of lift would deter application of dimples on wings, it should have no effect on the fuselage since the fuselage is not generally used to generate lift.

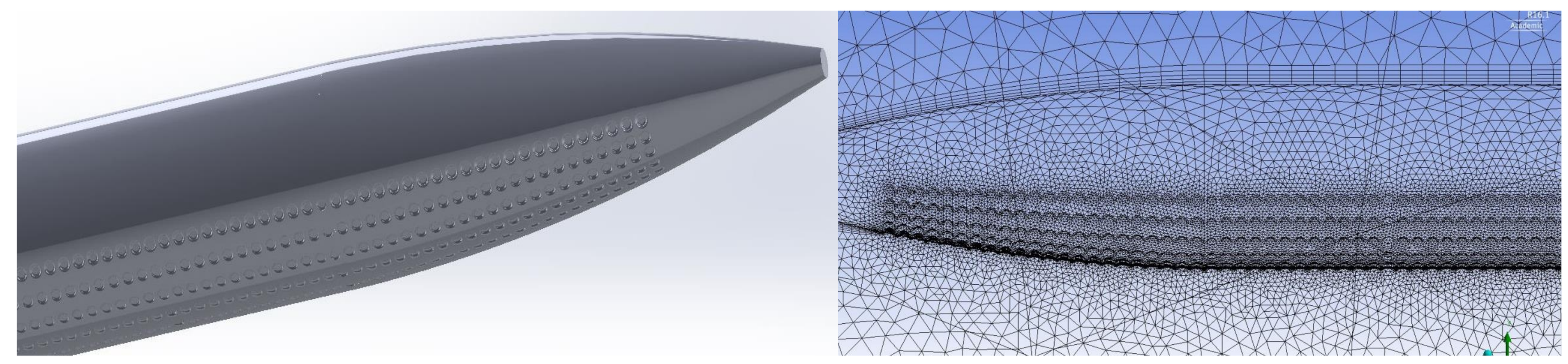
Method

This study analyzed the aerodynamic effects of dimples on the fuselage of a Boeing 787 Dreamliner using a 3-D CAD model. Although the aerodynamics being studied are somewhat independent of the specific aircraft as long as the geometries of the planes are similar, the Dreamliner was chosen due to the large amount of information and resources that are currently available.

Using SolidWorks, two 3-D CAD models were made. The first model was undimpled and was used the determine the baseline values. The second model had dimples in a linear pattern along the underside of the tail section of the fuselage. Once both models were completed, they were exported to ANSYS Fluent, a computational fluid dynamics (CFD) program. Using ANSYS, both models were discretized into a mesh that was used in the CFD analysis.



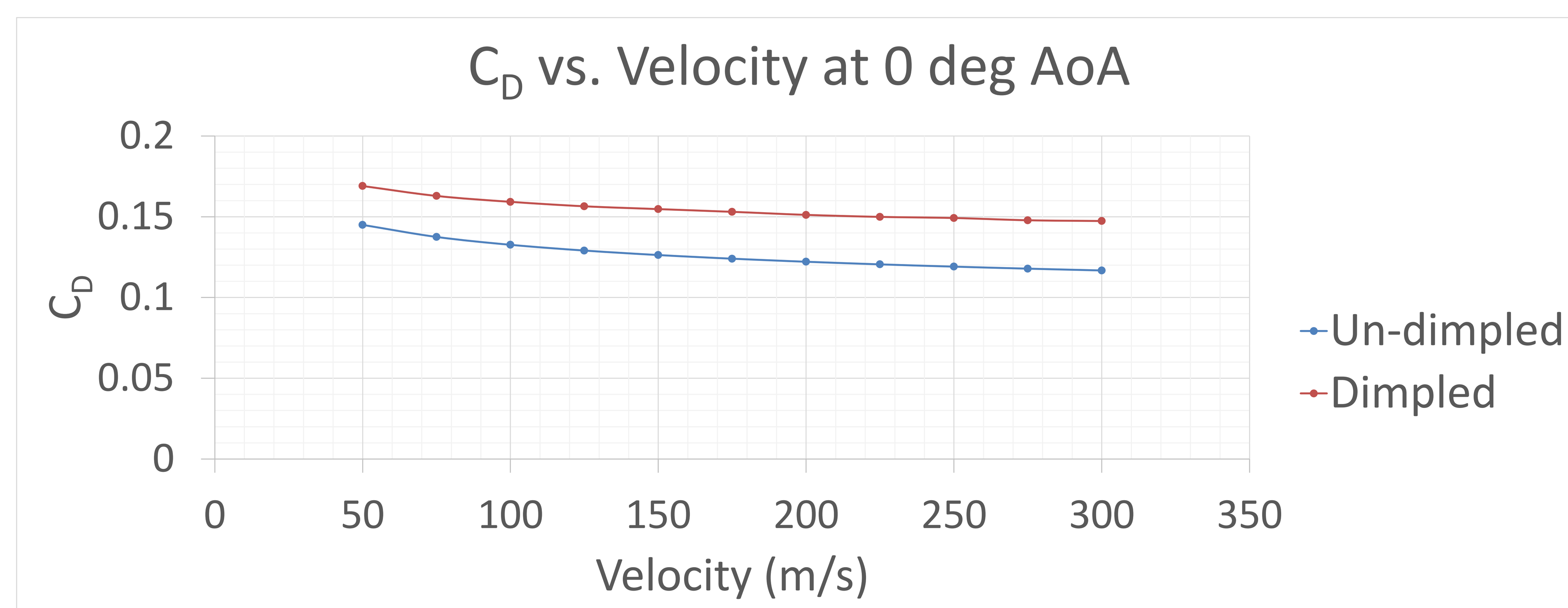
Undimpled vs. Dimpled Fuselage Mesh



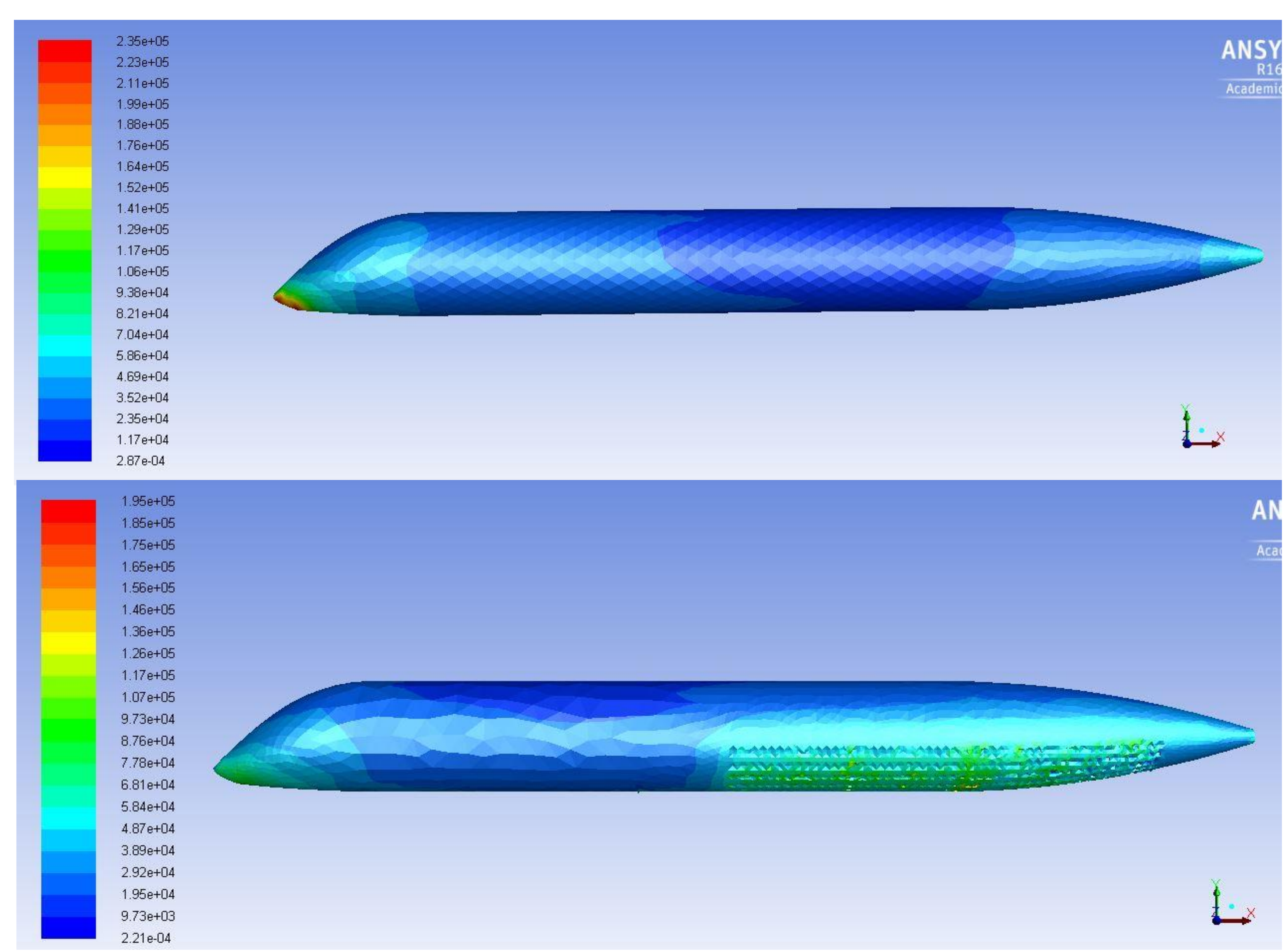
Dimpling Pattern CAD and Mesh

Results and Conclusions

In an effort to understand the flow characteristics in various conditions, the CFD analysis was conducted at 0, ± 4, ± 8, and ± 12 degrees angle of attack (AoA) at velocities ranging from 50 m/s to 300 m/s at increments of 25 m/s. These conditions were used for both models in order to have a valid comparison. Shown below are the results for the 0□ angle of attack.



To better understand how the airflow is interacting with the dimples, the contours of vorticity magnitude were generated at a simulated cruise condition of 250 m/s at 0 degrees AoA.



By comparing the collected data, it is clear that the dimples are not beneficial and are ineffective at decreasing the total drag. Rather than decreasing the drag, the dimples actually caused the total drag to increase by approximately 20% or more regardless of the flight condition. As can be seen in the Vorticity Magnitude Contours above, the dimples are generating a large amount of vorticity in a region that would have otherwise had little vorticity. In other words, the dimples are creating turbulence in an area that does not suffer from flow separation. Although this dimpling pattern resulted in adverse effects, refining the dimpling pattern might improve their performance.

Acknowledgments

Dr. Todd Coburn – Mentor

Dr. Ali Ahmadi

McNair Scholars Program