TO: Joseph M. Powers
FROM: James Gallagher
DATE: 17 April 1997
RE: AE360 Project: Part II

The purpose of this part of the project is to design an airfoil. This airfoil is to be utilized at a Mach number of $M = 2.2$ in an ambient atmosphere of 100 kPa and 300 K. This airfoil should be able to create sufficient lift to keep a 2000 kg plane airborne. The airfoil and a program to find the lift and drag are to be designed by myself, but the program used to find the pressure, temperature, and density around the airfoil was supplied by Prof. Powers. In this memorandum I will present my design and explain how it was analyzed to find the lift and drag. The results of the analysis will then be given followed by a discussion of the results. Also a copy of the first part of the project is in Appendix A.

The design for the airfoil to be discussed in shown in Figure 1. The airfoil is basically a diamond shape with a cord of .6 m and a thickness of .1 m. The maximum thickness is at the quarter cord location and it will be used at an angle of attack of 5°. I came upon this design through a process of trial and error. The first design that was analyzed was a flat plate, the flat plate was used to check the code and make sure it would produce the correct answer of zero lift. Once the program was running fine a triangular airfoil was used but since it was producing a negative lift it was quickly discarded. Finally a diamond shaped airfoil was brought into the picture and after fine tuning the dimension a design for the airfoil was decided upon.

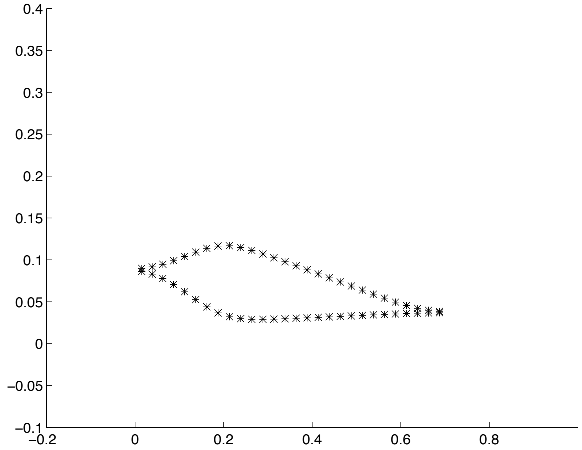

Figure 1: Cross-Sectional View of Airfoil Design

In order to analyze the airfoil a supplied Fortran77 code was used to find the pressure, temperature, and density distribution over the air foil. From the pressure distribution the lift and drag on the airfoil were calculated using a Matlab code. Fortran77 code gave an output of specific pressures at x and y locations on the airfoil. The Matlab code used took those pressures and locations and calculated the total force acting on the body by multiplying each pressure by the surface area that it is acting upon. Then those forces were broken up in to their lift and drag components and summed to obtain the total lift and drag acting upon the airfoil. Once the lift and drag were calculated the lift and drag coefficient were then calculated using Equations (1) and (2).

$$C_l = \frac{L'}{1/2\ \rho\ u^2\ c} \tag{1}$$

$$C_d = \frac{D'}{1/2\ \rho\ u^2\ c} \tag{2}$$

where C_l and C_d are the lift and drag coefficients, L' and D' are the lift and drag per unit span, ρ is the ambient density, u is the free stream velocity, and c in the cord length.

Through this analysis of the airfoil it was discovered than at five degrees of attack the airfoil produces a lift of 41 kN and a drag of 12 kN, which is more than enough to keep a 2000 kg airplane airborne. These lift and drag values translate to a lift coefficient of $C_l = .2$ and a drag coefficient of $C_d = .062$. The contour plots of the pressure over the airfoil are given in Figures 2 and 3. (Note: all contour plots of the lower surface of the airfoil will be presented in an inverted formate, this is because that was the best way for the Fortran77 code to plot them.) In these figures the shock waves produced by the leading edge can be seen. Also there are the expansion waves as the flow passed the bend in the airfoil. By the shading in the figures it can be seen that the shock wave on the bottom is larger than the shock wave over the top of the air foil. It is the larger shock on the bottom of the airfoil that helps to produce much of the lift because as the flow passes through the shock it's pressure increases more than the flow crossing the shock on the top thus creating

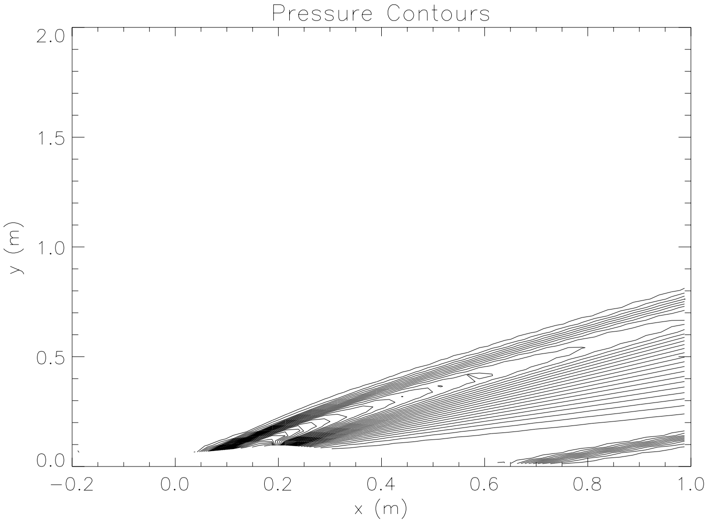

Figure 2: Pressure Contour Over the Top of the Airfoil

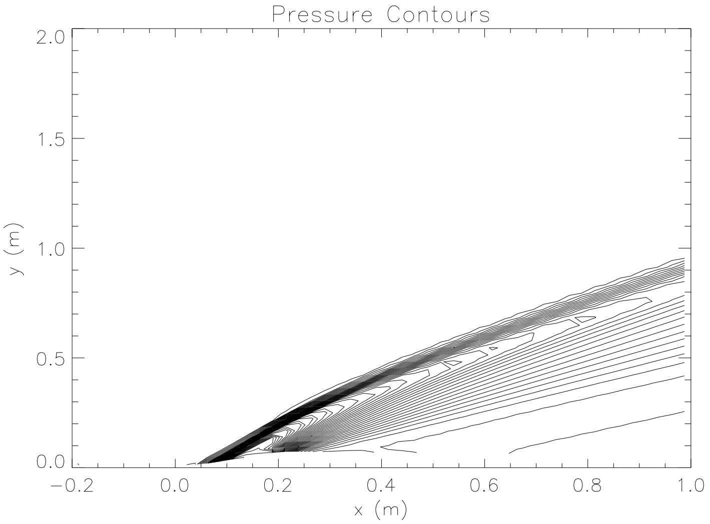

Figure 3: Pressure Contour Over the Bottom of the Airfoil

force acting up on the airfoil. Also the expansion wave on the top is larger than the expansion wave on the bottom. This also leads to positive lift because the larger the expansion wave the more it decreases the pressure and again with a smaller pressure on the top creates an upward force acting on the airfoil. These relations can also be seen in Figures 4 and 5 where the pressure is plotted vs. the x position. In Figures 4 and 5 it is obvious where the high and low pressures are distributed over the airfoil. Also by looking at where those high and low areas of pressure occur it can be seen where the oblique shocks and the expansion waves are on the airfoil. Where the lift comes from also becomes obvious by looking at this plot. With the large area of low pressure on the top and the large area of high pressure on the bottom it is understandable that there would be a force acting up on the airfoil.

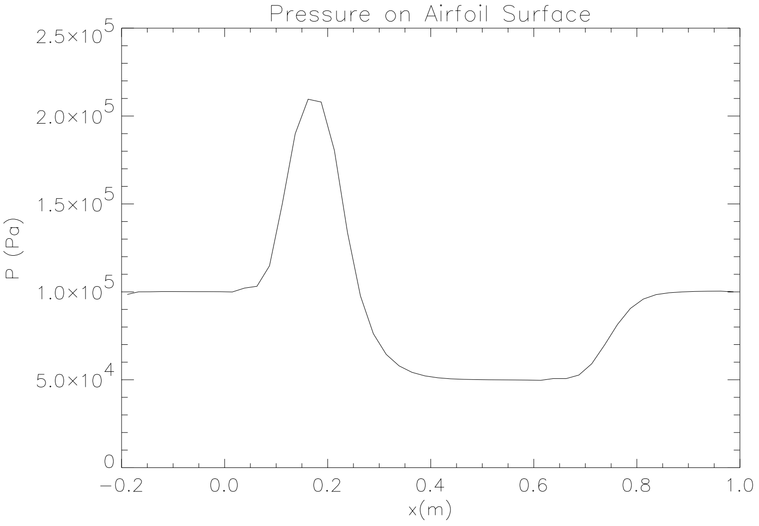

Figure 4: Pressure Distribution Over the Top of the Airfoil

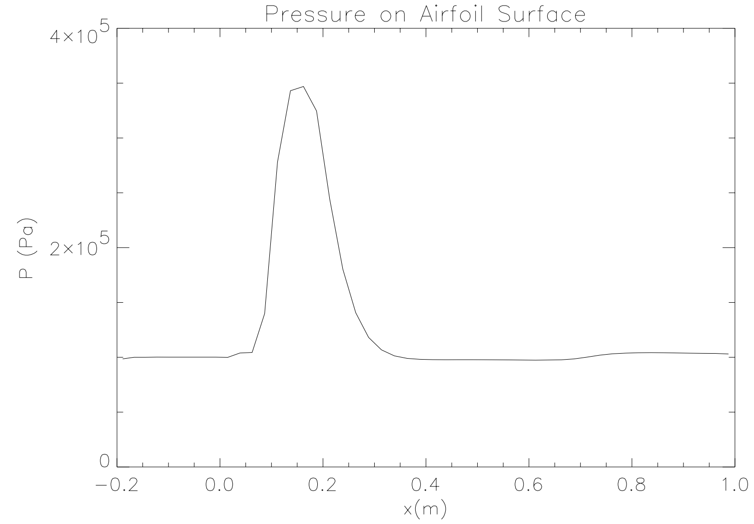

Figure 5: Pressure Distribution Over the Bottom of the Airfoil

The temperature contour plots for the top and bottom of the airfoil are in Figures 6 and 7. As with

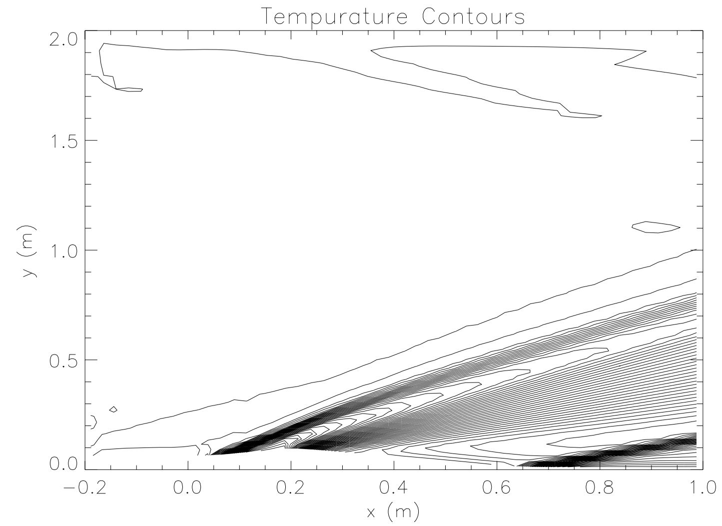

Figure 6: Temperature Contour Over the Top of the Airfoil

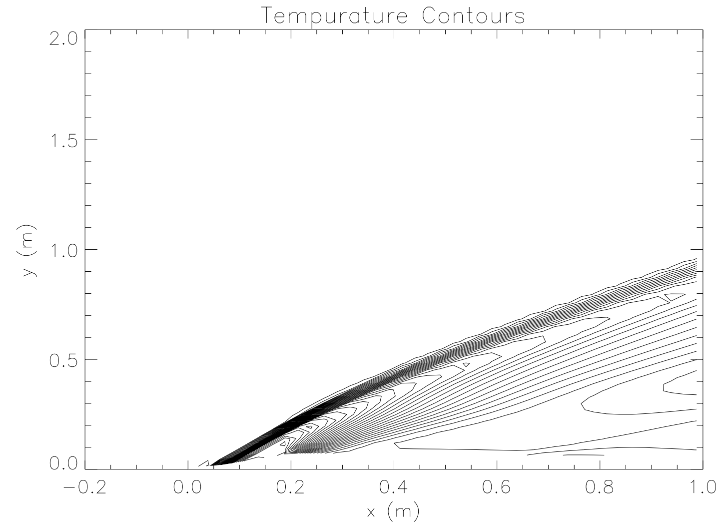

Figure 7: Temperature Contour Over the Bottom of the Airfoil

the pressure contour plots it can be seen in the temperature plots were the oblique and expansion waves occur. It can also be seen in the temperature plots how the shock waves increase the temperature of the flow.

In Figures 8 and 9 the contour plots of the density are given. In these plots the oblique shock and expansion waves can be seen. Also it is obvious that the oblique shock on the bottom of the flow in larger then the oblique shock on the top of the air foil by the fact that the bottom shock gives a much larger change in density than the top shock.

The important thing to learn from this project is that in designing a supersonic wing it is very important where the oblique and expansion waves occur. It is beneficial to design the airfoil with the larger shock wave on the bottom to increase the pressure pushing up on the airfoil. Also it is important to place the larger expansion waves on the top of the airfoil in order to reduce the amount of force pushing down on the airfoil.

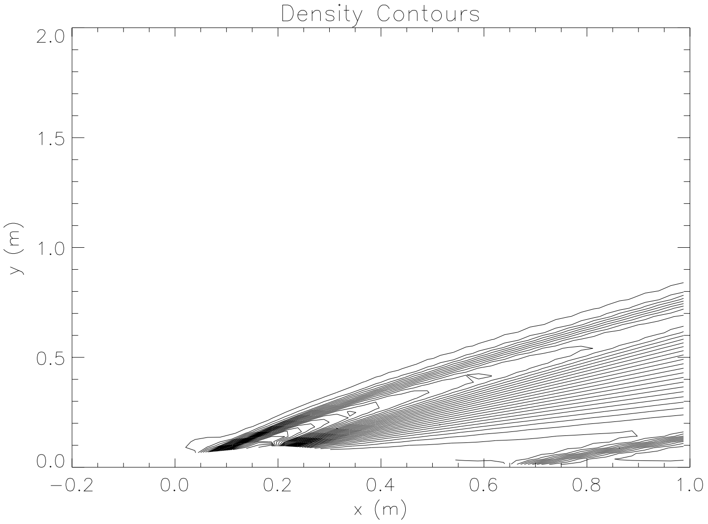

Figure 8: Density Contour Over the Top of the Airfoil

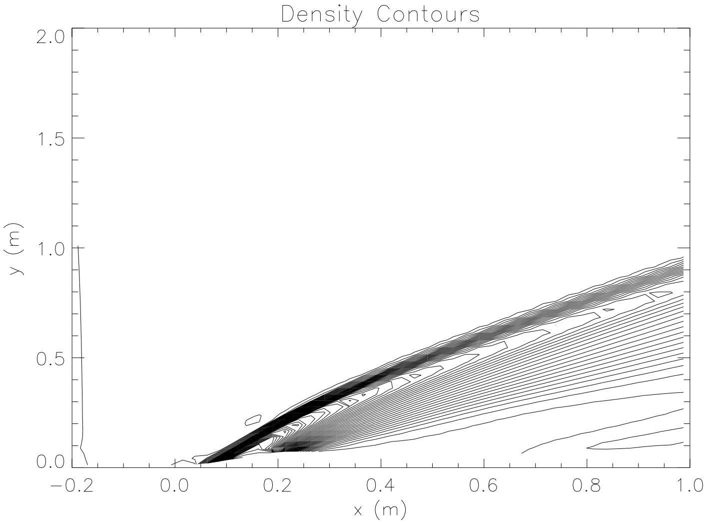

Figure 9: Density Contour Over the Bottom of the Airfoil