Airfoil Analysis Instructions

I. Introduction

Airfoil Analysis is a windows-based application that computes the aerodynamic performance of airfoil sections. It uses several different theoretical methods to compute the lift, drag, and moment coefficients, along with distributions of the pressure coefficient and boundary layer properties. If desired, the user may also compute the drag polar for the airfoil, which is useful for comparing the performances of different airfoils.

Airfoil selection is done either by the user interacting with a number of NACA airfoil windows or through reading airfoil coordinate data files. For the latter purpose the UIUC data base with over 1000 airfoils is included with the application. The user may also enter other data files. To adjust for various file formats, a preview window shows the data file so that the starting line of the coordinates may be determined by the application.

Flight conditions may be entered either as Mach and Reynolds numbers on the performance windows or from the Flight Conditions Window that computes flight conditions based on altitude and freestream velocity. The 1976 US Standard Atmospheric model is used for determining static conditions at a given altitude. The results are presented in a table along with the isentropic relations for the Mach number.

The remainder of this document briefly describes the theoretical methods used and then describes the use of each of the features of the program.

II. Theoretical Methods

The inviscid pressure distribution is found by using a vortex panel method that assumes a linear variation of vortex strength along each panel. The Kutta condition is imposed and a value of the surface stream function is computed along with the panel vortex strengths.

The boundary layer is first computed by using the method of Thwaites up to the point of transition. The user may choose between several transition models. Transition may be forced at a specified location or one of the natural transition models may be used. The transition model of Michel should be used if the freestream is known to have a higher turbulence level or that of Wazan, et. Al. if the freestream turbulence level is lower. Downstream of the point of transition, Head’s turbulent boundary layer method is used.

The Lift and moment coefficients are determined from the pressure distribution and the drag coefficient is found from applying the Squire-Young formula to the boundary layer at the trailing edge or just upstream of separation. For most flight conditions this gives a reasonable estimate but becomes less so with angles of attack near stall. Compressibility corrections are imposed if the Mach number is given by using the Karman-Tsien formula.

III. Airfoil Analysis Main Window

When executing the program the main Airfoil Analysis window opens, as shown in Figure 1. The window is blank with pulldown menus labeled Flight Conditions, Airfoil Definition, Airfoil Performance, and Help. Help is not presently active but is there for future implementation and will complement this document. To get started, the user clicks on any of the pulldown menus. Although the general order of using these menus would be from left to right, it is only necessary to activate the Flight Conditions window when one wishes to set the flight conditions based on altitude. The elements of the pulldown menus will next be described.

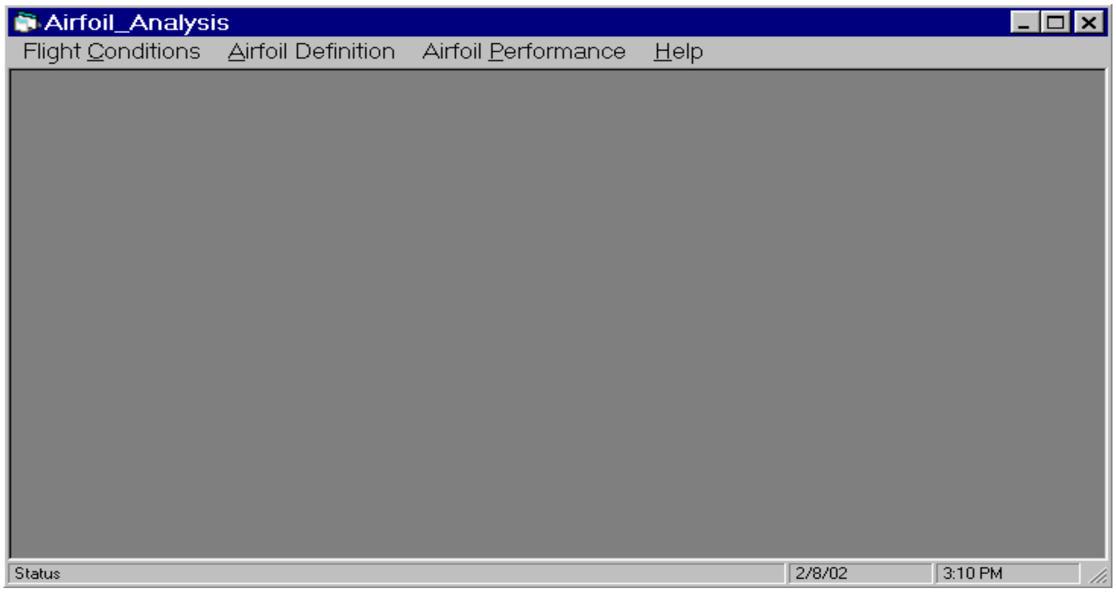

Figure 1. Airfoil Analysis main window.

Flight Conditions Pulldown Menu

There is only one item on this menu and it has the same name. So when this menu is clicked, the Flight Conditions window opens as shown in Figure 2. This window uses the 1976 US Standard Atmosphere definitions to compute the static properties at any given altitude.

Some simple instructions are given in the Instructions frame indicating how to interact with this window. Note that, along with the standard atmospheric conditions at altitude, the user may opt to enter various combinations of flight speed, Reynolds number per unit length and Mach number. In addition, the user may opt to change the ratio of specific heats to something other than 1.4 for the isentropic relations that are evaluated for the given Mach number. The quantities that get used by the rest of the application from this window are the Reynolds number per unit length and the Mach number.

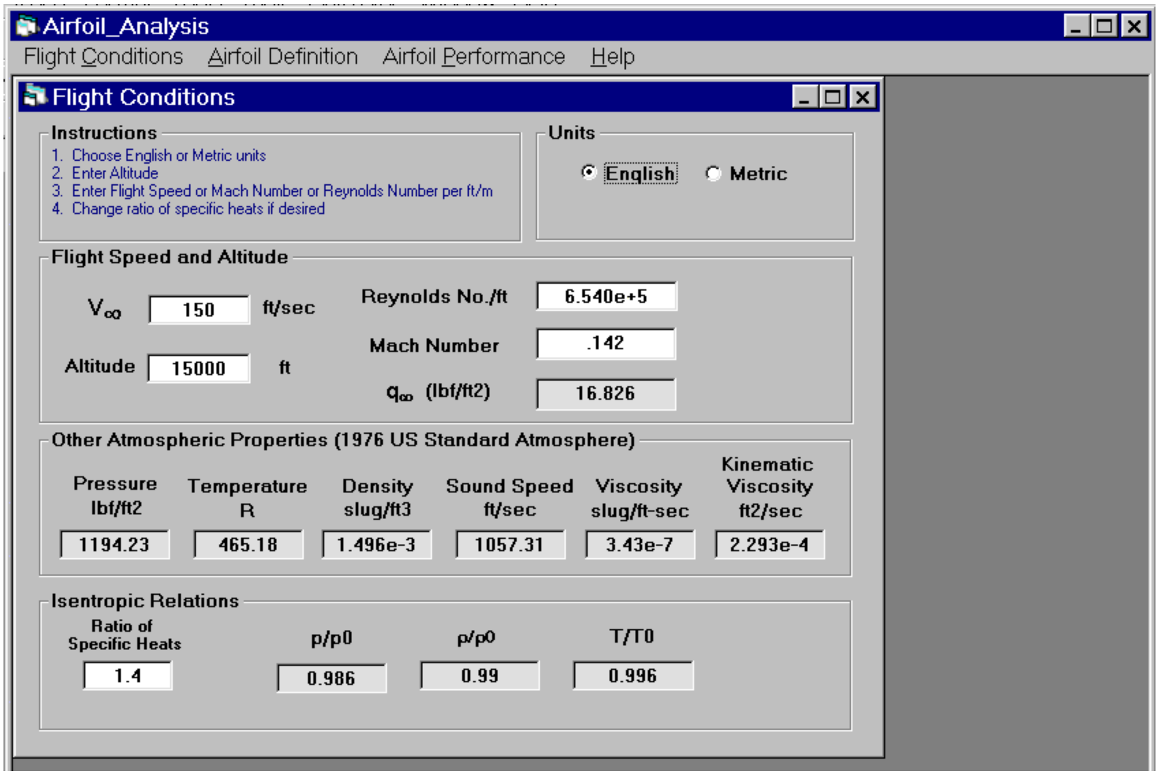

Figure 2. Flight Conditions window.

Airfoil Definition Pulldown Menu

Selecting the Airfoil Definition menu affords the user several choices as shown in Figure 3. The choices include the various NACA defined airfoils as well as the choice of

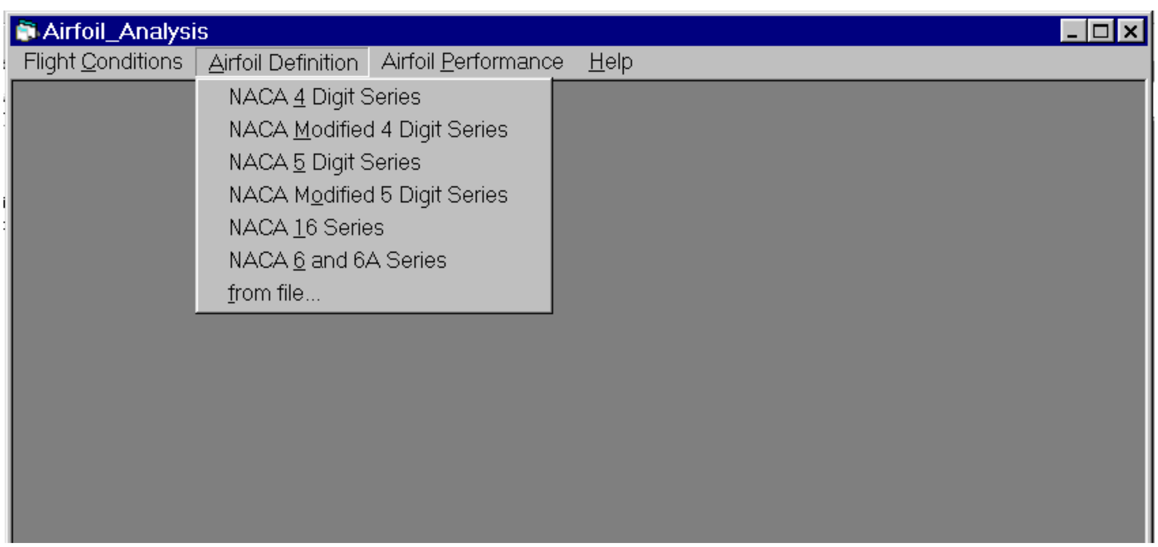

Figure 3. Choices on the Airfoil Definition Pulldown menu.

reading the airfoil coordinates from a file. Since the NACA airfoils are described more fully elsewhere, there is no great need to do so here. However, to see how the choices would be used, two of them and the 'from file' choice are covered in some detail.

Menu Choice: NACA Modified 5 Digit Airfoil

Modified 5-digit airfoils are described by their 7-digit number. The first 5 numbers correspond to the usual 5-digit numbering, but the thickness distribution is modified near the leading edge by the last two parameters.

The input window for the NACA 5 Digit Modified Series is shown in Figure 4. The window, like all the NACA airfoil choices, consists of several frames allowing the user to enter the parameters of the airfoil. A graphic window shows the airfoil and responds instantly to any changes in the airfoil parameters.

Airfoil frame - contains the numerical designation of the airfoil that the user may enter directly if it is known.

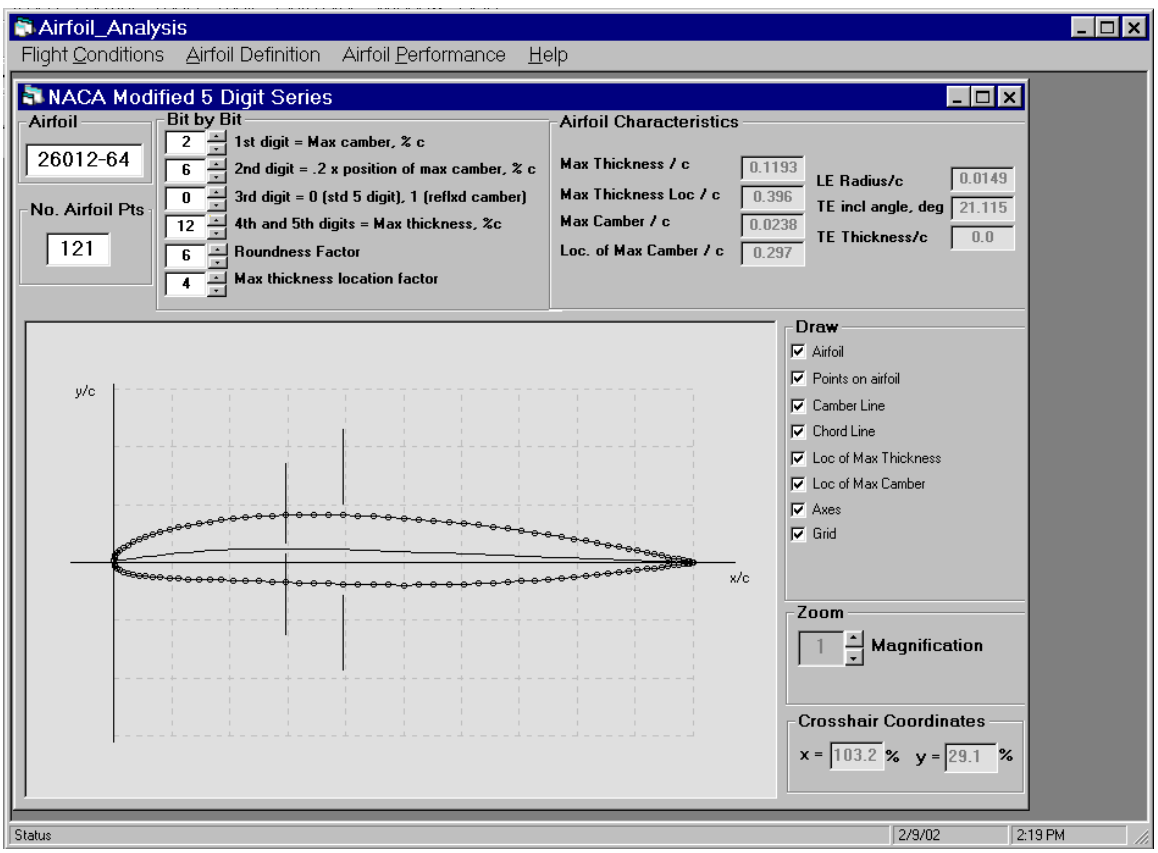

Figure 4. Input window for the NACA 5 Digit Modified Series Airfoil.

No. Airfoil Pts frame – In this frame the user specifies how many points are to be used in the computations of the airfoil characteristics. For accuracy, this number should be at least 120 with more points improving the accuracy further. Be advised, though, that the computation time varies as the square of the number of these points. With PC's becoming faster and faster, on the other hand, it usually takes only a few seconds to compute the solution for a large number of points. Note that if an odd number of points is used, most of the airfoil generation windows will place a point directly at the leading edge. This is not the case with an even number of points. Hence most default values are odd.

Bit by Bit frame - allows the user to easily change the individual numbers of the airfoil designation. This is convenient for studying the effects of the parameters on the airfoil shape as shown in the graphic window. Like most input boxes in the entire program, minimum and maximum values of the parameters are built into the input boxes so the user cannot exceed them.

Airfoil Characteristics frame – Every airfoil has interesting geometric features. These are summarized here and are computed from the user's input parameters.

Draw frame – This frame contains check boxes for the user to indicate what items are to be shown in the graphic of the airfoil. Checking any box will cause the corresponding item to appear in the graphic window. The user may thus view the airfoil, the points on the airfoil (corresponding to panel endpoints), the airfoil camber line, airfoil chord line, vertical lines indicating locations of max thickness and max camber, the coordinate axes, and a background grid.

Zoom frame – Not yet implemented, but will allow the user to zoom in on different places on the airfoil.

Crosshair Coordinates frame – When the mouse cursor is in the graphic window, it changes from the usual arrow to a crosshair. The x and y coordinates of the mouse cursor on the graphic picture are given in the Crosshair Coordinates frame in % chord.

Menu Choice: NACA 6 & 6A Series Airfoil

The airfoil construction window for this series is shown in Figure 5. The 6 series airfoils, like some others, use a design lift coefficient to determine some of the airfoil geometry. In addition, the position of minimum pressure is specified. Together, these determine the maximum camber, its location, and location of maximum thickness. The 6A series provides a modification to the camber function near the trailing edge. The modifications are well-described elsewhere and need not be covered here. Since the only difference between this window and the one for the modified 5 digit series are the elements in the Bit by Bit frame, there is not much need to describe all the remaining frames.

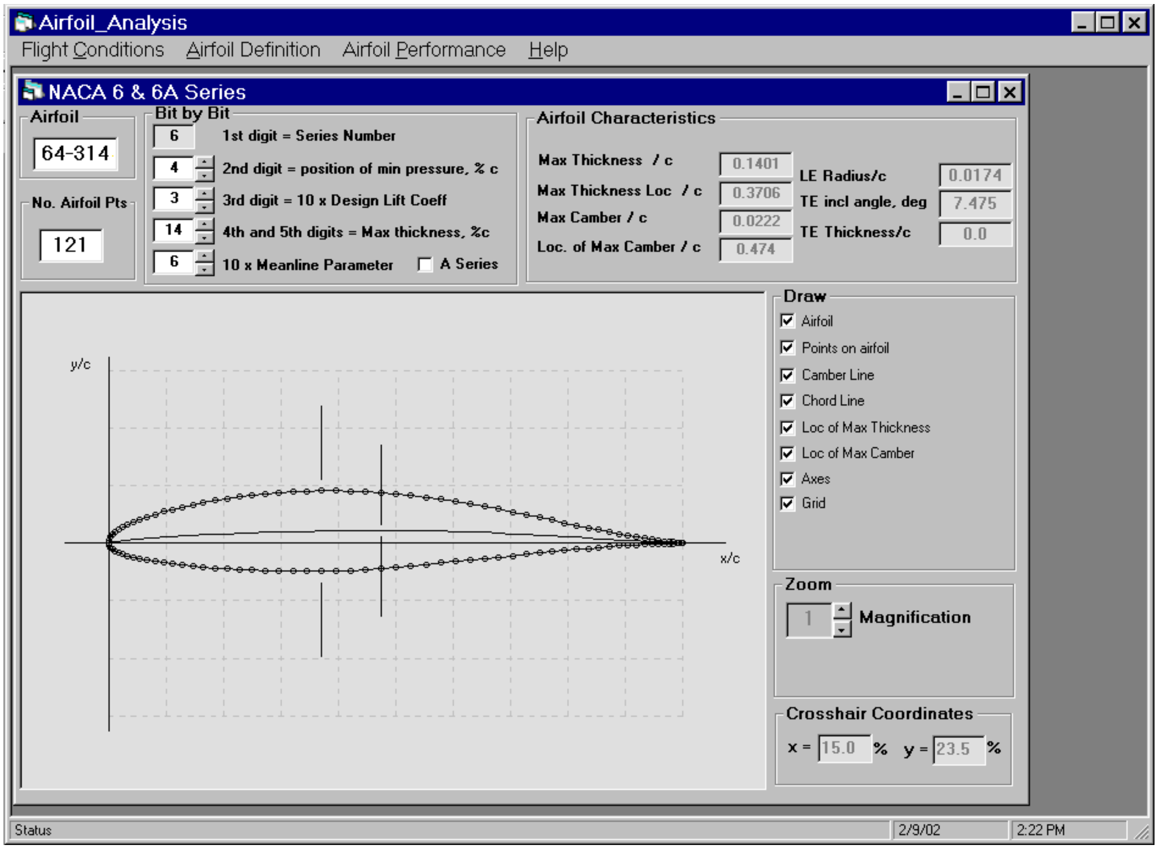

Figure 5. Input window for the 6 and 6A Series airfoils.

Menu Choice: from file

This choice allows the user to use files containing airfoil coordinates as input to the program. File input is done using the Windows style browse and select operations as is shown in Figure 6. A significant number of such files is provided in the UIUC data base included for convenience with the program. A File Previewer window opens to allow the user to examine the data file as well as to indicate the line number of the first line of the coordinate data as shown in Figure 7.

When the user clicks on the browse button to the right of the file name in this window, the usual Windows file browse window opens as shown in Figure 6. The user then finds the desired data file by continuing to the relevant directory and double clicking on the file name or typing the filename in the filename box.

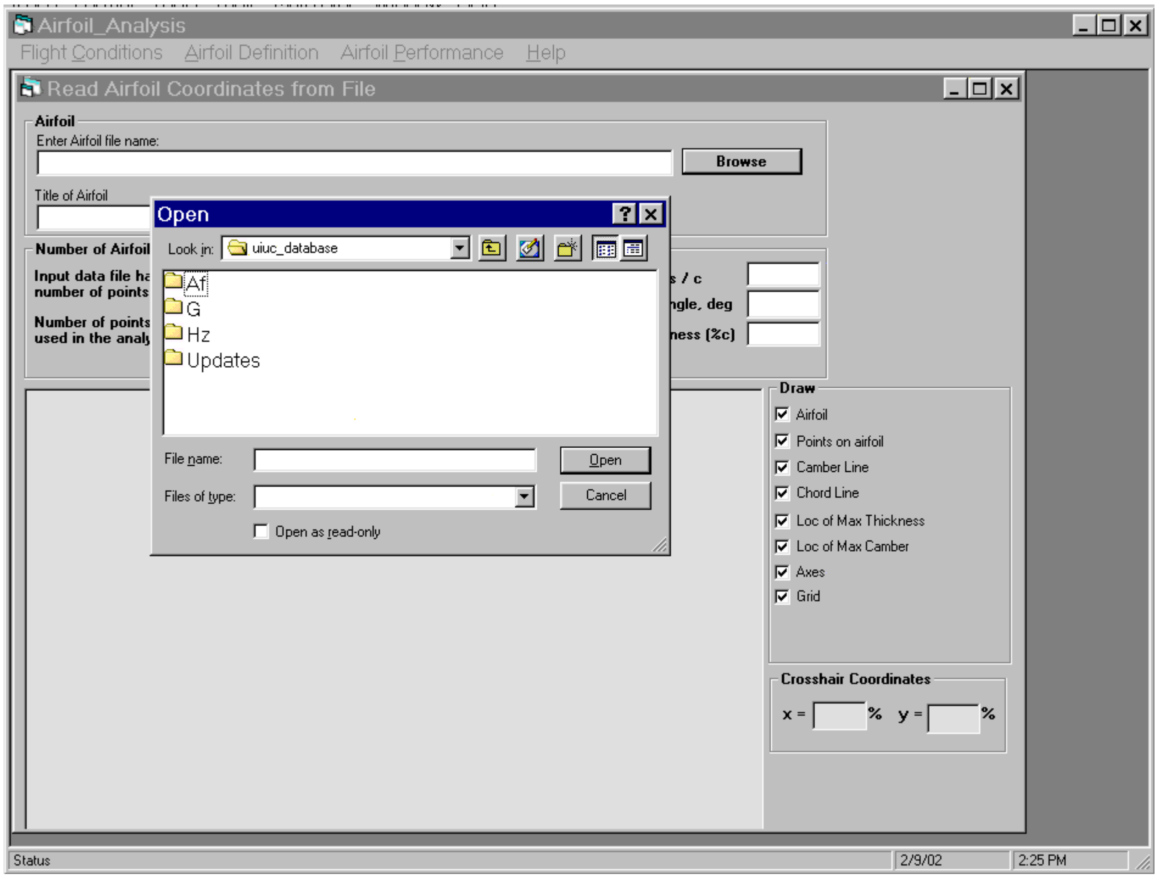

Figure 6. File Browser in the from file menu option.

When the file opens, it is immediately placed into the File Previewer as shown in Figure 7. In Figure 7, the user has selected the RAE 2822 airfoil. The full path of the file is given in the filename box. The File Previewer can also be used to view the entire contents of the input data file. This may be useful if the user is uncertain as to whether the desired file has been selected. The File Previewer allows the user to tell the program what line contains the first coordinate pair. Having done so the user closes the File Previewer and then should have a graphic of the input airfoil similar to the ones already seen, as shown in Figure 8.

Another feature of the 'from file' window is to allow the user to add more points to the airfoil for attaining a more accurate estimate of the performance. Cubic spline interpolation is used for this purpose. To use cubic splines on the complete airfoil, the x-coordinate is mapped to an angle, θ, using the usual double cosine distribution [$x = 0.5*(1+\cos\theta)$]. This version of cubic spline interpolation does a reasonable job of preserving the amount of smoothness present in the original coordinates. In Figure 8, 211 points on the airfoil were chosen. The large number of points is sometimes necessary to obtain a smooth drag polar.

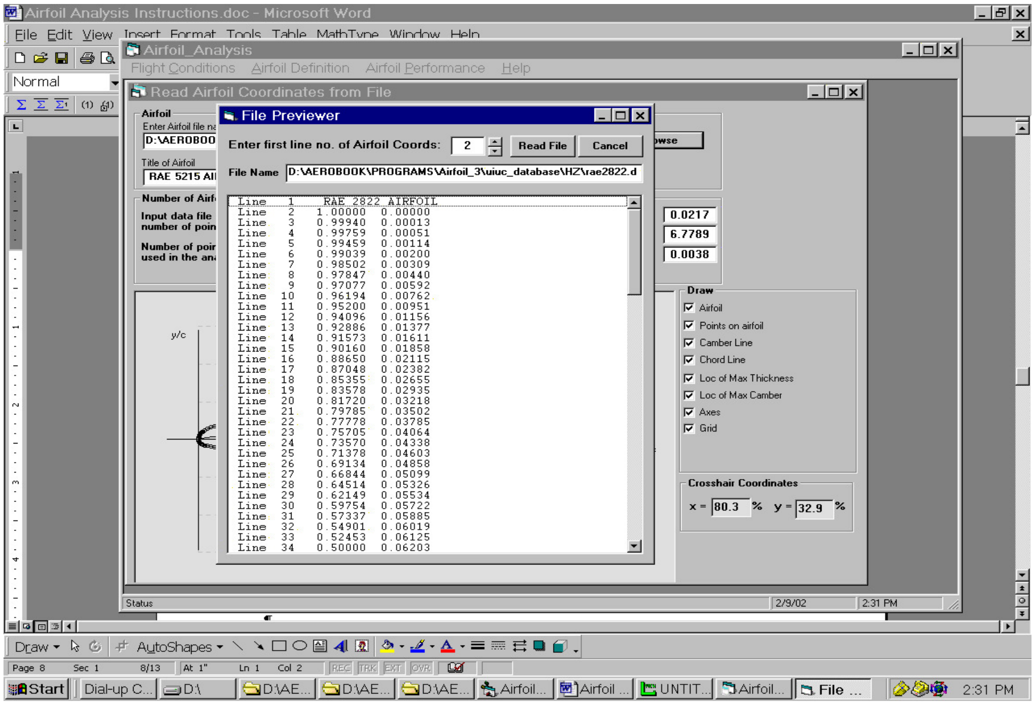

Figure 7. File Previewer in the from file option.

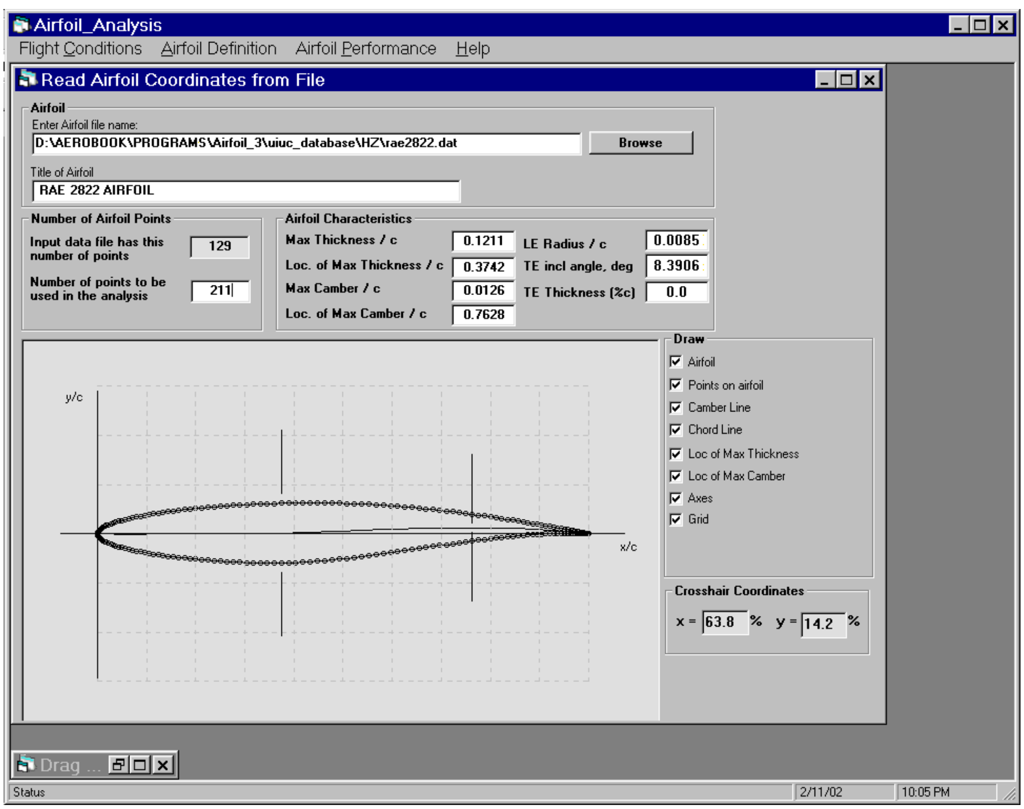

Figure 8. Example of an airfoil defined from coordinate data.

Airfoil Performance Pulldown Menu

There are two choices on the Airfoil Performance pulldown menu, Cp Distribution and Drag Polar. The Cp distribution provides the aerodynamic performance of the airfoil at a user-selected angle of attack. This includes the force and moment coefficients along with a graph of Cp vs x/c. The drag polar evaluates the airfoil at a number of angles of attack and then shows several graphs of quantities as functions of the lift coefficient.

Menu Choice: Cp Distribution

When the user selects the Cp Distribution menu item, the program checks to ensure that an airfoil has already been specified. If so, the Cp Distribution window opens, as shown in Figure 9 and the name of the airfoil appears in a box in the Airfoil frame. The user should then check to see whether the Reynolds and Mach numbers are correct and set the angle of attack in the Flight Conditions frame. If a different transition criteria is desired other than the default, then the user should click on the alternative choice in the 'Transition Criteria' frame.. If desired, the user may opt for either an inviscid calculation (in which case, the Reynolds number is irrelevant) or a laminar calculation (in which case, the transition criteria is irrelevant) in the 'Go!' Frame. Finally, the user clicks on the 'Compute' button and the calculation of the Cp distribution by the panel method ensues along with the appropriate viscous calculation.

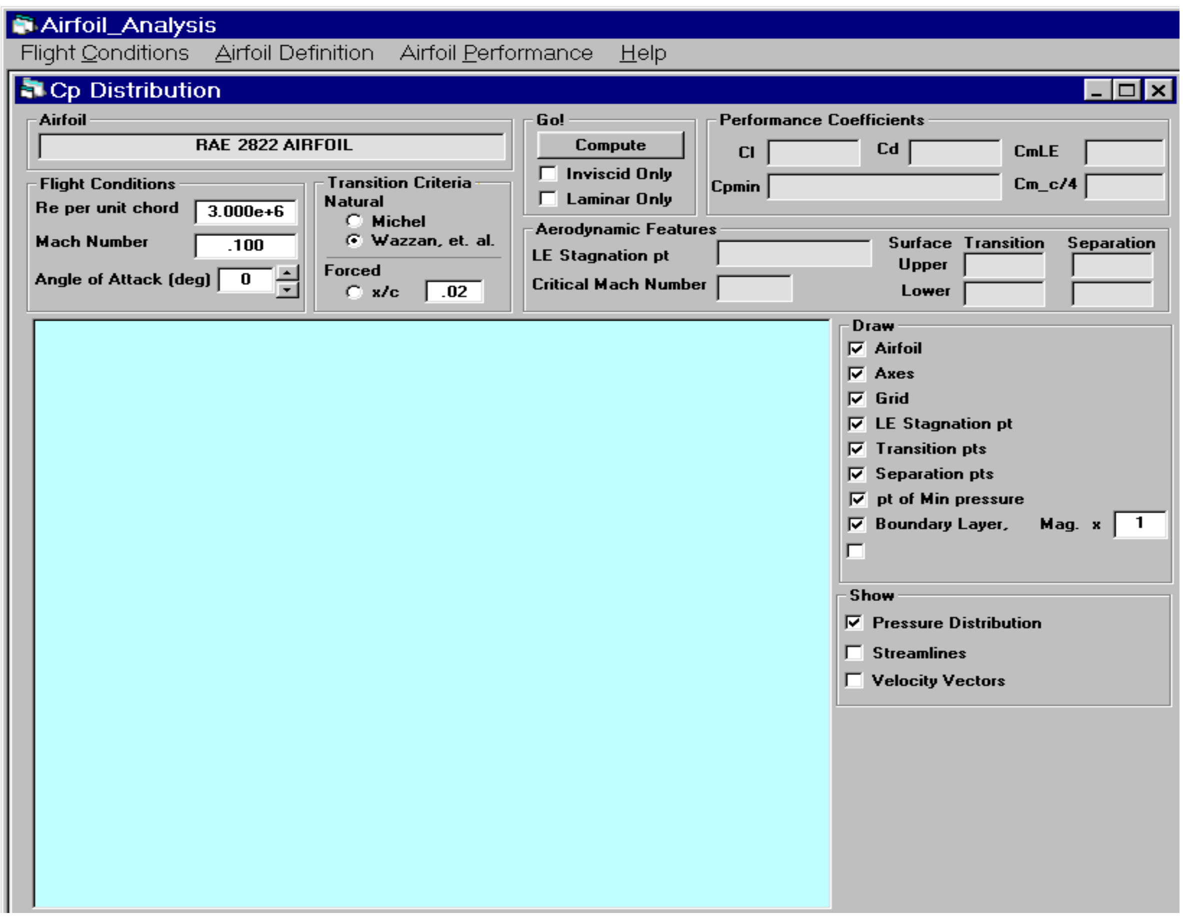

Figure 9. Cp Distribution page upon first opening.

During the calculation, the mouse cursor changes to an hourglass indicating that the user must wait until the computation is finished. This should take only a few seconds before the solution is presented on the Cp Distribution Window.

When the hourglass returns to the usual mouse cursor, the performance quantities are filled in and a graph of the Cp Distribution appears in the graphic window. Locations of the LE stagnation point, positions of minimum Cp on each surface, and transition and separation points on both surfaces are indicated on the Cp distribution graph as well as on a sketch of the airfoil under the graph. Other quantities are given in the Aerodynamic Features frame. These include coordinates of the predicted LE stagnation point, the x/c locations of transition and separation for both surfaces, and the critical Mach number. A graphic of the airfoil with lines indicating the boundary layer thickness is also shown at the bottom of the window.

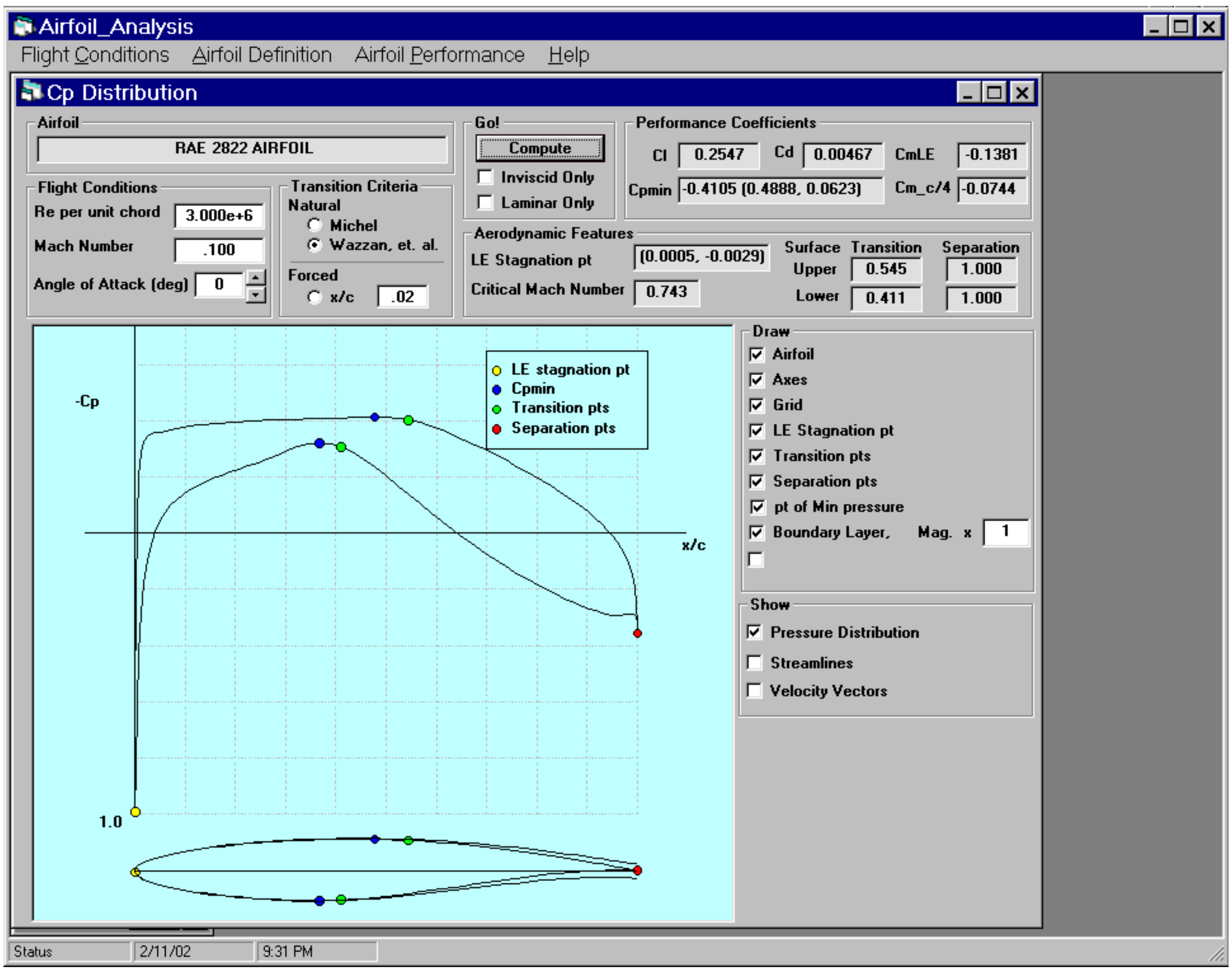

Figure 10. Cp Distribution window after computing Cp distribution.

Menu Choice: Drag Polar

This choice opens the Drag Polar window which, like the Cp Distribution window, checks to see whether an airfoil has been specified. The user should then check the flight

Reynolds number and Mach number and then click on the Compute Drag Polar button. The three graphic windows contain graphs of Cl vs. Cd, Cl vs. alpha, and Cl vs. locations of transition and separation.

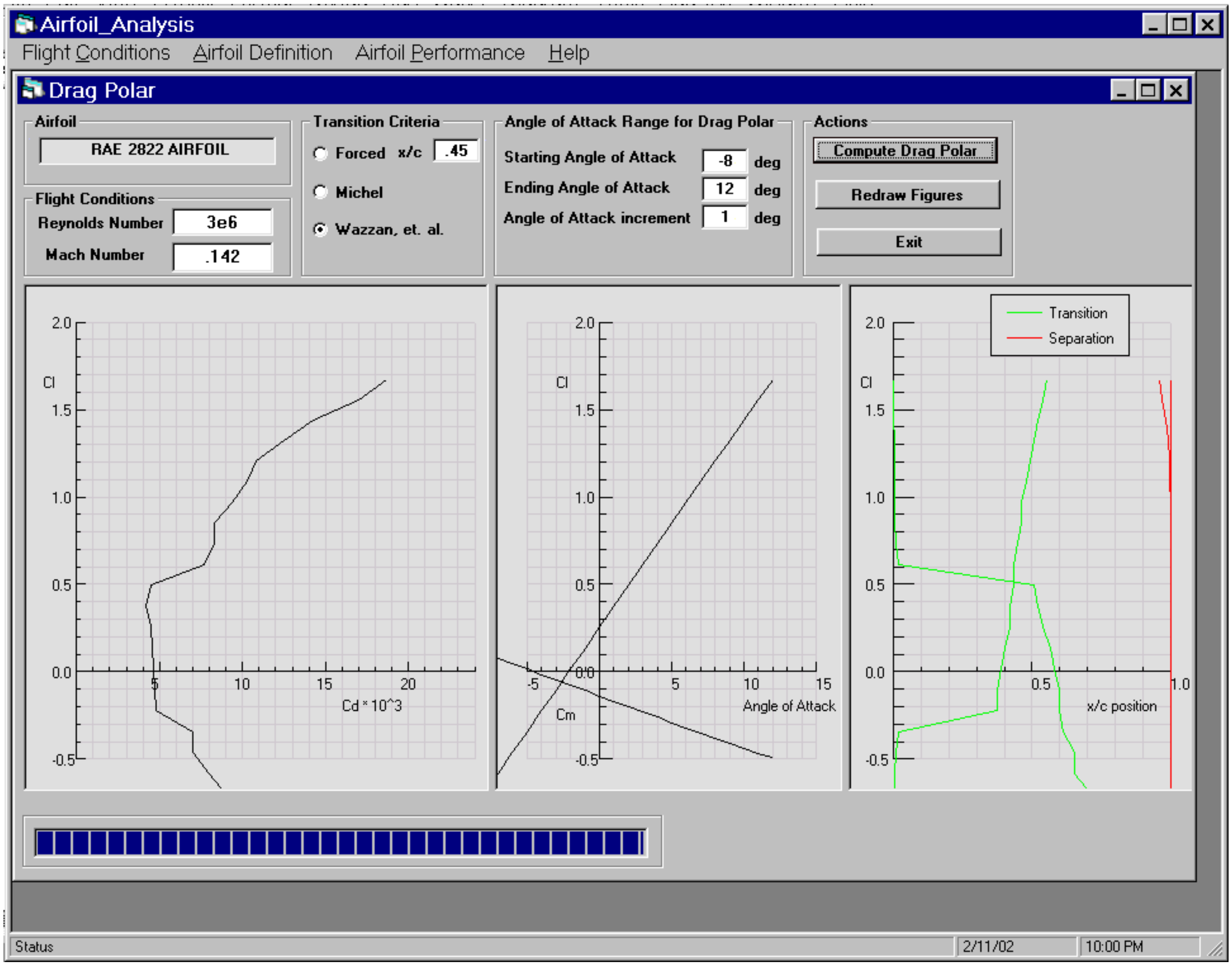

Figure 11. Drag Polar window.