

**DEVELOPMENT AND APPLICATION  
OF A PROGRAM FOR THE  
COMPUTER AIDED DESIGN  
OF SIMPLE GLIDERS**

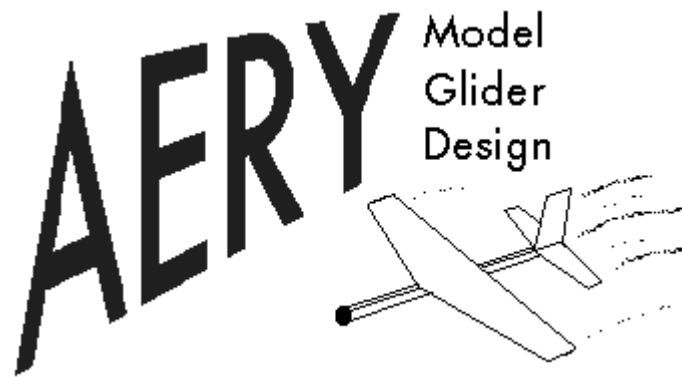
A PROJECT  
SUBMITTED  
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
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## **Abstract**

A computer program, named “Aery”, was developed for the interactive, computer aided design of simple gliders. This program was written using the Visual Basic language for use on PC type computers running the Windows operating system. Through the Minnesota Department of Transportation, Office of Aeronautics, Aery was tested at the Aviation Career Education Academy. At this summer camp, high school students were lead in a session which taught the engineering process as applied to airplane design. Aery played an integral part in this session; it allowed the students to design, construct, and test-fly their own glider designs.

Aery analyzes gliders through the application of equations traditionally used in the preliminary design phases of aircraft. The validity of this method was confirmed through test flights of gliders designed in Aery.

Aery will be distributed for free use by individuals and educational institutions.

## Symbols

AR	Aspect ratio
b	Span of a surface.
$c_r$	Root chord.
$c_t$	Tip chord.
$C_{l\alpha}$	Two dimensional lift curve slope.
$C_{L\alpha}$	Three dimensional lift curve slope.
$h_n$	Neutral point.
$Q_y$	First moment about y-axis.
S	Planform area.
V	Velocity.
$\alpha$	Angle of attack.
$\varepsilon$	Downwash angle.
$\lambda$	Taper ratio.
$\Lambda$	Sweep angle.
$\rho$	Air density.

## **Introduction**

A program for the computer aided design of simple gliders has been developed. This program, called “Aery”, began development during the summer of 1995 and continued through the summer of 1996. Testing of the program occurred during this time period at the Aviation Career Education Academy summer camp. This program was written for a Masters of Science Plan B Project in conjunction with ACE Academy and with the support of the Minnesota Department of Transportation, Office of Aeronautics.

Aery has a target audience at the secondary and post-secondary education levels. It allows any computer user to design a simple glider, analyze the glider’s flight stability and aerodynamic performance, and then print plans sufficient to allow the glider’s construction.

The following sections discuss Aery from its conception, through its programming methods and analytical approach, to the results of its testing at ACE Academy.

## **Background**

In the spring of 1995, Mr. Gordon Hoff of the Minnesota Department of Transportation, Office of Aeronautics, contacted Professor Andrew Vano about finding a person to lead a technically-oriented session at ACE Academy. ACE (Aviation Career Education) Academy is a week-long summer camp for students at the high school level where they learn about various aviation careers and participate in aviation-related activities. In particular, Mr. Hoff wanted a session which would inform the students about aerospace engineering while involving the use of computers.

As one of Professor Vano's teaching assistants, I expressed interest in this proposal and discussed the project with Mr. Hoff. I proposed to Mr. Hoff that I could develop a computer program for PC's which would allow the students to interactively design a simple glider. This application of computer aided airplane design would analyze the glider, determine if it would fly, and then print detailed plans from which the students could construct their gliders. These activities would be incorporated into a lesson plan which would teach the students about aerospace engineering and the design process for real aircraft.

The idea for this computer program was inspired, in part, by a Macintosh computer program called "Glider Design" which I had previously encountered. "Glider Design" had been developed by Mr. Michael Kamprath and the Michigan Space Grant Consortium in 1992. My program would be an entirely new, independent effort which would owe only a few basic ideas to "Glider Design." I have never had access to the source code for "Glider Design."

During initial development, I secured permission to use this program, now called "Aery", for my Masters Degree Plan B Project.

### **Project Statement**

The primary goal of this project was to develop an interactive application for the computer aided design and analysis of simple, small, gliders. This computer program would be written entirely in Microsoft Visual Basic 3.0 and would run on any PC type machine under Microsoft Windows 3.1, or later versions. The gliders designed in this



program would be primarily of wood construction, balsa and spruce, and would utilize only simple, flat-plate airfoils. This program, named “Aery”, would analyze the glider to determine flight stability, performance estimates, specifications and information. If the current glider design was not flyable, it would provide suggestions for design changes to the program user . When a successful glider had been designed, Aery would print out all necessary drawings and plans, so the glider could be constructed and flown. Aery would also be capable of handling either conventional or canard configuration gliders. The intended audience for Aery would be students at the high school and early college level.

An additional goal was to use Aery within a half-day session at ACE (Aviation Career Education) Academy to teach students about airplane design and the engineering process. This would not only serve as a form of community outreach but also provide real-world testing opportunities for Aery. Feedback from these sessions would serve to isolate programming errors and suggest program improvements.

### **Approach**

Aery was written in Visual Basic 3.0 for Windows 3.1. The source code for Aery is contained within several code modules and form modules; in Visual Basic, there is a form module for each “window” that is displayed. The form modules contain the definitions of all the graphical objects placed on the form as well as the code associated directly with those objects. A full source code listing for Aery is contained in the separate report File and Subroutine Listing.

The Approach to this project is subdivided into sections: interface and graphical display, file handling, configuration entry, plans printing, and analytical methods.

### Interface and Graphical Display

The interface of Aery is fully graphical and follows the Windows “point-and-click” convention. At the top of the main window is a drop-down menu structure. Under the File menu, a new glider may be started, the current glider saved to disk, or a previously-designed glider loaded into the program. Also, the baseline configuration data may be loaded from a file, edited, or saved to disk. Also in the File menu, the user may print plans or exit the program. The Analyses menu allows on screen statistics to be updated or the glider design to be fully analyzed. The Preferences menu allows two choices. The first enforces that all of the glider’s surfaces will fit on a single piece of wood. The second controls the scaling of the on-screen representation of the glider.

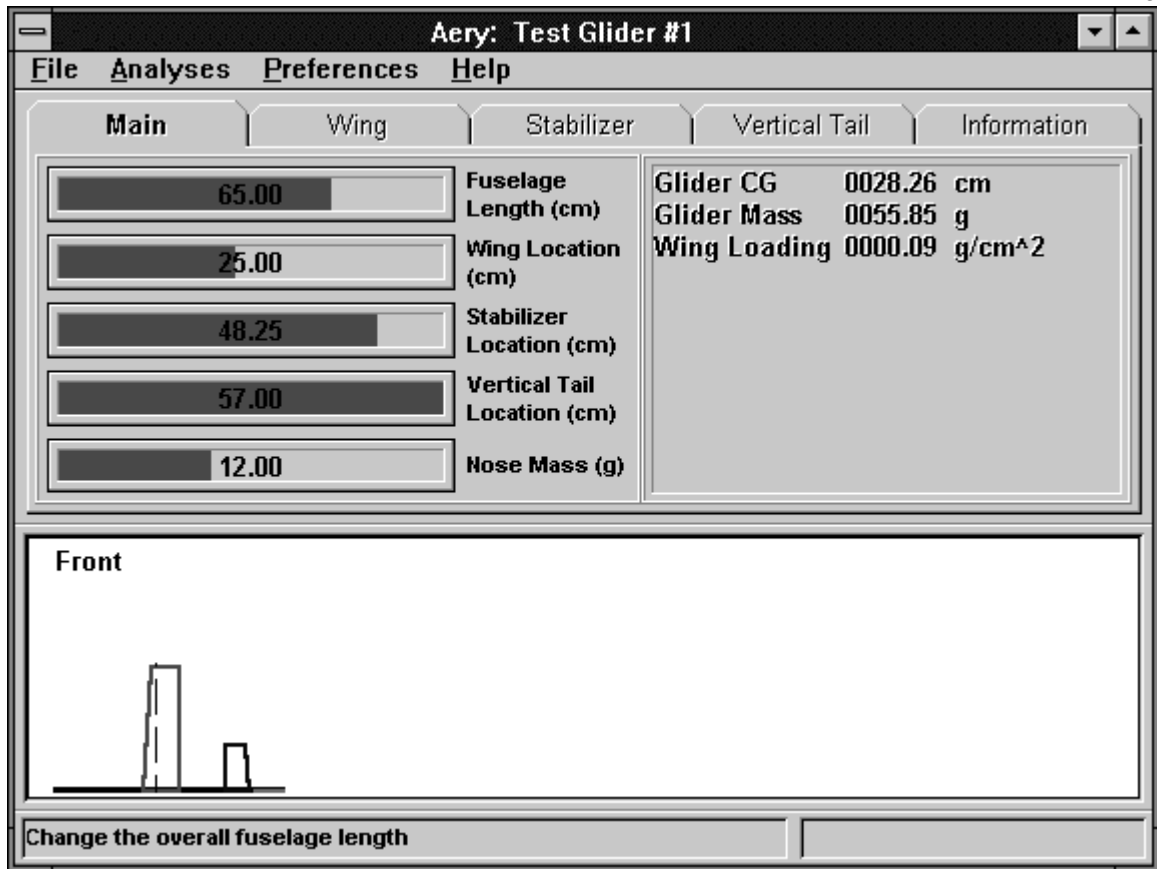


Figure 1: Aery Main Tab Display

Aery is organized by the “tab” metaphor common to Windows programs.

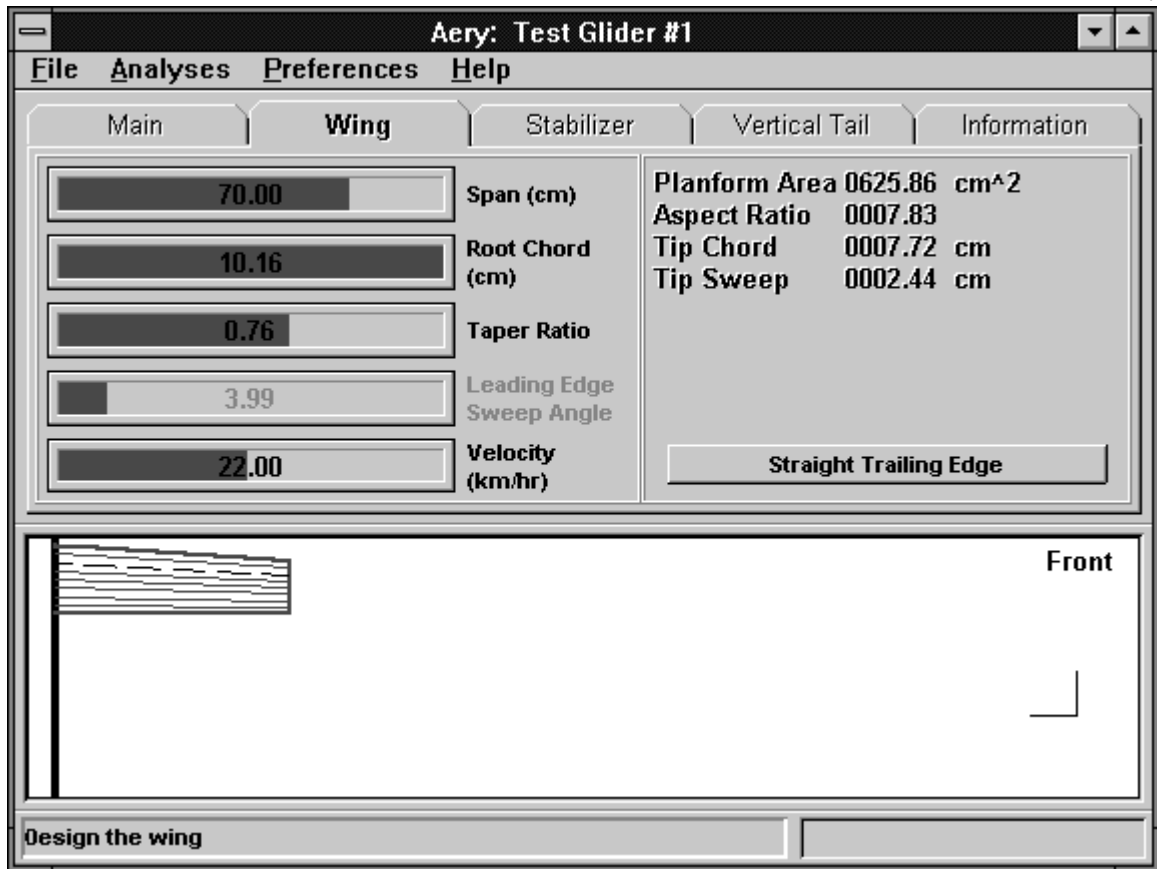
Clicking on each tab with the mouse changes the type of information that is displayed and available for change. The first tab, “Main” as shown in Figure 1, controls the location of the flying surfaces as well as the amount of mass at the nose of the glider and the overall length of the fuselage. A simple depiction of the right half of the glider is shown in the graphical pane at the bottom of the window. Below the graphical pane is a caption area where simple help messages and prompts appear based upon the mouse pointer’s location.

The glider is modified through the use of the horizontal “fill” bars in the upper left-hand portion of the window. By clicking and holding the left mouse button while the mouse pointer is positioned over a bar, the mouse may be moved left and right over the bar. As this is done, the shaded portion of the bar changes size and the number within the bar changes value. As the parameter value is changed, Aery updates the graphical display of the glider automatically. Aery also checks other design parameters that depend upon the parameter being changed and, if necessary, modifies them. For example, if the fuselage length is shortened such that the vertical tail moves off of the fuselage, Aery will automatically move the vertical tail to compensate. When the desired value of the parameter is reached, the left mouse button is released.

While this method of parameter adjustment is very quick and intuitive, it is not particularly precise. Therefore, clicking the right mouse button while positioning the mouse pointer over a parameter bar brings up a small edit window where the parameter value may be changed directly.

The area to the right of the parameter bars is used to display certain glider information particular to the current tab.

The second tab controls the glider’s wing, as shown in Figure 2. The parameter bars on this tab control the wing span, root chord, taper ratio, and leading edge sweep angle. Also on this tab, the throwing velocity of the glider is specified. The graphical pane for this tab shows the right half of the wing.



**Figure 2: Aery Wing Tab Display**

The button to the right of the Velocity parameter bar controls the type of wing sweep. Clicking on this button successively changes the sweep type from arbitrary, where the sweep value is set by the parameter bar, to straight trailing edge and then to centered wingtip.

The Stabilizer and Vertical Tail tabs are similar in configuration to the Wing tab. The vertical tail graphical display, however, shows the entire vertical tail as opposed to only half the surface for the wing and stabilizer.

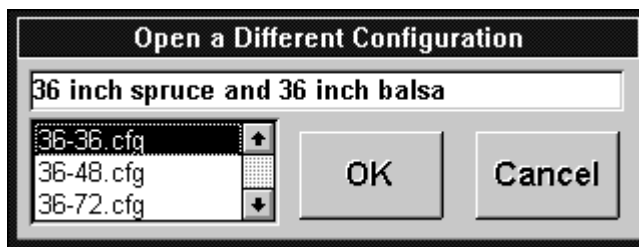
The Information tab contains an edit box for the glider's name, for example "Test Glider #1". Also on this tab is a scrolling Information box. This box is where suggestions and information appear when the glider is analyzed.

The "tab" interface was accomplished using a licensed third-party custom control, VSVBX by Videosoft.

### File Handling

The glider design files and configuration data files are saved to disk as simple, sequentially formatted text files. Therefore, they may be changed, if necessary, by any text editing program. These files are also very small, about 1100 bytes for the glider file and about 400 bytes for the configuration file. The Windows common dialogs are used for loading and saving the glider design files and for saving the configuration files.

Loading a configuration file is done through a specialized window, as shown in Figure 3.



**Figure 3: Open Configuration Window**

The configuration file contains certain program parameters and the specifications for the wood being used in the glider's design. The use of configuration files allows different wood data to be loaded into an existing glider design. A sample configuration file is listed in Appendix A. The glider design file contains the specifications necessary

to fully describe the glider. It also contains the current configuration data for the design.

A sample glider file is listed in Appendix B.

### Configuration Entry

The configuration data, as mentioned previously, contains the specifications for the wood being used in the glider's design. This data is entered and modified through a specialized window, as shown in Figure 4.

The screenshot shows a window titled "Edit Configuration" with the following fields and values:

Field	Value
Configuration Name	36 inch spruce and 36 inch balsa
Configuration Filename	36-36.cfg
Max Wing Span (cm)	91.44
Max Fuselage Length (cm)	91.44
Max Wing Width (cm)	10.16
Fuselage Width (top) (cm)	0.63
Wing Thickness (cm)	0.32
Fuselage Depth (side) (cm)	0.95
Wing Density (kg/m <sup>3</sup> )	104.76
Fuselage Mass/Length (kg/m)	0.02221
Buttons: Calculate Wing Density, Calculate Fuselage Mass/Length	
Max Nose Mass (g)	30.0
Airfoil CL <sub>alpha</sub> (1/radian)	5.7
Air Density (kg/m <sup>3</sup> )	1.22
Buttons: OK, Cancel	

Figure 4: Edit Configuration Window

When the data entered is that measured from the exact pieces of wood intended for the glider's construction, Aery can predict the center of gravity to within a few millimeters of the center of gravity on the completed glider. However, usually this data represents typical or average values for the wood; in this case, Aery's prediction may be

off by a centimeter or more. These length and mass measurements are the only data required from the program's user. The nose mass, airfoil lift curve slope, and air density values are provided for convenience; however, they are rarely changed.

### Plans Printing

Once a glider has been designed and analyzed, the user may print three pages of plans that contain dimensioned, scale views of the glider components. The first page shows a top view of the right-hand side of the entire glider. It describes the overall glider length and placement of the flying surfaces on the fuselage. Also, it lists the mass added to the nose, the throwing velocity, and the stabilizer incidence angle. The second page of plans shows top views of the wing and horizontal stabilizer. The last page shows a side view of the vertical tail as well as a full-size pattern for the stabilizer incidence angle. Also listed on this page are the center of gravity and neutral point locations.

The printed pages are sent to the default Windows printer driver. Thus, they may be printed on any type or brand of printer.

The source code required to print the plans is larger and required more development time than the code which analyzes the glider's design.

Sample plans for a conventional-configuration glider are shown in Appendix C. Sample plans for a canard-configuration glider are shown in Appendix D.

### Analytical Methods

The analysis module and submodules are the heart of Aery. For the most part, they do not represent a computationally intense approach to glider aerodynamics and stability. Instead, they apply the methods and approximations that are commonly used in



the early phases of airplane design. The following sections will detail the analysis process that is coded into Aery.

To begin the analytical process, a submodule calculates the planform areas of the wing, stabilizer, and vertical tail. The series of equations used for this purpose were developed by a generic integration over a trapezoidal surface. Note that  $K = b / 2$  for the wing and stabilizer, but  $K = b$  for the vertical tail. The computed area is thus half of the planform area for the wing and stabilizer, and the entire planform area for the vertical tail.

$$\begin{aligned} a &= \tan \Lambda_{LE} \\ c &= \frac{\lambda c_r + Ka - c_r}{K} \\ \text{area} &= \frac{1}{2} K^2 (c - a) + Kc_r \end{aligned}$$

**Equation 1: Planform Area**

Another submodule then calculates the first moments,  $Q_y$ , for the wing and stabilizer half-areas and the vertical tail whole area. Similarly to the planform area, the equation for the first moment was derived by integrating over a generic surface.

$$Q_y = \frac{1}{6} K^3 (c^2 - a^2) + \frac{1}{2} K^2 c c_r + \frac{1}{2} K c_r^2$$

**Equation 2: First Moment**

The submodule then computes the local centroids of the surfaces with respect to the root leading edge of each surface. The mass of each glider component is then estimated using sizing and density data. From the sums of centroids and masses, the location of the overall glider center of gravity is calculated.

A different submodule then locates the aerodynamic center for each of the three primary surfaces. Because the surfaces are all flat-plate airfoils, the aerodynamic center is at approximately one quarter of the mean aerodynamic chord.

$$\bar{c} = \frac{2}{3} c_r \frac{1 + \lambda + \lambda^2}{1 + \lambda}$$

$$\text{if } \lambda = 1 \text{ then } Y = \frac{K}{2}$$

$$\text{else } Y = \frac{K}{6} (1 + 2\lambda)(1 + \lambda)$$

$$x_{ac,local} = Y \tan \Lambda_{LE} + \frac{\bar{c}}{4}$$

**Equation 3: Local Aerodynamic Center (Raymer 1992, 49)**

The local aerodynamic center coordinates are then converted into global coordinates with respect to the glider's nose. Following the aerodynamic center calculations, the aspect ratios are calculated for the wing and stabilizer. Then, an estimate of  $e$ , the Oswald efficiency factor, is made for the wing and stabilizer. This empirical formula provides reasonable results for straight or slightly swept flying surfaces.

$$e = 1.78(1 - 0.045AR^{0.68}) - 0.64$$

**Equation 4: Oswald Efficiency Factor (Raymer 1992, 299)**

Aery next calculates the weight of the glider, the mean geometric chord of the wing, and the total wetted area. Then, a very rough estimate of the parasitic drag coefficient,  $C_{Do}$ , is calculated using an empirical formula.

$$C_{Do} = 0.0055 \frac{S_{wetted}}{S_{wing}}$$

**Equation 5: Parasitic Drag Coefficient (Raymer 1992, 280)**

Following this calculation, the three dimensional lift curve slopes are computed for the wing and stabilizer based upon the two dimensional lift curve slope for a flat plate.

$$C_{L,\alpha} = \frac{(2.14)\pi AR}{2 + \sqrt{4 + \frac{AR^2 4\pi^2}{C_{l,\alpha}^2} (1 + \tan^2 \Lambda_{LE})}}$$

**Equation 6: 3D Lift Curve Slope (Raymer 1992, 266)**

Next, an estimate is made of the rate of change of the downwash angle with angle of attack.

$$\frac{\partial \varepsilon}{\partial \alpha} = \frac{2C_{L,\alpha,wing}}{\pi AR_{wing}}$$

**Equation 7: Rate of Change of Downwash (Nelson 1989, 48)**

Having computed the necessary parameters, Aery then checks the sizing of the vertical tail using a “rule of thumb” procedure. This procedure serves as a check of the glider’s directional stability.

$$C_{vt} = \frac{(x_{ac,vt} - x_{ac,wing})S_{vt}}{b_{wing}S_{wing}}$$

**Equation 8: Vertical Tail Volume Coefficient (Raymer 1992, 111)**

Aery calculates  $C_{vt}$ , the vertical tail volume coefficient, and compares it to the suitable range of this coefficient. If the coefficient is less than 0.035, Aery warns that the glider is not flyable because the vertical tail is too small or poorly placed. If the coefficient is larger than 0.07, Aery informs the user that the glider will fly, but the tail may be larger than necessary.

Following the vertical tail, Aery checks the sizing of the stabilizer (horizontal tail or canard) by computing the stabilizer volume coefficient,  $C_{stab}$ .

$$C_{stab} = \frac{(x_{ac,stab} - x_{ac,wing})S_{stab}}{\frac{S_{wing}^2}{b_{wing}}}$$

**Equation 9: Stabilizer Volume Coefficient (Raymer 1992, 111)**

If this coefficient is smaller than 0.5 and larger than -0.1, the glider is judged not flyable due to incorrect stabilizer sizing or placement. If the coefficient is larger than 0.7 or smaller than -0.2, then the glider is judged flyable but the user is warned that the stabilizer may be larger than necessary.

After calculating the quarter chord sweep angle of the wing, Aery performs an estimate of the wing's stall angle of attack. This calculation is based upon the approximate stall angle of attack for a flat-plate airfoil. Based upon available literature, this angle was set to eight degrees within Aery.

$$\alpha_{stall,wing} = \frac{.9C_{l,\alpha} \alpha_{max,airfoil} \cos \Lambda_{c/4}}{C_{L,\alpha}}$$

**Equation 10: Wing Stall Angle of Attack (Raymer 1992, 270)**

In the next step of analysis, an estimate of the maximum available lift is compared to the glider's weight. If the lift required is too large, the glider is judged not flyable. The glider designer is then prompted to increase the flight velocity, increase the size of the wing, or decrease the glider's weight.

Before analyzing the glider's flight stability, Aery calculates another stabilizer volume coefficient using the wing's mean geometric chord.

$$V_H = \frac{(x_{ac,stab} - x_{cg,glider})S_{stab}}{C_{wing} S_{wing}}$$

**Equation 11: Stabilizer Volume Coefficient (Anderson 1989, 379)**

The longitudinal stability analysis within Aery is done through a calculation of the neutral point location and its comparison with the center of gravity location. For longitudinal static stability, the center of gravity must be forward of the neutral point.

$$h_n = \frac{C_{L,\alpha,\text{wing}} \frac{x_{ac,\text{wing}}}{c} + 0.9 \frac{S_{\text{stab}}}{S_{\text{wing}}} C_{L,\alpha,\text{stab}} \left(1 - \frac{\partial \varepsilon}{\partial \alpha}\right) \frac{x_{ac,\text{stab}}}{c}}{C_{L,\alpha,\text{wing}} + 0.9 \frac{S_{\text{stab}}}{S_{\text{wing}}} C_{L,\alpha,\text{stab}} \left(1 - \frac{\partial \varepsilon}{\partial \alpha}\right)}$$

**Equation 12: Neutral Point (Raymer 1992, 417)**

If the center of gravity is behind the neutral point, the glider is judged to be unstable and not flyable. The designer is then prompted to move the wing back or add mass to the glider's nose. If the static margin, the dimensionless distance between the neutral point and the glider center of gravity, is calculated as less than 0.05 but greater than zero, the designer is informed that the glider will fly; however, the longitudinal stability may be marginal. In Equation 12, the rate of change of downwash term is neglected for a canard design.

Following this stability check, Aery calculates the stabilizer incidence angle necessary for the given glider design and flight conditions. The following series of equations was developed by simultaneously solving the equilibrium force and moment equations for a simple glider. Again, for a canard configuration, the rate of change of downwash term is neglected. Also for a canard, the modifier 0.9, which represents a horizontal tail efficiency, is set equal to one. As is customary, the stabilizer incidence angle is defined as positive upwards and negative downwards.

$$\begin{aligned}
R_s &= \frac{S_{stab}}{S_{wing}} \\
k_1 &= \frac{2W}{\rho V^2 S_{wing}} \\
k_2 &= 0.9 R_s C_{L,\alpha,stab} \frac{(x_{ac,stab} - x_{cg,glider})}{c} \\
k_3 &= C_{L,\alpha,wing} \frac{(x_{cg,glider} - x_{ac,wing})}{c} - 0.9 R_s C_{L,\alpha,stab} \left(1 - \frac{\partial \epsilon}{\partial \alpha}\right) \frac{(x_{ac,stab} - x_{cg,glider})}{c} \\
k_4 &= C_{L,\alpha,wing} + 0.9 R_s C_{L,\alpha,stab} \left(1 - \frac{\partial \epsilon}{\partial \alpha}\right) \\
k_5 &= 0.9 R_s C_{L,\alpha,stab} \\
i_h &= \frac{k_1}{\frac{k_2}{k_3} k_4 + k_5}
\end{aligned}$$

**Equation 13: Calculation of Stabilizer Incidence Angle**

If the stabilizer incidence angle is calculated as having an absolute value greater than five degrees, the glider is declared unflyable. The designer is then prompted to decrease the nose mass or modify the design to decrease the static margin.

Using the components calculated for the incidence angle, Aery next calculates the flight angle of attack.

$$\alpha_{flight} = \frac{k_2}{k_3} i_h$$

**Equation 14: Flight Angle of Attack**

For a canard configuration, Aery compares the flight angle of attack to the stall angle for the canard. If the canard is stalled under the glider's flight conditions, the glider is judged unflyable, and the designer is prompted to change the glider. Similarly, if the flight angle of attack is within one degree of the wing's stall angle, the glider is judged not flyable.

The final calculation within the analysis code determines an “evaluation” number.

During early tests of Aery, students felt that they had no way to tell if changes made to their glider would improve its performance. Likewise, they tended to design several different gliders; however, since they could only build one glider, they wanted to know which design was the best. The dimensionless evaluation number allows comparison between different glider designs or before and after design changes to the same glider. The form and components of this number are still under study and may be subject to future changes.

$$Eval = 5 \frac{\alpha_{stall}}{\alpha_{flight}} + \frac{2}{C_{Do}} + \frac{AR_{wing} + AR_{stab}}{2} + \frac{\pi}{6 \arctan \frac{C_D}{C_L}} + \frac{5}{\lambda_{wing}} + \frac{5}{\lambda_{stab}} + \frac{5}{\lambda_{vt}} - 10 \frac{V_{stall}}{V_{flight}}$$

**Equation 15: Evaluation Number**

If Aery has not found any problems with the glider design, the analysis code finishes by informing the user that “It will fly!” Aery also then displays a variety of information about the glider. A sample of this information is listed in Appendix E.

## **Results**

Preliminary testing of Aery began in July of 1995 after completion of the glider analysis code modules. A few test gliders were designed and constructed. The materials chosen for these and all subsequent gliders were: a square or rectangular cross-section spruce stick for the fuselage, and 1/8 inch or 3/32 inch thick balsa sheet for the flying surfaces. For these first gliders, each piece of wood was massed and measured individually. This information was used in the glider configuration data. When constructed, these gliders were found to have a center of gravity location that was within a few millimeters of the location predicted by Aery.

Testing of these prototypes began on a nearby soccer field. Early glider flights displayed good longitudinal stability, but marginal yaw and roll characteristics. Enlarging the vertical tails solved the yaw problem, so Aery was modified to require slightly larger vertical tails. The roll problem was alleviated by laterally balancing the gliders. Due to the variable density of balsa wood, one wingtip was usually heavier than the other wingtip. However, the gliders still displayed a tendency towards a slight roll resulting in a curved flight path. Instituting wing dihedral or polyhedral would likely solve this problem. This idea was not implemented because it would increase glider complexity and building time.

As expected, a trial-and-error process was required to find the proper glider throwing speed and initial angle. Because the gliders are trimmed for the design flight condition, throwing them at too high a velocity results in a climb and stall. Furthermore, throwing them at too low a velocity results in a short flight. Overall, glider performance



was viewed as adequate for this type of craft. Sanding the blunt edges of the balsa surfaces boosted performance slightly. Sealing, finishing, and sanding the rough balsa would likely also increase aerodynamic performance. However, this was not pursued because it would increase the glider's weight. With experience, some glider flights eventually approached 70 feet in length.

The first large-scale test of Aery came in August of 1995 at ACE Academy which was held at Camp Ripley, Minnesota. Approximately 12 students were in attendance. At this point, all the basic functions of Aery worked, but the program could not yet print the glider plans. As a temporary measure, worksheets were developed upon which the students copied down their glider design from the computer display. The available computers were 486SX/25 machines. These proved marginal in performance due to Aery's graphic updates during design changes.

The day's session began with a short talk about engineering. This proceeded to a discussion of airplanes, flight, and stability. Then, the engineering design process for airplanes was explained. Following an explanation of some terms, the students were introduced to Aery. After a brief tutorial, they were turned loose in groups of two to design their own gliders. Later, each group constructed a glider. To speed the building process, cyanoacrylate glues (similar to "super glue") were used throughout construction. Because the wood data used was the average for all of the wood, center of gravity locations for the finished gliders were up to one centimeter from the predicted location. In this case, the students were instructed to add or remove weight until the center of gravity closely approached the predicted location.

According to reports, the test flights went well although they had to be postponed until the next day due to high winds. However, many of the gliders reportedly suffered from the flying surfaces breaking off the fuselage after strong impacts with the ground.

Aery testing went on hiatus until the next ACE Academy in June of 1996 at Mankato State University. At this point, nearly all of Aery's functions were working including the printing of plans. However, the printing of the plans was slowed by an inability to print to the available laser printers. Instead, slower dot matrix printers had to be used. As Pentium 90 computers were available, program performance was quite good.

A session plan similar to 1995 was used for this full capacity , 24 student, session. Glider construction went smoothly although, as usual, frequent assistance was needed by all twelve groups. To reinforce the gliders, a woven nylon tape was glued over the joints between the fuselage and the wing, and the fuselage and horizontal stabilizer. A "kicker" was also used to set the glue instantly for quick repairs.

Because of rainy weather, flight tests were held in large interior hallways. This proved to be a wind-free but obstacle-rich environment with many gliders suffering collision damage. Glider performance was quite good as many of the students had done the extra step of sanding their machines. Since colored markers were available, most groups personalized and decorated their gliders. Prizes were awarded to the group winning a contest for the longest flight. Student response to the session was very good.

Another ACE Academy session was held in August of 1996. This session, with about 21 students, was very similar to the June session. The problems with using the laser printers had been remedied which greatly improved the quality and speed of the

glider plans. Flight tests were held outdoors on a large grass-covered field with great success.

The ACE Academy sessions were invaluable not only in testing Aery but also in developing ideas for lesson plans and glider construction methods. The students were able to find several minor problems within Aery, and they also provided valuable feedback and ideas for improvements and new features. Over the several sessions, new methods for reinforcing the gliders were tested. Also, various methods for attaching the vertical stabilizer and horizontal tail were tried. The use of Aery at ACE Academy will continue in 1997.

### **Summary**

In conclusion, the program "Aery" represents an application of computer aided design to simple gliders. Developed using Visual Basic for PC's running Windows, Aery allows the interactive design, analysis, and creation of plans for gliders.

As shown by its use and testing at ACE Academy, Aery utilizes a valid analytical approach. Yet, it is simple enough to be used by people with only minimal preparation. Aery can thus be made a worthwhile component of the process of teaching simple aerodynamics, stability, and airplane design.

In the near future, Aery will be made available for free distribution via the World Wide Web and free non-commercial use by any individual or institution. A user's manual, lesson plan, and glider construction guide will accompany Aery to facilitate its use. Future programming plans for Aery include the creation of a Windows help file and

the eventual rewrite and release of Aery as a 32 bit application for the Windows 95 environment.

## References

- Abbott, Ira H. and Albert E. Von Doenhoff. 1959. Theory of Wing Sections. New York: Dover Publications.
- Anderson, John D. 1989. Introduction to Flight. New York: McGraw-Hill.
- Anderson, John D. 1991. Fundamentals of Aerodynamics. New York: McGraw-Hill.
- Nelson, Robert C. 1989. Flight Stability and Automatic Control. New York: McGraw-Hill.
- Raymer, Daniel P. 1992. Aircraft Design: A Conceptual Approach. Washington, D.C.: American Institute of Aeronautics and Astronautics.
- Simons, Martin. 1994. Model Aircraft Aerodynamics. Hemel Hempstead, England: Argus Books.

## **Appendix A: Sample Configuration Data File**

## **Appendix B: Sample Glider File**

## **Appendix C: Sample Glider Plans, Conventional**



## **Appendix D: Sample Glider Plans, Canard**

## **Appendix E: Sample Glider Information**