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EGADS: A Microcomputer Program for Estimating the Aerodynamic Performance of General Aviation Aircraft

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Symbols

a	local speed of sound
A	propeller disk area
AR	aspect ratio = b^2/S
b	wingspan
BSFC	brake specific fuel consumption
c	chord length
C_D	aircraft drag coefficient
C_{D_o}	aircraft zero-lift drag coefficient
C_{D_π}	landing gear drag coefficient based on gear frontal area
C_f	skin friction coefficient
CG	center of gravity
C_L	aircraft lift coefficient
C_{L_α}	aircraft lift curve slope = $\partial C_L/\partial\alpha$
C_M	aircraft pitching moment coefficient
C_{M_o}	aircraft pitching moment coefficient at zero lift
C_{M_α}	pitching moment curve slope = $\partial C_M/\partial\alpha$
C_p	pressure coefficient
D	drag
e	Oswald efficiency factor
f	equivalent flat-plate area
g	acceleration due to gravity
GTV	geometric tail volume
h	location of CG aft of leading edge of MAC as a fraction of MAC
h_n	location of neutral point aft of leading edge of MAC as a fraction of MAC
hp	horsepower
hp_r	sea-level horsepower ratio = hp/hp_o
L	lift
M	Mach number
n	load factor = L/W
P	power
q	dynamic pressure = $\rho V^2/2$
Re	Reynolds number
S	planform area
SM	static margin as a fraction of MAC
t/c	thickness-to-chord ratio
T	thrust
V	velocity
W	weight
x	longitudinal coordinate
z	vertical coordinate
α	angle of attack
γ	climb angle
η	non-ideal propeller efficiency factor
η_i	ideal propeller efficiency from actuator disk theory
λ	taper ratio
Λ	sweep angle of line through quarter-chord points
μ	viscosity
υ	kinematic viscosity = μ/ρ
ρ	atmospheric density
σ	dynamic pressure ratio at tail
ϕ	bank angle

Subscripts

A/C	aircraft
ac	aerodynamic center
av	available
CG	center of gravity
EW	empty weight
f	fuel
GE	in ground effect
hz	horizontal stabilizer
i	ideal or induced
MAC	mean aerodynamic chord
mid	midspan
MW	minimum weight
n	neutral point
o	sea-level or zero lift
req	required
shaft	engine shaft

ver	vertical stabilizer	wet	wetted area
w	wing	∞	free stream

Summary

EGADS is a comprehensive preliminary design tool for estimating the performance of light, single-engine general aviation aircraft. The software runs on the Apple® Macintosh™ series of personal computers and assists amateur designers and aeronautical engineering students in performing the many repetitive calculations required in the aircraft design process. The program makes full use of the mouse and standard Macintosh interface techniques to simplify the input of various design parameters. Extensive graphics, plotting, and text output capabilities are also included.

Introduction

EGADS (Easy General Aviation Design System) for the Apple Macintosh is organized as a collection of simple "design worksheets" in which the designer can vary individual aircraft parameters (such as wing aspect ratio or gross weight) and immediately calculate the resulting effects on aircraft performance. The classic equations for low-speed flight mechanics are solved without approximation whenever possible, requiring numerical root-finding algorithms in a few cases. Basic propeller characteristics are determined using actuator disk theory, and engine performance is adjusted for altitude by means of a simple density relationship. A lifting-line algorithm is available for computing aircraft lift, drag, and pitching moment characteristics, and for determining lift, load, and bending moment distributions on simple one- and two-surface configurations. A parametric plotting routine provides visual insight into the effects of single-parameter changes on aircraft performance. Help-screens provide information for the calculations on each worksheet, and extensive input checking provides users with on-screen diagnostic error messages for trouble-free calculations. Although EGADS facilitates the input of all design parameters and the display of results, the input and output files are also formatted for easy editing and specialized plotting using standard word processing or spreadsheet programs. (When editing the design files with a word processor, the use of an equi-spaced font—e.g., Monaco—will correctly align the data into columns.)

The main body of this report describes the basic installation and operation of EGADS, and the appendixes describe (in limited detail) the assumptions and equations used in the EGADS calculations. Throughout the figures, examples of the various worksheets are given and reference is made to a variety of aircraft.

> *NOTE: The numerical input data and the resulting performance estimates shown in the figures and included in the accompanying design files are not implied to be accurate for any of the aircraft that are displayed or discussed in the text and figures or included on the diskette. This document is expressly* not *intended to provide the reader with information on proper design guidelines, but instead to provide basic instructions for operating the software.*

It is assumed that the reader has an understanding of the basic vocabulary, goals, and techniques used in aircraft design work. Neither this document nor the EGADS software is intended to be a substitute for the information and insight available from a thorough study of the past and current states of the design art and from the many classic and modern texts on the analysis, design, and construction of aircraft.

Installing EGADS on the Macintosh

The EGADS diskette contains the application software and a folder containing some aircraft design files. No system file is included on the diskette, so computers that do not have a hard disk should first be started with a diskette that contains the system file. A backup copy of the EGADS diskette should then be made *before* running EGADS. On computers that have hard disks, all the files and folders on the EGADS diskette should be copied onto and run from the hard disk for the fastest operation. The author recommends creating a new folder on the hard disk with the name "EGADS Folder," and transferring the files from the diskette to the newly created folder.

Starting EGADS

After making a backup copy of the EGADS diskette, the EGADS program can be started by double-clicking on the EGADS icon. The EGADS startup screen, consisting of the NASA logo on a field of blinking stars, will be displayed (fig. 1). If instead of the NASA logo the message "ERROR 7" is printed, make sure that the application's memory size is sufficient and that the system has at least 1 megabyte of available RAM memory. The application memory size can be changed by returning to the Finder and using the Get Info command on the EGADS application file, then editing the number in the Application Memory Size box so that it is at least as large as the Suggested Memory Size (the amount of RAM memory available can usually be found by choosing the About the Finder option under the Apple menu). Once the program has been successfully started, the NASA logo will be displayed. To begin using EGADS, hit any letter key or click the mouse button while the cursor is inside the field of blinking stars. Important information including a legal disclaimer and an EGADS overview is then automatically displayed, and the menu bar becomes active (the menu selections change from gray to black). At this point, the user can view some information about the best way to begin using EGADS, read in a previously created aircraft file, or begin to enter the important geometric parameters for a totally new design.

Using EGADS

Figure 2 is a simplified flowchart depicting the operational organization of EGADS. After starting the program, the user typically reads in a previous design from the A/C Files menu. Changes in the wing, tail, fuselage, and landing gear geometry are then made on the Layout worksheets, engine modifications are made in the Propulsion worksheets, and new component weights are entered in the W & B worksheets. Once these modifications to the design have been made, the drag buildup is recomputed in order to provide the most current drag estimate to the Performance worksheets. The diamond-shaped decision box in the flowchart indicates that *the drag buildup must always be updated before new performance estimates are computed whenever any geometry changes are made in the Layout worksheets.* Finally, the Performance worksheets are used to make estimates of the new design's capabilities.

After review, the aircraft geometry, propulsion system, and weights can again be modified, the drag buildup recomputed, and new performance estimates analyzed. Multiple iterations of this "modify-recompute-reanalyze" procedure form the basis of the aircraft design process, and typically continue until all the design requirements are met or until a reasonable compromise between the requirements is reached. Once the design is completed (or as soon as the designer reaches the exhaustion/frustration limit), the aircraft information should be saved to a file, and the EGADS program halted.

The following six sections provide descriptions of the various worksheets and their use, starting with the Control menu and continuing through the A/C Files, Layout, Propulsion, W&B, and Performance menus. The selections available under each menu choice are displayed in figures 3(a)–3(f). Help-screens (available on many worksheets by pressing the button labeled with a "?") also provide the user with useful information, and are reproduced in the figures. A short discussion of the major equations and assumptions used in the EGADS worksheets can be found in the appendixes.

Control Menu

The selections available under the Control menu are shown in figure 3(a) and are described in the following paragraphs.

Some Information about EGADS

The Some-Info-about-EGADs worksheet (fig. 4) contains the author's name and the address to which written correspondence about EGADS should be addressed, the programming environment used to create EGADS (Microsoft® QuickBASIC), and some general information about the easy-to-use philosophy behind EGADS.

How To Get Started

The How-to-Get-Started worksheet (fig. 5) contains information about getting started, learning to use EGADS, using screen dump files to save copies of the worksheets, and printing instructions.

What EGADS Can't Do . . . Yet

Because EGADS is a program for making initial performance estimates of low-speed, propeller-equipped, general aviation aircraft, certain types of calculations are not included. These excluded topics are displayed on the What-EGADS-Can't Do . . . Yet worksheet, which is reproduced in figure 6.

Disclaimers and Responsibilities

The Disclaimers-and-Responsibilities worksheet states that the user of EGADS relies on it and its results at his or her own risk (fig. 7). The successful design of an aircraft requires that performance estimates be viewed with the clear understanding that they are "best guess" predictions, and that they are subject to the uncertainties of the inputs and assumptions in the calculations. There is simply no substitute for thorough understanding and experience when reviewing design predictions.

Print the Current Worksheet

A copy of any worksheet can be sent to the printer by selecting the Print-the-Current-Worksheet menu option. On worksheets containing plots, this menu option is replaced by a button labeled Print.

Quit (with Save Option)

The Quit- (with Save Option) menu selection allows the user to save the current design information to disk, then quit EGADS and return to the Finder. This final screen picture is reproduced at the end of the figures (fig. 33).

A/C Files Menu

The selections available under the A/C Files menu are shown in figure 3(b) and are described in the following paragraphs.

Read a Stored Aircraft File

Using standard Macintosh dialog box techniques, the user can read in a stored design file from disk (fig. 8). A three-view of the configuration is drawn to verify the selection after it is read from the disk.

Save the Current Aircraft File

The current design can be written to a disk file by selecting the appropriate folder, entering the file name, and pressing the Save button. The required dialog box inputs are shown in figure 9.

See Parameters of Some Famous Aircraft

Design information from a few selected historical aircraft is provided on the See-Parameters-of-Some-Famous-Aircraft worksheet to give the user some guidelines for basic aircraft sizing (fig. 10). The numbers in this worksheet were derived using published performance data from a wide variety of sources, and are approximate at best.

Layout Menu

The Layout menu worksheets allow the user to input the basic geometry of the aircraft, with all dimensions in decimal feet and angles in degrees. The F, S, and P buttons found at the bottom of the worksheets draw front, side, and plan (top) views when pressed, and the "?" button provides access to the help information. The selections available under the Layout menu are shown in figure 3(c).

Fuselage

The dimensions of the fuselage cross sections are individually input on the Fuselage worksheet (fig. 11(a)); X refers to the longitudinal location of the section from the forward datum, and Z is the location of the bottom of the cross section from the vertical datum (in most cases, the ground should be used as the vertical datum, where Z = 0). The width and height of each cross section are entered in decimal feet, along with the corner radius. Iso Angle (fig. 11(a)) refers to the angle at which the sections are drawn in the quasi-isometric view when the Draw Isometric button is pushed.

Scrolling through the sections is done by pressing the Next Section and Previous Section buttons. While scrolling, the section is drawn unscaled next to the edit fields and highlighted in the larger isometric view. Lines connecting the middle of the top and side of each section are also drawn. Cross sections are saved only after the buttons labeled Save this Section or Replace Section are pressed. Clicking the Delete This Section button removes the current highlighted cross section from the list of fuselage sections. Under the Performance menu, the wetted area of the fuselage is calculated in the Drag Buildup worksheet, and the volume and fineness ratio of the fuselage are displayed when the EstFusAero button is pressed in the Lift Distributions worksheet. The F, S, and P buttons draw front, side, and plan views when pressed (fig. 11(a)), and the button labeled "?" provides the user with help information (fig. 11(b)).

Wing

Permanent design changes to the wing geometry can only be made in the Wing worksheet (with the exceptions of the wing incidence and twist, which can also be permanently changed in the Lift-distributions worksheet, Performance menu). All dimensions should be entered in decimal feet and degrees. See figure 12(a) for a descriptive diagram of the Wing worksheet. The quantities Aileron Inboard and Flap Inboard refer to the spanwise distance (in feet) of the aileron and flap from the wing centerline chord. The quantity Wing Z-Location is the location of the wing centerline chord from the vertical datum, and Wing X-Location is the distance of the leading edge of the wing centerline chord from the horizontal datum. Wing area, taper ratio, aspect ratio, and mean aerodynamic chord (MAC) are printed at the bottom of the worksheet, along with the sweep (in degrees) of a line through the wing quarter chords and the ratio of aileron and flap areas to wing area. The location of the MAC shows up as an extended chord line. Although the wing area and aspect ratio appear in other worksheets, they are provided in those worksheets only for "what if" analysis. Wing changes made in other worksheets are temporary, and apply only to the calculations performed in those worksheets. Wing and tail airfoil-thickness ratios are entered, and the wetted area of the wing is calculated in the Performance menu, Drag Buildup worksheet. The F, S, and P buttons draw front, side, and plan views when pressed, and the "?" button provides the user with help information (fig. 12(b)). The wing is redrawn and its geometric parameters updated whenever the Update (fig. 12(a)) button or keyboard carriage return key is pressed.

Tail

Permanent changes to the tail geometry can only be made on the Tail worksheet (with the exceptions of the horizontal tail incidence and twist, which can also be permanently changed in the Lift Distributions worksheet). The quantity Hz Z-Location (fig. 13(a)) is the location of the horizontal stabilizer centerline chord from the vertical datum (which should be the same as that used for the fuselage cross sections); the Ver X-Location provides a similar input for the vertical stabilizer. Rudder Inboard is the distance of the bottom of the rudder from the bottom of the vertical stabilizer. Note that the vertical tail is drawn lying on its side next to the horizontal stabilizer in the plan view (fig. 13a). Horizontal and vertical stabilizer areas and aspect ratios are printed at the bottom of the worksheet, along with the geometric tail volume coefficients. The longitudinal location of the gross-weight center of gravity (CG) is displayed with the standard CG symbol. The wetted areas of the tail are calculated on the Drag Buildup worksheet under the Performance menu. The F, S, and P buttons draw front, side, and plan views when pressed, and the "?" button provides the user with help information (fig. 13(b)). The plan view is redrawn and the geometric information updated whenever the Update button (fig. 13(a)) or keyboard carriage return key is pressed.

Landing Gear

The dimensions and locations of the landing gear should be entered on the Landing Gear worksheet in units of decimal feet. See figure 14(a) for a descriptive diagram of the worksheet. The gear loads for the various loading conditions are calculated using simple force and moment balances after pressing on the appropriate button; for example, the gear loads in the minimum weight condition will be calculated and displayed when the Minimum button is pressed. If the CG moves out from between the landing gear, the user is warned of a tip-over condition by a beep tone and by a gear load that is less than or equal to zero. If changes are made to the loadings contained in the weight-information edit fields, the user can reset this weight information to the original values by pressing the "R" (restore) button. (Permanent changes to the weight and loading data can only be made on the W & B menu, CG Location worksheet.) Note that the gear loads displayed are the *individual* strut loads, with the assumption that there is a single nose/tail gear strut and two main gear struts. If the aircraft has retractable landing gear, the button labeled Retractable should be activated so that the drag of the landing gear will be correctly handled on the Performance menu worksheets. The button labeled "?" provides the user with help information (fig. 14(b)).

Plan View

A full-screen plan view is drawn when this menu item is selected (fig. 15).

Front View

A full-screen front view is drawn when this menu item is selected (fig. 16).

Side View

A full-screen side view is drawn when this menu item is selected (fig. 17).

Big Wing

A full-screen plan view of the wing is drawn when this menu item is selected (fig. 18).

3-View

A full-screen three-view of the aircraft is drawn when this menu item is selected (fig. 19). Note that the three views are *not* drawn to the same scale.

Propulsion Menu

The only selection available under the Propulsion menu (fig. 3(d)) is the Piston & Propeller worksheet (fig. 20(a)). This is the only worksheet in which permanent changes to the engine horsepower and propeller can be made. Plots of propeller efficiency, thrust, and available power versus airspeed and altitude can be made in a manner similar to that used in the Parametric Plots worksheet. Engine supercharging can also be included by pressing the Supercharged button and entering the critical altitude. The critical altitude is defined as the altitude below which there is no change in engine shaft horsepower with altitude. *The user is cautioned that the efficiency of a fixed-pitch propeller will vary dramatically with airspeed, and will have a strong effect on performance.* A sample plot is shown in figure 20(b), and the help information ("?" button) in figure 20(c). Additional information about the calculations is presented in appendix A.

Weight and Balance Menu

The selections available under the Weight and Balance (W & B) menu are CG Location and Aerodynamic Center (fig. 3(e)).

CG Location

The CG Location worksheet (fig. 21(a)) is used to estimate the gross, empty, and minimum aircraft weights and center of gravity locations. The weights and longitudinal locations (moment arms) of the major components should be entered in the associated edit fields. The location of the area centroids of the wing and tails can also be computed by pressing the Centroids button. Note that this worksheet is extremely limited in the number of components available, and cannot be used for the detailed CG calculations required for a real aircraft. It also makes no attempt to calculate the vertical location of the center of gravity.

When the button labeled Recalculate the CG Limits is pressed, a side view of the aircraft is drawn, along with a marker for the gross-weight center of gravity location. The empty weight is the sum of all structural and propulsion components. The minimum weight is the sum of the empty weight plus the minimum pilot weight. The gross weight is the sum of all components, including fuel, maximum pilot weight, passengers, and baggage. The CG locations and weights calculated in this worksheet are used as inputs for other worksheets, but can be permanently changed only on this worksheet. Help information (fig. 21(b)) is displayed when the "?" button is pushed.

Aerodynamic Center

The Aerodynamic Center worksheet (fig. 22(a)) is used to provide a quick estimate of the stick-fixed longitudinal location of the aircraft neutral point (aerodynamic center) and static margin. Upon entry to the worksheet, the lift curve slopes of the wing and tail are computed using the Helmbold equation, and the downwash gradient is calculated using the method of Torenbeeck (ref. 1). The fuselage's contribution to the pitching moment and the dynamic pressure ratio at the tail can also be input, but their estimation is currently left to the user. The neutral point location and static margin for the various aircraft loadings are graphically displayed at the bottom of the screen. (The aerodynamic center of the wing/tail combination can also be estimated when using the Lift Distribution worksheet by adjusting the CG location until no change in the total aircraft moment occurs when the angle of attack is varied. When this CG location is determined, the CG and neutral point are co-located.) When the button labeled Recalculate the AC is pressed, a side view of the aircraft is drawn, along with a marker for the gross-weight center of gravity location and designators for the minimum weight CG and neutral point location. Help information is displayed when the "?" button is pushed (fig. 22(b)). Additional details of these calculations are presented in appendix B.

Performance Menu

Once the geometry has been adequately specified using the Layout menu, the performance of the aircraft can be estimated using the various selections found on the Performance menu. The selections available under this menu are shown in figure 3(f). A list of the equations used in the performance worksheet calculations is given in appendix C. Because of the variation in propeller and engine performance with airspeed and altitude, a discussion of the actuator disk theory used to estimate propeller performance is given in appendix D. *The user is cautioned that the efficiency of a fixed-pitch propeller will vary dramatically with airspeed, and will have a strong effect on an aircraft's performance.*

Drag Buildup

Before any performance computations can be completed, an estimate of the drag coefficient of the aircraft must be made. Upon entry to the Drag Buildup worksheet (fig. 23(a)), the wetted areas for the wing, tails, fuselage, and landing gear are calculated. An average flat-plate skin-friction coefficient (C_f) for each of the various components is entered in the first column. The thickness ratios of the wing and tails are entered in the second column of edit fields, along with drag coefficients (C_{D_π}) for the landing gear based on its frontal area. Allowance can be made for portions of the wing or tails that lie inside the fuselage by entering the percentage of the overlapping area to be included in the wetted area calculations under the column labeled "% Overlap Wetted."

For example, 10% of the planform areas of the wing and of the horizontal tail that overlap the fuselage are included in the wetted-area computations shown in figure 23(a). If none of the overlapping planform area of a component is to be included in a component's wetted area, then a zero should be entered in the appropriate % Overlap field. The associated wetted and equivalent flat-plate areas (in square feet) are computed and displayed along with each component's contribution to the zero-lift drag coefficient in the upper right quadrant of the worksheet. The gear wetted area is computed using the approximate wetted area of the wheels only, but the landing gear equivalent flat-plate and drag increments are a function of the gear frontal (not wetted) areas. The help screen (accessible by pressing the "?" button) provides useful information about the range of C_f and C_{D_π} for a variety of aircraft and landing gear types; it is reproduced in figure 23(b).

The total wetted area, zero-lift drag coefficient (C_{D_0}), total equivalent flat-plate area, and overall skin-friction coefficients for gear-up and gear-down configurations are re-computed and displayed in the center of the worksheet after the Recalculate Drag Buildup button is pressed. The user is cautioned that no automated estimates for form, cooling, base, interference, excrescence, strut, or other significant sources of drag are made on this worksheet; instead, a single edit field is provided to allow the user to include his own estimate of these important miscellaneous drag contributions.

In order that the drag estimates remain concurrent with geometry changes, the computations on this worksheet must always be performed after making any changes in the layout worksheets and before computing any new performance estimates. By enabling the Performance menu selections only after the computations in the Drag Buildup worksheet have been completed, EGADS ensures that the drag estimates for a design remain concurrent with its geometry changes.

The aircraft C_{D_0} and Oswald efficiency factor appear in many of the performance worksheets, but they can be permanently changed only on the Drag Buildup worksheet. Although the Oswald efficiency factor for the wing + tail combination is computed on the Lift Distribution worksheet, EGADS currently leaves the estimation of the total aircraft (wing + tail + fuselage) Oswald efficiency to the user. Note also that the C_{D_0} found upon entry to the performance worksheets is chosen according to the type of landing gear (fixed or retractable). Additional details of these calculations are presented in appendix E.

Climb and Turn

The Climb-and-Turn worksheet is useful when calculating many of the important parameters in constant-speed climbing, diving, level, and turning flight. The aircraft design parameters that affect these calculations are automatically copied into the worksheet from the Layout pages. Note that any changes made in this worksheet to aircraft design parameters such as C_{D_0}, Oswald efficiency, wing area, aspect ratio, and gross weight are temporary, and will not be copied into other worksheets.

The user should enter the desired flight Mach number, airspeed, or lift coefficient (C_L) into the appropriate edit field (fig. 24(a)), then click on the corresponding button or press the keyboard carriage return key in order to perform the calculations. The two corresponding values will then be automatically displayed in the neighboring edit fields, along with a full display of other flight parameters in the lower half of the worksheet. For example, if flight at a specific Mach number is desired, the Mach number should first be entered into the Mach number edit field, then the Mach button (or keyboard carriage return key) should be pressed. The corresponding values of airspeed and lift coefficient will then be displayed in their respective edit fields, along with a large variety of other additional numerical information characterizing the flight conditions at this Mach number.

Help information is displayed when the "?" button is pushed (fig. 24(b)), and all design data are restored to their original values when the "R" button is pressed. Additional details of these calculations are presented in appendix F.

Range

The Range worksheet (fig. 25(a)) is used to estimate the aircraft's range and endurance using the Breguet equations. The aircraft design parameters that affect these calculations are automatically copied into the worksheet from the Layout pages. Note that any changes made in this worksheet to aircraft design parameters such as C_{D_0}, wing area, aspect ratio, and gross weight are temporary, and will not be copied into other worksheets. The C_L for best range is automatically displayed in the lower region of the left column. The actual C_L used for cruising can be entered in the upper rightmost edit field, along with the fraction of total fuel consumed during the flight. (Most general aviation aircraft cruise at a C_L that requires approximately 75% of their available power, resulting in airspeeds significantly higher than those given by the Breguet optimum.)

Flights of different lengths can be simulated by adjusting the fraction of fuel used, with a fraction of "1" denoting the maximum tank-empty range. The range, endurance, airspeeds, and fuel flow rate corresponding to the cruise C_L and fuel fraction are then displayed in the lower right portion of the worksheet when the Recalculate the Range button or the keyboard carriage return key is pressed. Note the sensitivity of the computations to the value of brake specific fuel consumption (BSFC). Help information is displayed when the "?" button is pushed (fig. 25(b)), and all design data are restored to their original values when the "R" button is pressed. Additional details of these calculations are presented in appendix G.

Speeds

The Speeds worksheet (fig. 26(a)) can be used to calculate the effects of design changes on many of the important aircraft operating speeds. The aircraft design parameters that affect these calculations are automatically copied into the worksheet from the Layout pages. Note that any changes made on this worksheet to aircraft design parameters such as C_{D_0}, Oswald efficiency, wing area, aspect ratio, and gross weight are temporary, and will not be copied into other worksheets. The sea-level engine horsepower should be entered in the upper rightmost edit field, along with the propeller diameter and estimates for the propeller efficiency and maximum lift coefficient of the aircraft. The minimum, maximum, best rate of climb (V_y), and best angle of climb (V_x) airspeeds and the corresponding flight parameters are then displayed in the lower portion of the worksheet when the Recalculate the Speeds button or the keyboard carriage return key is pressed. Pressing the button labeled Show Glide Speeds displays the power-off speeds for best glide range and glide endurance. *The user is cautioned that the efficiency of a fixed-pitch propeller will vary dramatically with airspeed, and will have a strong effect on performance.* Help information is displayed when the "?" button is pushed (fig. 26(b)), and all design data are restored to their original values when the "R" button is pressed. Additional details of these calculations are presented in appendix H.

Ceilings

The Ceilings worksheet (fig. 27(a)) can be used to calculate the effects of design changes on the aircraft service and absolute ceilings. The aircraft design parameters that affect these calculations are automatically copied into the worksheet from the Layout pages. Note that any changes made in this worksheet to aircraft design parameters such as C_{D_0}, Oswald efficiency, wing area, aspect ratio, and gross weight are temporary, and will not be copied into other worksheets. The sea-level engine horsepower should be entered in the upper rightmost edit field, along with the propeller diameter and efficiency. One half of the fuel weight is automatically subtracted from the gross weight upon entry to this worksheet. The ceilings and associated flight parameters are displayed in the lower portion of the worksheet when the Recalculate the Ceilings button or the keyboard carriage return key is pressed. Help information (fig. 27(b)) is displayed when the "?" button is pushed, and all design data are restored to their original values when the "R" button is pressed. Additional details of these calculations are presented in appendix I.

Takeoff Roll

The Takeoff Roll worksheet (fig. 28(a)) can be used to calculate the effects of design changes on the aircraft takeoff ground roll distance. The ground roll displayed in the lower left corner of the worksheet is the runway distance required for the aircraft to accelerate to the rotation velocity. The aircraft design parameters that affect these calculations are automatically copied into the worksheet from the Layout pages. Note that any changes made on this worksheet to aircraft design parameters such as C_{D_0}, Oswald efficiency, wing area, aspect ratio, and gross weight are temporary, and will not be copied into other worksheets. The Takeoff Roll C_L item refers to the lift coefficient produced by the wing while the aircraft is rolling down the runway, and the $C_{L_{max}}$ of Takeoff Configuration item refers to the maximum lift coefficient of the aircraft in the takeoff configuration. The ratio of rotation to stall speeds is $V_{(rotate)}/V_{(stall)}$. The Ground Friction Coefficient is used to characterize the relative roughness of different runways. Wing Height above Ground is calculated in and automatically copied from the Landing Gear worksheet; it is important for determining the effect of the ground's proximity on the induced drag. Aircraft C_{D_0} refers to the C_{D_0} of the aircraft without landing gear; the gear flat-plate area is now included as an input, and the C_{D_0} used in the takeoff roll computations combines both the clean aircraft and landing gear drag. Takeoff parameters are then displayed in the lower portion of the worksheet when the Recalculate the Takeoff Roll button or the keyboard carriage return key is pressed. Help information (fig. 28(b)) is displayed when the "?" button is pushed, and all design data are restored to their original values when the "R" button is pressed. Additional details of these calculations are presented in appendix J.

Landing Roll

The Landing Roll worksheet (fig. 29(a)) can be used to calculate the effects of design changes on the aircraft landing ground roll distance. The aircraft design parameters that affect these calculations are automatically copied into the worksheet from the Layout pages. Note that any changes made on this worksheet to aircraft design parameters such as C_{D_0}, Oswald efficiency, wing area, aspect ratio, and gross weight are temporary, and will not be copied into other worksheets. The Landing Roll C_L item refers to the lift coefficient produced by the wing while the aircraft is rolling down the runway, and the $C_{L_{max}}$ of Landing Configuration item refers to the maximum lift coefficient of the aircraft in the landing approach configuration. $V_{(approach)}/V_{(stall)}$ is the ratio of approach to stall speeds, and Approach Angle is the flight-path angle of the approach (EGADS assumes a positive approach angle for descent). The Braking Friction Coefficient is used to characterize the relative braking power available on different runways. Seconds to Zero Power is the time in seconds that it takes the pilot to move the throttle from the approach to idle setting during the landing roll (EGADS uses a default value of 0.5 sec). Wing Height above Ground is calculated on the Landing Gear worksheet, and is important for determining the effect of the ground's proximity on the induced drag. Aircraft C_{D_0} refers to the C_{D_0} of the aircraft without landing gear; the gear flat-plate area is now included as an input, and the C_{D_0} used in the landing-roll computations combines both the clean aircraft and landing gear drag. Landing parameters are then displayed in the lower portion of the worksheet when the Recalculate the Landing Roll button or the keyboard carriage return key is pressed. Help information (fig. 29(b)) is displayed when the "?" button is pushed, and all design data are restored to their original values when the "R" button is pressed. Additional details of these calculations are presented in appendix J.

Standard Atmosphere

Atmospheric properties are calculated in EGADS according to the formulas given by the U.S. Extension to the International Civil Aviation Organization (ICAO) standard atmosphere (ref. 2). Note that these formulas are for a standard day only. After entering the altitude, Mach number, and chord length combination of interest, pressing the Recalculate Quantities button or keyboard carriage return key causes the corresponding atmospheric conditions and Reynolds number to be computed and displayed in the lower half of the worksheet. The Standard Atmosphere worksheet is reproduced in figure 30(a), and the help information is given in figure 30(b).

Parametric Plots

The Parametric Plots worksheet (fig. 31(a)) is one of the most powerful worksheets in the EGADS program, because it greatly simplifies the creation of many of the plots required for aircraft design and analysis. After pressing the Select Variables button, the user selects the variable to be displayed on the horizontal axis of the plot by clicking one of the highlighted buttons. Once the selection of the horizontal axis variable has been made, the variables available for plotting along the vertical axis are highlighted in the second column. The user next selects the vertical axis variable by clicking on the appropriate button. The equation to be plotted then appears at the bottom of the screen. The third column of buttons is then activated, from which the user selects the parametric variable. The parametric variable is the one parameter that will be changed between the different curves on the final plot. The user is then prompted to enter appropriate information into the outlined edit fields in order to make the plots.

Edit fields labeled Fixed will contain parameters that will be constant for each of the curves. Edit fields labeled X-Step and P-Step determine the size of the step between the minimum and maximum values of the X- and parametric values, respectively, and therefore determine the number of divisions along the x-axis and the number of curves on the plot. Once the fields have been properly filled, the Make the Plot button becomes active, and the user makes the plot by pressing this button or the carriage return key. The plot is then drawn, with the various curves labeled with the value of the parametric variable along the right side of the plot. The x- and y-values displayed at the top of the chart correspond to the current location of the cursor within the plot.

The numeric values that make up the individual curves can be written to a text file by pressing the Text button. After clicking the close box in the upper left corner of the plot or pressing the mouse button or return key, the user is returned to the Parametric Plots input worksheet, where a different range of variables can be entered or an entirely different plot can be made. A sample plot is shown in figure 31(b). The list of plottable equations is given in the help screen reproduced in figures 31(c) and 31(d).

Lift Distributions

The Lift Distribution worksheet (fig. 32(a)) employs elementary lifting-line theory to do a simplified low-speed aerodynamic analysis of the lift, bending moment, and load distributions on the wing and tail (or canard, if the "tail" is in front of the wing). Plots of the total aircraft lift curve (C_L vs α), drag polar (C_L vs C_D), and moment curve (C_M vs C_L) can also be made over a user-specified range of α. The wing and tail incidence and twist (also known as "washout") are copied from the Layout worksheets, but *can* be changed permanently on this worksheet by pressing the Save Twist and Incidence button. The Vortices item refers to the number of horseshoe vortices distributed along the half-span of the wing and tail. Airfoil C_{MAC} is the pitching moment of the wing and horizontal tail airfoils about their sectional aerodynamic centers (which by definition do not change much with angle of attack), and Airfoil ZLA is the zero-lift angle of attack of the airfoils used in the wing and tail.

The effect of the fuselage on the aircraft pitching moment can be included by entering the fuselage zero-lift pitching moment (C_{m_0}) and the fuselage pitching-moment-curve slope (C_{m_α}) in the appropriate edit fields in the upper right corner of the worksheet. EGADS computes (using the methods of ref. 3) and displays approximations for these values and the fuselage volume and fineness ratio whenever the EstFusAero (estimate fuselage aerodynamics) button (fig. 32(a)) is pressed. The gross-weight center of gravity location is copied from the CG Location worksheet on the W & B menu. By clicking on the Vortices button (fig. 32(a)), a plan view of the configuration showing the distribution of the vortices and normal flow control points is drawn, along with the current CG location (fig. 32(b)). Note that the outboard vortices have purposely been inset slightly from the tips of the wing and tail.

After pressing the Return button, the lift, load, and bending moment distributions on the wing and tail can be viewed by pressing the appropriate buttons. These distributions correspond to the range of angles of attack entered in the AoA Start and AoA Finish edit fields. A text file containing a complete listing of all the numerical information can be produced by pressing the Text Output button.

An example plot of the load distributions is shown in figure 32(c). Note that the location of the wingtip corresponds to a span fraction of 1.0, and the centerline chord is located at span fraction 0. As on the Parametric Plots worksheet, the user can simply point to the desired screen location and have the current x- and y-location of the cursor displayed above the plot. The numeric values that make up the individual curves can also be written to a text file when the Text Output button is pressed. After clicking the close box in the upper left corner of the plot or pressing the mouse button or return key, the user is returned to the main worksheet, where different inputs can be entered.

The time required to perform the calculations is a function of both the number of panels (vortices) and the speed of the Macintosh CPU. While performing the calculations, the current status is displayed below the control buttons. Recomputations that do not require a redistribution of vortices are completed much faster than the initial calculations. Plots of the aircraft lift curve, drag polar, and moment curve (figs. 32(d)–32(f)) can be drawn with self-scaled limits, or fixed plotting limits can be used by deselecting the Autoscale button and entering the plot limits in the edit fields in the lower right corner of the worksheet. Help information (fig. 32(g)) is displayed when the "?" button is pushed, and all design data are restored to their original values when the "R" button is pressed.

The Quit (with Save Option) (on the Control Menu) final screen is shown in figure 33.

Pitfalls of Computer Design and Analysis

Computed estimates of aircraft performance are subject to the uncertainties of the inputs and to the assumptions involved in the derivations of the governing equations. The old adage "garbage in—garbage out" is still true and worth remembering when checking computational inputs for correctness, but it is just as important to realize that *even correct inputs will give incorrect results if any of the assumptions inherent in the governing equations and computations are violated by any of the inputs.* It is also helpful to remember that the absolute magnitude of a specific calculation is often not as important as understanding the performance trends that result from changes in design parameters.

Understanding this trend information requires both a study of the assumptions made when developing the governing equations, and a critical examination of predicted performance characteristics over a range of input values. Although the Parametric Plots worksheet automates much of the plotting required when examining predictions and trends, studying the discussion of the equations given in the appendixes is only a first step toward the complete development of this understanding. As stated in the Introduction, this document and the EGADS software are intended to supplement and not substitute for the many classic and modern texts on the analysis, design, and construction of aircraft.

Conclusion

The EGADS software provides a quick and simple method for obtaining preliminary aerodynamic performance estimates for propeller-driven aircraft operating at low subsonic speeds. The software was written to take full advantage of the user interface and graphic capabilities of the Apple Macintosh computer. EGADS allows the user to easily examine the many effects of various aircraft design parameters on aerodynamic performance. The software is intended for use primarily by home-built aircraft designers, general aviation pilots, and undergraduate students of aeronautical engineering.

This report serves as an introductory operations manual; as such, it does not include a fully detailed development of all the equations and assumptions used throughout the software. It should be emphasized that the information contained in this report and that provided by the EGADS software do not provide sufficient guidance for the successful design of an actual aircraft.

Appendix A

Propulsion Computations

Equations (7)–(14) (appendix C) are used to estimate propeller efficiency, and engine thrust and power available throughout various flight regimes. Because of the nonlinear relationship between ideal propeller efficiency and velocity, equations (9) and (11) must be solved in order to investigate the manner in which the available power and thrust vary with velocity and altitude (ref. 4). Above the critical altitude, engine horsepower decreases according to equation (7).

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Appendix B

Aerodynamic Center Computations

A precise prediction of the location of the aerodynamic center requires the estimation and input of some aerodynamic parameters that are currently beyond the calculation capabilities of EGADS. Equation (30) (appendix C) is first used to compute approximate values of wing and horizontal tail lift curve slopes, then equation (31) is used to estimate the change in downwash angle at the tail with changes in angle of attack. Accurate estimation and input of $\partial C_{M_{fus}} / \partial C_{L_w}$ and the tail dynamic pressure ratio is left up to the user. Equation (33) is then used to estimate the aerodynamic center of the aircraft.

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Appendix C

Partial List of Equations Used in EGADS

1. $n = \dfrac{\cos\gamma}{\cos\phi}$

   Constant rate turns and climbs

2. $q = \dfrac{1}{2}\rho V^2$

   Definition of dynamic pressure

3. $L = qSC_L = nW = W\dfrac{\cos\gamma}{\cos\phi}$

   Constant rate turns and climbs

4. $C_D = C_{D_o} + \dfrac{C_L{}^2}{\pi AR e}$

   Low speed, AR > 2, no flow separation, uncambered aircraft, constant rate turns and climbs

5. $D = qSC_D = T - W\sin\gamma$

   Thrust opposite drag, steady flight

6. $L^2 + (T - D)^2 = W^2$

   Thrust opposite drag, steady flight

7. $hp_r = \dfrac{\dfrac{\rho}{\rho_o} - 0.12}{\beta - 0.12}$

   $$\beta = \begin{cases} 1 & \text{normally aspirated engine} \\ \dfrac{\rho}{\rho_{critical}} & h > h_{critical}\text{, supercharged} \\ \dfrac{\rho}{\rho_o} & h < h_{critical}\text{, supercharged} \end{cases}$$

   Approximate variation of reciprocating engine power with altitude (ref. 4)

8. $P_{req} = DV$

   Required power, steady level flight

9. $P_{shaft} = 2\rho AV^3 \dfrac{(1-\eta_i)}{\eta_i{}^3} hp_r\ P_{shaft_o}$

   Actuator disk theory assumptions (ref. 4)

10. $P_{av} = \eta\eta_i P_{shaft}$

    Available power reduced by non-ideal and actuator disk propeller efficiencies

11. $T_i = 2\rho AV^2 \dfrac{(1-\eta_i)}{\eta_i{}^2}$

    Actuator disk theory assumptions (ref. 4)

12. $T = \eta T_i$

    Available thrust reduced by non-ideal propeller efficiency

13. $T_{static} = (2\rho A)^{1/3}\ P_{shaft}^{2/3}$

    Actuator disk theory assumptions

14. $T_i = T_{static}(1-\eta_i)^{1/3}$

    Actuator disk theory assumptions

15. $V = M_\infty a$

    Definition of free-stream Mach number

16. $S = S_w$

    (In EGADS, the reference area is the wing planform area)

17. $S_{wet} = 2\ S\left(1 + \dfrac{t/c}{4}\right)$

    Wetted-area estimate for wing and tail surfaces (ref. 1)

18. $X_{ac} = \dfrac{C_{mid}}{4} + b\tan\Lambda\left[\dfrac{1+2\lambda}{6(1+\lambda)}\right]$

    Linearly tapered, simple wing

19. $C_{MAC} = 2C_{mid}\dfrac{(1+\lambda+\lambda^2)}{3(1+\lambda)}$

    Linearly tapered, simple wing

20. $GTV_{hz} = \left(x_{ac_{hz}} - x_{ac_w}\right)\dfrac{S_{hz}}{C_{MAC}S}$

    Definition of geometric tail volume for horizontal stabilizer

21. $GTV_{ver} = \left(x_{ac_{ver}} - x_{ac_w}\right)\dfrac{S_{ver}}{bS}$

Definition of geometric tail volume for vertical stabilizer

22. $f = C_f S_{wet}$

Equivalent flat-plate area

23. $C_{D_o} = \dfrac{\Sigma f}{S}$

Parasite drag coefficient

24. $\text{Turn radius} = \dfrac{V^2 \cos\gamma}{g \tan\phi}$

Constant rate turns and climbs

25. $\text{Turn rate} = \dfrac{V \cos\gamma}{\text{Turn radius}}$

Constant rate turns and climbs

26. $\text{Fuel flow} = \dfrac{BSFC}{P_{shaft}}$

Reciprocating engine

27. $\text{Range} = \eta\eta_i \dfrac{C_L}{BSFC\, C_D} \ell n\left(\dfrac{w}{w - w_{fuel}}\right)$

Cruise without winds at constant altitude, BSFC, and C_L

28. $\text{Endurance} = \eta\eta_i \dfrac{C_L{}^{3/2}}{BSFC\, C_D} (\rho S)^{1/2}$

$$\times\left[\frac{1}{\left(w - w_{fuel}\right)^{1/2}} - \frac{1}{w^{1/2}}\right]$$

Cruise without winds at constant altitude, BSFC, and C_L

29. $C_{D_{i_{GE}}} = C_{D_i}\left[\dfrac{\left(\dfrac{16Z_w}{b}\right)^2}{1+\left(\dfrac{16Z_w}{b}\right)^2}\right]$

Biot-Savart estimate for horseshoe vortex (ref. 1)

30. $C_{L_\alpha} = 0.1\left[\dfrac{AR}{2+\left(4+AR^2\right)^{1/2}}\right]$

Approximate lift-curve slope

31. $\dfrac{\partial\varepsilon}{\partial\alpha_{hz}} = 1.75\left[\dfrac{C_{L_{\alpha_w}}}{\pi AR_w \left(\lambda_w r\right)^{1/4}\left(1+|m|\right)}\right]$

$$r = 2\frac{\ell_{hz}}{b} \qquad m = 2\frac{z_{hz} - z_w}{b}$$

$$\ell_{hz} = x_{hz} + x_{ac_{hz}} - x_w - x_{ac_w}$$

Approximate downwash gradient (ref. 1)

32. $h_{n_w} = \dfrac{X_w + X_{ac_w}}{C_{MAC}}$

Wing neutral point

33. $h_n = h_{n_w} + \dfrac{F - \left(\partial C_{M_{fus}}/\partial C_{L_w}\right)}{1 + F\left(C_{MAC}/\ell_{hz}\right)}$

$$F = \sigma\, GTV_{hz}\frac{C_{L_{\alpha_{hz}}}}{C_{L_{\alpha_w}}}\left(1 - \frac{\partial\varepsilon}{\partial\alpha_{hz}}\right)$$

Approximate aircraft neutral point as a fraction of MAC (ref. 5)

34. $X_{ac_{(A/C)}} = h_n C_{MAC}$

Longitudinal location of neutral point

35. $h = \dfrac{X_{CG}}{C_{MAC}}$

CG location as a fraction of MAC

36. $SM = h_n - h$

Static margin as a fraction of MAC

Appendix D

Assumptions behind the Actuator Disk Theory Used in EGADS

A complete discussion of the development and assumptions underlying actuator disk theory can be found in many introductory texts on aircraft aerodynamics and flight mechanics. The assumptions underlying the theory are given by McCormick as the following: (1) velocity is constant over the propeller disk; (2) pressure is uniform over the propeller disk; (3) rotation imparted to the flow as it passes through the propeller is neglected; (4) flow passing through the propeller can be separated from the rest of the flow by a well-defined stream tube; and (5) the flow is incompressible (ref. 6, p. 343). An additional assumption is that the pressure in the slipstream returns to the free-stream value far downstream of the propeller disk.

These assumptions lead to inaccuracies when using actuator disk theory to predict actual propeller efficiency. In order to make actuator disk theory more realistic for use in performance estimations, the efficiency factor η (input by the user, and always less than 1) is used to represent additional non-ideal propeller losses neglected by the theory. These include hub and tip losses as well as blade profile drag losses. From equations (9) and (11) (appendix C), it is clear that a cubic or quadratic equation must be solved to determine the value of the ideal (actuator disk theory) propeller efficiency η_i. EGADS attempts to determine the exact value of η_i whenever it is required. The total available power (P_{av}) is then determined by equation (10) (appendix C), in which the total propeller efficiency is assumed to be the product of the non-ideal and ideal propeller efficiencies. Because of the dependence of η_i (and P_{av}) on the velocity, the best rate speeds and ceilings are computed within EGADS using simple iterative techniques. The takeoff and landing roll distance computations use a simple explicit Euler-Cauchy time-integration technique for approximating the thrust and airspeed as a function of time during the ground roll, and therefore require the computation of the variation in η_i (and T_{av}) with airspeed throughout the duration of the ground rolls.

Some of the limitations of actuator disk theory can be seen in figure 20(b). As the airspeed increases, the actual propeller efficiency (and the available power) should reach a maximum and then decrease as a result of two effects: the angle of attack seen by the blades (and hence the thrust) is continually reduced as the forward speed of the aircraft increases, and as the blades reach transonic speeds, the formation of shock waves on the blades will further increase the blade drag while reducing the thrust. More advanced propeller estimation techniques based on blade-element or vortex theory can compute improved estimates of propeller efficiency, but they lack the simplicity of the actuator disk theory.

Appendix E

Drag Buildup Computations

The wetted area of the fuselage is computed using numerical integration. The wetted areas of the wing and tail surfaces are estimated using equation (17) (appendix C) upon entry to the Drag Buildup worksheet. When the Recalculate the Drag Buildup button or the keyboard carriage return key is pressed, the equivalent flat-plate areas for the individual components are computed (eq. (22), appendix C) and displayed in the right-most column, along with the total wetted area, total equivalent flat-plate area, overall skin-friction coefficient, and aircraft zero-lift drag coefficient C_{D_0} (eq. (23)). Note that the wetted-area computations for the landing gear neglect the wetted areas of the struts and assume that there are two main gear wheels and one nose/tail wheel. The drag increment due to the landing gear is computed by multiplying the tire frontal areas by the value of C_{D_π}. Although the aircraft C_{D_0} and the Oswald efficiency factor appear in many of the performance worksheets, they can be permanently changed only on this worksheet.

Appendix F

Climb and Turn Computations

The equation numbers cited below refer to those in appendix C.

Calculations based on Mach number:

1. Use atmosphere calculations to determine a and ρ
2. Use equation (1) to determine n
3. Use equation (15) to determine V
4. Use equation (2) to determine q
5. Use equation (3) to determine C_L
6. Use equation (4) to determine C_D
7. Use equation (5) to determine T
8. Use equation (12) to determine T_i
9. Use equation (11) to determine η_i
10. Use equations (7) and (9) to determine hp_r and P_{shaft}
12. Use equation (24) to determine turn radius
13. Use equation (25) to determine turn rate

Calculations based on C_L:

1. Use atmosphere calculations to determine a and ρ
2. Use equation (1) to determine n
3. Use equation (4) to determine C_D
4. Use equation (3) to determine V
5. Use equation (14) to determine M_∞
6. Use equation (2) to determine q
7. Use equation (5) to determine T
8. Use equation (12) to determine T_i
9. Use equation (11) to determine η_i
10. Use equations (7) and (9) to determine hp_r and P_{shaft}
11. Use equation (24) to determine turn radius
12. Use equation (25) to determine turn rate

Calculations based on airspeed:

1. Use atmosphere calculations to determine a and ρ
2. Use equation (1) to determine n
3. Use equation (15) to determine M_∞
4. Use equation (2) to determine q
5. Use equation (3) to determine C_L
6. Use equation (4) to determine C_D
7. Use equation (5) to determine T
8. Use equation (12) to determine T_i
9. Use equation (11) to determine η_i
10. Use equations (7) and (9) to determine hp_r and P_{shaft}
11. Use equation (24) to determine turn radius
12. Use equation (25) to determine turn rate

Appendix G

Range Computations

The equation numbers cited below refer to those in appendix C.

1. Use atmosphere calculations to determine a and ρ
2. Use equation (3) to determine q when half of trip fuel is consumed
3. Use equation (2) to determine V
4. Use equation (4) to determine C_D
5. Use equation (5) to determine T
6. Use equation (12) to determine T_i
7. Use equation (11) to determine η_i
8. Use equations (7) and (9) to determine hp_r and P_{shaft}
9. Use equation (26) to determine fuel flow
10. Use equation (27) to determine range
11. Use equation (28) to determine endurance

Appendix H

Speed Computations

The equation numbers cited below refer to those in appendix C.

Calculations for V_{min}:

1. Use atmosphere calculations to determine a and ρ
2. Use equation (3) to determine q at $C_{L_{max}}$
3. Use equation (2) to determine V
4. Use equation (15) to determine M_∞
5. Use equation (4) to determine C_D
6. Use equation (5) to determine T
7. Use equation (12) to determine T_i
8. Use equation (11) to determine η_i
9. Use equations (7) and (9) to determine hp_r and P_{shaft}

Calculations for V_{max}:

1. Use atmosphere calculations to determine a and ρ
2. Since η_i is a function of V, V_{max} is found by using a bisection search assuming $P_{shaft} = hp_r P_{shaft_{o_{max}}}$

Calculations for V_y (best rate of climb speed):

1. Use atmosphere calculations to determine a and ρ
2. Since η_i is a function of V, V_y is found by using a bisection search assuming $P_{shaft} = hp_r P_{shaft_{o_{max}}}$

Calculations for V_x (best angle of climb speed):

1. Use atmosphere calculations to determine a and ρ
2. Since η_i is a function of V, V_x is found by using a bisection search assuming $P_{shaft} = hp_r P_{shaft_{o_{max}}}$

Calculations for best power-off glide speed assume $C_L = (\pi\ e\ AR\ C_{D_o})^{1/2}$ for maximum glide ratio.

Calculations for best power-off glide endurance use a bisection search to determine the C_L for maximum endurance.

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Appendix I

Ceilings Computations

The service ceiling calculation uses two bisection searches: an outer search is performed for the altitude at which V_y = 100 ft/min, and an inner bisection search determines the maximum V_y at the trial altitude. The absolute ceiling calculation also uses two bisection searches: an outer search is performed for the altitude at which V_y = 0 ft/min, and an inner bisection search determines the maximum V_y at the trial altitude. In both cases, equations (7) and (9) (appendix C) are used to determine the shaft power available as a function of altitude, and equation (11) is used to determine the variation in ideal thrust with airspeed.

Appendix J

Takeoff and Landing Roll Computations

The equations of motion for the aircraft during the takeoff and landing rolls are integrated forward in time using a simple explicit Euler-Cauchy technique. The ideal static thrust is calculated using equation (13), and then equation (9) (appendix C) is solved to determine η_i as a function of airspeed. Equations (12) and (14) are then used to compute the actual thrust. The effect of the ground's proximity on the induced drag is calculated by using equation (29). The integration time-step is 0.02 sec. For the takeoff roll, the integration is halted upon reaching the rotation airspeed—no estimations of rotation and first-segment climb distances are made. The value of the thrust at the beginning of the landing roll is computed using the approach airspeed and descent angle, then the thrust is linearly decreased to zero during the Time to Zero Power. The landing-roll integration is halted as soon as the aircraft comes to a complete stop. No estimations of the flare and landing rotation distances are made.

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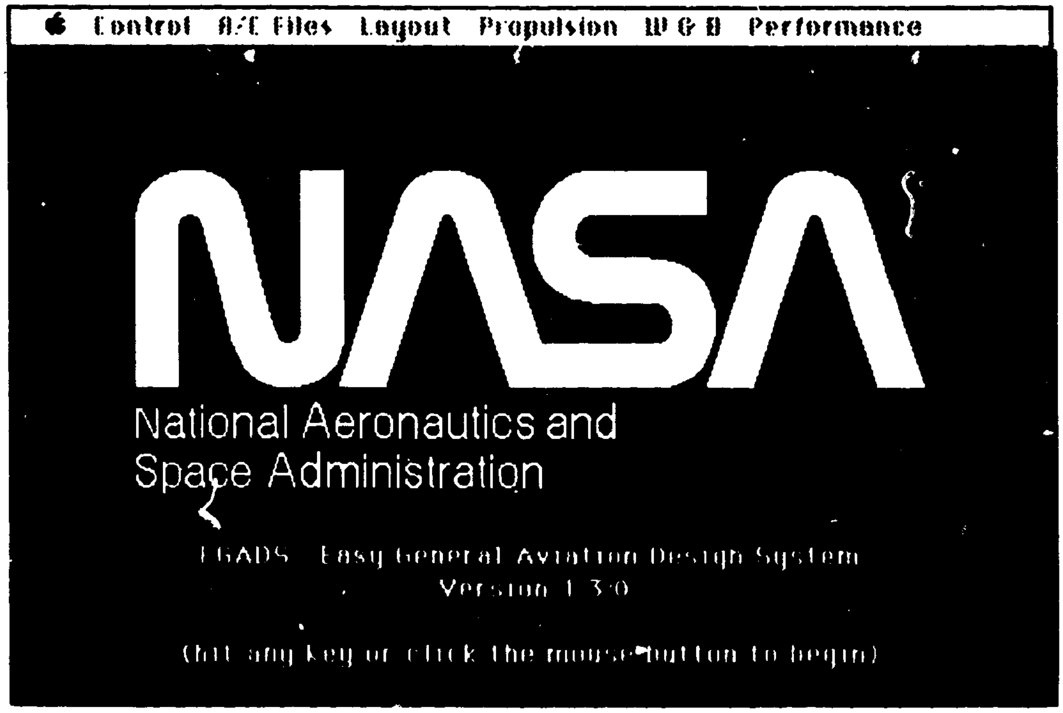

Figure 1. EGADS startup screen.

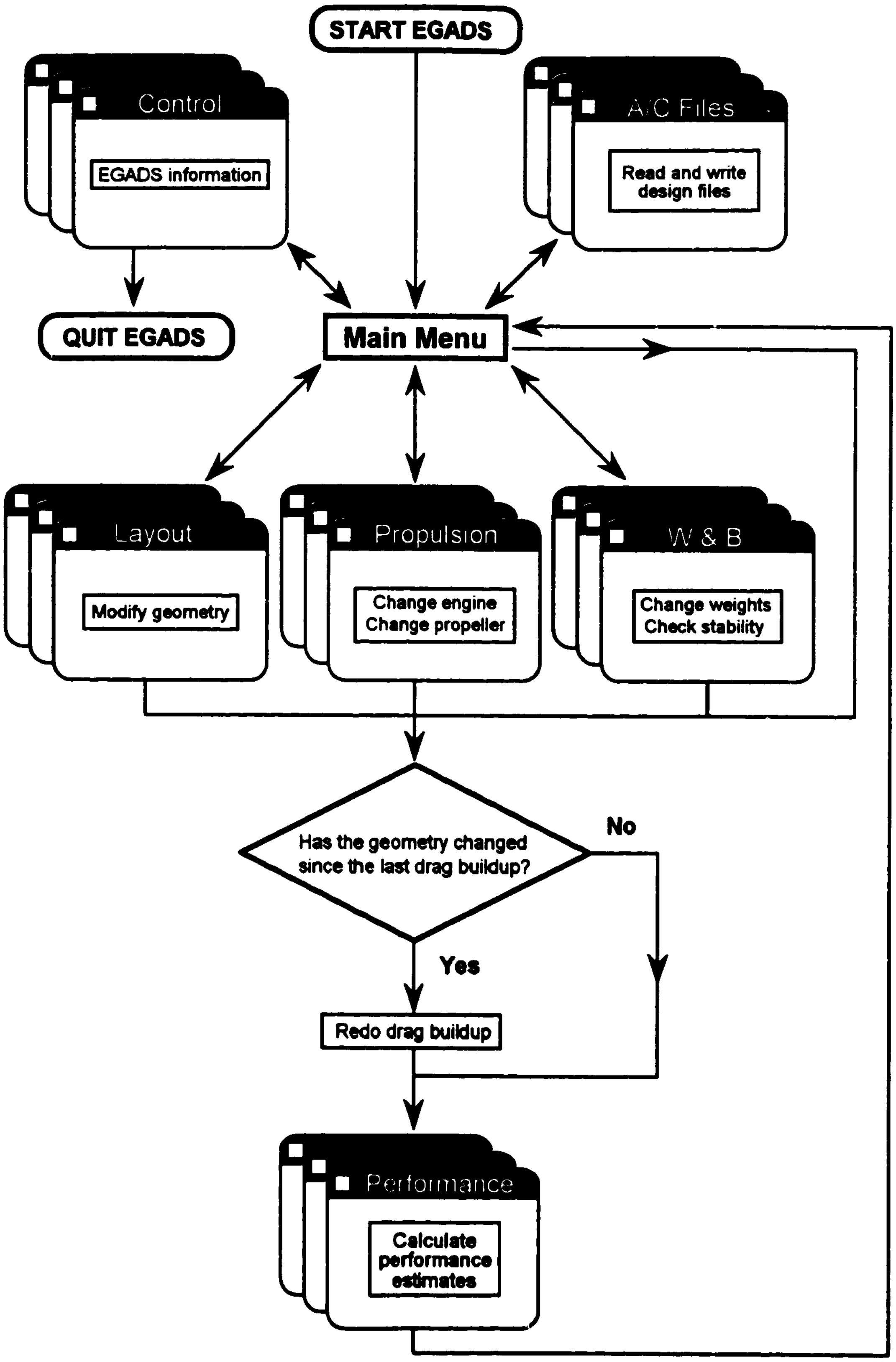

Figure 2. Simplified flowchart of EGADS.

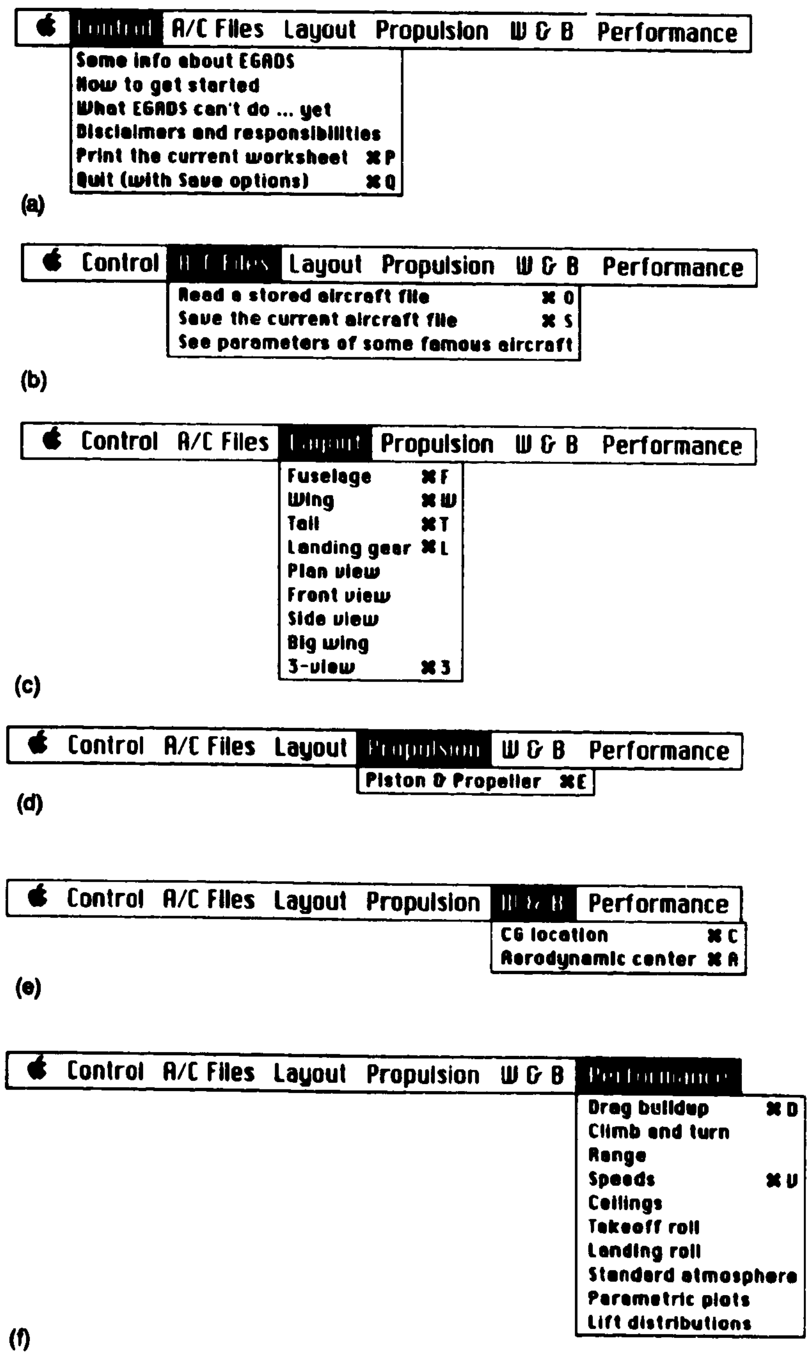

Figure 3. Menu Selections. (a) Control menu, (b) A/C Files menu, (c) Layout menu, (d) Propulsion menu, (e) Weight and Balance (W&B) menu, (f) Performance menu.

EGADS : (E)asy (G)eneral (A)viation (D)esign (S)ystem

Author : John Melton
Applied Aerodynamics Branch, Aerodynamics Division (RAA)
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Moffett Field, CA 94035
ATTN : EGADS
Environment : MICROSOFT® QuickBASIC on the Apple® Macintosh™
Documentation : NASA TM 104013

EGADS is a collection of "computer worksheets" intended to help the designers of home-built and general aviation aircraft. Because aircraft design is an iterative process, EGADS provides the user with :

1 : Design variables that are quick to input and easy to change
2 : Fast recalculation of the results
3 : Lots of graphics

The organization of EGADS allows the designer to run through a multitude of design alterations in a minimum amount of time, and have fun in the process.

Figure 4. Control menu: Some-Info-about-EGADS worksheet.

Getting Started with EGADS

EGADS : Easy General Aviation Design System

The easiest way to learn EGADS is to begin by modifying an existing aircraft. Simply choose one of the designs already stored on this disk (see the "Read a stored aircraft file" option under the "A/C Files" menu), then proceed to alter the wing, tail, and fuselage geometry (under the "Layout" menu). After the geometry has been altered, calculate the new performance characteristics (under the "Performance" menu). All of the inputs are "standard Macintosh" : program controls are mouse-activated by pulling down a menu or clicking on a button. Use Command-Shift-3 to create a screen dump file of a current worksheet (on many Macs, the screen must be set to two-color mode for this to work), or use the "Print the current worksheet" command from the "Control" menu to send the worksheet straight to the printer. Please refer to the EGADS user's guide (NASA TM 104013) for additional information, detailed operating instructions, and a discussion of the capabilities and limitations of EGADS

Figure 5. Control menu: How-to-Get-Started worksheet.

Limitations and the Future of EGADS

EGADS : Easy General Aviation Design System

EGADS currently has no provisions for :

- Transonic/supersonic calculations
- Jet engines
- Power effects on stability
- Cockpit layouts
- Weight estimation
- Rotation and flare distances
- Lateral stability derivatives
- Structures calculations
- Lots of other good things ...

But someday ... !

Figure 6. Control menu: What-EGADS-Can't-Do . . . Yet worksheet.

Boring Legal Stuff about EGADS

EGADS : Easy General Aviation Design System

The author of EGADS does not warrant, guarantee, or make any representations regarding the use of, or the results of the use of, the EGADS program in terms of correctness, accuracy, reliability, currentness, or otherwise; the user of the program relies on it and its results solely at his/her own risk.

Figure 7. Control menu: Disclaimers-and-Responsibilities worksheet.

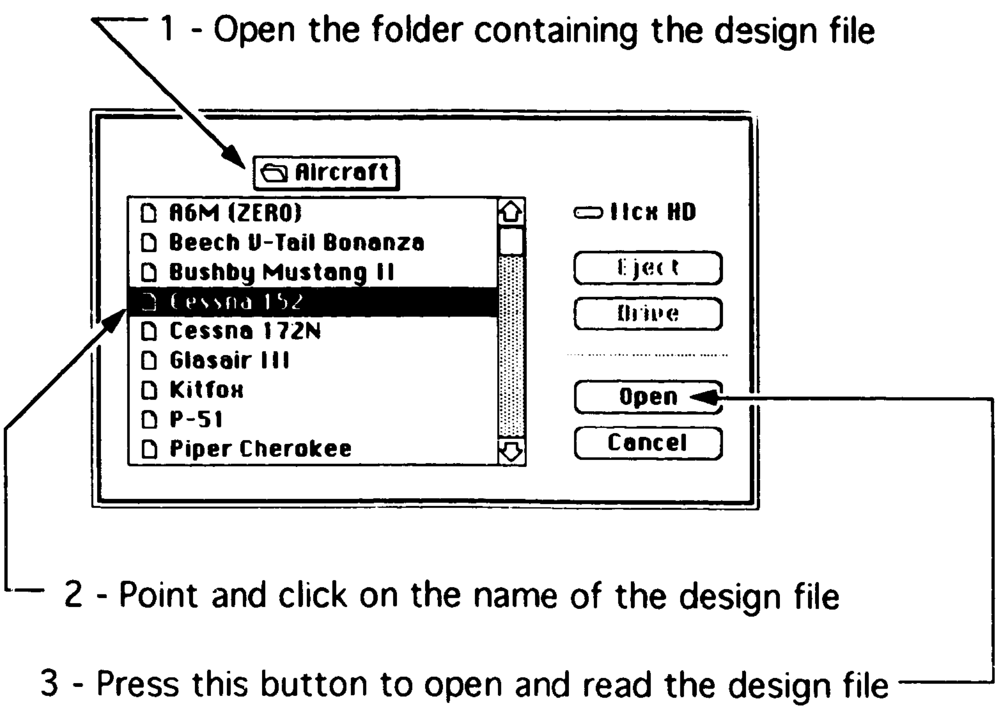


Figure 8. A/C Files menu: Read-a-Stored-Aircraft-File worksheet.

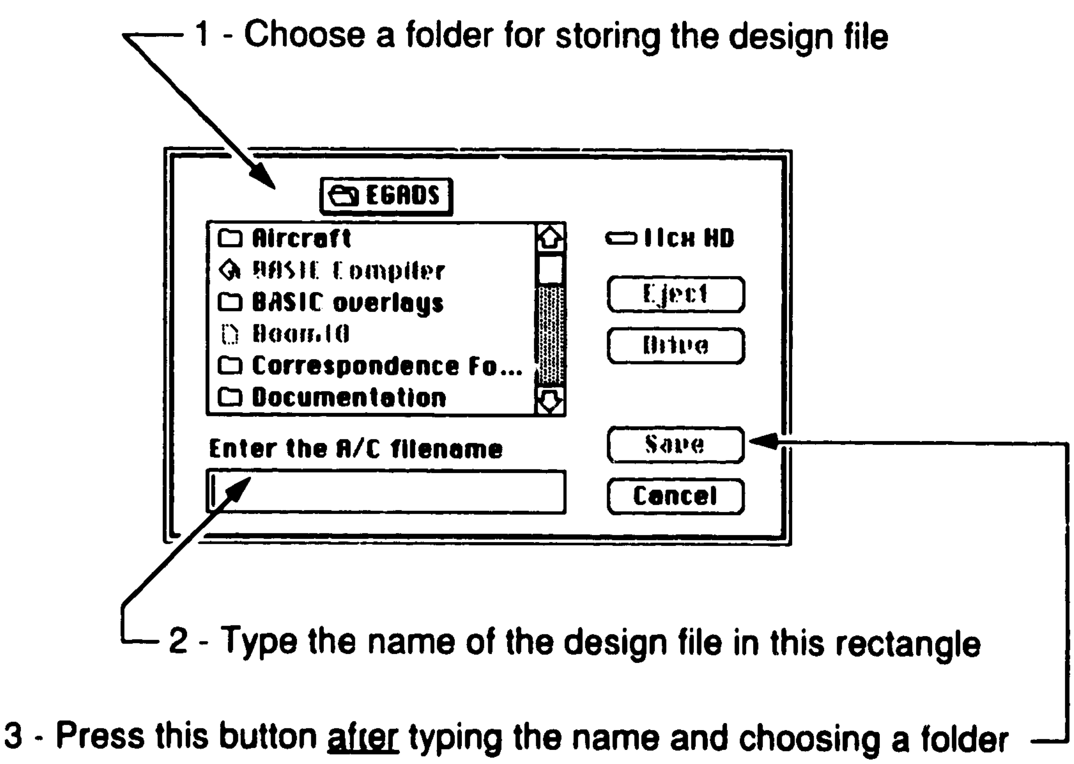


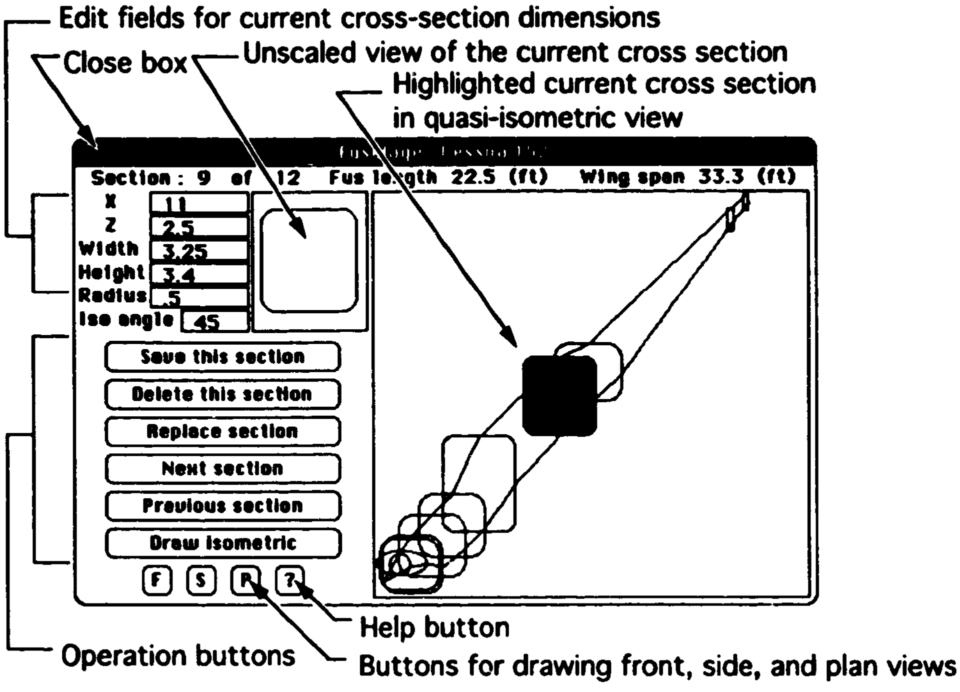
Figure 9. A/C Files menu: Save-the-Current-Aircraft-File worksheet.

EGADS Help Information

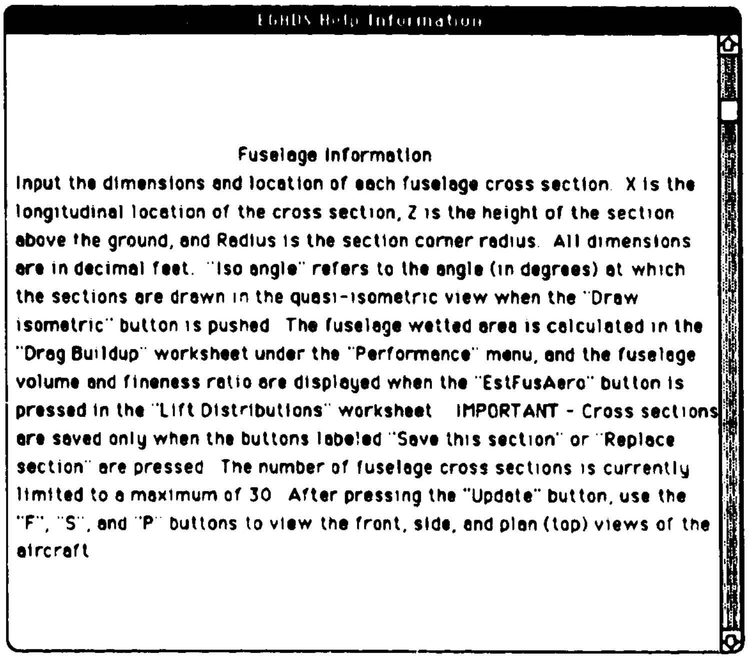
Use these parameters as design guidelines:

Aircraft	CL max	CD min	Wing Area	Aspect Ratio	Gross Weight	Oswald Factor	HP
Fokker D-7	1.28	.0404	115	6.58	1238	0.72	185
Ryan NYP	1.25	.0379	319	6.63	5135	0.74	220
Cessna 152	1.70	.0372	160	6.97	1670	0.77	160
Cessna 172	2.10	.0319	175	7.32	2300	0.77	160
Piper Cherokee	1.75	.0358	170	6.02	2400	0.75	180
Beech V-35	1.85	.0192	181	6.20	3400	0.75	285
P-51D	1.70	.0163	233	5.86	10100	0.75	1490
B-17G	1.90	.0302	1420	7.58	55000	0.82	4800
Thorp T-18	2.10	.0353	85.4	5.08	1500	0.74	150
Glasair III	2.20	.0180	81.3	6.68	2500	0.75	300

Figure 10. A/C Files menu: See-Parameters-of-Some-Famous-Aircraft worksheet.

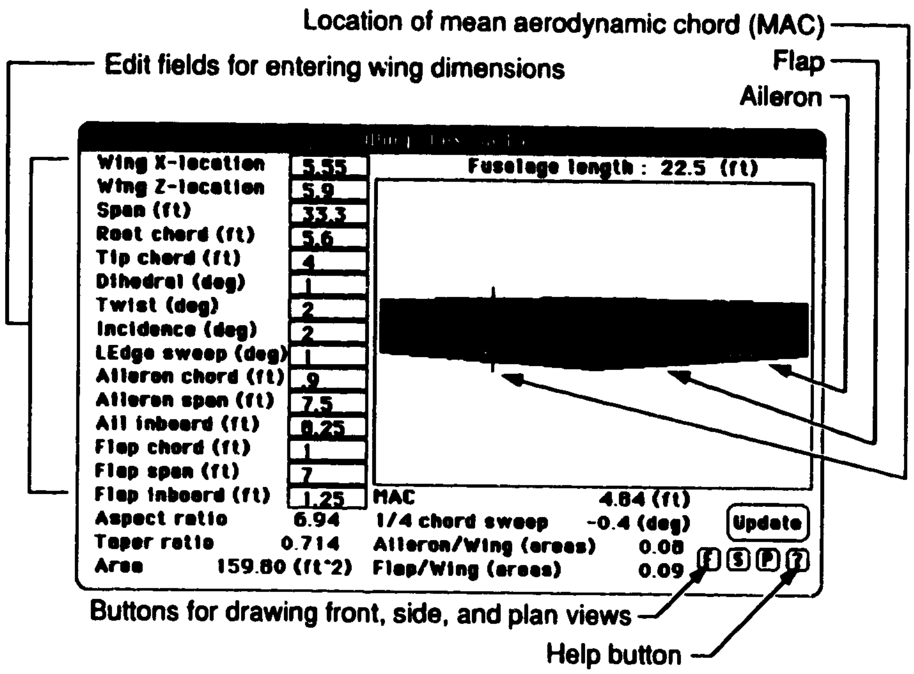


(a)

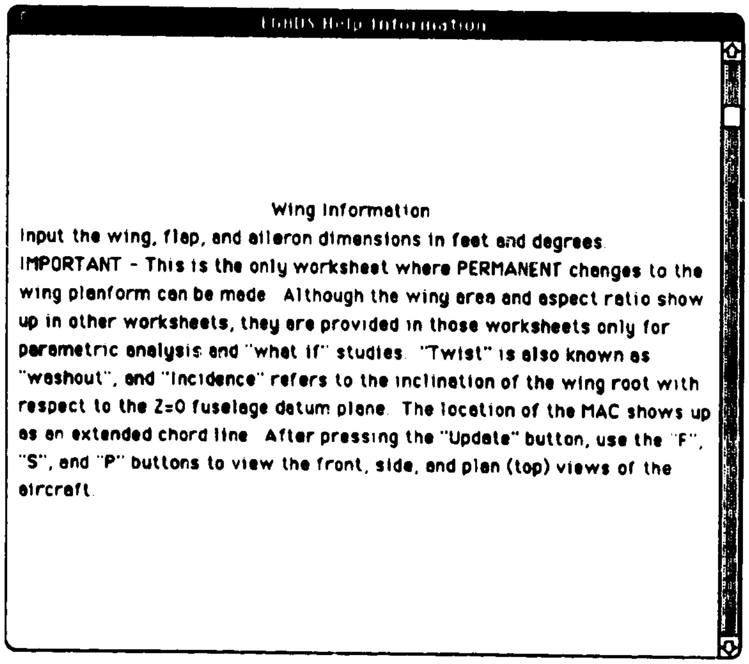


(b)

Figure 11. Layout menu. (a) Fuselage worksheet, (b) Help information.



(a)



(b)

Figure 12. Layout menu. (a) Wing worksheet, (b) Help information.

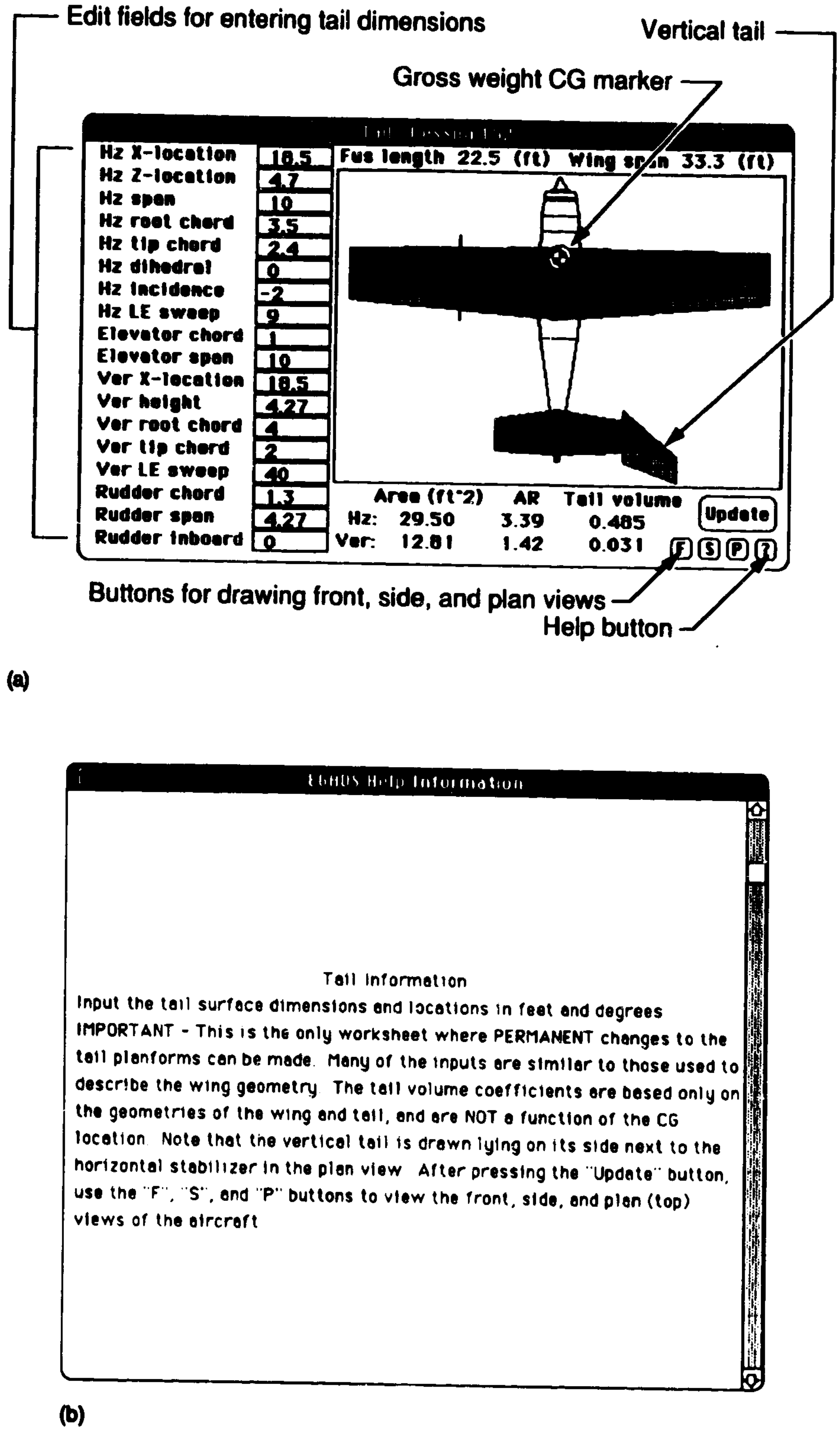
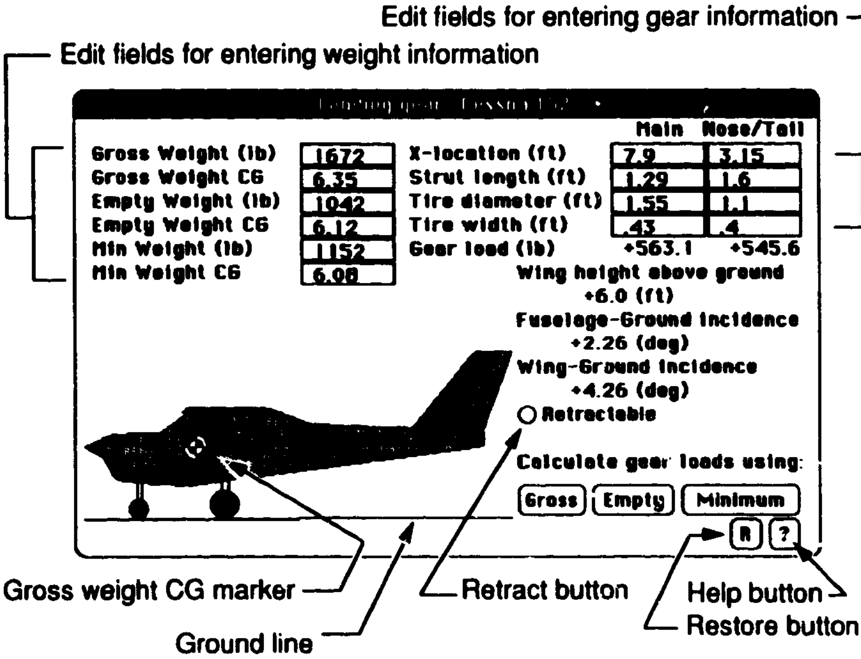
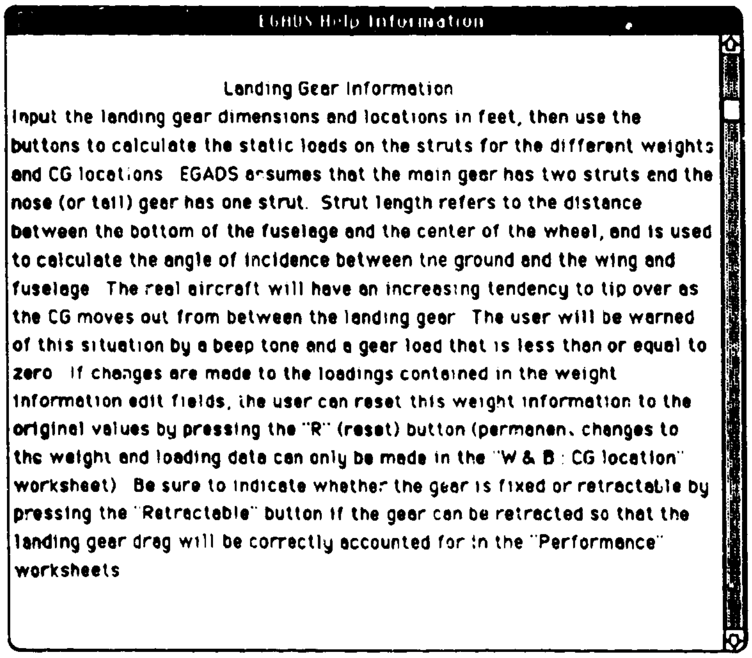


Figure 13. Layout menu. (a) Tail worksheet, (b) Help information.



(a)


EGADS Help Information

Landing Gear Information

Input the landing gear dimensions and locations in feet, then use the buttons to calculate the static loads on the struts for the different weights and CG locations EGADS assumes that the main gear has two struts and the nose (or tail) gear has one strut. Strut length refers to the distance between the bottom of the fuselage and the center of the wheel, and is used to calculate the angle of incidence between the ground and the wing and fuselage The real aircraft will have an increasing tendency to tip over as the CG moves out from between the landing gear The user will be warned of this situation by a beep tone and a gear load that is less than or equal to zero If changes are made to the loadings contained in the weight information edit fields, the user can reset this weight information to the original values by pressing the "R" (reset) button (permanent changes to the weight and loading data can only be made in the "W & B : CG location" worksheet) Be sure to indicate whether the gear is fixed or retractable by pressing the "Retractable" button if the gear can be retracted so that the landing gear drag will be correctly accounted for in the "Performance" worksheets

(b)

Figure 14. Layout menu. (a) Landing Gear worksheet, (b) Help information.

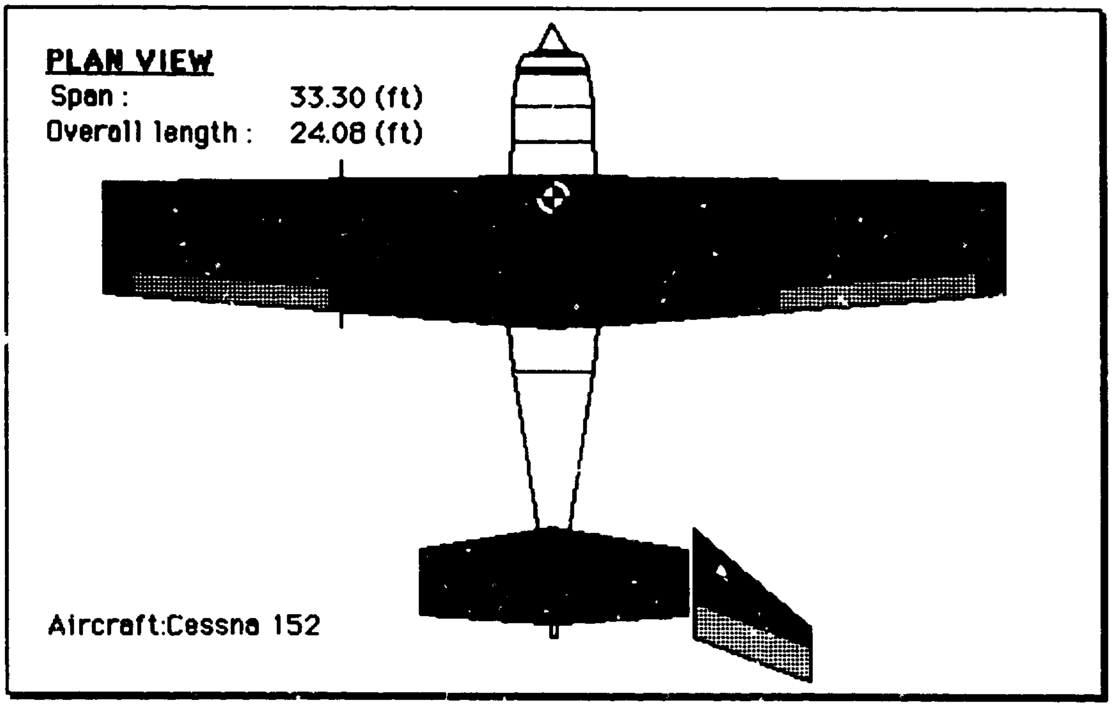


Figure 15. Layout menu: Plan View worksheet.

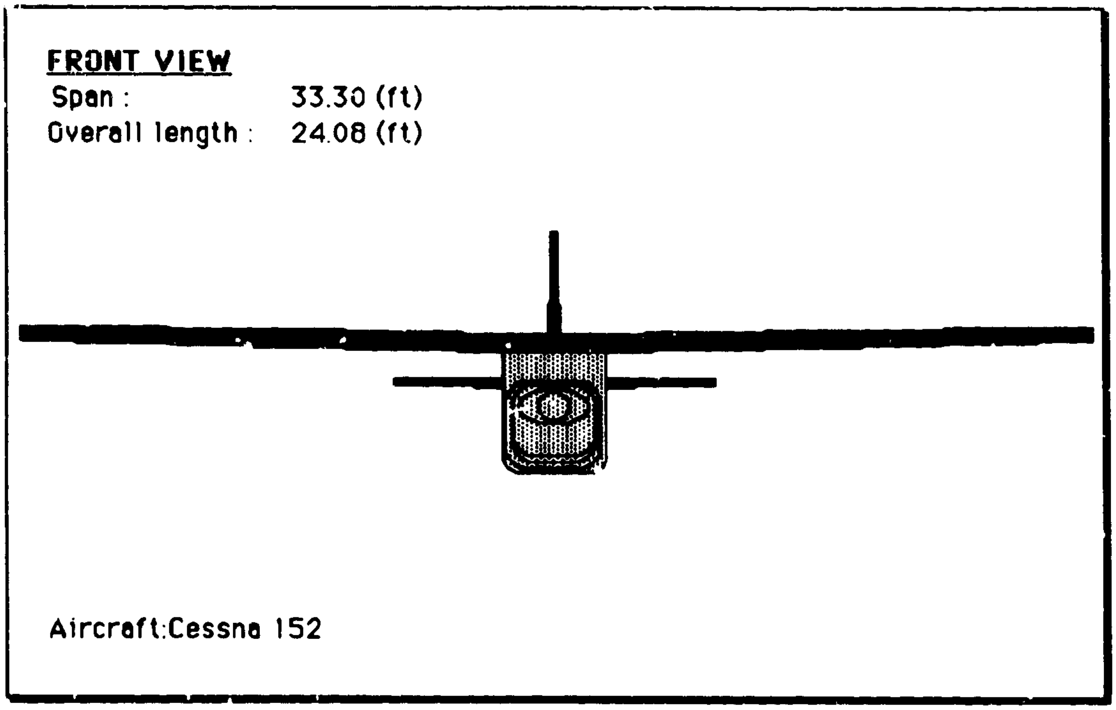


Figure 16. Layout menu: Front View worksheet.

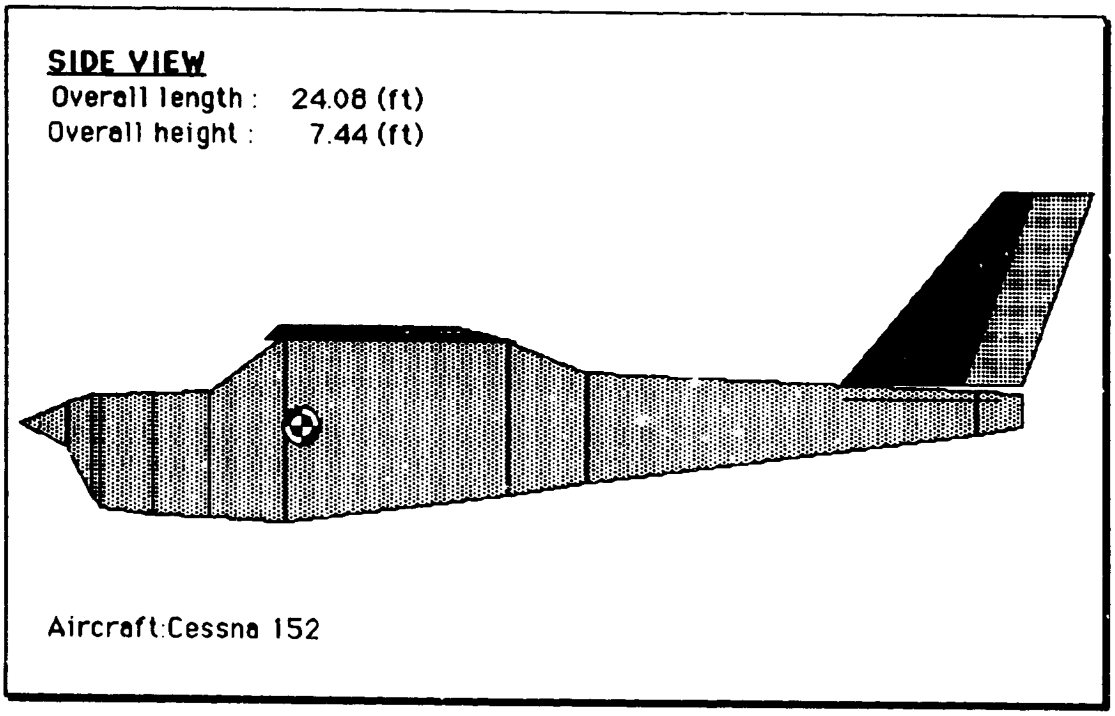


Figure 17. Layout menu: Side View worksheet.

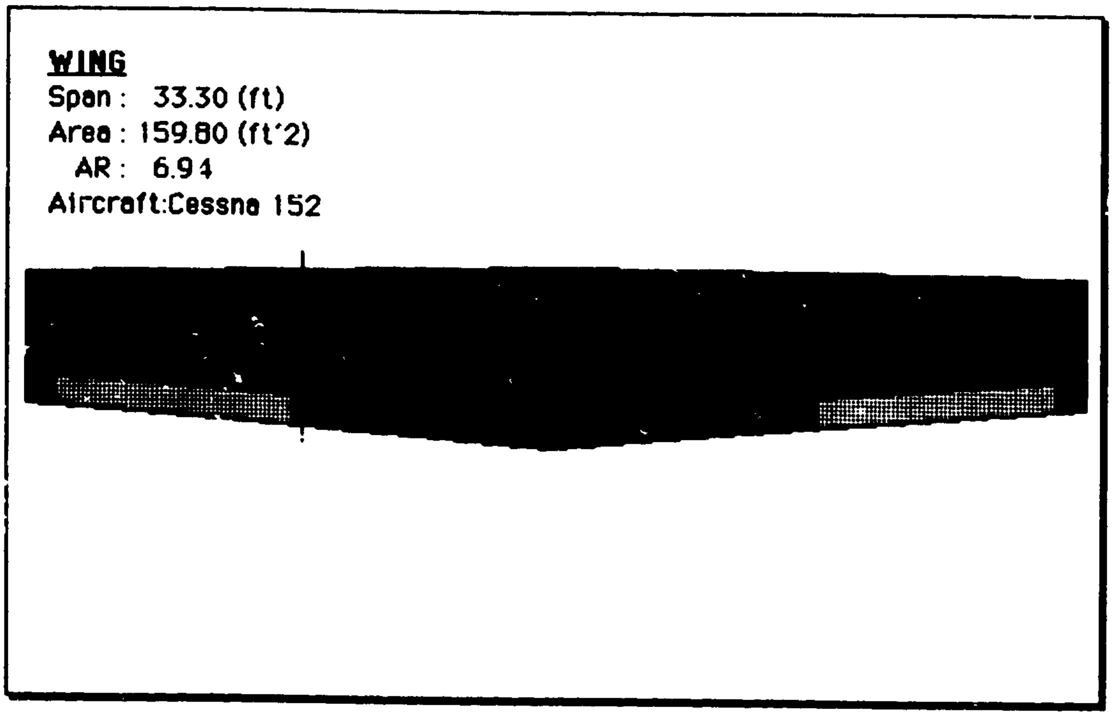


Figure 18. Layout menu: Big Wing worksheet.

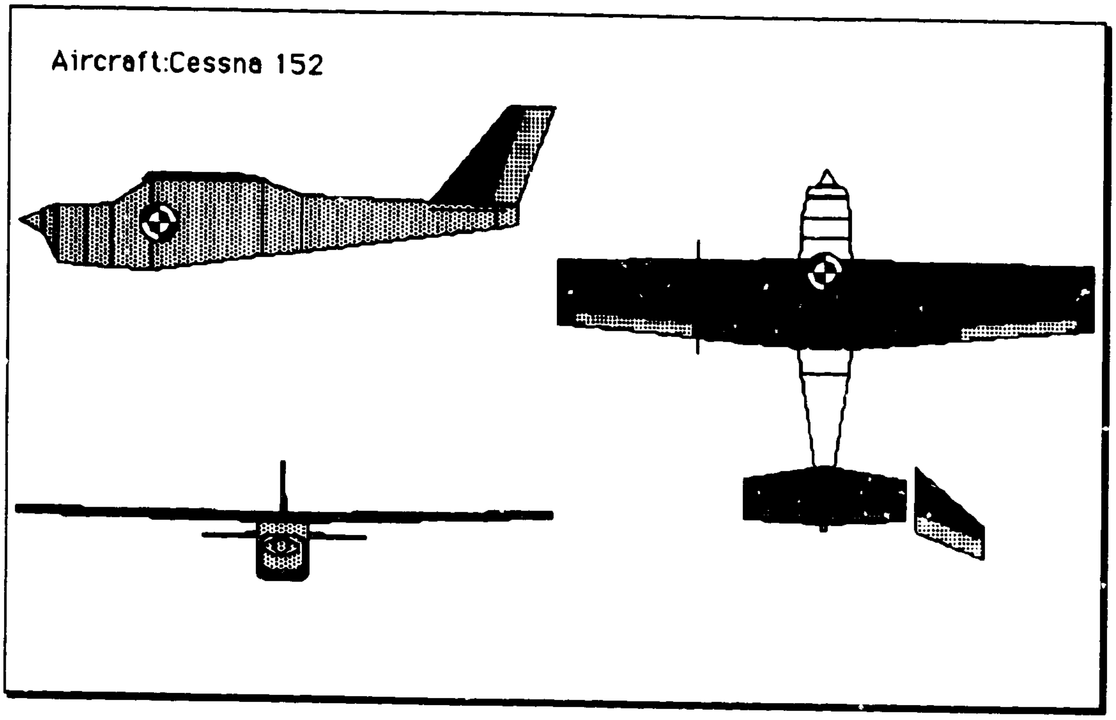
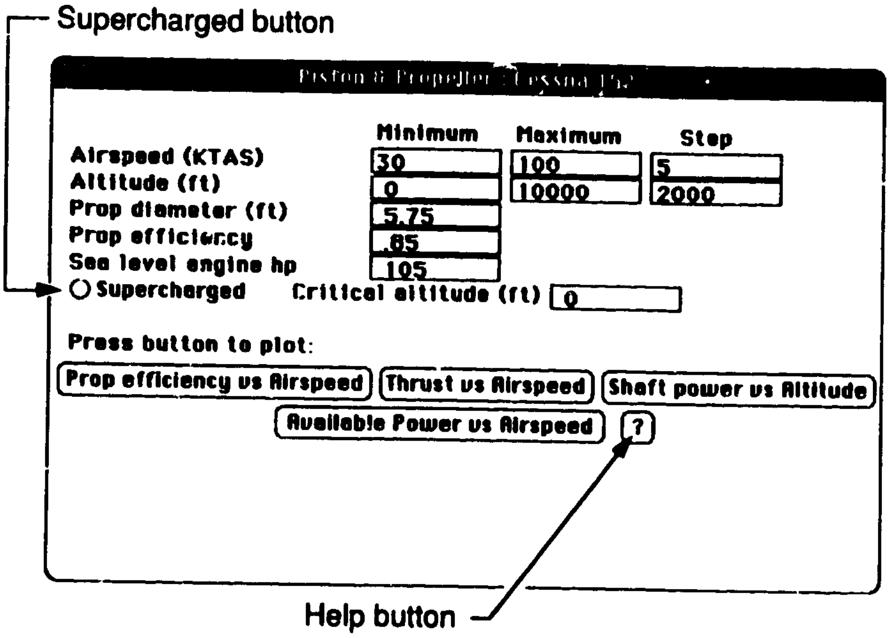
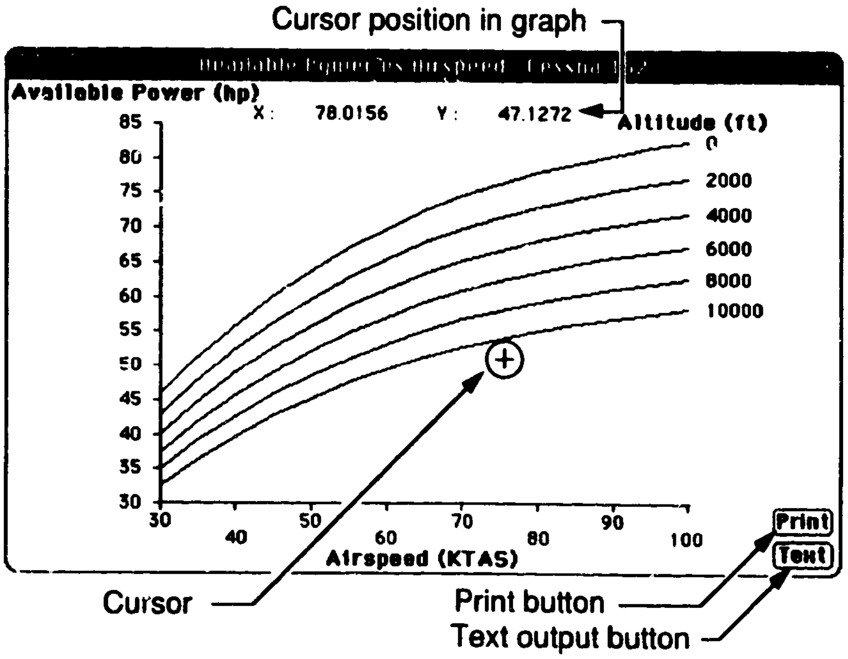


Figure 19. Layout menu: 3-View worksheet.

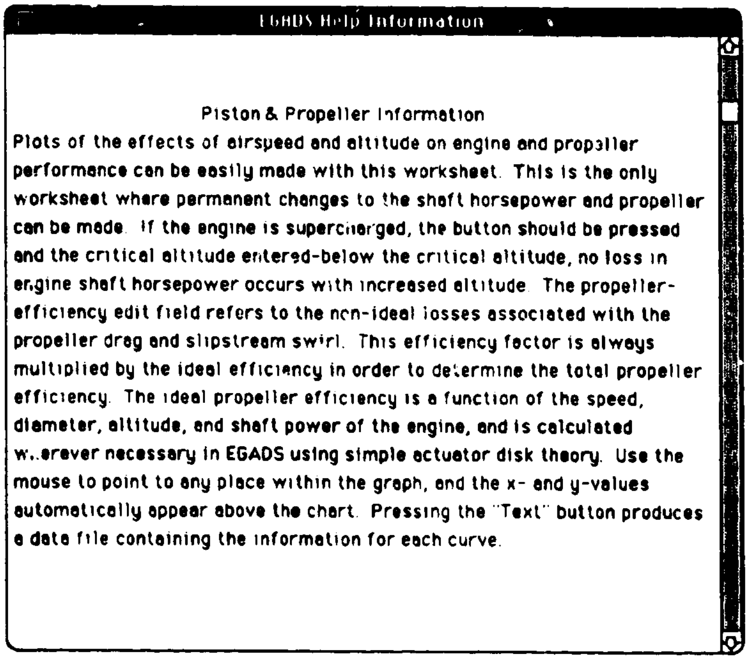


(a)

Figure 20. Propulsion menu. (a) Piston & Propeller worksheet.

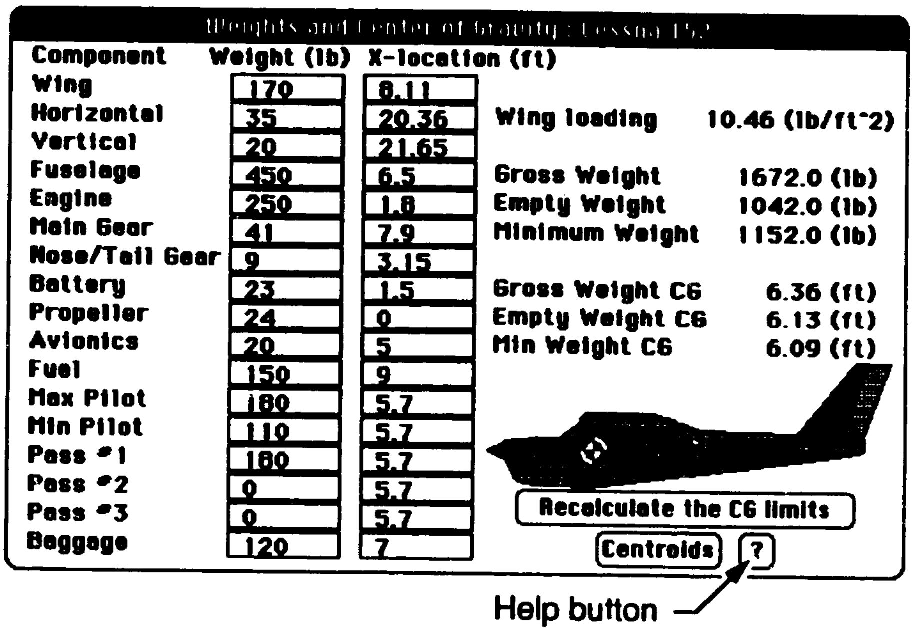


(b)

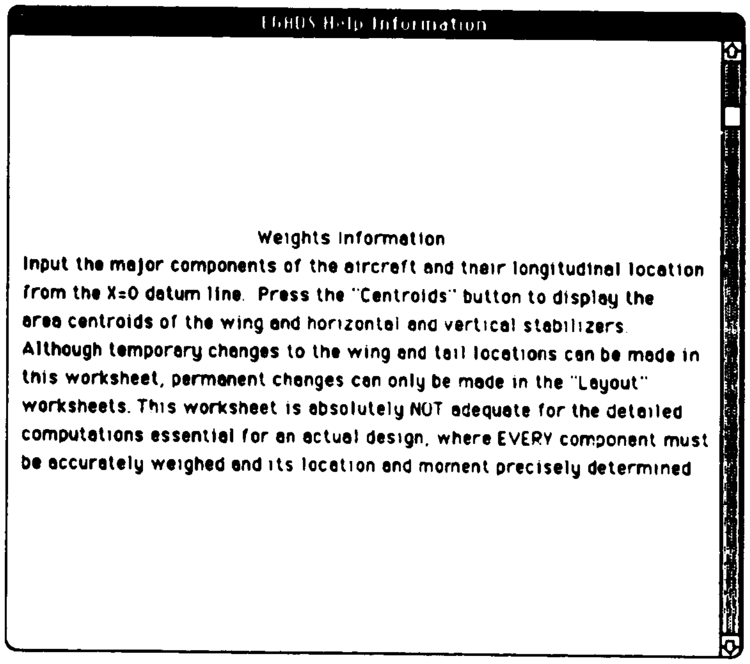


(c)

Figure 20. Concluded. (b) Sample plot, (c) Help information.



(a)



(b)

Figure 21. W & B menu. (a) CG Location worksheet, (b) Help information.

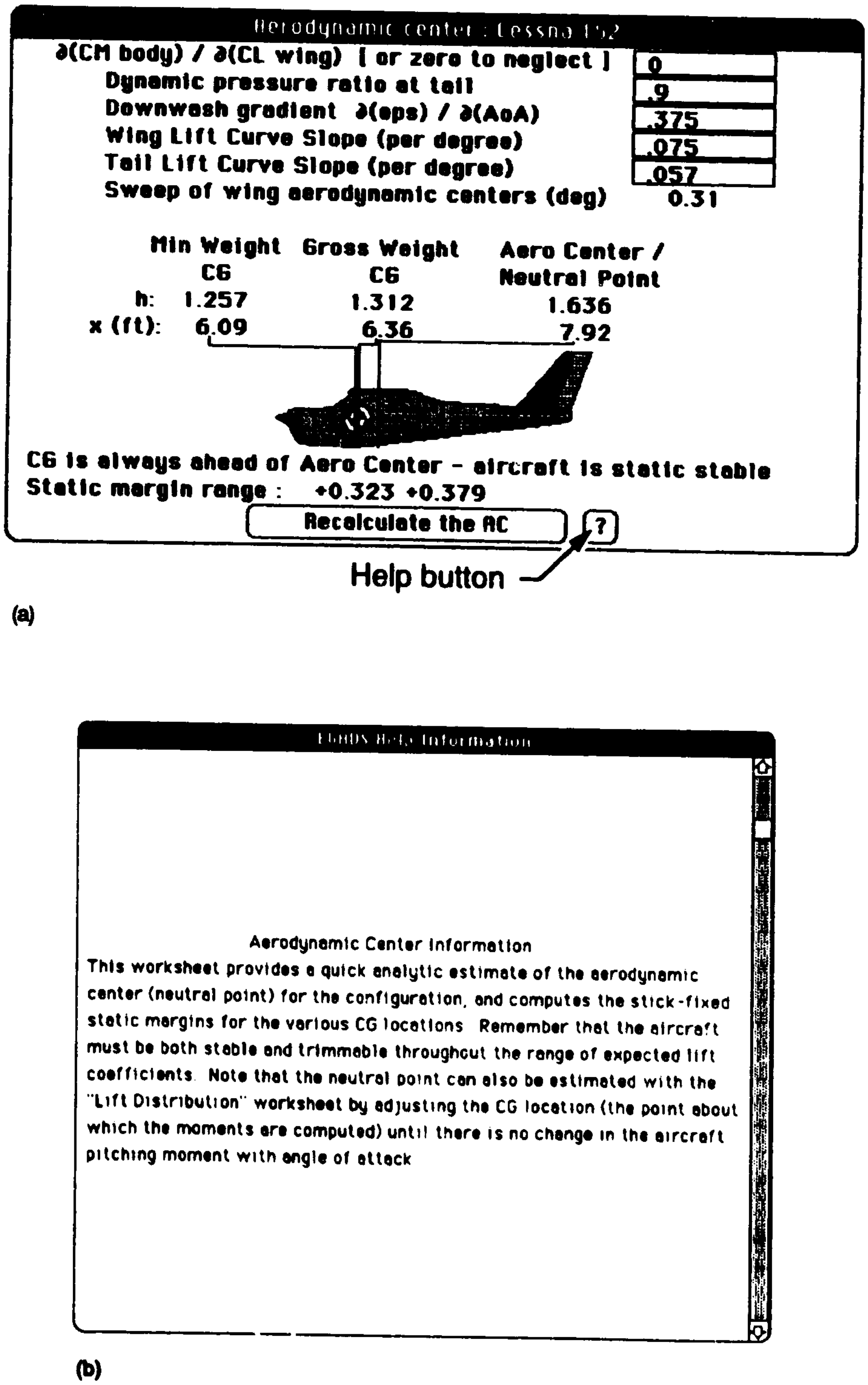
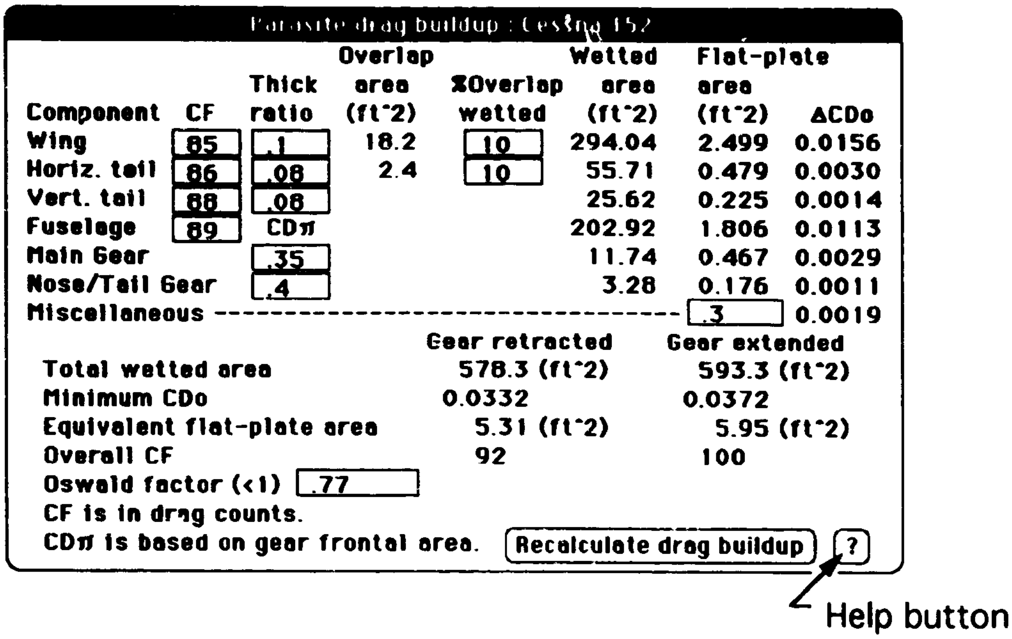
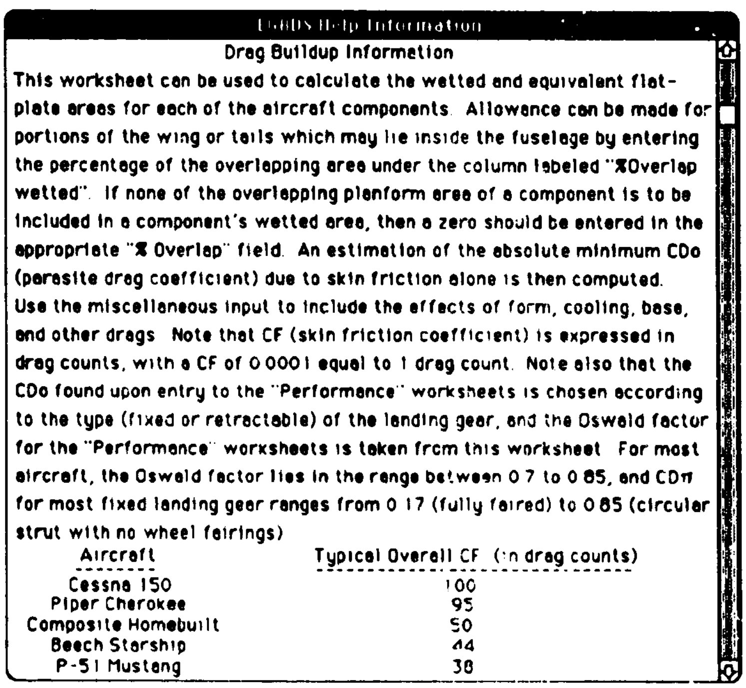


Figure 22. W & B menu. (a) Aerodynamic Center worksheet, (b) Help information.

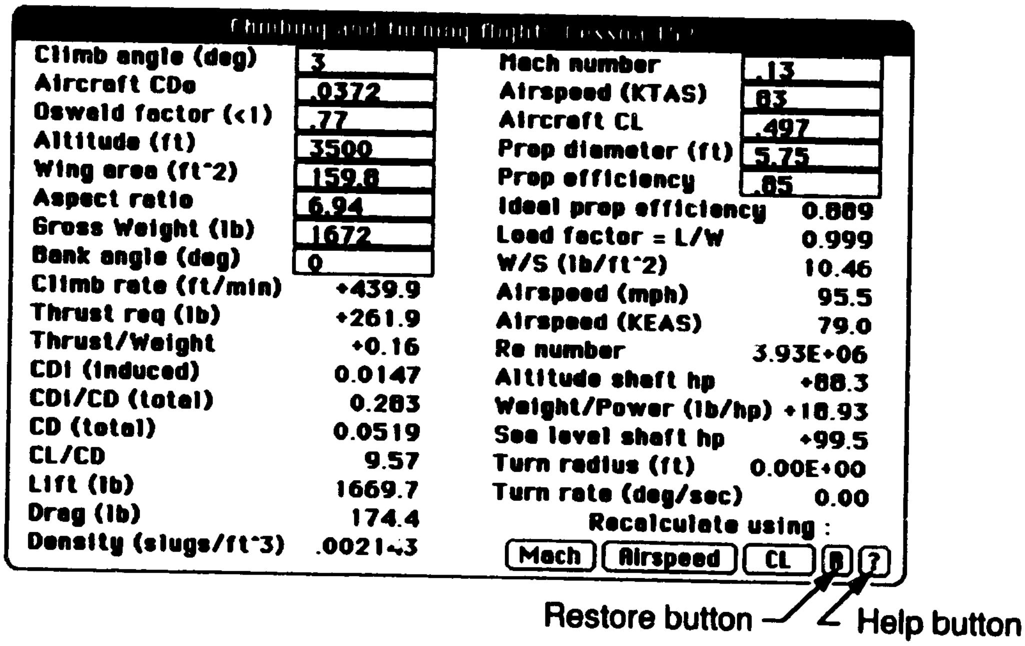


(a)

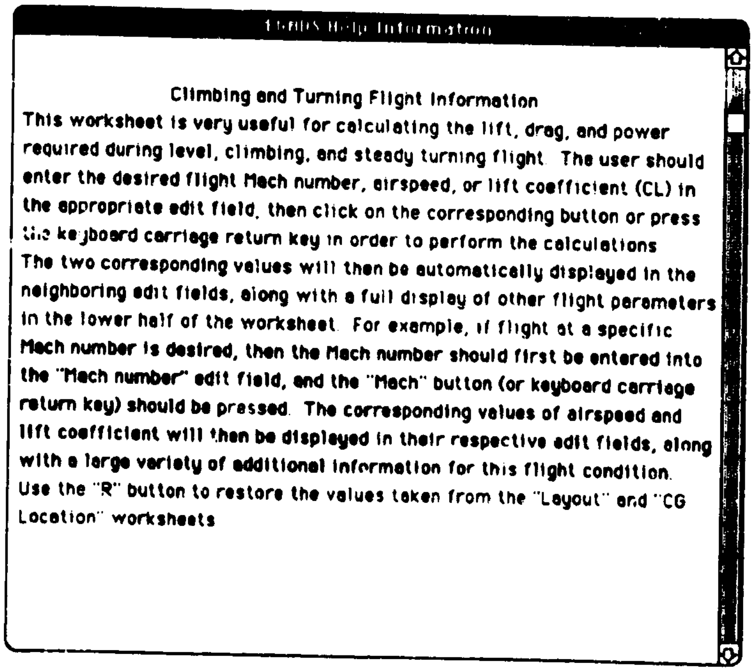


(b)

Figure 23. Performance menu. (a) Drag Buildup worksheet, (b) Help information.

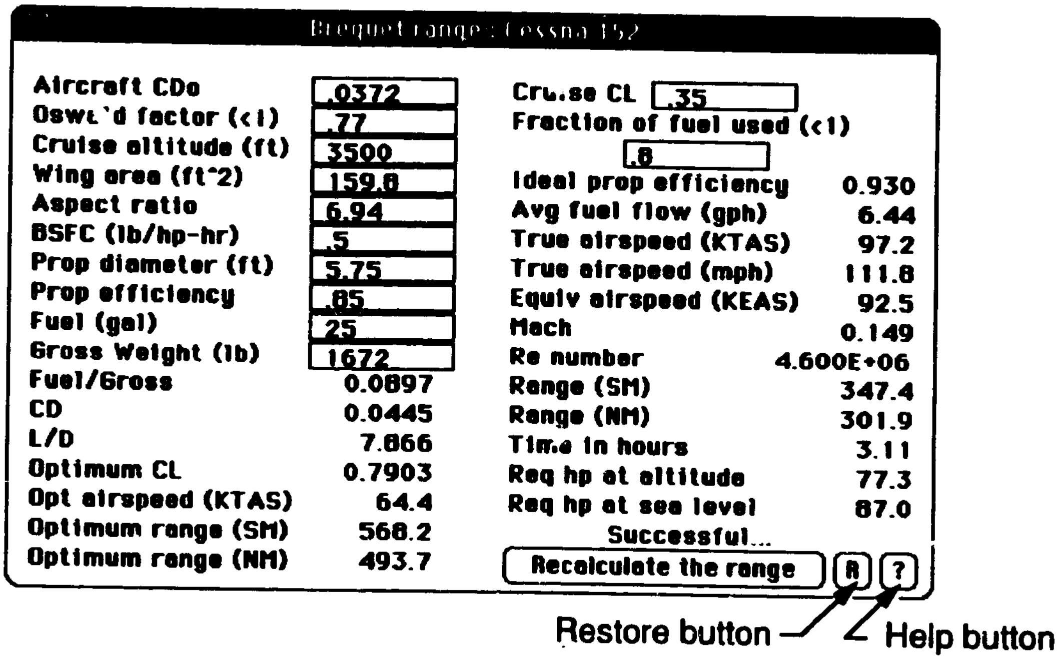


(a)

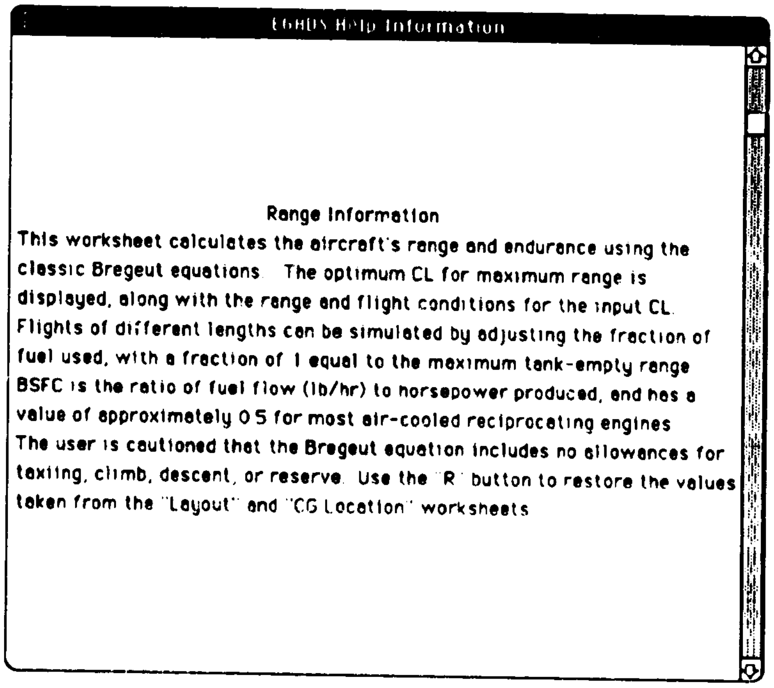


(b)

Figure 24. Performance menu. (a) Climb and Turn worksheet, (b) Help information.

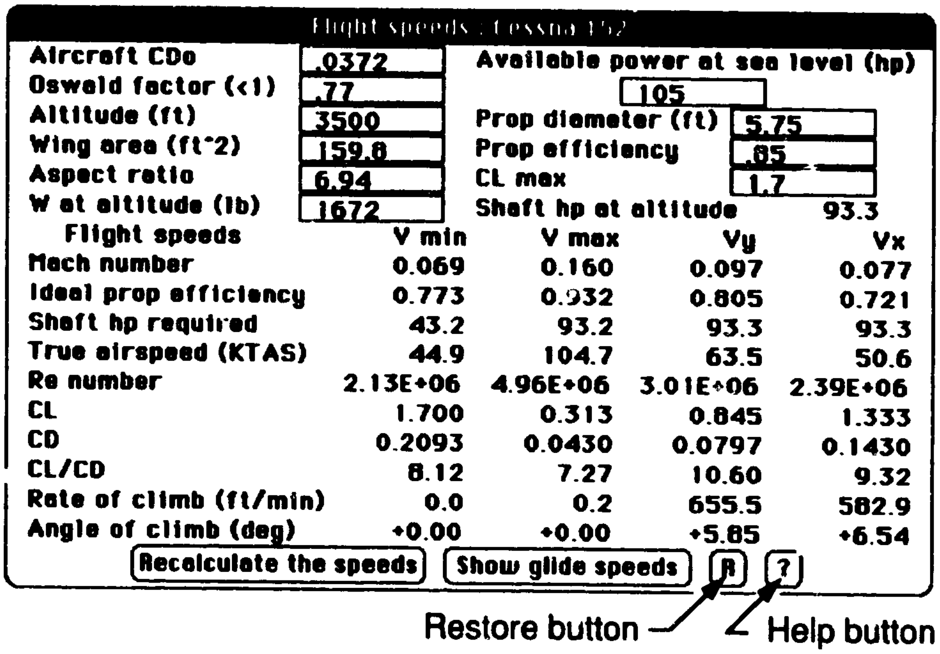


(a)

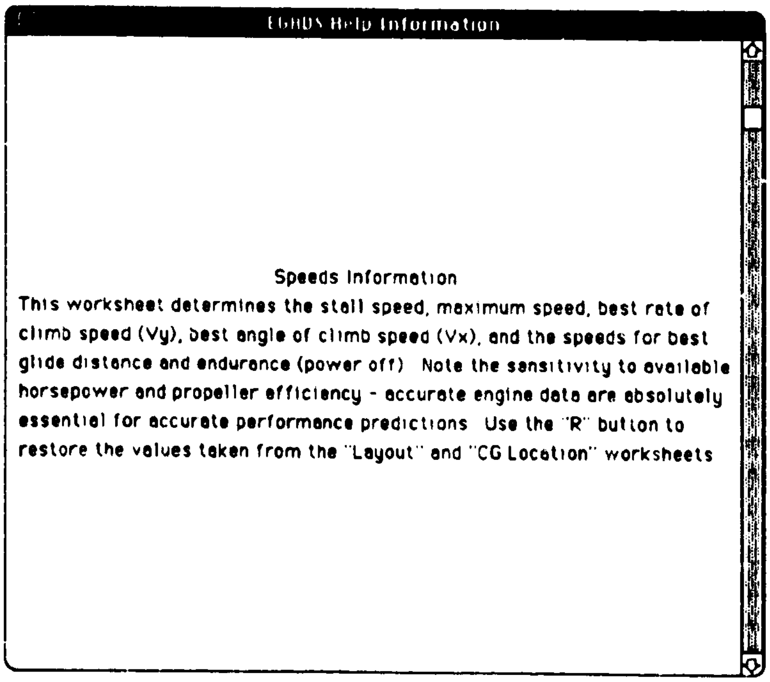


(b)

Figure 25. Performance menu. (a) Range worksheet, (b) Help information.

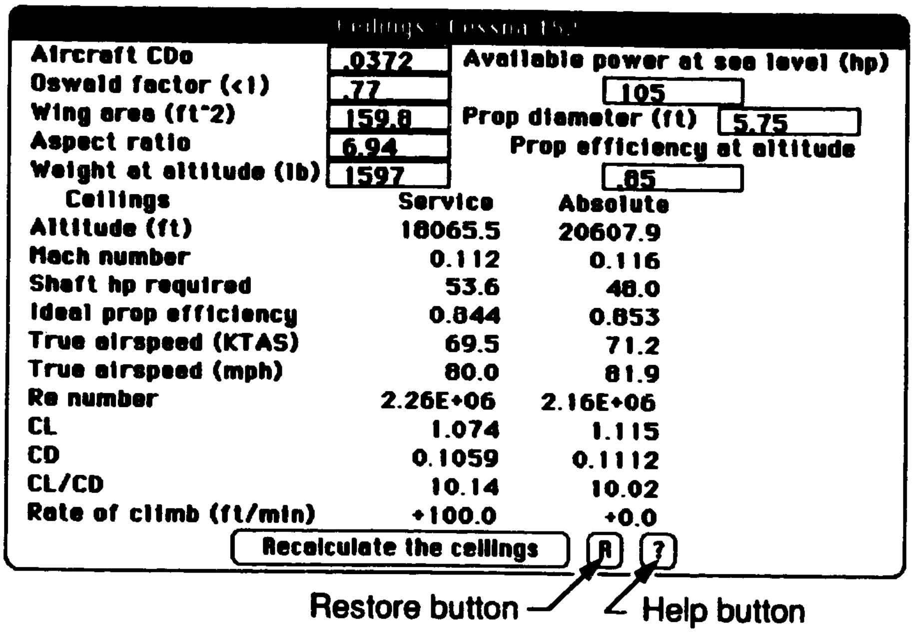


(a)

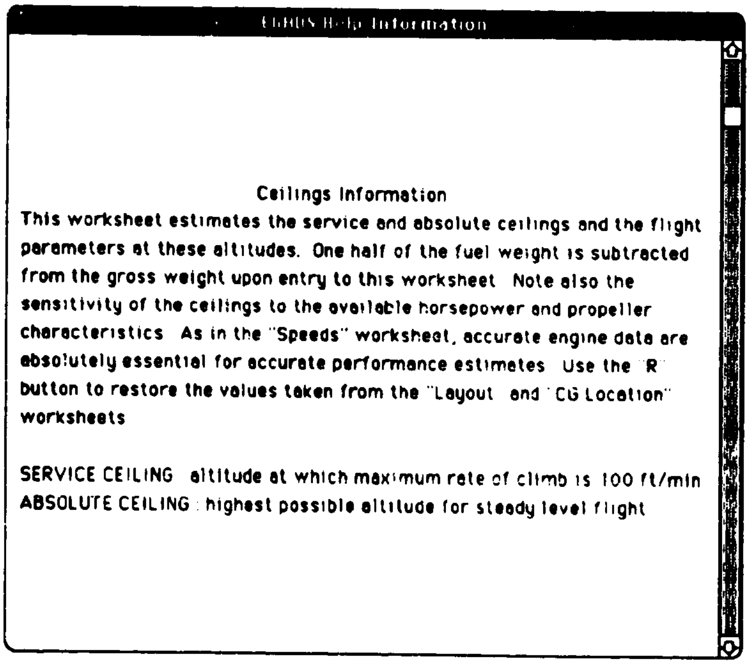


(b)

Figure 26. Performance menu. (a) Speeds worksheet, (b) Help information.



(a)



(b)

Figure 27. Performance menu. (a) Ceilings worksheet, (b) Help information.

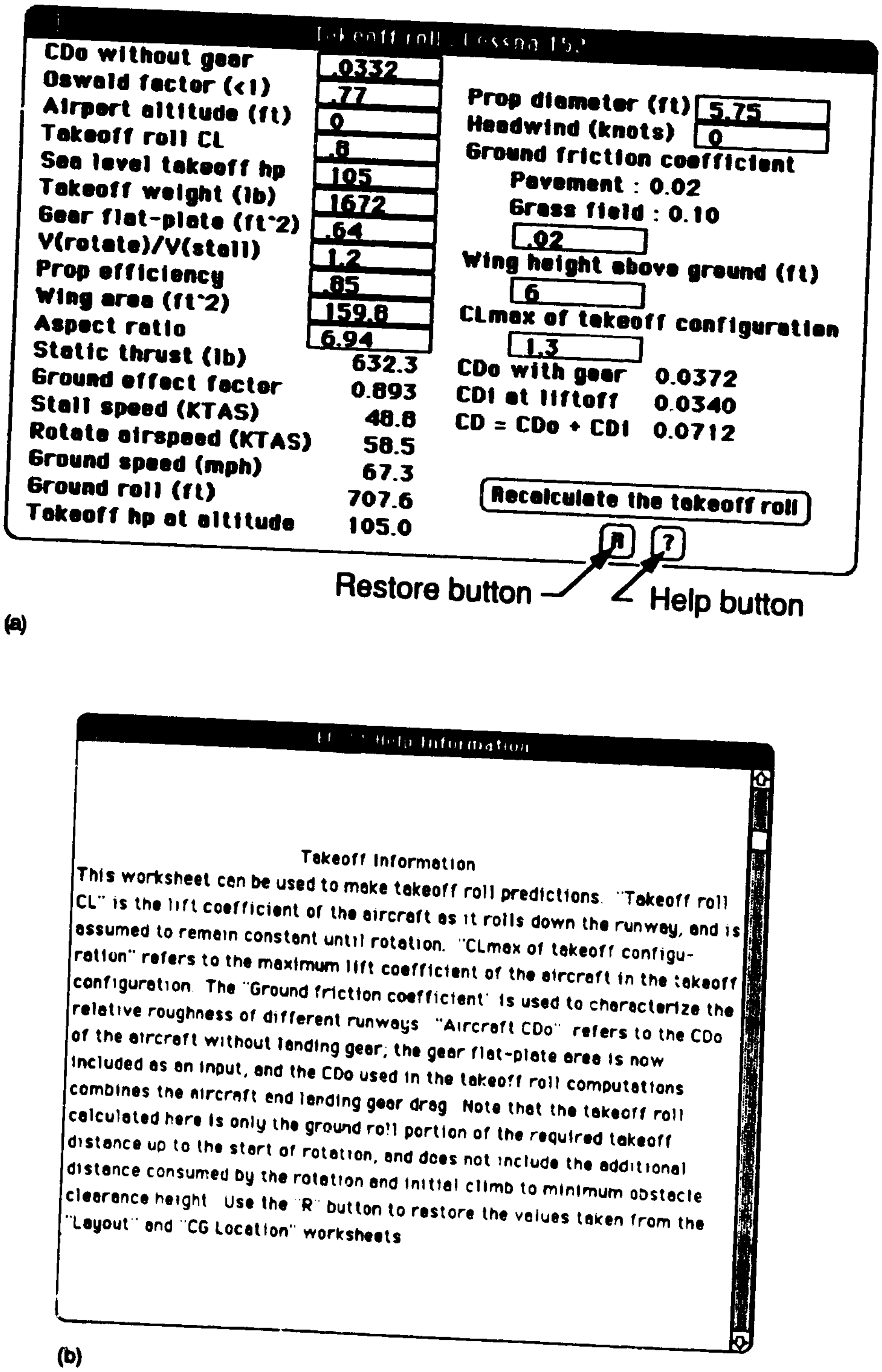
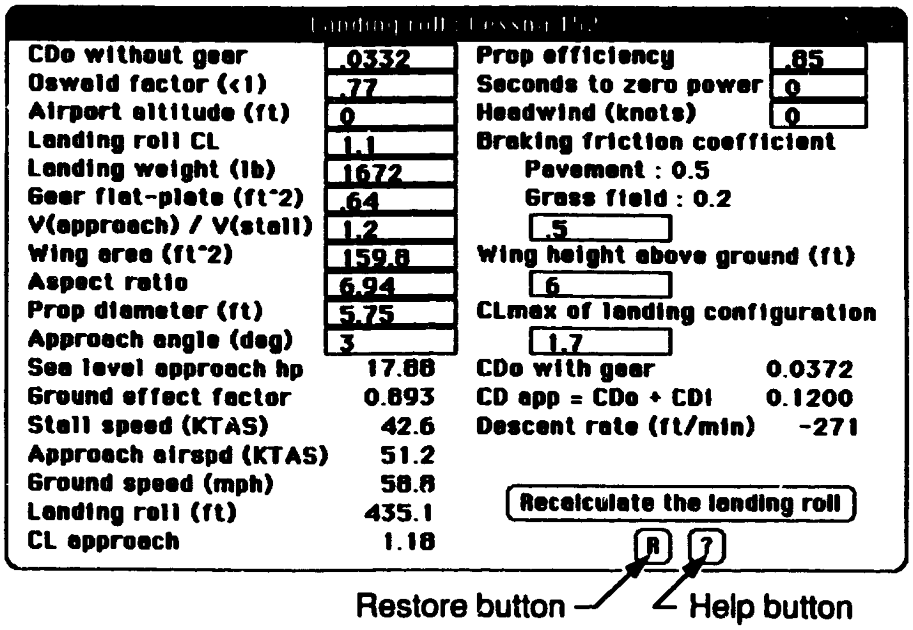
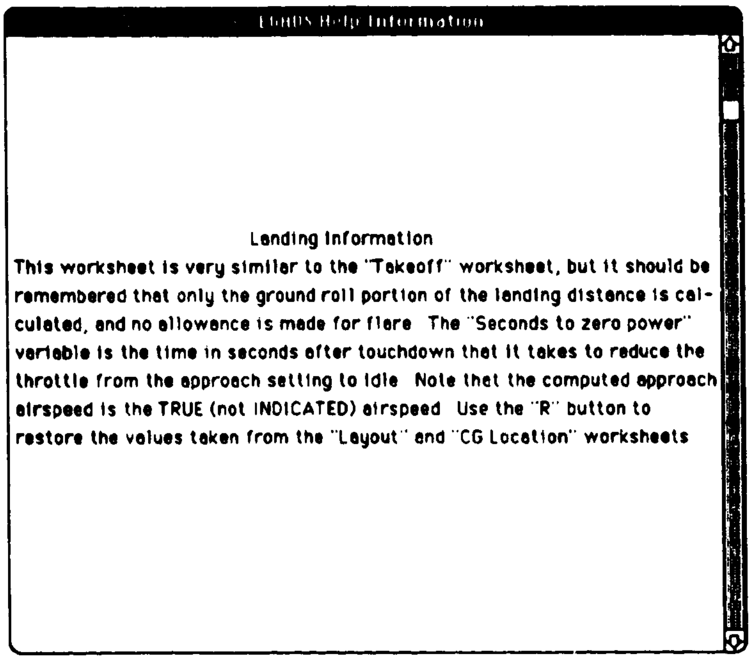


Figure 28. Performance menu. (a) Takeoff Roll worksheet, (b) Help information.

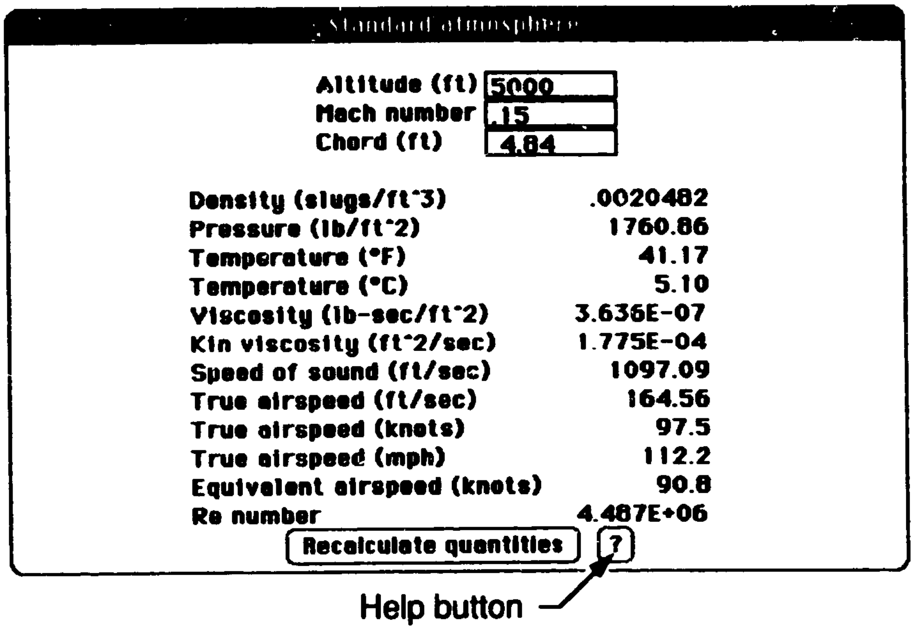


(a)

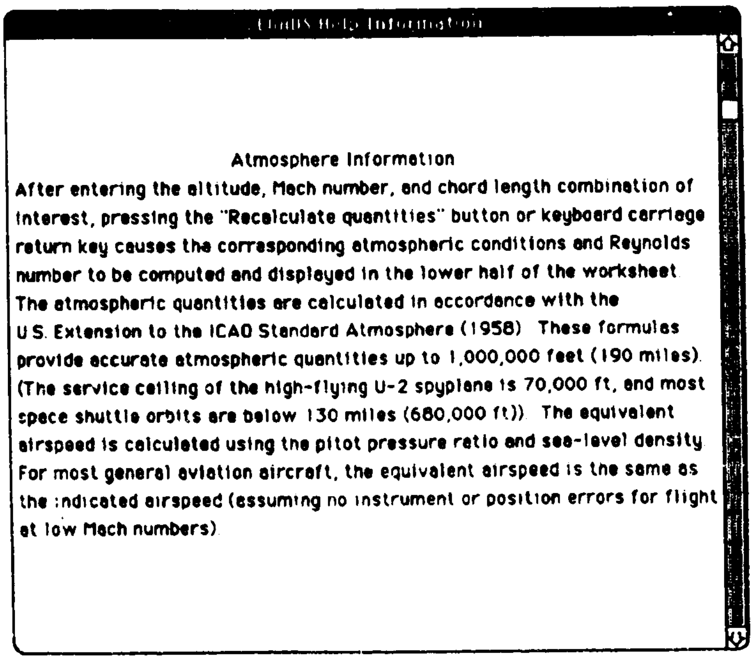


(b)

Figure 29. Performance menu. (a) Landing Roll worksheet, (b) Help information.

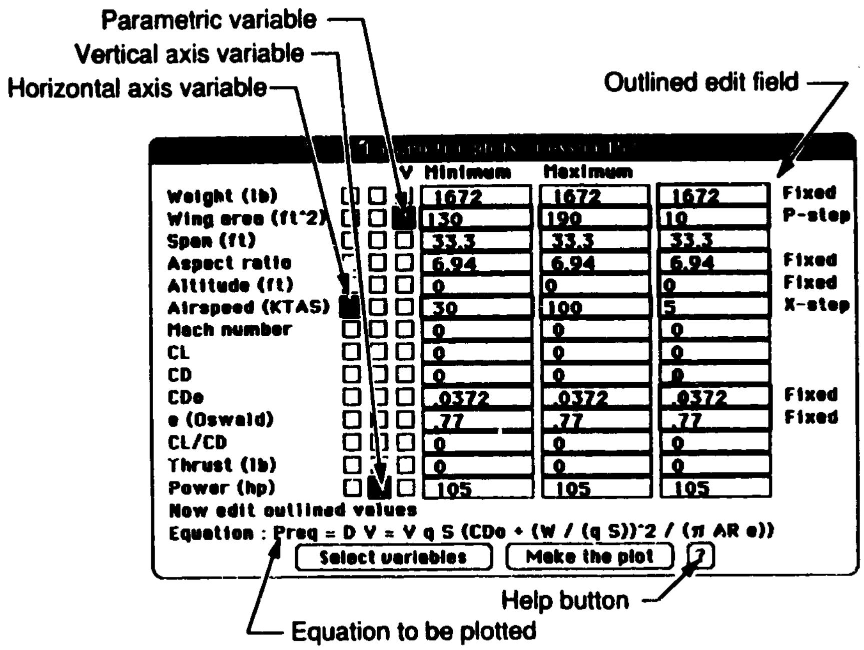


(a)

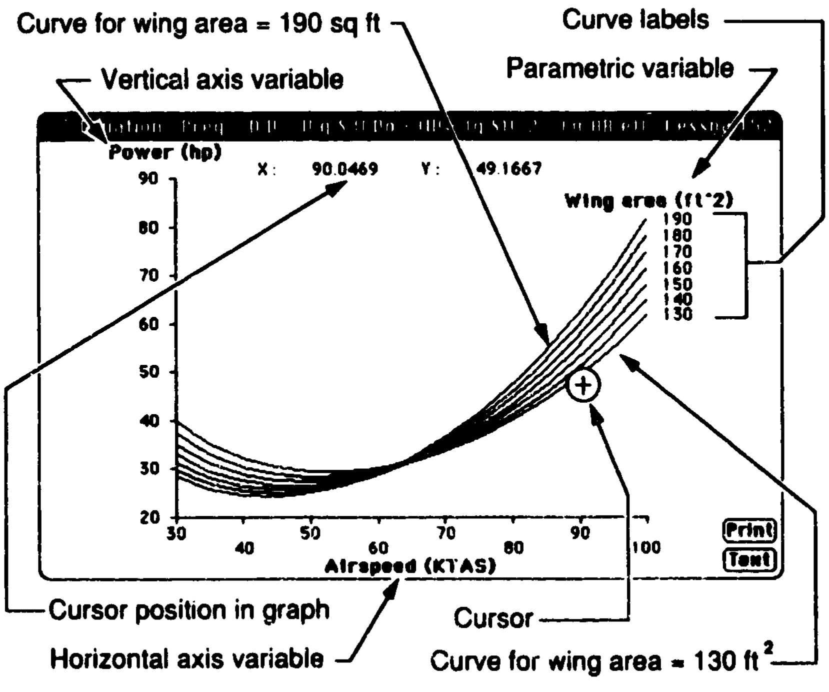


(b)

Figure 30. Performance menu. (a) Standard Atmosphere worksheet, (b) Help information.



(a)



(b)

Figure 31. Performance menu. (a) Parametric Plots worksheet, (b) Sample plot.

Parametric Plots Information

This worksheet provides an easy way to produce many of the standard plots used in aircraft design and to develop a good understanding of the relationship between many of the basic design parameters. After selecting the values for the x- and y-axes of the plot, choose the parametric variable, then edit the outlined values as required. Click on the "Make the plot" button to draw the graph. Each individual curve represents a different value of the parametric variable (note the labels on the right side of the plot). Use the mouse to point to any place within the graph, and the x- and y-values automatically appear above the chart. Press the "Text" button to write a data file containing the information for each curve. (Note - if the step increments are too small, the labels may overwrite each other and become practically illegible.) The table below summarizes the combinations of variables and equations that can be plotted with this worksheet.

Effect of (X)	On (Y)	For different values of parameter (P)	Using equation
S	AR	Span	AR = Span 2 / S
Span	AR	S	AR = Span^2 / S
AR	CD	CL,CDo,e	CD = CDo + CL^2 / (πARe)
V	CD	W,S,AR,h,CDo,e	CD = CDo + (W/(qS))^2 / (πARe)

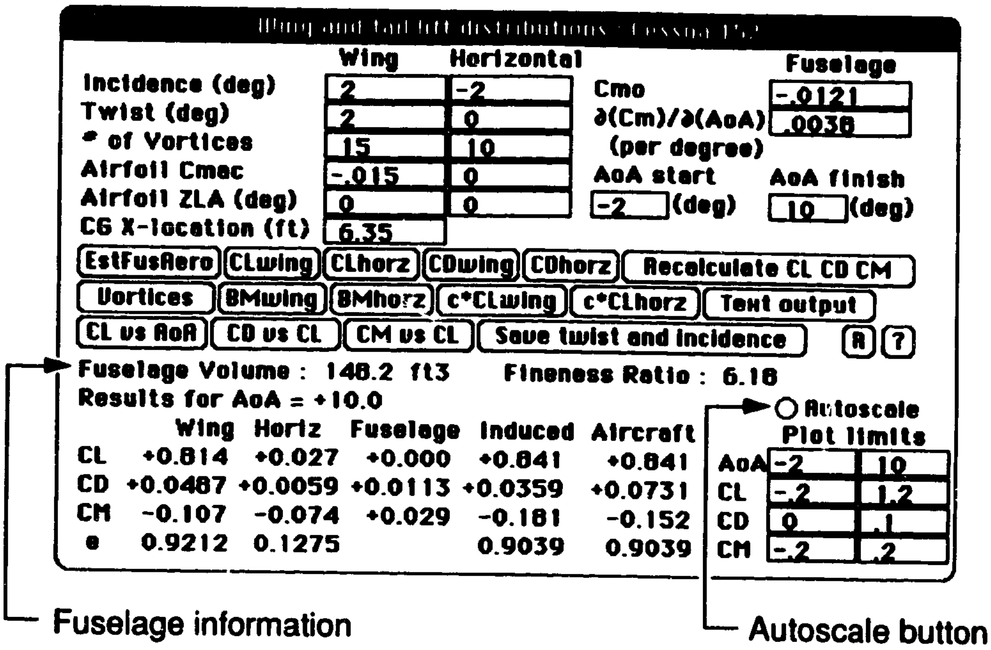
(c)

Effect of (X)	On (Y)	For different values of parameter (P)	Using equation
Mach	CD	W,S,AR,h,CDo,e	CD = CDo + (W/(qS))^2 / (πARe)
CL	CD	AR, CDo, e	CD = CDo + CL^2 / (πARe)
Mach	CL	W, S, h	CL = W / (qS)
CD	CL	AR, CDo, e	CD = CDo + CL^2 / (πARe)
V	CL	W, S, h	CL = W / (qS)
Mach	CL/CD	W,S,AR,h,CDo,e	CL = W / (qS) ; CD = CDo + CL^2 / (πARe)
V	CL/CD	W,S,AR,h,CDo,e	CL = W / (qS) CD = CDo + CL^2 / (πARe)
h	Mach	V	Mach = V / Speed of sound
V	Mach	h	Mach = V / Speed of sound
V	Preq	W,S,AR,h,CDo,e	Preq = DV = VqS (CDo + (W/(qS))^2 / (πARe))
Span	S	AR	AR = Span^2 / Wing area
S	Span	AR	AR = Span^2 / Wing area
Mach	Treq	W,S,AR,h,CDo,e	Treq = D = qS (CDo + (W/(qS))^2 / (πARe))
V	Treq	W,S,AR,h,CDo,e	Treq = D = qS (CDo + (W/(qS))^2 / (πARe))
W	V	S,h,CL	L = W = 1/2 rho V^2 S CL

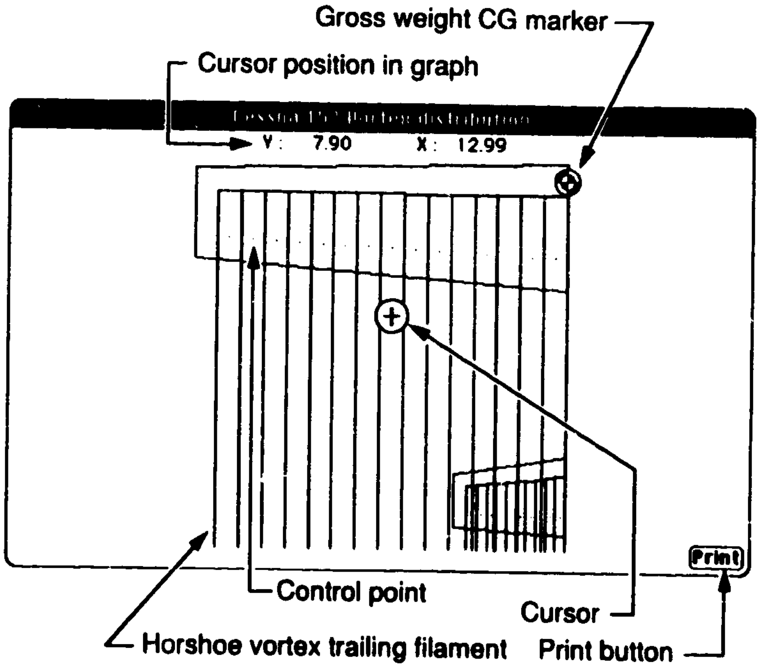
where h = Altitude, q = 1/2 rho V^2, S = Wing area, V = Velocity, W = Weight

(d)

Figure 31. Concluded. (c) Help information, (d) Help information.

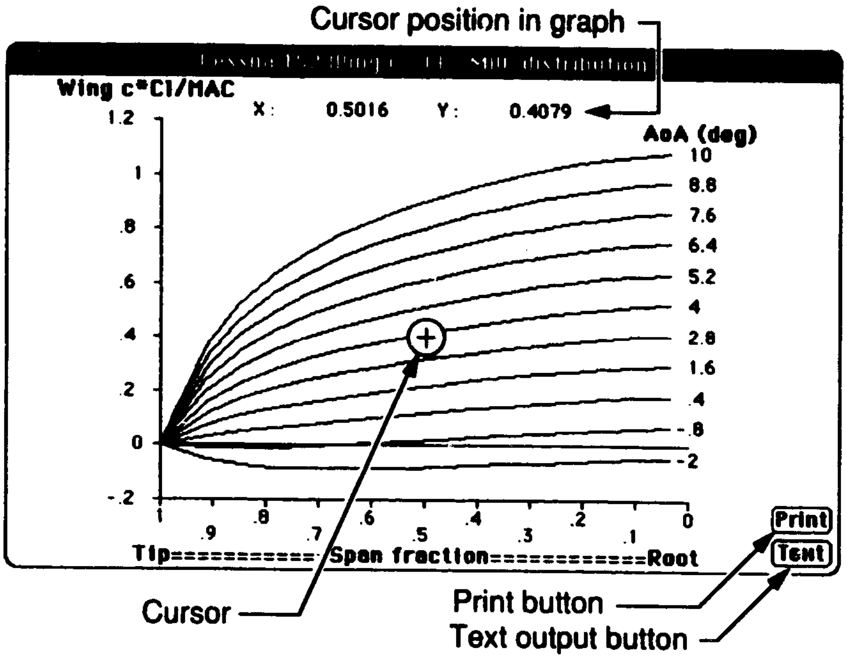


(a)

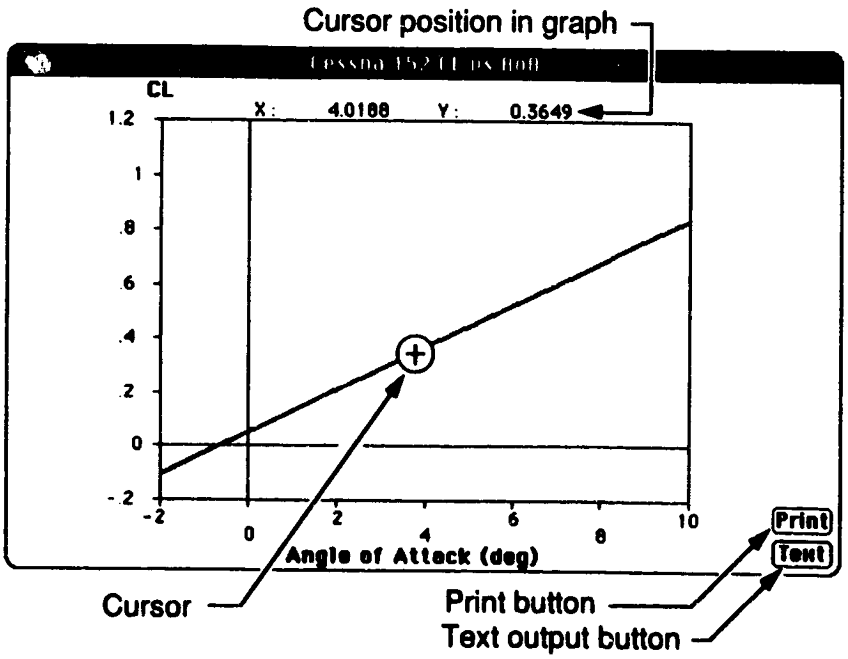


(b)

Figure 32. Performance menu. (a) Lift Distribution worksheet, (b) Horseshoe vortices and control points.

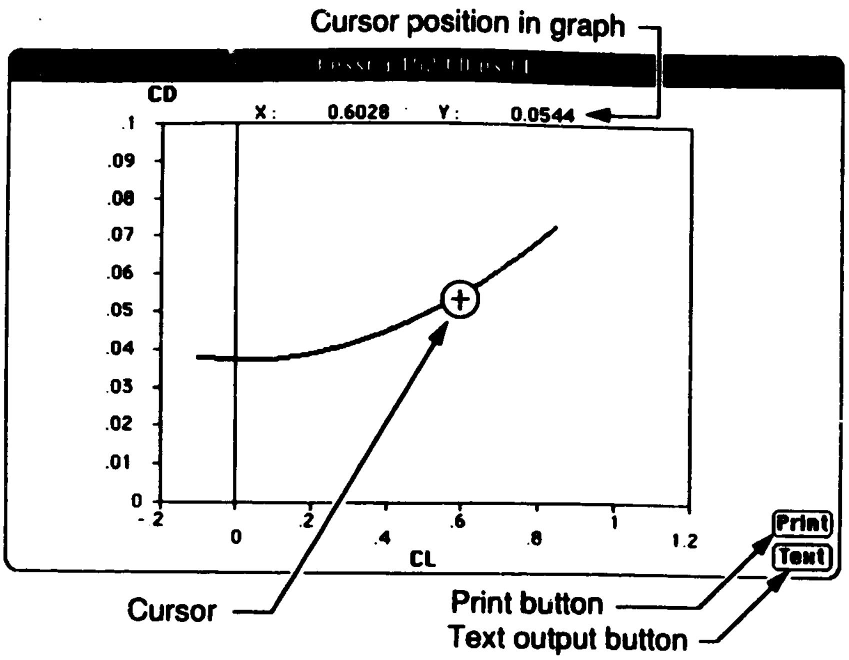


(c)

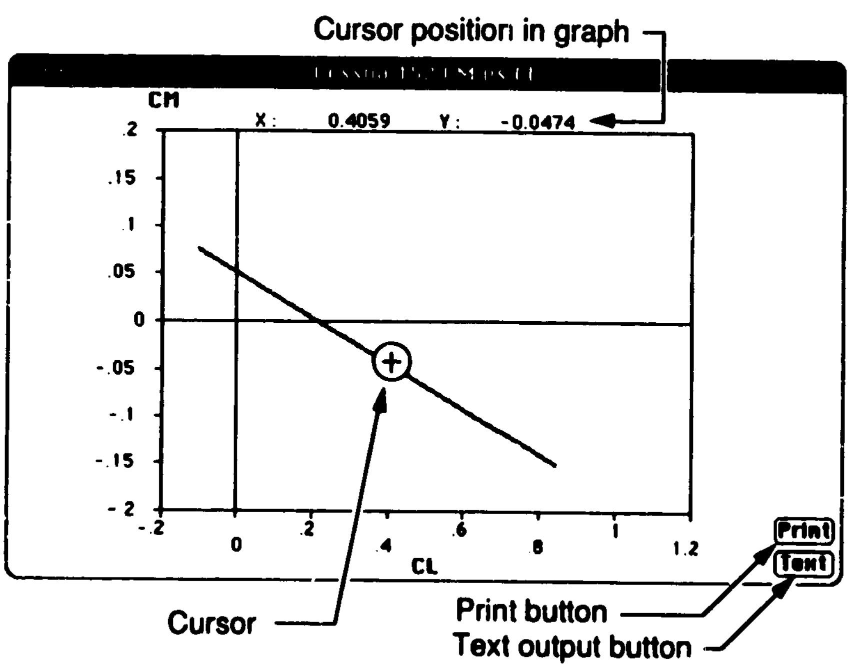


(d)

Figure 32. Continued. (c) Wing load distributions, (d) C_L vs. Angle of Attack.

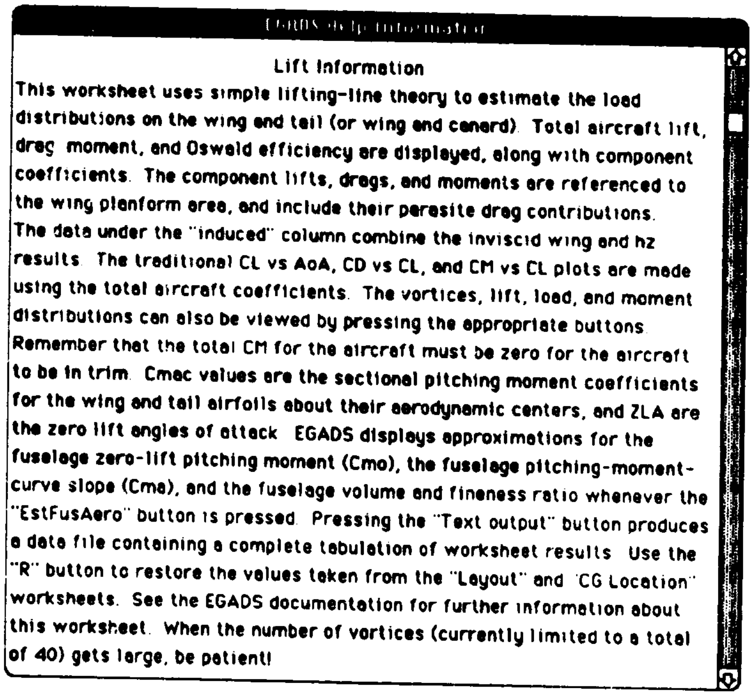


(e)



(f)

Figure 32. Continued. (e) C_D vs. C_L, (f) C_M vs. C_L.



Lift Information

This worksheet uses simple lifting-line theory to estimate the load distributions on the wing and tail (or wing and canard). Total aircraft lift, drag, moment, and Oswald efficiency are displayed, along with component coefficients. The component lifts, drags, and moments are referenced to the wing planform area, and include their parasite drag contributions. The data under the "induced" column combine the inviscid wing and hz results. The traditional CL vs AoA, CD vs CL, and CM vs CL plots are made using the total aircraft coefficients. The vortices, lift, load, and moment distributions can also be viewed by pressing the appropriate buttons. Remember that the total CM for the aircraft must be zero for the aircraft to be in trim. Cmac values are the sectional pitching moment coefficients for the wing and tail airfoils about their aerodynamic centers, and ZLA are the zero lift angles of attack. EGADS displays approximations for the fuselage zero-lift pitching moment (Cmo), the fuselage pitching-moment-curve slope (Cma), and the fuselage volume and fineness ratio whenever the "EstFusAero" button is pressed. Pressing the "Text output" button produces a data file containing a complete tabulation of worksheet results. Use the "R" button to restore the values taken from the "Layout" and "CG Location" worksheets. See the EGADS documentation for further information about this worksheet. When the number of vortices (currently limited to a total of 40) gets large, be patient!

(g)

Figure 32. Concluded. (g) Help information.

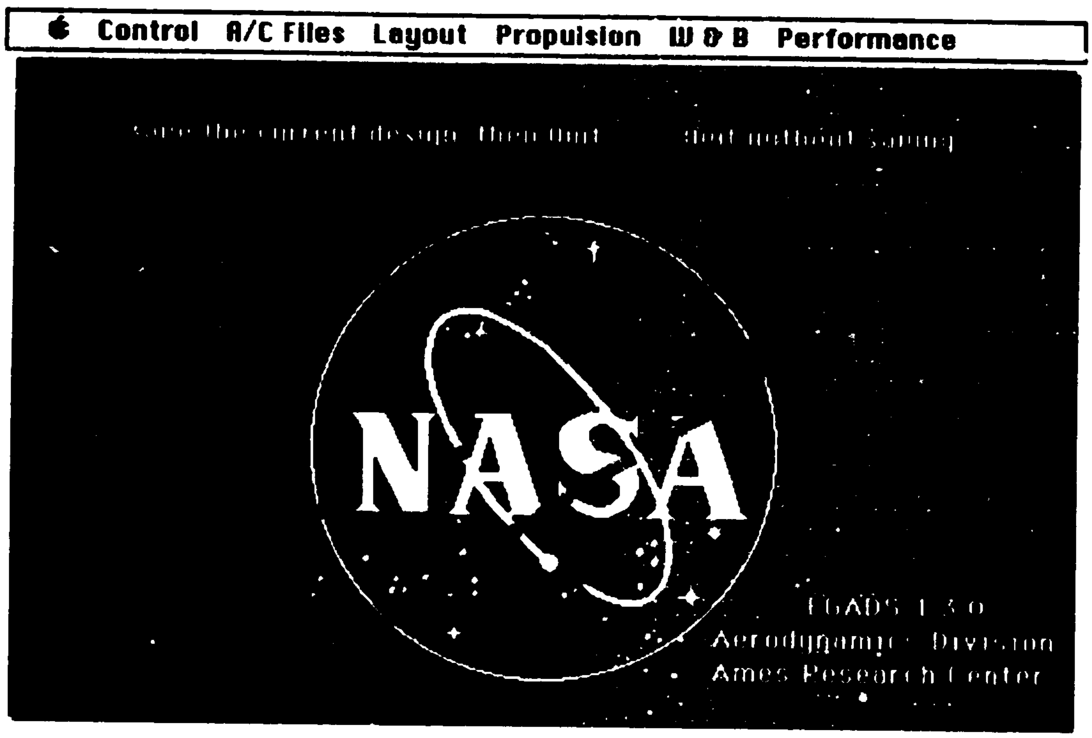


Figure 33. Control menu: Quit-(with-Save-Options) final screen.

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13. ABSTRACT *(Maximum 200 words)*

EGADS is a comprehensive preliminary design tool for estimating the performance of light, single-engine general aviation aircraft. The software runs on the Apple® Macintosh™ series of personal computers and assists amateur designers and aeronautical engineering students in performing the many repetitive calculations required in the aircraft design process. The program makes full use of the mouse and standard Macintosh interface techniques to simplify the input of various design parameters. Extensive graphics, plotting, and text output capabilities are also included.

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