AAA (ADVANCED AIRCRAFT ANALYSIS): A USER-FRIENDLY APPROACH TO PRELIMINARY AIRCRAFT DESIGN

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Abstract

The paper demonstrates the utility of a user-friendly code developed for preliminary aircraft designers and for aircraft design students to rapidly evolve a new airplane design. The code applies to civil and military airplanes: all applicable performance and flying quality regulations have been 'built-in'. This provides the designer with instant appraisal about the status of his design relative to these regulations. Important features of the program are: 1) a common data base, 2) built-in help files for theory and for design decision making and 3) report quality graphics for display of design decision results and trade studies.

1. Introduction

The purpose of this paper is to demonstrate the utility of a user-friendly code developed for preliminary aircraft designers and for aircraft design students. The program is currently hosted on Apollo DN3000 and DN4000 series engineering work stations. A detailed description of the architecture of the program is given in Ref.1. A user's manual is also available: Ref.2. The preliminary design methodology on which the AAA code is based is that of Refs 3-10. The code has been developed at The University of Kansas under partial funding from General Dynamics Corporation and the University of Kansas Endowment Association. The AAA code is used in two undergraduate and two graduate aircraft design classes taught at The University of Kansas.

The AAA program consists of 15 independent modules. Table 1 lists the operating modules with a very brief indication of their purpose. Figure 1 shows the screen display of the main menu of the AAA program. Each module is designed to perform one or more tasks which need to be performed to evaluate the characteristics of a given aircraft at some stage in its preliminary design development. The designer interacts with AAA through a mouse which is used to select menus and to command most functions. Whenever a function demands the entry of numerical data, a calculator pad automatically appears on the screen. Figure 2 shows the calculator pad. The mouse/cursor combination is then used to enter data into the calculator pad and thus into the AAA program.

In this paper the assumption is made that a preliminary airplane design specification is available. The example airplane used in this paper is an advanced stealth bomber: called the ASB. Table 2 contains the mission specification for the ASB. The remainder of the paper takes the reader step-by-step through several of the AAA application modules to illustrate how a new airplane design can be rapidly evolved. To limit the length of this paper, only the following preliminary design steps are discussed:

- Determination of takeoff weight, empty weight and fuel weight
- Preliminary drag polar calculation
- Determination of wing-loading versus thrust-to-weight ratio
- Component weight estimation and construction of the loading diagram
- Analysis of lateral-directional open loop dynamics

2. Determination of Takeoff Weight, Empty Weight and Fuel Weight

The weight sizing module (Item 1 in Table 1) is designed to estimate airplane takeoff weight, empty weight and fuel weight. In this module it is assumed that a mission profile is available. Table 2 shows the mission profile of the ASB. Next, a weight fraction is assigned to each flight phase in the mission profile. These weight fractions account for the

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Table 1 Application Modules Installed in AAA

1. WEIGHT SIZING: Allows determination of Take-off Weight, Empty Weight and Fuel Weight for a given mission specification. Performs sensitivity analyses of takeoff weight with respect to many mission, aerodynamic and propulsion parameters.

2. PERF.SIZING: Allows determination of Wing Loading and Thrust-to-Weight Ratio (or Weight-to-power ratio) to meet Stall. Climb, Takeoff, Landing, Cruise and Maneuvering Requirements. All pertinent civil and military airworthiness regulations are automatically accounted for. The effect of high lift requirements is accounted for. The end product of this module is a plot of T/W (or W/P) versus W/S of all pertinent performance requirements.

3. GEOMETRY: Designed to determine the planform geometries of wing, fuselage and empennage. Non straight tapered plan-forms can be handled.

4. HIGH LIFT: Designed to determine high lift characteristics of wings with and without flaps. Draws simple flap geometries to allow the designer to 'check' the feasibility of high lift requirements identified in Module 2.

5. DRAG POLAR: Allows for first order estimate of drag polars: clean low speed, clean high speed, takeoff and landing, gear up and down. Also gives drag polar plots. User can also determine how realistic an estimated drag polar is by comparison to existing (built-in) data.

6. STAB.&CONTROL: Allows the user to size the empennage surfaces: vertical tail, horizontal tail and canard. This module also is used to prepare a trim diagram.

7. WEIGHT&BALANCE: Allows the user to arrive at first and/or second order component weight breakdowns. Plots of c.g. excursion versus weight loadings are automatically prepared.

8. INST.THRUST: Helps the user estimate installed thrust and s.f.c. data from given engine manufacturer's data for piston engines, turboprop engines and turbojet/fan engines. Installed data can be plotted versus altitude and Mach number.

9. PERF.ANALYSIS: In this module the user can verify the performance characteristics of a new airplane design. Fieldlength, climb, range and maneuvering performance can be evaluated. This module uses more sophisticated performance equations than those used in module 2.

10. S&C DERIVATIVES: Computes subsonic stability and control derivatives for 2- and 3-surface airplanes.

11. DYNAMICS: Determines open loop airplane transfer functions. Checks handling qualities against Mil-F-8785C specification. Performs derivative sensitivity analyses.

12. CONTROL: Does Bode and Root-locus plots for open and closed loop systems: stability augmentation and simple auto-pilot loops. Airplane transfer functions are transferred into the appropriate blocks of a feedback network. Sensitivity of dynamic behavior versus variations in derivatives and inertial characteristics is plotted.

13. COST ANALYSIS: Allows user to estimate R&D cost, Manufacturing cost and operating cost (DOC and IOC) of civil and military airplanes.

14. DATA BASE: Manages all input and output data. There is a common data base for ALL modules of the code. Data, when generated in a given module are automatically transferred to other modules as needed. The user never has to enter design data twice. This module also saves all design information for future use.

15. HELP: This module allows the user to get 'off-line' help. Off-line help is designed to assist the user with questions about certain operational features of the AAA program. Off-line help is available from the main menu only. There exists another help feature in AAA: 'on-line' help. This feature is available within each module through the calculator pad (See Figure 2) by depressing either the INFO button or the SHF button. These buttons allow the user to call up design information tables of design graphs from Refs 3-10.

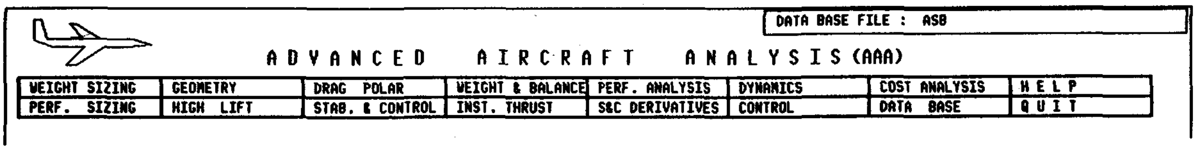


Figure 1 Screendump of Main Menu of the AAA Code

Table 2 Mission Specification for an Advanced Stealth Bomber

Military Load: 50,000 lbs internal capacity for conventional or nuclear ordnance. Primary weapons are the Boeing AGM-131A SRAM II and the B83 gravity drop bomb, in rotary launchers with eight weapons each.

Crew: Two, at 300 lbs each with physical provision for three.

Range/Speed/Alt. See mission profile.

Fieldlength: 8,000 ft for takeoff and landing. Groundrun of 5,000 ft. Std. day.

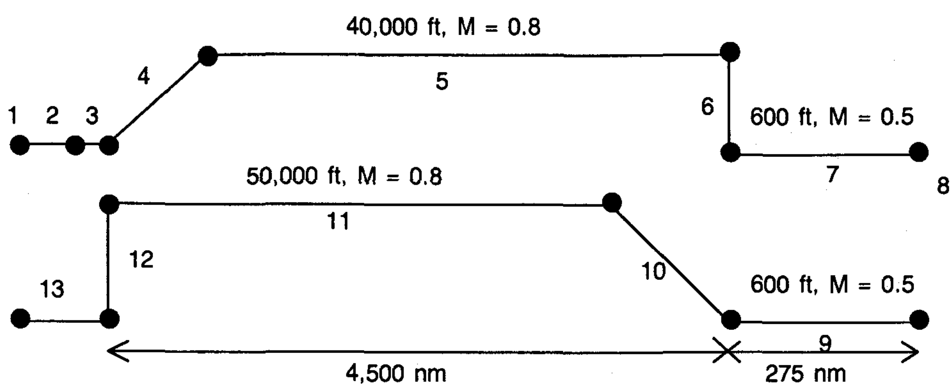
Engines: Four F118-GE-100 engines.

Certification: Military

Mission Phases:

1. Engine start and warm-up	2. Taxi	3. Takeoff
4.Climb with range credit	5. Cruise out	6. Descent
7. Dash out	8. Drop Mil. load	9. Dash in
10. Climb with range credit	11. Cruise in	12. Descent
13. Land, taxi and shutdown		

Mission Profile:



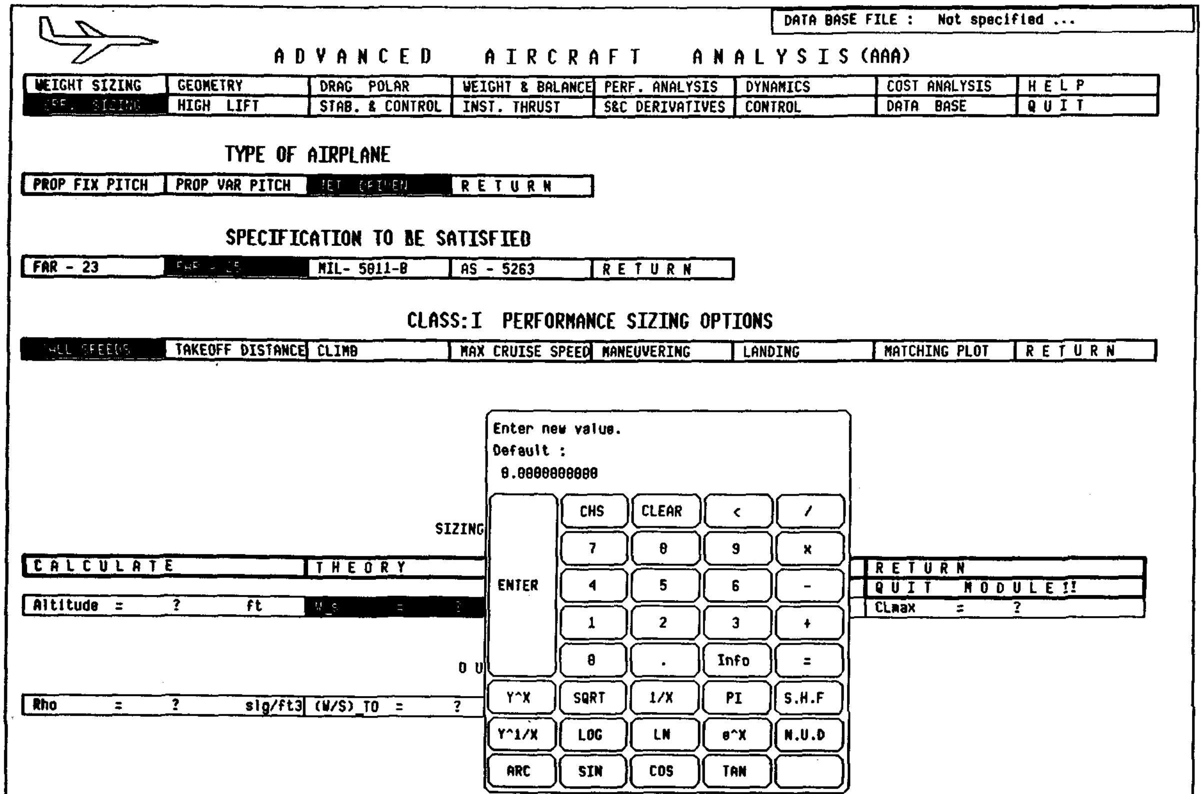


Figure 2 Example of the Calculator Pad Used in AAA

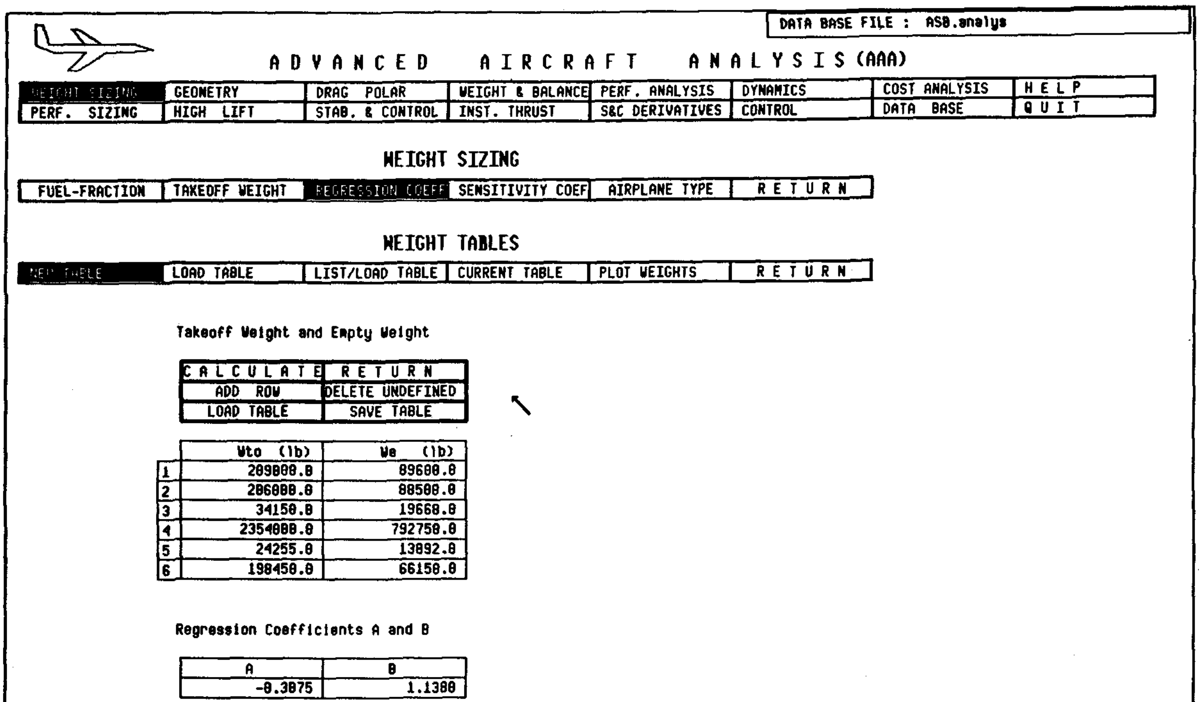


Figure 3 Statistical Weight Pairs for Flying Wing Configurations

fuel used during each phase of the mission. They are estimated from statistical data for non-fuel-intensive phases in the mission profile. For fuel-intensive phases of the mission profile these fuel-weight fractions are estimated with the help of Breguet's range equation.

The procedure for determining takeoff weight, empty weight and fuel weight is based on the following two equations from Ref.3:

$$B\log_{10}W_E = (\log_{10}W_{TO}) - A \quad (1)$$

and:

$$\log_{10} W_{TO} = A + B\log_{10}(CW_{TO} - D) \quad (2)$$

where:

A and B are regression coefficients which relate takeoff weights and empty weights for existing airplanes. Ref.3 contains values for A and B for twelve different categories of airplanes.

W_E and W_{TO} are the airplane empty weight and takeoff weight respectively

D is the sum of payload weight and crew weight

$$C = 1 - (1 + M_{res})(1 - M_{ff}) - M_{tfo} \quad (3)$$

where:

$(1 - M_{res})$ is the reserve fuel weight fraction
$(1 - M_{ff})$ is the mission-fuel-used weight fraction
$(1 - M_{tfo})$ is the trapped fuel and oil weight fraction

Methods for determining these weight fractions are developed in detail in Ref.3.

Since the ASB configuration is dominated by the requirement to be stealthy, it probably should be a flying wing. The AAA program does not contain any statistical weight data on flying wing airplanes. After searching the literature for flying wing configurations a number of data sets were obtained for takeoff weight and empty weights of flying wings. Fig.3 shows the statistical data pairs entered into the AAA program. The program then determines the corresponding regression coefficients A and B. Fig.4 shows a plot of these data. Having such a plot is useful to see how much scatter there is. In this case, there is not much scatter.

The weight data base for flying wings applies only to aluminum structures. For the ASB it is foreseen that composite materials will have to be used. It is estimated that this can result in a potential weight saving of 14% of the empty weight. This information is used to determine a 'new material' value for the intercept coefficient A as follows:

$$A_{new} = A_{old} - B\log_{10}(\frac{W_{E_{new}}}{W_{E_{old}}}) \quad (4)$$

For the ASB this yields A = - 0.2330. Fig.4 also shows the 'new' weight line. With this information the problem of estimating the new airplane takeoff weight, empty weight and fuel weight can be tackled.

Fig.5 shows a AAA screendump after all mission phase weight fractions have been entered. Of greatest importance are the four cruise phase fuel fractions. Fig.6 shows an example of how these fuel-intensive weight fractions are computed. Note that they require an estimate of the lift-to-drag ratio, L/D. How L/D can be found at this stage of the design process is illustrated in Section 3.

Note from Figure 5 that the results of the weight sizing calculations are:

W_{TO} = 244,825 lbs $\quad$ W_E = 87,123 lbs
W_F = 105,878 lbs

Before continuing the development of the ASB design it is useful to ask the following question: "How sensitive is the ASB takeoff weight to variations in mission performance, aerodynamic and engine s.f.c. parameters?". This question is easily answered by performing a takeoff weight sensitivity analysis. The method for doing that is given in Ref.3. Fig.7 shows a AAA screendump which indicates the required sensitivities. It is of interest to interpret the meaning of some of these sensitivities.

Note that in the cruise-out and cruise-in mission phases the sensitivity of takeoff weight to L/D is very large: on the average -7,600 lbs/(unit of L/D). This means that if the estimated cruise L/D of 22.0 (See Figure 6) is only, say 20, the takeoff weight of the ASB would increase by 2x2x7,600 lbs = 30,400 lbs. Therefore, the aerodynamic efficiency of this airplane is extremely important as a controlling factor of takeoff weight and therefore of cost!

Note that engine s.f.c. in the cruise-out and cruise-in mission phases is also very large: on the average 268,000 lbs/(unit of s.f.c.). This means that if the engine s.f.c. were to increase by 0.05 (from 0.60 in Fig.6), the takeoff weight of the ASB would increase by 2x0.05x268,000 = 26,800 lbs. Thus, controlling engine s.f.c. during the development of this airplane is also going to be very important.

3. Preliminary Drag Polar Calculation

The drag polar module (See Figure 1 and item 5 in Table 1) is designed to estimate drag polars (including the effect of landing gear and flaps). In this module it is assumed that the preliminary drag polar takes the classical parabolic form:

$$C_D = C_{D_0} + \frac{C_L^2}{\pi Ae} \quad (5)$$

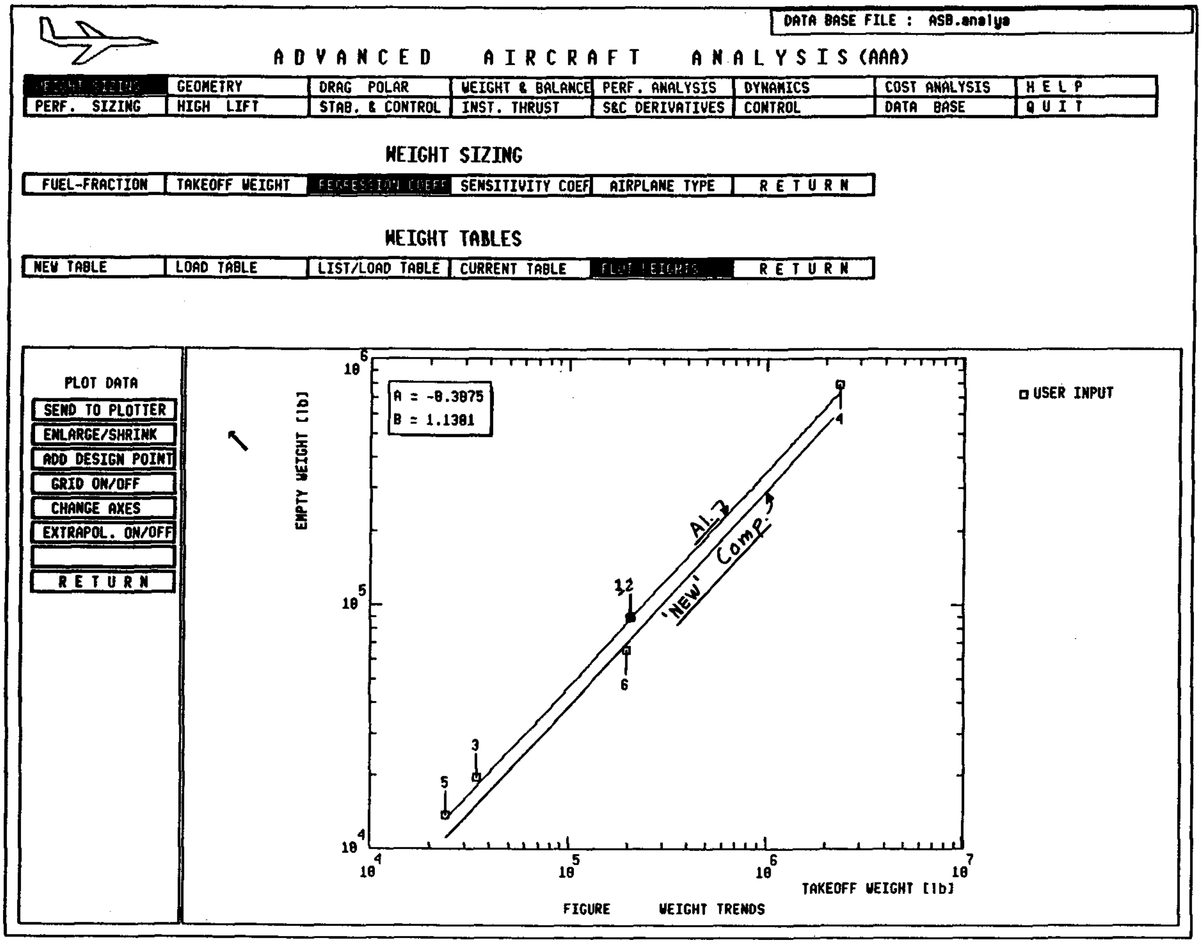
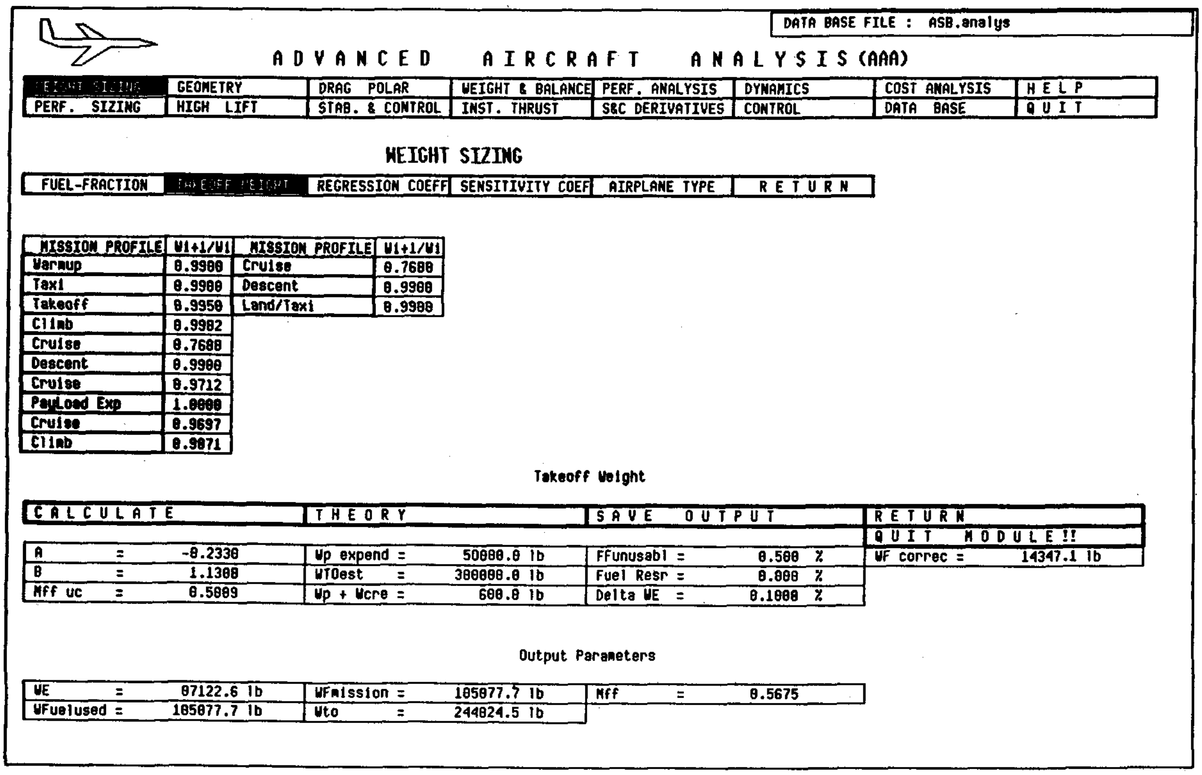


Figure 4 Logarithmic Plot of Statistical Weight Pairs for Flying Wing Configurations



MISSION PROFILE	Wi+1/Wi	MISSION PROFILE	Wi+1/Wi
Warmup	0.9900	Cruise	0.7680
Taxi	0.9900	Descent	0.9900
Takeoff	0.9950	Land/Taxi	0.9900
Climb	0.9982		
Cruise	0.7680		
Descent	0.9900		
Cruise	0.9712		
PayLoad Exp	1.0000		
Cruise	0.9697		
Climb	0.9871		

Takeoff Weight

CALCULATE	THEORY	SAVE OUTPUT	RETURN / QUIT MODULE!!
A = -0.2330	Wp expend = 50000.0 lb	FFunusabl = 0.500 %	WF correc = 14347.1 lb
B = 1.1300	WTOest = 300000.0 lb	Fuel Resr = 0.000 %	
Mff uc = 0.5009	Wp + Wcre = 600.0 lb	Delta WE = 0.1000 %	

Output Parameters

WE = 87122.6 lb	WFmission = 105077.7 lb	Mff = 0.5675
WFuelused = 105077.7 lb	Wto = 244024.5 lb	

Figure 5 Weight Fractions for All Mission Phases and Estimated Takeoff Weight, Empty Weight and Fuel Weight for the ASB

DATA BASE FILE : Not specified ...

ADVANCED AIRCRAFT ANALYSIS (AAA)

WEIGHT SIZING	GEOMETRY	DRAG POLAR	WEIGHT & BALANCE	PERF. ANALYSIS	DYNAMICS	COST ANALYSIS	H E L P
PERF. SIZING	HIGH LIFT	STAB. & CONTROL	INST. THRUST	S&C DERIVATIVES	CONTROL	DATA BASE	Q U I T

WEIGHT SIZING

FUEL-FRACTION	TAKEOFF WEIGHT	REGRESSION COEFF	SENSITIVITY COEF	AIRPLANE TYPE	R E T U R N

MISSION PROFILE	Wi+1/Wi	MISSION PROFILE	Wi+1/Wi
Warmup	0.9900	Cruise	0.7600
Taxi	0.9900	Descent	0.9900
Takeoff	0.9950	Land/Taxi	0.9900
Climb	0.9902	SEGMENT COMMANDS	
Cruise	0.7600		
Descent	0.9900		
Cruise	0.9712		
PayLoad Exp	1.0000		
Cruise	0.9697		
Climb	0.9871		

SEGMENT INPUT AND FUEL-FRACTION CALCULATION

NEW SEGMENT	SHOW SEGMENT	DELETE SEGMENT	INSERT SEGMENT	MOVE SEGMENT	FUEL-FRACTION	H E L P	R E T U R N

Fuel Used in Cruise Segment for a Jet Driven Aircraft

C A L C U L A T E	T H E O R Y	S A V E O U T P U T	R E T U R N / Q U I T M O D U L E !!
Range = 4435.0 n.mi	V = 460.00 kts	Cj = 0.600 #/#-hr	L/D = 22.00

Output Parameter

Wi+1/Wi = 0.7607

Figure 6 Calculation of Weight Fraction for One of the Four ASB Cruise Phases

DATA BASE FILE : ASB.analys

ADVANCED AIRCRAFT ANALYSIS (AAA)

WEIGHT SIZING	GEOMETRY	DRAG POLAR	WEIGHT & BALANCE	PERF. ANALYSIS	DYNAMICS	COST ANALYSIS	H E L P
PERF. SIZING	HIGH LIFT	STAB. & CONTROL	INST. THRUST	S&C DERIVATIVES	CONTROL	DATA BASE	Q U I T

WEIGHT SIZING

FUEL-FRACTION	TAKEOFF WEIGHT	REGRESSION COEFF	SENSITIVITY COEF	AIRPLANE TYPE	R E T U R N

SENSITIVITY STUDY AND GROWTH FACTORS : INPUT

C A L C U L A T E	T H E O R Y	N E X T P A G E	R E T U R N
B = 1.1380	Mff uc = 0.5089	Wp expend = 50000.0 lb	Wp + Wcre = 600.0 lb
FFunusabl = 0.500 %	Fuel Resr = 0.000 %	WF correc = 14347.1 lb	Wto = 244824.5 lb
WE = 87122.6 lb			

SENSITIVITY : OUTPUT

dWto/dWpl = 5.22	dWto/dWe = 3.19

MISSION PROFILE	dWto/dWpExp	dWto/dCj lb*hr	dWto/dR lb/nm	dWto/dLD lb	dWto/dE lb/hr
Warmup					
Taxi					
Takeoff					
Climb		8043.8		-357.5	28957.7
Cruise		285535.2	38.6	-7787.3	
Descent					
Cruise		31677.7	69.1	-1108.9	
PayLoad Exp	3.7				
Cruise		31937.2	72.8	-1177.9	
Climb		18494.4		-495.8	30667.5
Cruise		250338.7	33.9	-7152.5	
Descent					
Land/Taxi					

Figure 7 Sensitivity of Takeoff Weight to ASB Mission and Performance Parameters

The zero lift drag component is estimated with the help of logarithmic correlations between wetted area and takeoff weight for twelve categories of airplanes (See Ref.3):

$$\log_{10} S_{wet} = c + d \log_{10} W_{TO} \qquad (6)$$

The regression constants 'c' and 'd' are different for each category of airplane. Fig.8 shows a help file in AAA which the user can call up to assist in deciding what value for 'c' and 'd' to enter on the calculator pad (also shown in Fig.8). Having estimated the wetted area of the new airplane, the next business is to find the equivalent parasite area: f. For this, AAA utilizes the following equation:

$$\log_{10} f = a + b \log_{10} S_{wet} \qquad (7)$$

The regression constants 'a' and 'b' depend on the equivalent skin friction coefficient which the user believes the airplane can be built to. Fig.9 shows a help file which can be called to assist the user in deciding what value is reasonable for equivalent skin friction. With this information, the corresponding values for 'a' and 'b' are determined with another help file, shown in Fig.10. Finally, the estimated drag polar can be determined: see Fig.11. The polar can even plotted as shown in Fig.12: note that a plot of L/D is also given! The polar shown in Fig.12 applies only to the clean airplane at M=0.8. For other flight conditions and for other airplane configurations (i.e. flaps up or down and/or landing gear up or down) the corresponding drag polars can also be quickly determined.

4. Determination of Wing-Loading Versus Thrust-to-Weight Ratio

The next order of business in the design process is the determination of wing area and installed thrust. This is conveniently done with a so-called performance constraint analysis. For the ASB, the mission specification of Table 2 suggests the need to investigate the following performance constraints:

1) Takeoff fieldlength
2) Climb to altitude, as well as takeoff and landing climb gradients with all engines operating as well as with one engine out.
3) Maximum cruise speed at sea-level and at 40,000 ft
4) Landing fieldlength

In addition, the requirements of Mil-5011-B (Military airworthiness requirements) must be satisfied. The AAA code allows a designer to meet all these requirements through a module called Perf.Sizing: see Figure 1 and Item 2 in Table 1). Use of this module requires that estimates of the drag polars for the design in the various flight conditions are estimated. How to do this for one flight condition was illustrated in Section 3.

Fig.13 shows a composite performance constraint output of the AAA program for the ASB. Note the point P which is the 'matching point selected by the designer. The implication of this matching point is:

Takeoff wing loading: $(W/S)_{TO} = 48 \frac{lbs}{ft^2}$

and,

Takeoff thrust-to-weight ratio: $(T/W)_{TO} = 0.29$

In turn this yields: S = 5,100 ft2 and T_{TO} = 71,000 lbs.

Since four engines are specified for this airplane, the installed takeoff thrust for each should be 71,000/4 = 17,750 lbs. The GE-F118 engines are rated at about 19,000 lbs each, uninstalled. It is not unreasonable to expect that the effect of the 'stealthy' installation results in a thrust reduction at takeoff of about 7%.

5. Component Weight Estimation and Construction of the Loading Diagram

To perform a responsible component weight breakdown, it is necessary to have a conceptual sketch of the overall configuration available. This sketch should include some indication of the location of those components which contribute to the airplane weight. For lack of space, the design steps leading up to the establishment of the configuration have been omitted. Fig.14 shows the preliminary geometry of the proposed ASB configuration. The weight and balance module (See Figure 1 and Item 7 in Table 1) will now be invoked to assist with the development of a preliminary weight breakdown. Fig.15 shows a menu of weight breakdown data available within the AAA program. In this case, the jet-transport category was selected. Five four-engined jet transports were selected as a subset of component weight data in the AAA data base. Fig.16 shows the resulting weight ratios and the averages for the airplanes which were selected. The user now must use his design knowledge (or intuition) to alter these ratios so they apply to the flying wing ASB. Note the handwritten data added to Fig.16. These data were actually used to determine the preliminary weight breakdown for the ASB displayed in Fig.17. The AAA program allows the user to add these new ratios to the data base, if so desired. The X-coordinates in Figure 17 were assigned with the help of Fig.14. Next, a loading sequence must be prescribed by the user. Fig.18 shows the result of assigning the loading sequence. With this information, the AAA program now generates the weight-versus-c.g. diagram also shown in Fig.18. Note from Figure 14 that the aft c.g. is forward of the main landing gear and slightly aft of the cruise a.c. location.

6. Analysis of Lateral-Directional Open Loop Dynamics

To perform this type of analysis, it is required that the dimensionless stability and control derivatives for the airplane are available. These may be estimated with the help

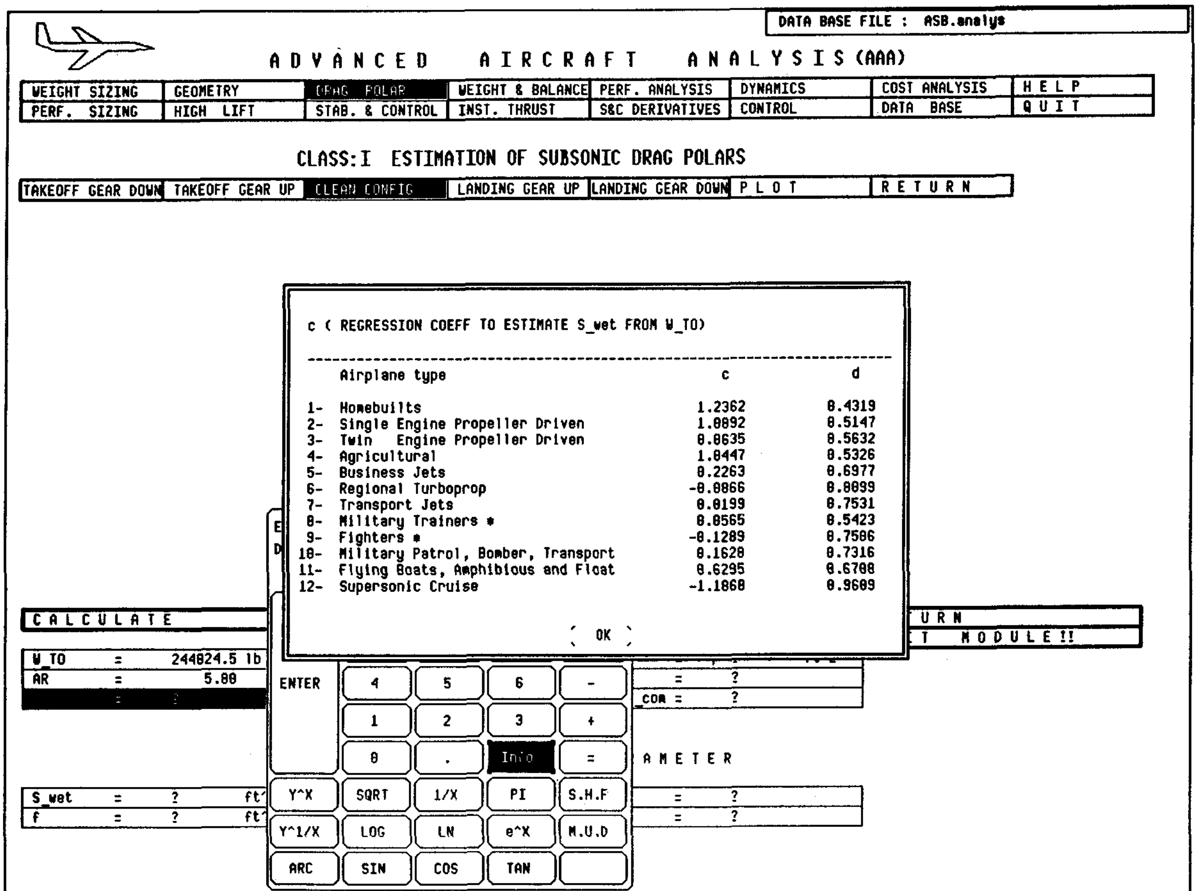


Figure 8 Help File for Estimating Wetted Area from a Known Takeoff Weight

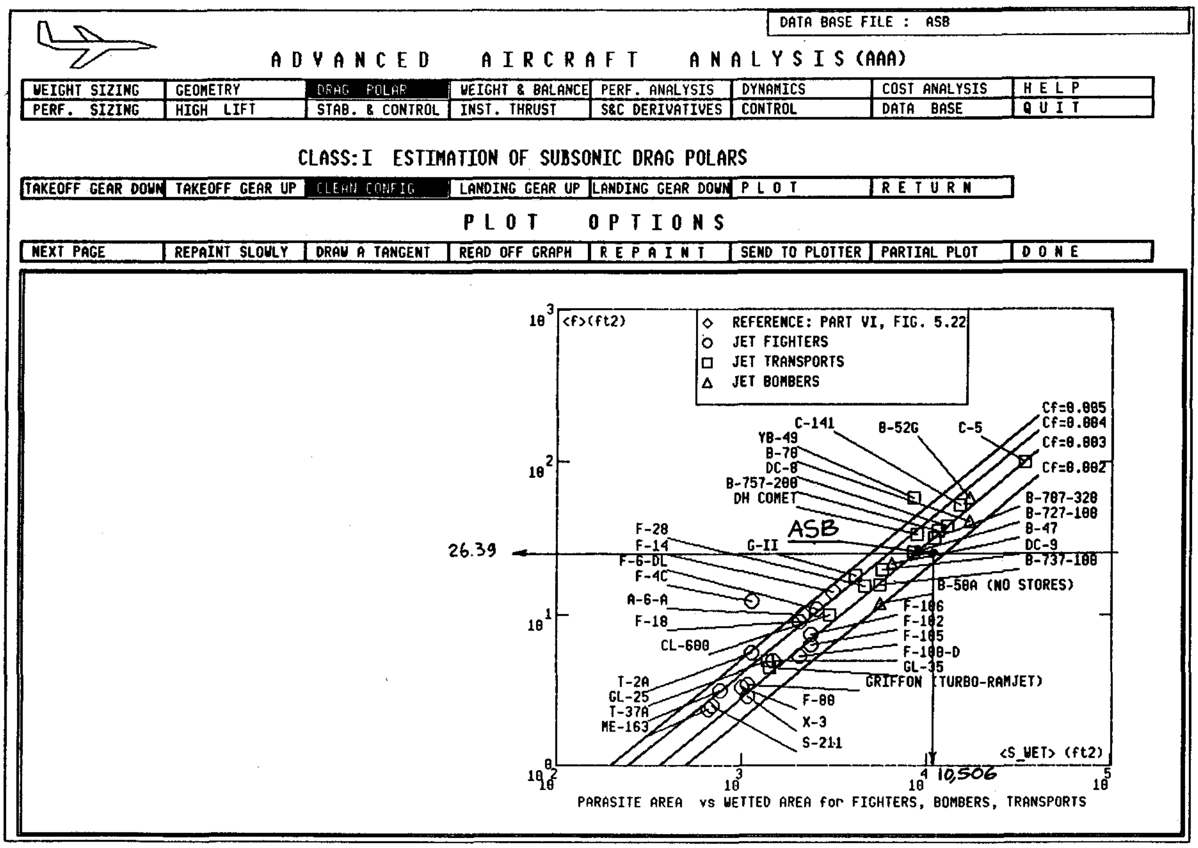


Figure 9 Help File for Determining the Achievable Value of Equivalent Skin Friction

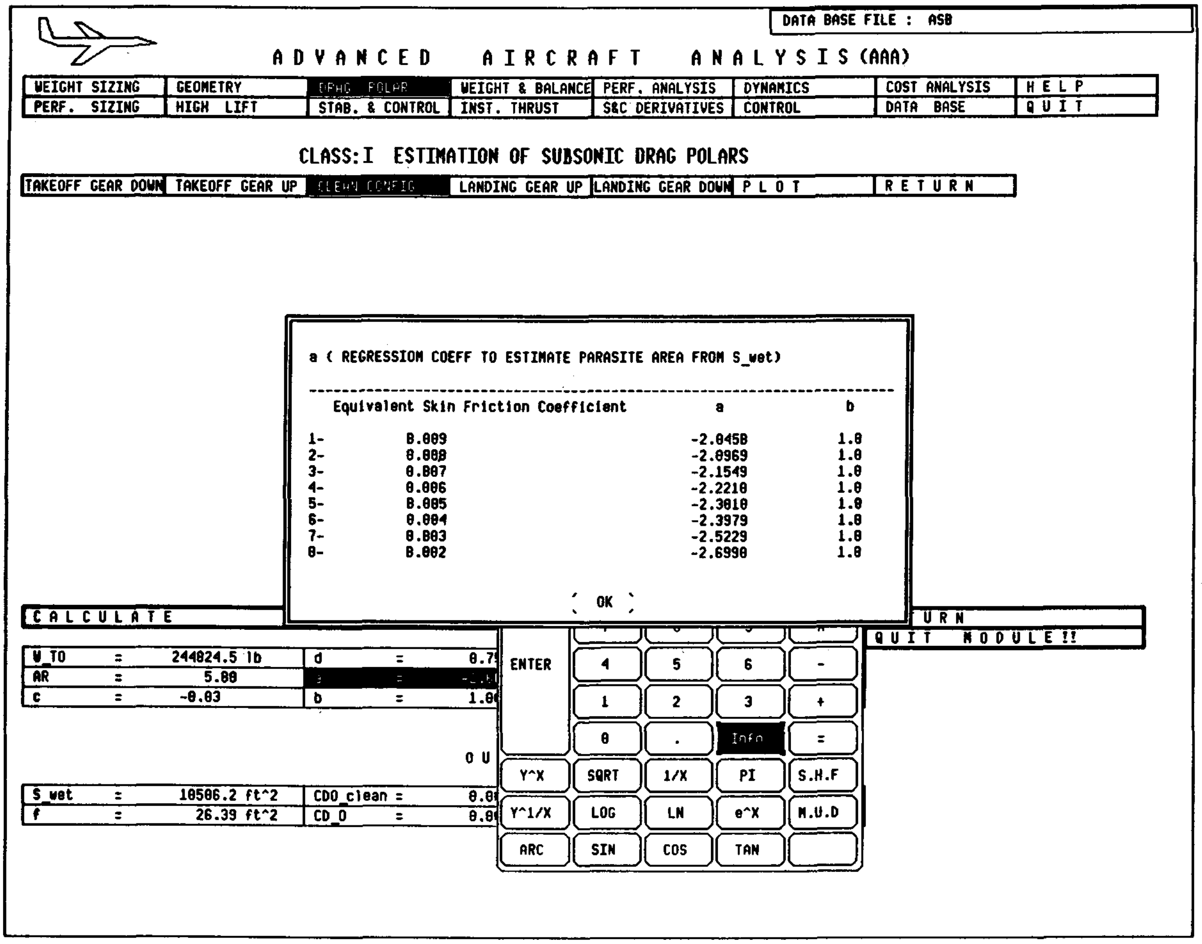


Figure 10 Help File for Correlation Coefficients Required for Estimating Equivalent Parasite Area

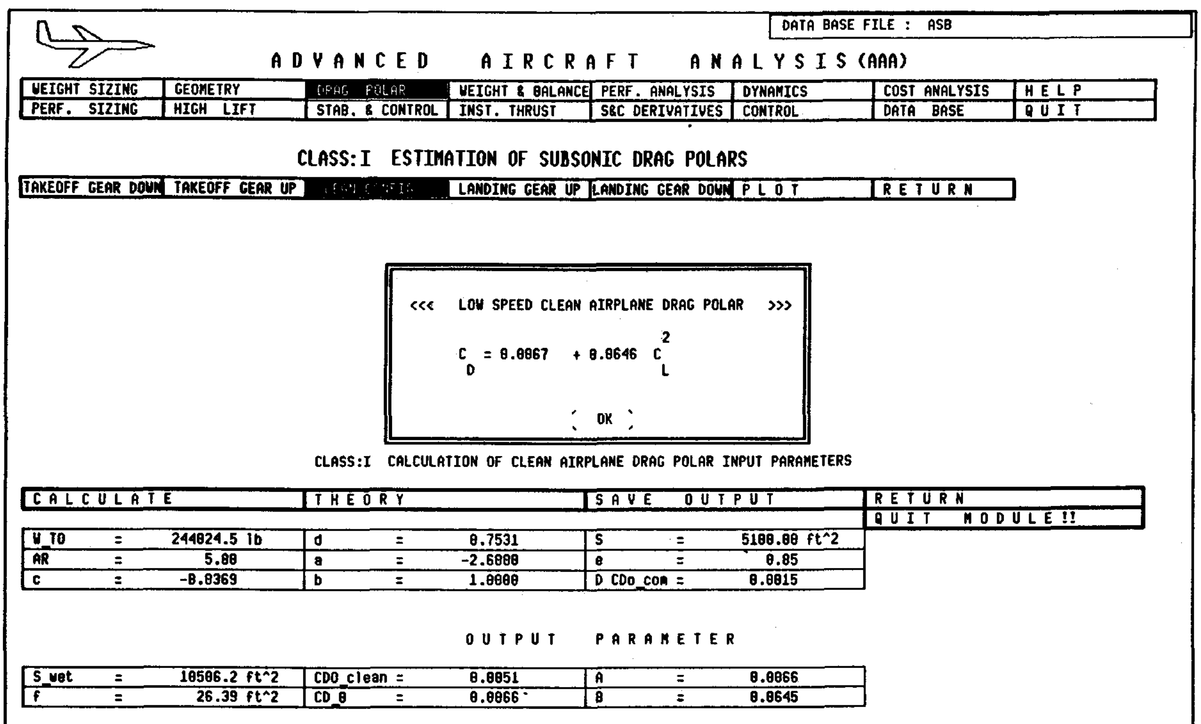


Figure 11 Estimated Cruise Drag Polar for the ASB

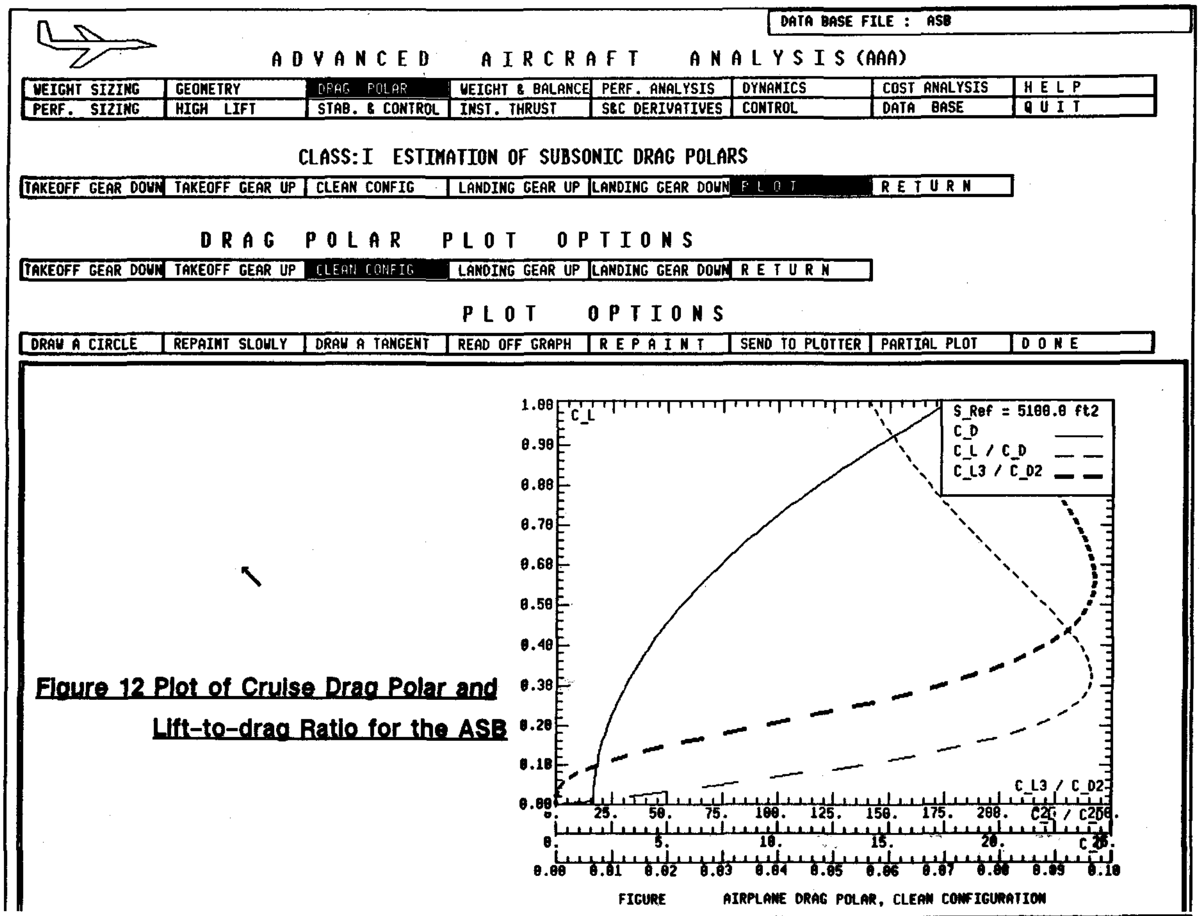


Figure 12 Plot of Cruise Drag Polar and Lift-to-drag Ratio for the ASB

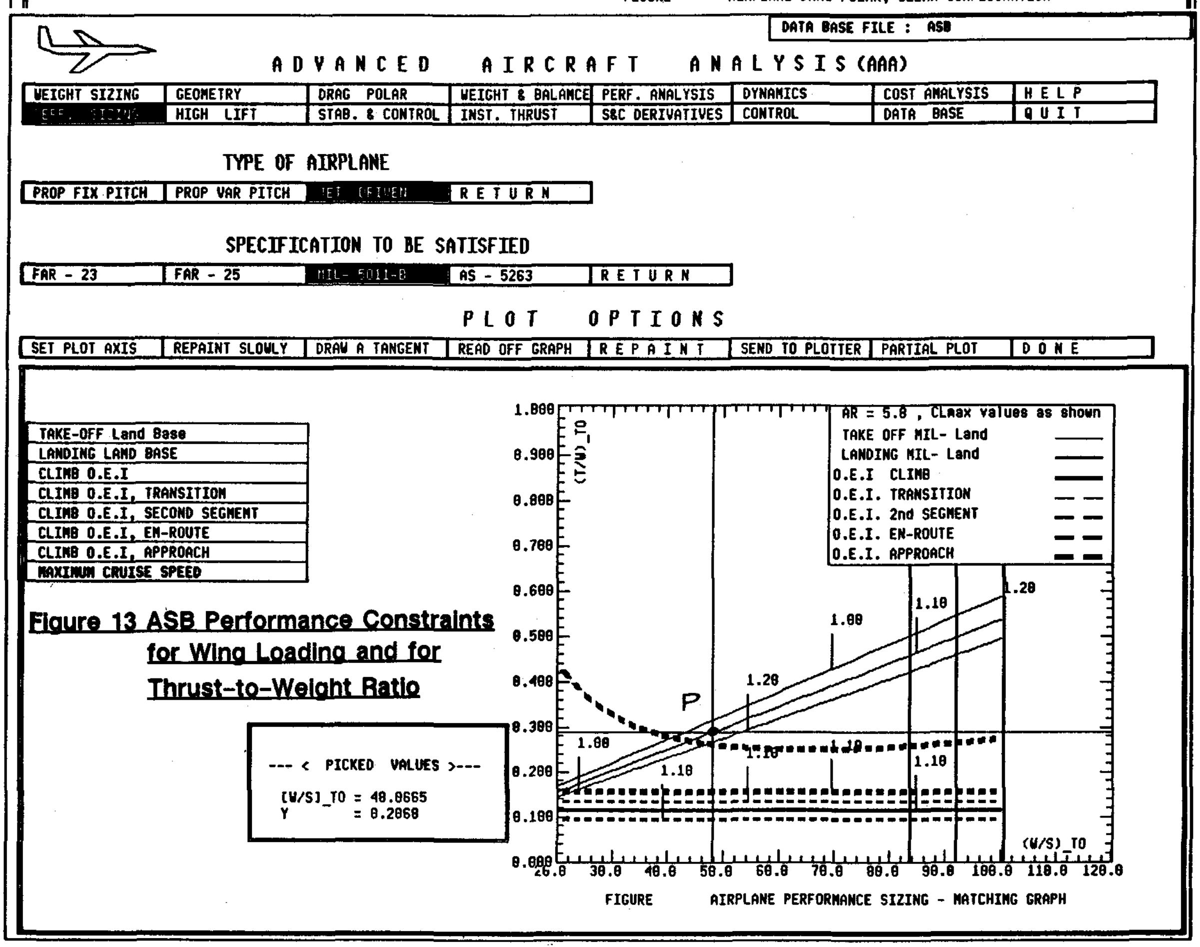


Figure 13 ASB Performance Constraints for Wing Loading and for Thrust-to-Weight Ratio

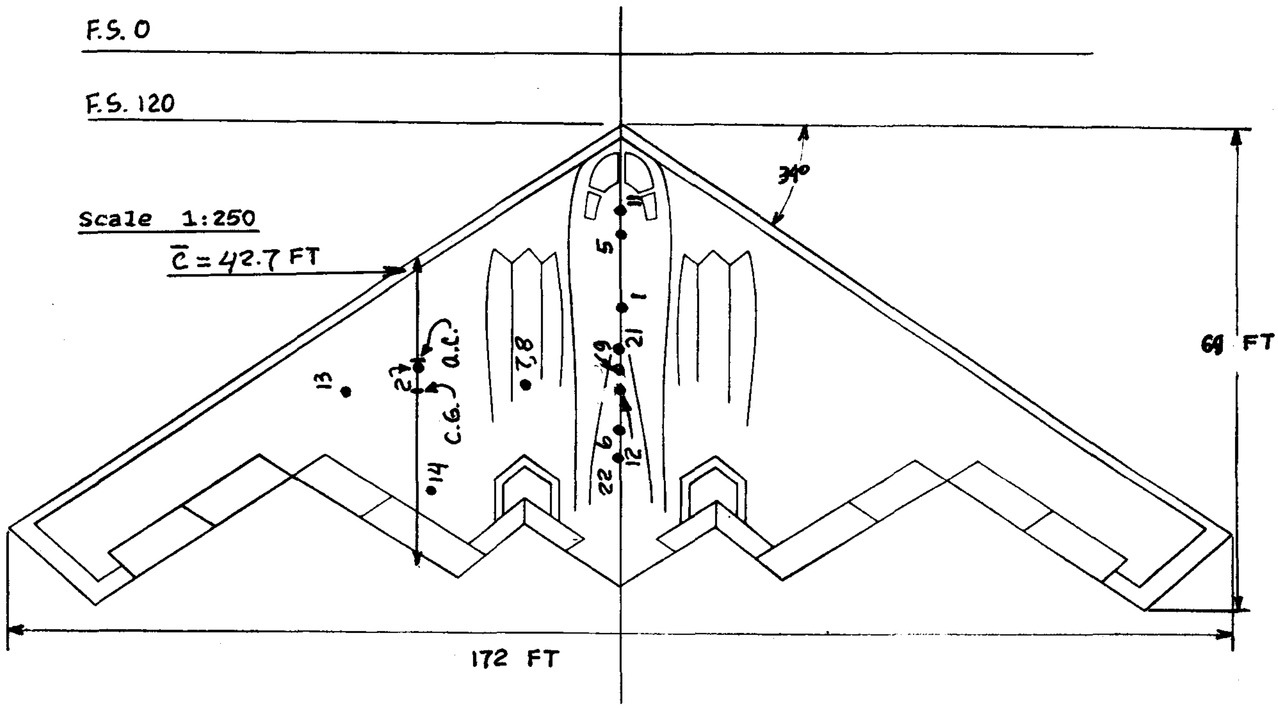


Figure 14 Preliminary Geometry for the ASB

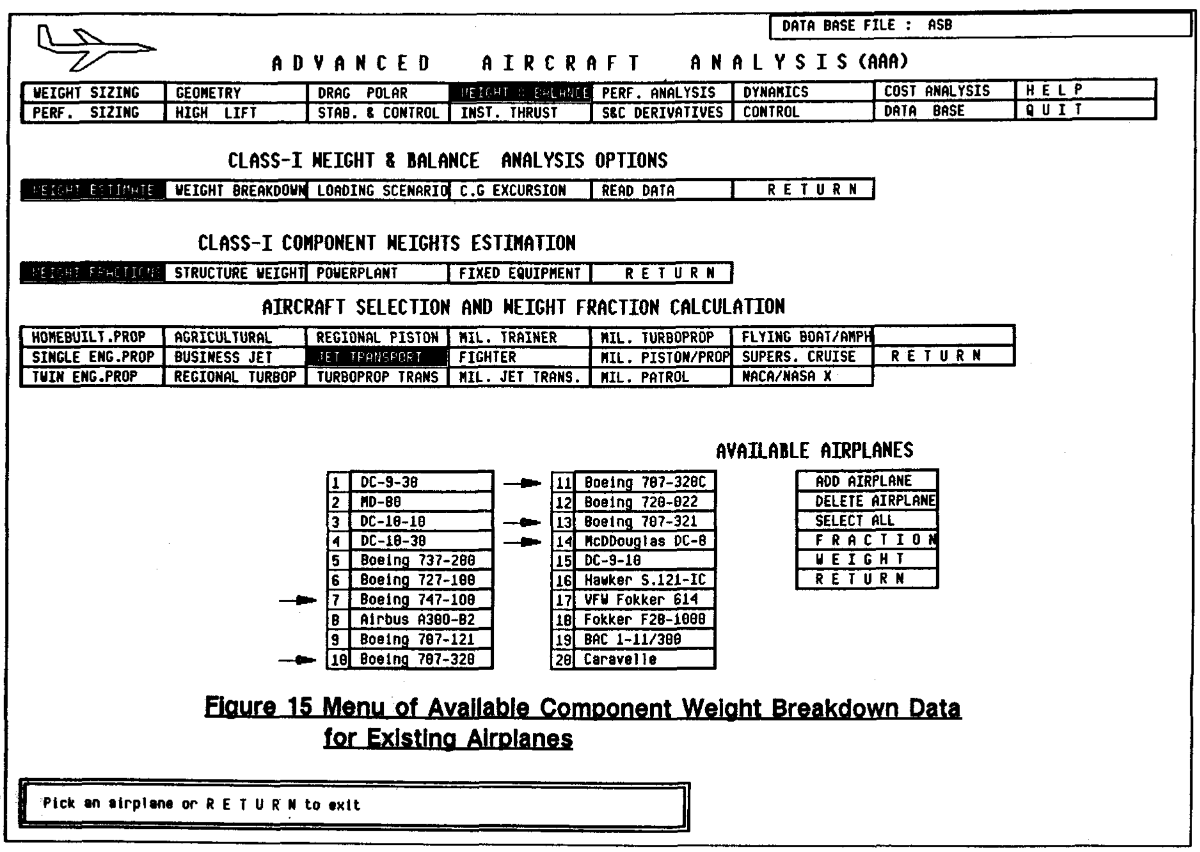


Figure 15 Menu of Available Component Weight Breakdown Data for Existing Airplanes

DATA BASE FILE : ASB

ADVANCED AIRCRAFT ANALYSIS (AAA)

WEIGHT SIZING	GEOMETRY	DRAG POLAR	WEIGHT & BALANCE	PERF. ANALYSIS	DYNAMICS	COST ANALYSIS	H E L P
PERF. SIZING	HIGH LIFT	STAB. & CONTROL	INST. THRUST	S&C DERIVATIVES	CONTROL	DATA BASE	Q U I T

CLASS-I WEIGHT & BALANCE ANALYSIS OPTIONS

WEIGHT ESTIMATE	WEIGHT BREAKDOWN	LOADING SCENARIO	C.G EXCURSION	READ DATA	R E T U R N

CLASS-I COMPONENT WEIGHTS ESTIMATION

WEIGHT FRACTIONS	STRUCTURE WEIGHT	POWERPLANT	FIXED EQUIPMENT	R E T U R N

AIRCRAFT SELECTION AND WEIGHT FRACTION CALCULATION

HOMEBUILT.PROP	AGRICULTURAL	REGIONAL PISTON	MIL. TRAINER	MIL. TURBOPROP	FLYING BOAT/AMPH	
SINGLE ENG.PROP	BUSINESS JET	JET TRANSPORT	FIGHTER	MIL. PISTON/PROP	SUPERS. CRUISE	R E T U R N
TWIN ENG.PROP	REGIONAL TURBOP	TURBOPROP TRANS	MIL. JET TRANS.	MIL. PATROL	NACA/NASA X	

COMPONENT WEIGHT FRACTIONS

C A L C U L A T E

R E T U R N

DEFINED BY DESIGNER :

	Boeing 747-100	Boeing 707-320	Boeing 707-320C	Boeing 707-321	McDDouglas DC-8	Average	
GROSS WEIGHT/TAKEOFF WEIGHT	1.00	1.00	1.00	1.00	1.00	1.00	1.00
STRUCTURE/GROSS WEIGHT	0.29	0.23	0.24	0.24	0.31	0.26	0.197
POWER PLANT/GROSS WEIGHT	0.06	0.08	0.07	0.09	0.11	0.08	0.078
FIXED EQUIPMENT/GROSS WEIGHT	0.08	0.08	0.07	0.09	0.11	0.09	0.040
EMPTY WEIGHT/GROSS WEIGHT	0.49	0.43	0.39	0.40	0.56	0.45	0.356
WING GROUP/GROSS WEIGHT	0.12	0.09	0.09	0.09	0.12	0.10	0.177
EMPENNAGE GROUP/GROSS WEIGHT	0.01	0.01	0.01	0.02	0.02	0.01	0
FUSELAGE GROUP/GROSS WEIGHT	0.10	0.07	0.08	0.07	0.09	0.08	0.010
NACELLE GROUP/GROSS WEIGHT	0.01	0.01	0.01	0.01	0.01	0.01	0.010
LAND. GEAR GROUP/GROSS WEIGHT	0.04	0.04	0.03	0.03	0.05	0.04	0.041

Figure 16 Average Component Weight Ratios for Selected Airplanes and Averages Defined by the Designer

DATA BASE FILE : ASB

ADVANCED AIRCRAFT ANALYSIS (AAA)

WEIGHT SIZING	GEOMETRY	DRAG POLAR	WEIGHT & BALANCE	PERF. ANALYSIS	DYNAMICS	COST ANALYSIS	H E L P
PERF. SIZING	HIGH LIFT	STAB. & CONTROL	INST. THRUST	S&C DERIVATIVES	CONTROL	DATA BASE	Q U I T

CLASS-I WEIGHT & BALANCE ANALYSIS OPTIONS

WEIGHT ESTIMATE	WEIGHT BREAKDOWN	LOADING SCENARIO	C.G EXCURSION	READ DATA	R E T U R N

CLASS:I BREAKDOWN FOR WEIGHT & BALANCE ANALYSIS

	CALCULATE	SAVE IN FILE	THEORY	RETURN
ITEM (I)	W (I) [lb]	X (I) [in]	Y (I) [in]	Z (I) [in]
1- FUSELAGE GROUP	2440.000	431.000	0.000	0.000
2- WING GROUP	43300.000	534.000	0.000	0.000
3- EMPENNAGE GROUP 1	0.000	0.000	0.000	0.000
4- EMPENNAGE GROUP 2	0.000	0.000	0.000	0.000
5- LANDING GEAR GROUP 1	2693.000	317.000	0.000	0.000
6- LANDING GEAR GROUP 2	7345.000	630.000	0.000	0.000
7- ENGINE GROUP 1	19096.000	555.000	0.000	0.000
8- ENGINE GROUP 2	2440.000	555.000	0.000	0.000
9- FIXED EQUIPMENT GROUP 1	9793.000	534.000	0.000	0.000
10- FIXED EQUIPMENT GROUP 2	0.000	0.000	0.000	0.000
11- CREW	600.000	276.000	0.000	0.000
12- TRAPPED FUEL and OIL (W_tfo)	1224.122	565.000	0.000	0.000
13- MISSION FUEL GROUP 1	105070.000	565.000	0.000	0.000
14- MISSION FUEL GROUP 2	0.000	741.000	0.000	0.000
15- PASSENGER GROUP 1	0.000	0.000	0.000	0.000
16- PASSENGER GROUP 2	0.000	0.000	0.000	0.000
17- PASSENGER GROUP 3	0.000	0.000	0.000	0.000
18- PASSENGER GROUP 4	0.000	0.000	0.000	0.000
19- BAGGAGE	0.000	0.000	0.000	0.000
20- CARGO	0.000	0.000	0.000	0.000
21- MILITARY LOAD GROUP 1	25000.000	493.000	0.000	0.000
22- MILITARY LOAD GROUP 2	25000.000	609.000	0.000	0.000

W_E [lb]	W_OE [lb]	W_TO [lb]	X_CG [in]	Y_CG [in]	Z_CG [in]
87123.0	88947.1	244025.1	560.12	0.00	0.00

Figure 17 Component Weight Breakdown and C.G. Locations for the ASB

DATA BASE FILE : ASB

ADVANCED AIRCRAFT ANALYSIS (AAA)

WEIGHT SIZING	GEOMETRY	DRAG POLAR	WEIGHT & BALANCE	PERF. ANALYSIS	DYNAMICS	COST ANALYSIS	H E L P
PERF. SIZING	HIGH LIFT	STAB. & CONTROL	INST. THRUST	S&C DERIVATIVES	CONTROL	DATA BASE	Q U I T

CLASS-I WEIGHT & BALANCE ANALYSIS OPTIONS

WEIGHT ESTIMATE	WEIGHT BREAKDOWN	LOADING SCENARIO	C.G EXCURSION	READ DATA	R E T U R N

C.G EXCURSION OPTIONS

X - DIRECTION	Y - DIRECTION	Z - DIRECTION	R E T U R N

PLOT OPTIONS

SET PLOT AXIS	REPAINT SLOWLY	DRAW A TANGENT	READ OFF GRAPH	R E P A I N T	SEND TO PLOTTER	PARTIAL PLOT	D O N E

ITEM (I)	LOAD	UNLOAD
1- EMPTY WEIGHT	1	13
2- CREW	13	11
3- TRAPPED FUEL and OIL (W tfo)	2	12
4- MISSION FUEL GROUP 1	10	3
5- MISSION FUEL GROUP 2	3	10
6- PASSENGER GROUP 1	4	9
7- PASSENGER GROUP 2	5	8
8- PASSENGER GROUP 3	6	7
9- PASSENGER GROUP 4	7	6
10- BAGGAGE	8	5
11- CARGO	9	4
12- MILITARY LOAD GROUP 1	11	1
13- MILITARY LOAD GROUP 2	12	2

--- < PICKED VALUES >---

X_cg = 567.7755
W = 220050.0000

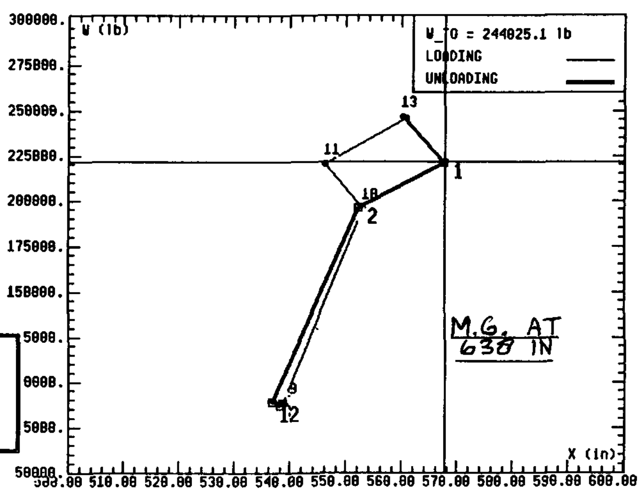


Figure 18 Loading and Unloading Sequence and Weight Versus C.G. Excursion Diagram for the ASB

DATA BASE FILE : ASB

ADVANCED AIRCRAFT ANALYSIS (AAA)

WEIGHT SIZING	GEOMETRY	DRAG POLAR	WEIGHT & BALANCE	PERF. ANALYSIS	DYNAMICS	COST ANALYSIS	H E L P
PERF. SIZING	HIGH LIFT	STAB. & CONTROL	INST. THRUST	S&C DERIVATIVES	CONTROL	DATA BASE	Q U I T

OPEN LOOP DYNAMICS

LONGITUDINAL	LATERAL DIRECTIO	ROLL-PITCH COUPL	R E T U R N

LATERAL DIRECTIONAL CASE OPTIONS

T-FUNCTION	CHECK MODES	SENSITIVITY	R E T U R N

LATERAL DIR. TRANSFER FUNCTIONS

SIDE-SLIP	LATERAL DIRECTIO	SIE L	R E T U R N

COMPUTATION OF LATERAL DIR. TRANSFER FUNCTIONS INPUT PARAMETERS

C A L C U L A T E	T H E O R Y	S A V E O U T P U T	R E T U R N / Q U I T M O D U L E !!
S = 5100.00 ft^2	I_xx_B = 4635000. slg-ft2	C_l_p = -0.3500	C_l_d_A = 0.0500 1/rad
Altitude = 40000. ft	I_zz_B = 5919000. slg-ft2	C_l_r = 0.0700	C_n_d_A = -0.0050 1/rad
W_current = 210000.0 lb	I_xz_B = 0. slg-ft2	C_n_b = 0.0150 1/rad	C_l_d_R = 0.0000 1/rad
U_1 = 460.00 kts	C_y_b = -0.1500 1/rad	C_n_p = -0.0300	C_y_d_R = 0.0000 1/rad
Theta_1 = 1.00 deg	C_y_p = 0.0000	C_n_r = -0.0060	C_n_d_R = 0.0070 1/rad
Alpha_1 = 1.00 deg	C_y_r = 0.0000	C_n_T_b = 0.0000	
b = 171.90 ft	C_l_b = -0.0500 1/rad	C_y_d_A = 0.0000 1/rad	

OUTPUT PARAMETER

W/S = 41.17 psf	Y_r = 0.0000 ft/sec	N_T_b = 0.0000 1/s^2	Y_del_A = 0.0000 ft/s^2
q_bar = 102.04 psf	L_b = -1.7299 1/s^2	W_d = 0.7306 rad/s	N_del_R = 0.1096 1/s^2
I_xx_S = 4635391. slg-ft2	L_p = -1.3403 1/sec	Z_d = -0.0190	L_del_R = 0.0000 1/s^2
I_zz_S = 5918609. slg-ft2	L_r = 0.2600 1/sec	ROLL_TC = 0.704 sec	Y_del_R = 0.0000 ft/s^2
I_xz_S = -22405. slg-ft2	N_b = 0.4064 1/s^2	SPIRAL_TC = -100.000 sec	
Y_b = -21.1643 ft/s^2	N_p = -0.0899 1/sec	L_del_A = 1.7299 1/s^2	
Y_p = 0.0000 ft/sec	N_r = -0.0179 1/sec	N_del_A = -0.1354 1/s^2	

Figure 19 Lateral-Directional Stability Derivatives and Open Loop Dynamics of the ASB in the Cruise Configuration

of the module called S&C Derivatives (See Figure 1 and Item 10 in Table 1). To limit the size of this paper it will be assumed that the derivatives for the ASB configuration developed so far are available. Next, the dynamics module (See Figure 1 and Item 11 in Table 1) is invoked. Fig.19 shows a screendump of the dynamics module with the dimensionless stability derivatives already transferred to the input. By hitting the 'calculate' box on the screen, the AAA program determines the dimensional derivatives as well as the open loop modes of the airplane: see also Fig.19. It is seen that the dutch roll damping ratio and the spiral mode time constant are both unstable. This is not unexpected for a flying wing configuration. To determine where the airplane stands with regard to open loop handling qualities, the program gives a diagnosis relative to the three handling quality levels defined in MIL-F-8785B. Table 3 shows an example output for the ASB.

The designer must next determine whether or not stability augmentation systems can improve the dynamic behavior. Before engaging in a feedback loop analysis (which can be done with the module labeled: Control, Item 12 in Table 1), it is wise to determine the sensitivity of the design to its critical stability derivatives and/or its critical inertias. Examples of sensitivity plots versus the yaw damping derivative, C_{n_r} and the lateral stability derivative (dihedral effect), C_{l_β} are given in Figures 20 and 21. With the help of this information the designer can determine whether or not sufficient control power is available to achieve the required levels of augmentation. To keep the size of this paper within acceptable bounds, this was not further pursued.

7. Conclusions

It has been shown that the AAA code can be used to rapidly evolve a preliminary aircraft design from early weight sizing through open-loop dynamic stability and sensitivity analysis. A significant feature of the AAA code is that all this can be done by one person, without the help of any group of specialists. Therefore, a new design can be quickly developed and analyzed as to its feasibility with very small levels of manpower expended. The AAA code is also shown to be user-friendly: it guides the user step-by-step through the design/analysis process while providing help files to assist in the design decision making. In addition, the program has been equipped with help files accessed through the 'theory' sub-menu boxes. When these are invoked, all relevant equations are displayed on the screen. Figure 22 shows an example of this feature. Finally, at any point the user may wish to know what the definition is, associated with any given symbol. By hitting the INFO button on the calculator pad the appropriate definition is displayed on the screen. Figure 23 provides an example.

8. References

1. Malaek, S.M.B.; Development of a System of Interactive Computer Programs for Airplane Conceptual Design and Advanced Airplane Analysis; Ph.D. Dissertation, The University of Kansas, 1989.

2. Malaek, S.M.B., Gerren, D. and Roskam, J.; User's Manual for the Advanced Aircraft Analysis Program, The University of Kansas, May, 1990.

3. Roskam, J.; Airplane Design, Part I: Preliminary Sizing of Airplanes, 1989.

4. Roskam, J.; Airplane Design, Part II: Preliminary Configuration Design and Integration of the Propulsion System, 1989.

5. Roskam, J.; Airplane Design, Part III: Layout Design of Cockpit, Fuselage, Wing and Empennage: Cutaways and Inboard Profiles, 1989.

6. Roskam, J.; Airplane Design, Part IV: Layout Design of Landing Gear and Systems, 1989.

7. Roskam, J.; Airplane Design, Part V: Component Weight Estimation, 1989.

8. Roskam, J.; Airplane Design, Part VI: Preliminary Calculation of Aerodynamic,Thrust and Power Characteristics, 1987.

9. Roskam, J.; Airplane Design, Part VII: Determination of Stability, Control and Performance Characteristics: FAR and Military Requirements, 1988.

10. Roskam, J.; Airplane Design, Part VIII: Airplane Cost Estimation: Design, Development, Manufacturing and Operating, 1990.

<u>Note:</u> References 3 - 10 are available from: Roskam Aviation and Engineering Corporation, Route 4, Box 274, Ottawa, Kansas, 66067, USA

Table 3 Diagnosis of Handling Quality Levels for the ASB Design

```
              A D V A N C E D       A I R P L A N E       A N A L Y S I S
 --------------------------------------------------------------------------------
       INPUT / OUTPUT  FOR :  CHECKING LATERAL. DIR MODES
 --------------------------------------------------------------------------------

AIRPLANE CLASS ACCORDING TO MIL-8785-B                           I  CLASS III
MAXIMUM AILERON DEFLECTION                                       I    20.0000 deg
DIMENSIONAL STABILITY DERIVATIVE  L_del_A                        I     6.7876 1/sec^2
DIMENSIONAL STABILITY DERIVATIVE  L_p                            I    -5.2589 1/sec
MAX BANK ANGLE TO MAX SIDE-SLIP ANGLE     PHI(S)/B(S) @D         I     0.8934
DUTCH ROLL FREQUENCY                                             I     1.4533 rad/sec
DUTCH ROLL DAMPING RATIO                                         I     0.0555
ROLL TIME CONSTANT                                               I     0.1893 sec
SPIRAL TIME CONSTANT                                             I  -100.0000 sec
TIME TO DOUBLE THE AMPLITUDE IN SPIRAL                           I   69.3 sec


* ACCORDING TO THE MIL-F 8785-B IN FLIGHT PHASE < A > :
1- DUTCH ROLL DAMPING RATIO  SATISFIES THE  LEVEL 2  REQUIREMENTS.
2- DUTCH ROLL NATURAL FREQUENCY  SATISFIES THE  LEVEL 1  REQUIREMENTS.
3- SPIRAL MODE SATISFIES THE  LEVEL 1  REQUIREMENTS.
4- ROLL TIME CONSTANT SATISFIES THE LEVEL 1  REQUIREMENTS.

FOR LEVEL 1 :1- MAXIMUM ROLL TIME CONSTANT =  1.4 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  1.5 sec
FOR LEVEL 2 :1- MAXIMUM ROLL TIME CONSTANT =  3.0 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  2.0 sec
FOR LEVEL 3 :1- MAXIMUM ROLL TIME CONSTANT = 10.0 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  3.0 sec
PHI(t) =   33.8 deg in  1.5 sec

5- ROLL PERFORMANCE SATISFIES THE LEVEL 1  REQUIREMENTS.


* ACCORDING TO THE MIL-F 8785-B IN FLIGHT PHASE < B > :
1- DUTCH ROLL DAMPING RATIO  SATISFIES THE  LEVEL 2  REQUIREMENTS.
2- DUTCH ROLL NATURAL FREQUENCY  SATISFIES THE  LEVEL 1  REQUIREMENTS.
3- SPIRAL MODE SATISFIES THE  LEVEL 1  REQUIREMENTS.
4- ROLL TIME CONSTANT SATISFIES THE LEVEL 1  REQUIREMENTS.

FOR LEVEL 1 :1- MAXIMUM ROLL TIME CONSTANT =  1.4 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  2.0 sec
FOR LEVEL 2 :1- MAXIMUM ROLL TIME CONSTANT =  3.0 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  3.0 sec
FOR LEVEL 3 :1- MAXIMUM ROLL TIME CONSTANT = 10.0 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  4.0 sec
PHI(t) =   46.7 deg in  2.0 sec

5- ROLL PERFORMANCE SATISFIES THE LEVEL 1  REQUIREMENTS.


* ACCORDING TO THE MIL-F 8785-B IN FLIGHT PHASE < C > :
1- DUTCH ROLL DAMPING RATIO  SATISFIES THE  LEVEL 2  REQUIREMENTS.
2- DUTCH ROLL NATURAL FREQUENCY  SATISFIES THE  LEVEL 1  REQUIREMENTS.
3- SPIRAL MODE SATISFIES THE  LEVEL 1  REQUIREMENTS.
4- ROLL TIME CONSTANT SATISFIES THE LEVEL 1  REQUIREMENTS.

FOR LEVEL 1 :1- MAXIMUM ROLL TIME CONSTANT =  1.4 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  2.5 sec
FOR LEVEL 2 :1- MAXIMUM ROLL TIME CONSTANT =  3.0 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  3.2 sec
FOR LEVEL 3 :1- MAXIMUM ROLL TIME CONSTANT = 10.0 sec
             2- MINIMUM ROLL PERFORMANCE    =  30.0 deg  IN  4.0 sec
PHI(t) =   59.6 deg in  2.5 sec

5- ROLL PERFORMANCE SATISFIES THE LEVEL 1  REQUIREMENTS.
```

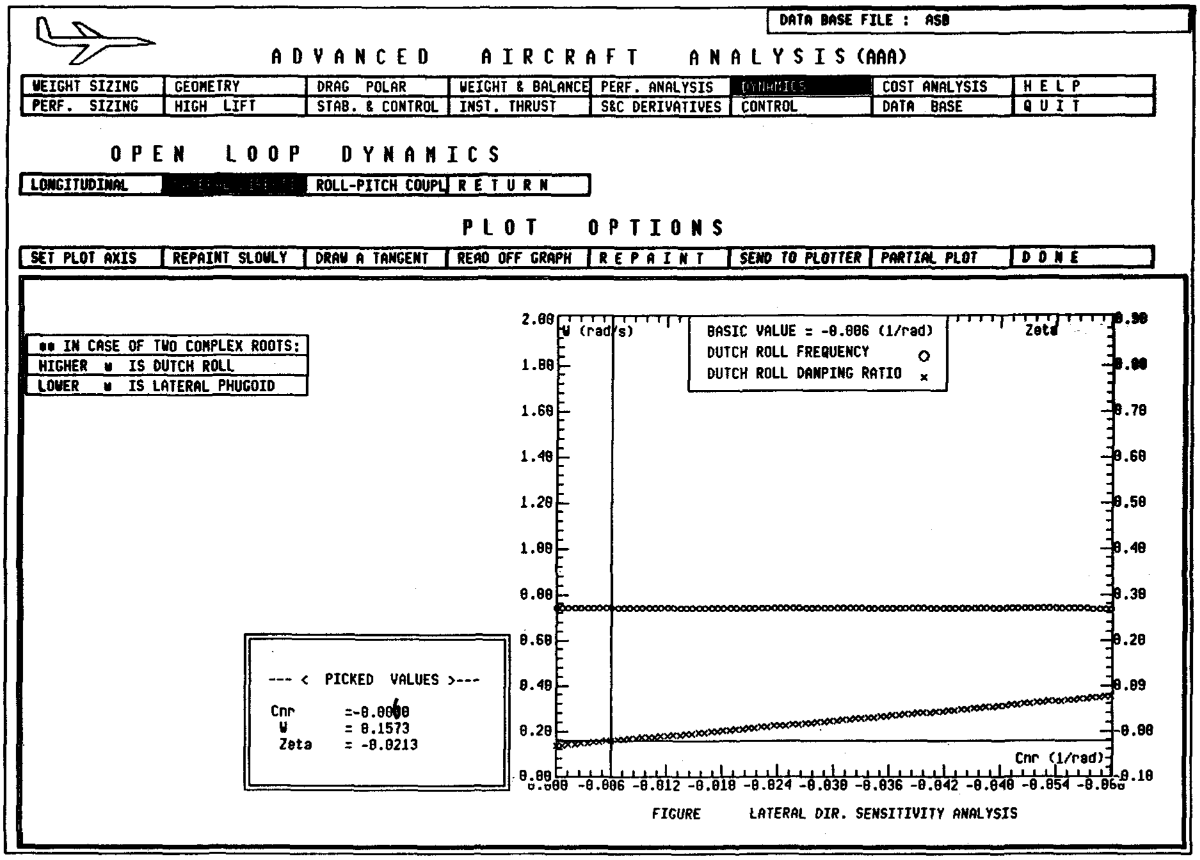


Figure 20 Sensitivity of Open Loop Dynamics to Changes in the Yaw Damping Derivative

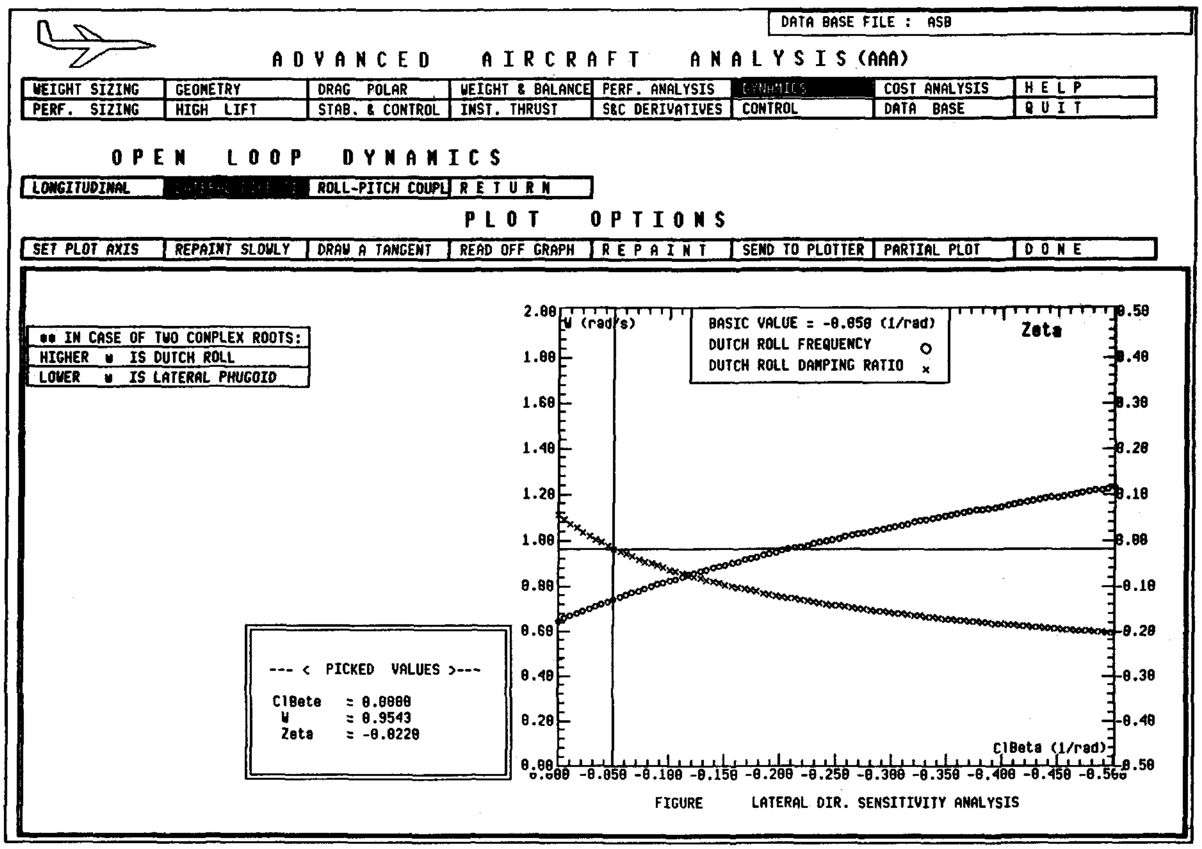


Figure 21 Sensitivity of Open loop Dynamics to Changes in the Rolling Moment due to Sideslip Derivative

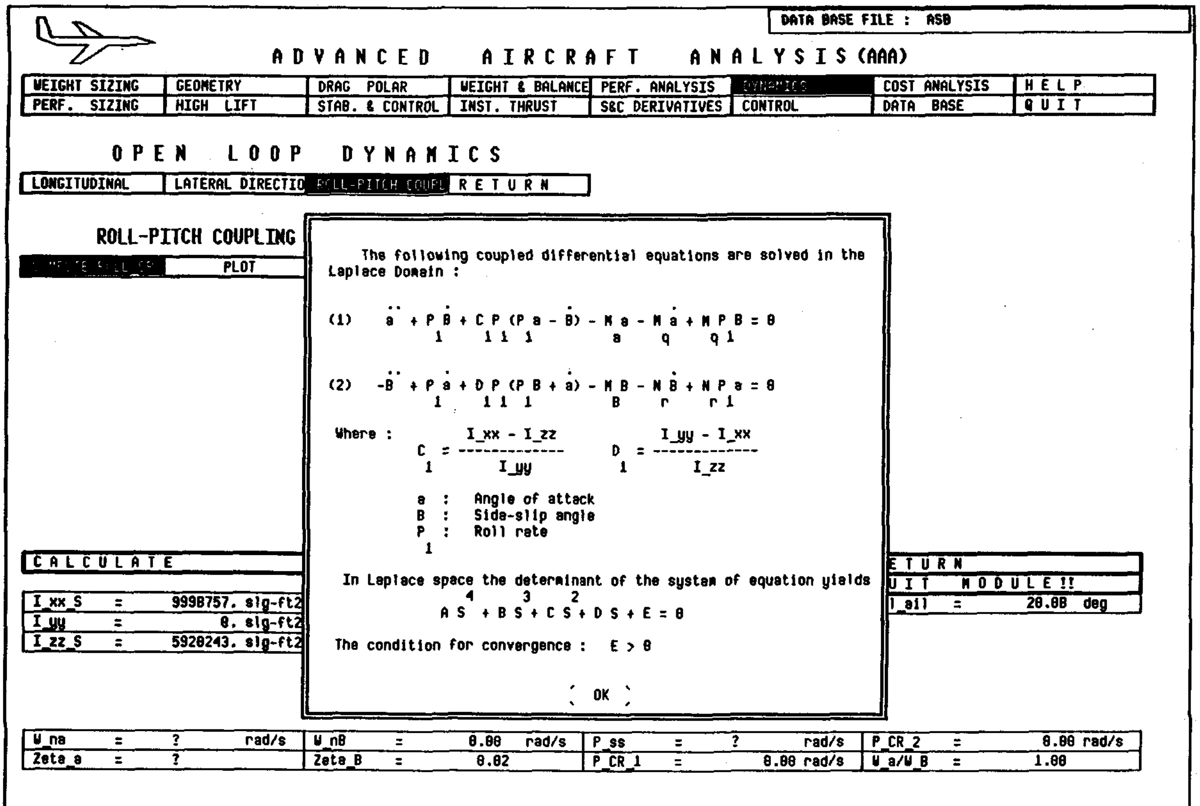


Figure 22 Example of 'THEORY' Help File

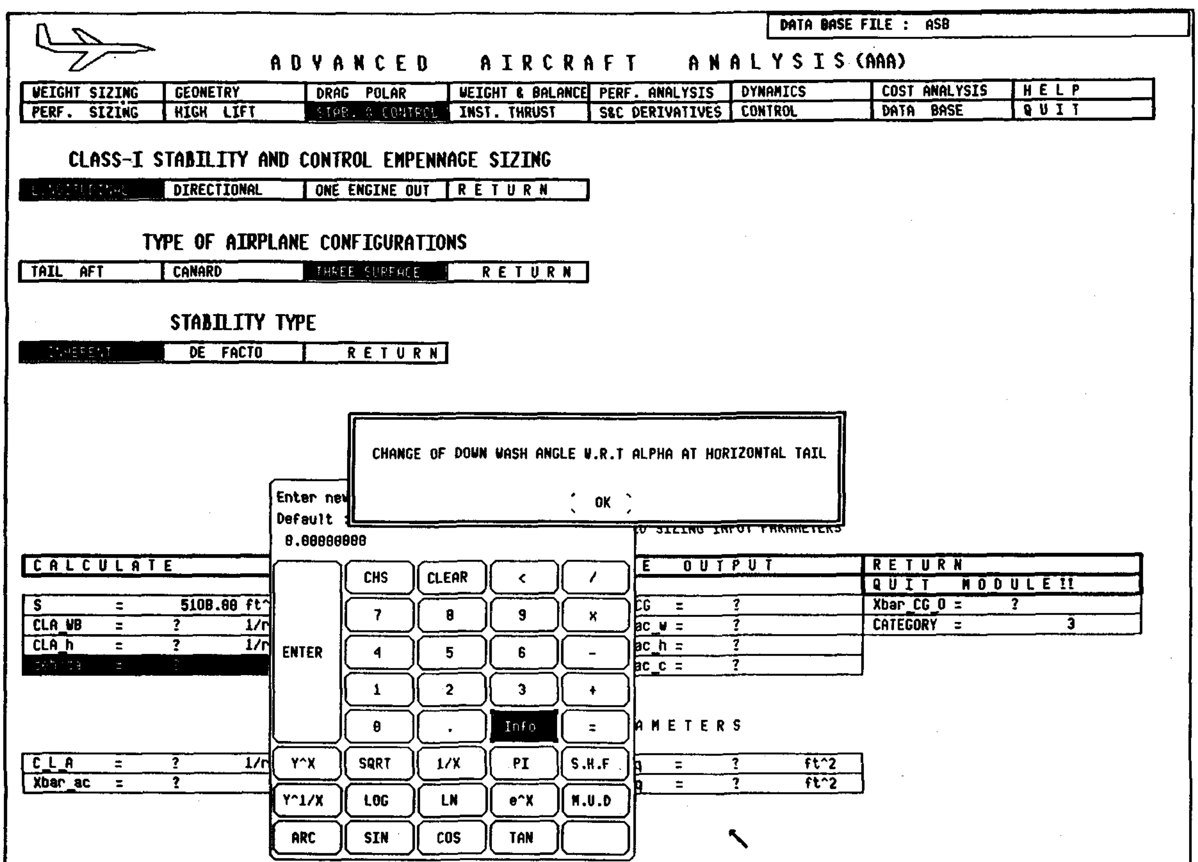


Figure 23 Example of the Use of INFO in the Definition of a Quantity