(T. Galloway)

GASP - GENERAL AVIATION SYNTHESIS PROGRAM

NASA-CR-152303

VOLUME II - GEOMETRY

PART 1 - THEORETICAL DEVELOPMENT

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II.1 GEOMETRY

The gross geometric characteristics of the aircraft under study are specified to the subroutine SIZE which follows the sequence shown in Figure II.1.1. The principal quantities specified are both geometric (lengths and areas) and operational (altitude, Mach number). The sequence of computations carried out by SIZE is controlled by the parameter NPC which is passed into SIZE by COMMON along with the input quantities. When NPC=0 the computation is initialized. Subsequently, NPC is set to 2,and the program advances through the geometric computations following the sequence shown in Figure II.1.1.

II.1.1 Fuselage Geometry

The fuselage is assumed to consist of four components as illustrated in Figure II.1.2: a nose cone, a pilot's compartment, a cylindrical cabin, and a tail cone. The external cabin width is found in inches as

$$W_C = S_{AB} * W_S + A_S * W_{AS} + 12 \qquad \text{(II.1.1)}$$

where

S_{AB} = number of passenger seats abreast

W_S = seat widths, in

A_S = number of aisles

W_{AS} = aisle width, in

and where the cabin walls are assumed to six inches thick on each side. This dimension is next converted to feet,

$$H_C = S_{WF} = W_C/12 \qquad \text{(II.1.2)}$$

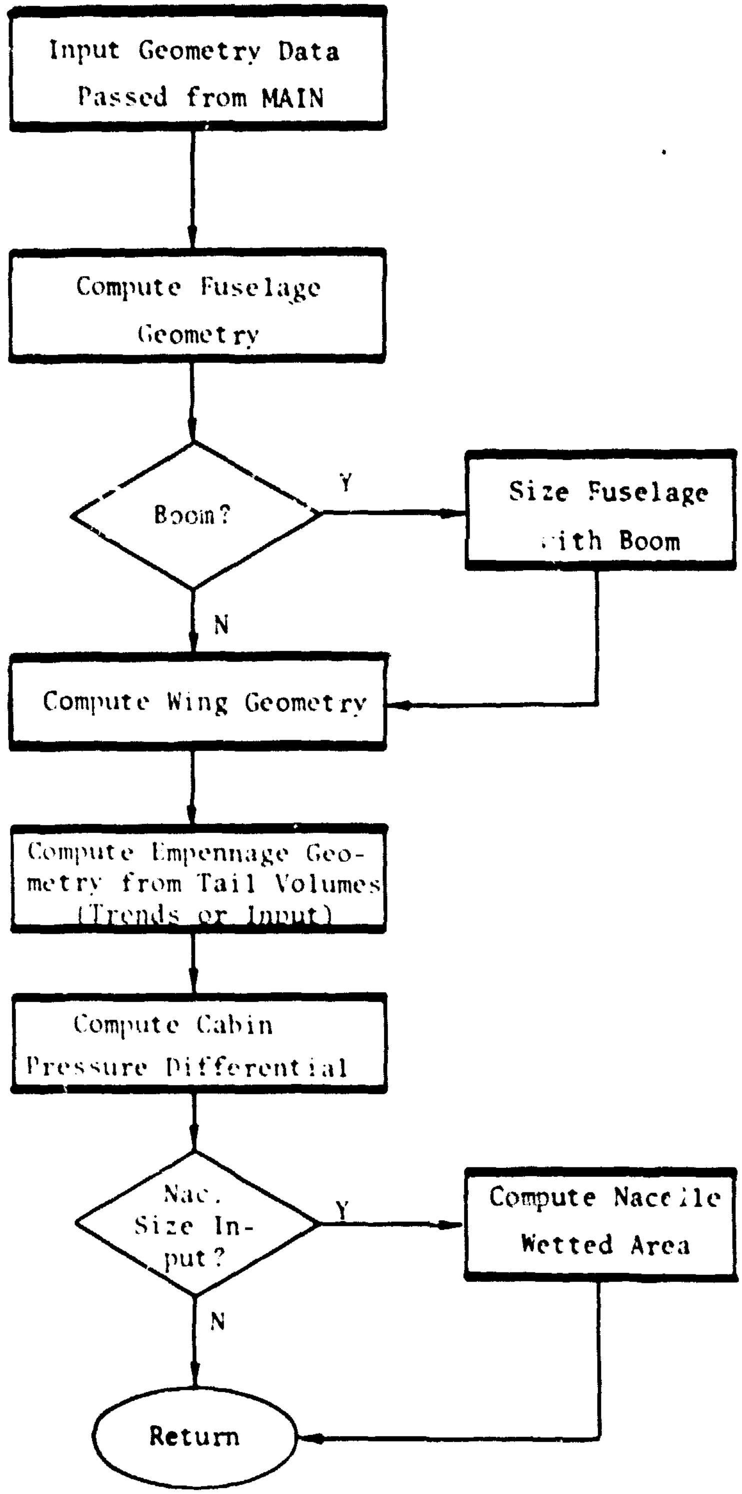


FIGURE II.1.1 - SUBROUTINE SIZE, COMPUTATIONAL FLOW

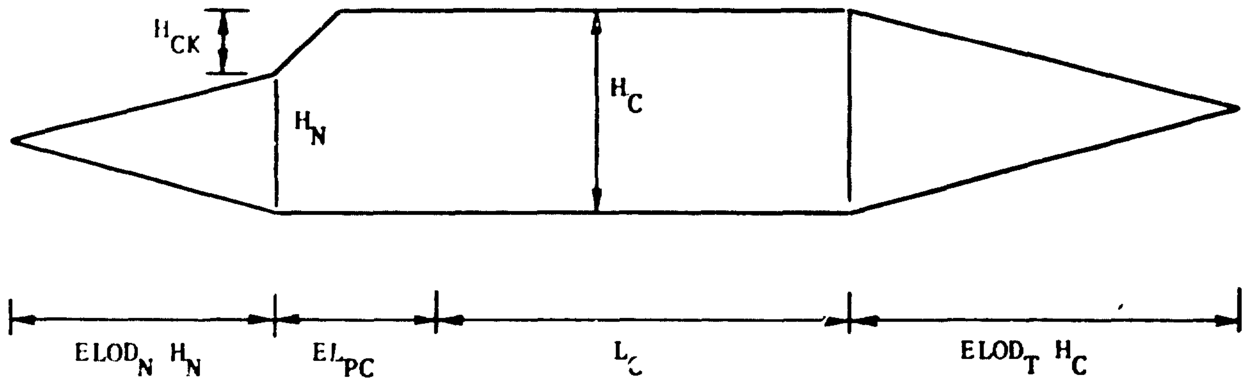


FIGURE II.1.2 - FUSELAGE GEOMETRY MODEL

and the cabin length is estimated in feet as

$$L_C = (P_{AX} - 1)P_S/(12\ S_{AB}) \tag{II.1.3}$$

where

P_{AX} = number of passengers -1

P_S = seat pitch, in.

Next, the nose cone diameter is found as the difference of the body diameter H_C and the windshield height,

$$H_N = H_C - H_{CK} \tag{II.1.4}$$

as shown in Figure II.1.2, and if $S_{AB} \geq 2$, the cabin computations are complete. If $S_{AB} < 2$, (in-line seating) however, the cabin length is found by

$$L_C = P_{AX} * P_S/12. \tag{II.1.5}$$

and the nose and tail cone diameters are

$$H_N = S_{WF} \tag{II.1.6}$$

$$H_C = H_N + H_{CK} \tag{II.1.7}$$

where H_{CK} is the input windshield height.

The total fuselage length is then given by the sum

$$EL_F = ELOD_N * H_N + EL_{PC} + L_C + ELOD_T * H_C \tag{II.1.8}$$

where

$ELOD_N$ = length to diameter of nose cone

EL_{PC} = length of pilot's cockpit

$ELOD_T$ = length to diameter of tail cone

The external fuselage wetted area is next given by

$$S_F = H_C[2.5(ELOD_N * H_N + EL_{PC}) + 3.14L_C + 2.1\ ELOD_T * H_C] \qquad (II.1.9)$$

where the first and last numerical coefficients approximate the effects of the nose and tail taper ratios. If the configuration incorporates a tail boom instead of a cone (K_{CONFG}=1), then the boom length is

$$EL_{BM} = EL_F - EL_{FFC} \qquad (II.1.10)$$

where

$$EL_{FFC} = ELOD_N * H_N + EL_{PC} + L_C \qquad (II.1.11)$$

The fuselage wetted area in this case does not include the tail cone portion, i.e.,

$$S_F = H_C[2.5(ELOD_N * H_N + EL_{PC}) + 3.14 * L_C] \qquad (II.1.12)$$

and the boom area is found assuming it to be cylindrical in shape:

$$S_{WBM} = 3.14\ EL_{BM}^2/BM_{LOD} \qquad (II.1.13)$$

where BM_{LOD} = tail boom length to diameter ratio. The cross sectional area of the tail boom is then given as

$$XAR_{BM} = S_{WBM}/(4. * BM_{LOD}) \qquad (II.1.14)$$

II.1.2 Wing Geometry

The wing area and span are given by

$$S_W = W_G/W_{GS} \qquad (II.1.15)$$

$$B = \sqrt{AR * S_W} \quad (II.1.16)$$

where

W_G = aircraft gross weight, lb.

W_{GS} = wing loading of aircraft, lb per sq ft

AR = aspect ratio of wing

Wing root chord at the fuselage center line is obtained from

$$CR_{CLW} = 2\,S_W/[B(1+S_{LM})] \quad (II.1.17)$$

and the mean aerodynamic chord,

$$CBAR_W = (2/3)CR_{CLW}[1 + S_{LM} - S_{LM}/(1 + S_{LM})] \quad (II.1.18)$$

where

S_{LM} = taper ratio of wing (tip chord/root chord)

The leading edge sweep angle is found as a function of the input quarter chord sweep angle (DLM_{C4})

$$T_{SWPLE} = \tan(SWPL_E) = (1 - S_{LM})/[AR(1 + S_{LM})] + \tan(DLM_{C4}) \quad (II.1.19)$$

and a similar expression gives the trailing edge sweep as

$$T_{SWPTE} = \tan(SWP_{TE}) = 3(S_{LM} - 1)/[AR(1 + S_{LM})] + \tan(DLM_{C4}) \quad (II.1.20)$$

The exposed root chord of the wing is next found as

$$C_{ROOTW} = CR_{CLW} - H_P + F_{HP} * T_{SWEPTE}/2 \quad (II.1.21)$$

where

$$H_P = F_{HP}\,T_{SWPLE}/2 \quad (II.1.22)$$

$$F_{HP} = S_{WF}/\sqrt{2} \tag{II.1.23}$$

as shown in Figure II.1.3.

II.1.3 Empennage Geometry

Preliminary tail sizing is performed in SIZE based on tail volume coefficients. Subsequent tail sizing may be performed in subroutine WGHT and/or TAIL according to the tail sizing option (LCWING).

Volume coefficients for the vertical and horizontal tails may be input as VBARVX and VBARHX respectively. Otherwise they are determined as empirical functions of fuselage and wing geometry as illustrated in Figure II.1.4:

$$V_{BARH} = .85\ EL_F\ S_{WF}^{\ 2}/(S_W\ CBAR_W) + C_{H1} \tag{II.1.24}$$

$$V_{BARV} = .336 EL_F\ H_C^{\ 2}/(S_W\ B) + C_{V1} \tag{II.1.25}$$

where

$$\left.\begin{aligned} C_{H1} &= .43 - .38 \times S_{AH} \\ C_{V1} &= .07 - .0434 \times S_{AH} \end{aligned}\right\} \text{Y Intercepts, Figure II.1.4)} \tag{II.1.26}$$

where S_{AH} is defined in Figure II.1.5. In particular

$S_{AH} = 0$, for low tail

$S_{AH} = 1$, for T tail

The horizontal and vertical tail areas are then computed from the volume coefficients:

$$S_{HT} = V_{BARH}\ S_W\ C_{H2} \tag{II.1.27}$$

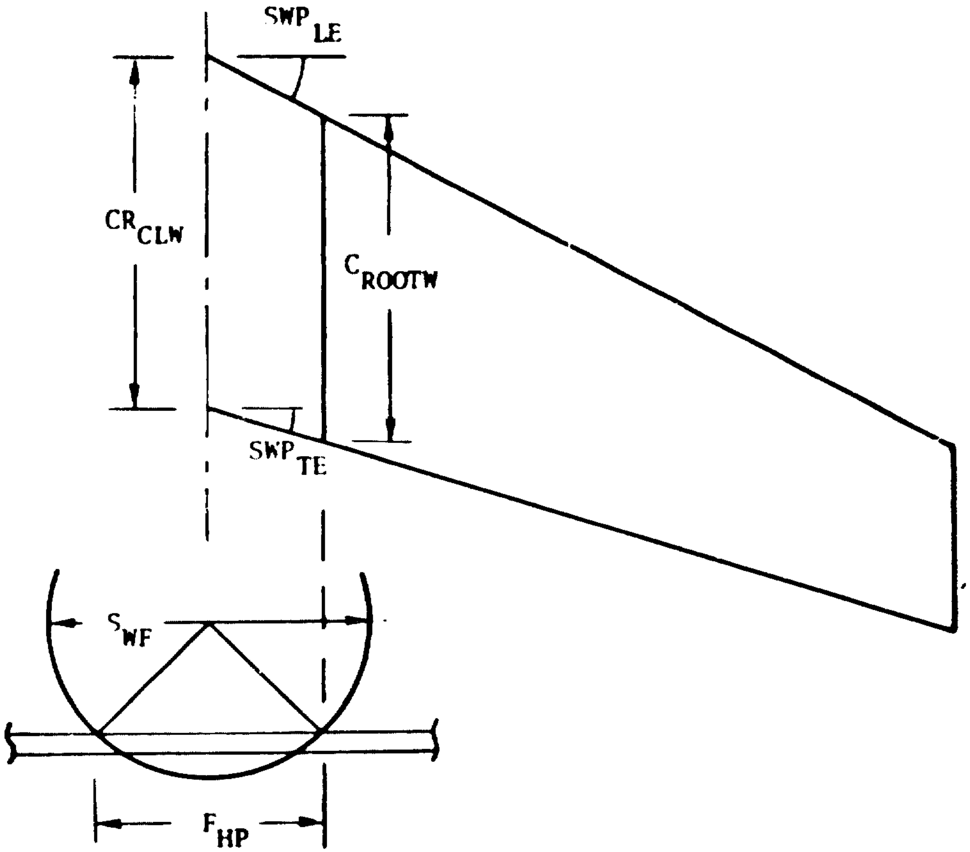
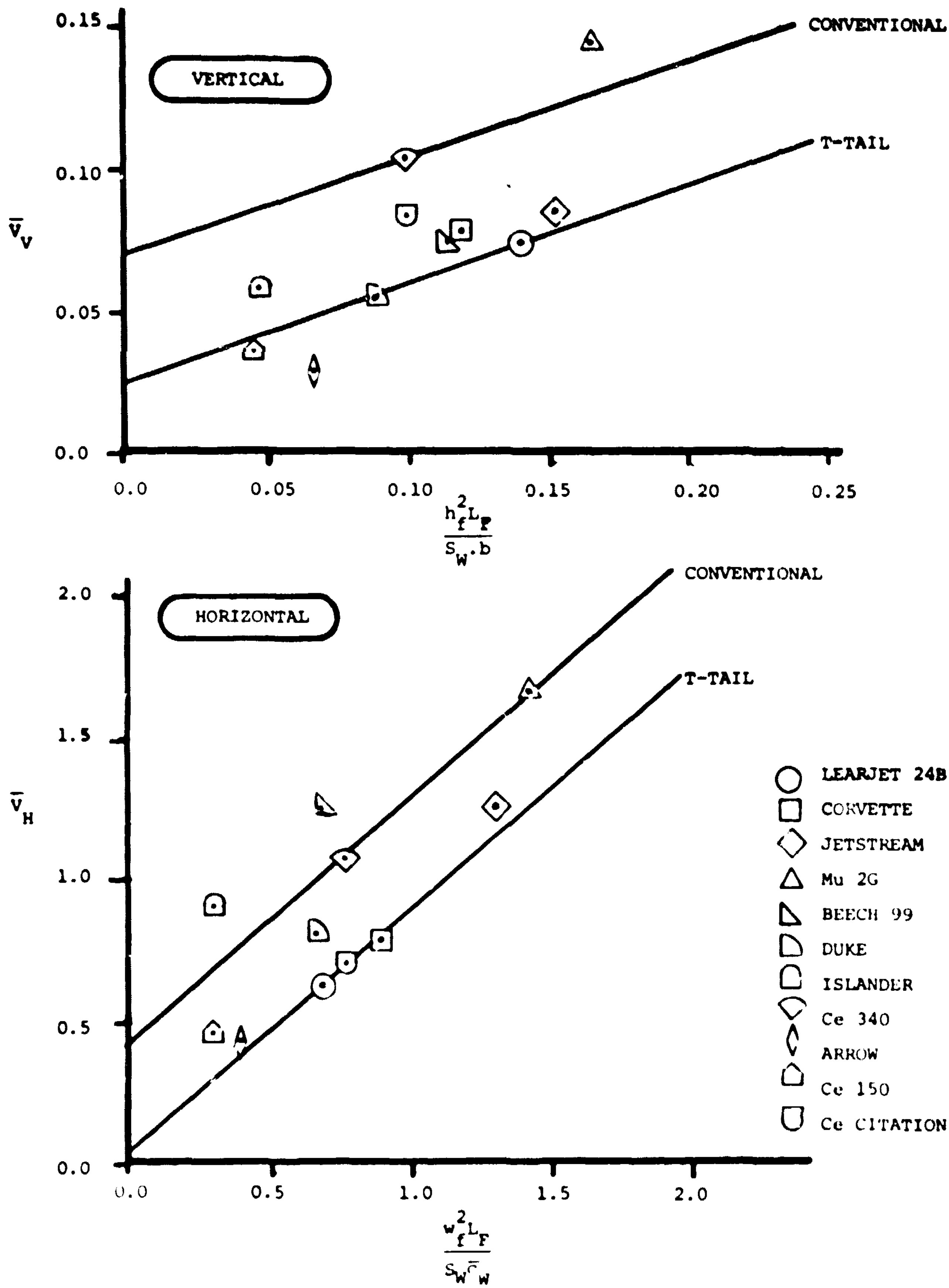


FIGURE II.1.3 - WING-FUSELAGE GEOMETRY

FIGURE II.1.4 - TAIL VOLUMES FOR REPRESENTATIVE AIRCRAFT DESIGNS



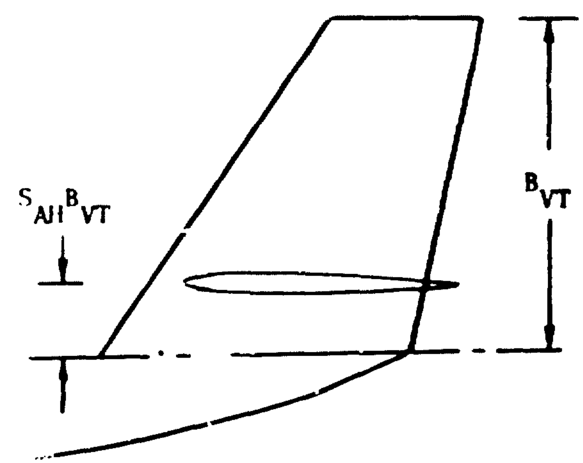


FIGURE II.1.5 - VERTICAL TAIL GEOMETRY

$$S_{VT} = V_{BARV} S_W C_{V2} \tag{II.1.28}$$

where

$$C_{H2} = \frac{\text{WING MAC}}{\text{horizontal tail moment aim}} = .271 + .0955\ S_{AH} \tag{II.1.29}$$

or input as COELTH

$$C_{V2} = \frac{\text{wing span}}{\text{vertical tail moment aim}} = 1.862 + .338\ S_{AH} \tag{II.1.30}$$

or input as BOELTV

The horizontal tail area is constrained to be less than or equal to $S_W/2$; if S_{HT} as computed above exceeds this limit, <u>both</u> tail volume coefficients are re-computed:

$$V_{BARH} = .5/C_{H2} \tag{II.1.31}$$

$$V_{BARV} = .1\ V_{BARH} \tag{II.1.32}$$

New tail areas are then computed based on these volume coefficients.

The horizontal and vertical tail moment arms are computed from

$$EL_{TH} = V_{BARH} S_W C_{BARW}/S_{HT}$$

$$EL_{TV} = V_{BARV} S_W B/S_{VT}$$

Once the tail areas are determined, various geometric characteristics of each tail surface are computed in the same manner as was done for the wing. For example, for the horizontal tail

$$\text{span:} \quad B_{HT} = (S_{HT} AR_{HT})^{1/2} \tag{II.1.33}$$

root chord: $CR_{CLHT} = 2 \times S_{HT}/[B_{HT}(1+SL_{MH})]$ (II.1.34)

mean aero chord: $CR_{CLHT} = 2 \times S_{HT}/[B_{HT}(1+SL_{MH})]$ (II.1.35)

where SL_{MH} is the horizontal tail taper ratio. Identical equations apply to the vertical tail.

II.1.4 Cabin Pressurization

The subroutine TPALT is called twice to give static pressures inside and outside the fuselage cabin. The inside pressure is specified by the cabin altitude of 8000 feet and the outside by the cruise altitude, HNCRU, and these altitudes are associated respectively with the pressures P_{CAB} and P_{AMBC}. The input pressure differential DEL_P is then checked to see if it is sufficient to maintain the 8000 ft cabin at the design cruise altitude; if not, the proper DEL_p is then calculated.

II.1.5 Nacelle Area

Finally, if the engine nacelle size is input, $K_{NAC} = 2$, the total nacelle wetted area is computed in square feet as

$$S_N = EN_P * PI * D_{BARN} * EL_N \quad \text{(II.1.36)}$$

where

EN_P = number of engines

D_{BARN} = average nacelle diameter, ft

EL_N = nacelle length, ft

PI = 3.1416

II.1.6 Geometry Summary

The calculations carried out by subroutine SIZE have defined the vehicle geometry with sufficient detail to permit the design to proceed to definition of aerodynamics, propulsive, weights, performance and economic characteristics. Section II.2 of this report defines all input parameters and output characteristics of subroutine SIZE together with the computer program symbology employed.

GASP - GENERAL AVIATION SYNTHESIS PROGRAM

VOLUME II - GEOMETRY

PART 2 - USER'S MANUAL

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II.2 GEOMETRY MODEL USER'S MANUAL

Subroutine SIZE is a relatively short program (110 cards) which requires about 35 input parameters related to the aircraft geometry and the design flight condition. These input variables are passed to SIZE from the MAIN control program through COMMON. The 36 output parameters are principally lengths and areas calculated according to the equations discussed in earlier sections of this volume. Most of the input data are specified by the user, since this is the first subroutine called by program MAIN, and no other subroutines have yet generated numerical results. However, many of the output quantities of SIZE will be needed as input to subsequent subroutines.

In addition to the input parameters two internally generated control parameters are employed in SIZE. These are NPC which determines the SIZE function as follows:

NPC = 1, 2 Geometry Computation

= 3 Geometry Initialization

and ALTCAB = Cabin design altitude (Nominally set to 8000 feet in data statement

A list of input parameters to SIZE is presented in Figure II.2.1. Characteristics computed by subroutine SIZE are tabulated in Figure II.2.2.

FIGURE II.2.1 SUBROUTINE SIZE INPUT PARAMETERS

VARIABLE	DESCRIPTION
AR	aspect ratio of wing
ARHT	aspect ratio of horizontal tail
ARVT	aspect ratio of vertical tail
AS	number of aisles
BMLOD	ratio of boom length to diameter
BOELTV	ratio of wing span to vertical tail moment arm
COELTH	ratio of wing chord to horizontal tail moment arm
DBARN	average nacelle diameter, ft
DELP	pressure difference, cabin minus ambient, lb per sq ft
DLMC4	quarter chord sweep angle, deg.
ELN	nacelle length, ft
ELODN	ratio of length to diameter of nose cone
ELODT	ratio of length to diameter of tail cone
ELPC	length of pilot's cockpit
ENP	number of engine phylons
HCK	cockpit height, ft
HNCRU	cruise altitude, ft
KCONFG	0, standard fuselage 1, tail boom fuselage
KNAC	0, nacelle drag computed as penalty to engine performance (turbofan only 1, nacelle drag part of aerodynamic drag; nacelle sized by engine 2, same as 1 except nacelle size input as DBARN, ELN
PAX	number of passengers

FIGURE II.2.1 SUBROUTINE SIZE INPUT PARAMETERS (Continued)

VARIABLE	DESCRIPTION
PS	seat pitch, inches
SAB	number of passenger seats abreast
SAH	dimensionless measure of horizontal tail height
SLM	taper ratio of wing
SLMH	taper ratio of horizontal tail
SLMV	taper ratio of vertical tail
TCR, TCT	thickness to chord ratios at root and tip of wing
VBARHX	horizontal tail sizing parameter
VBARVX	vertical tail sizing parameter
WAS	aisle width, inches
WG	gross weight, lb
WGS	wing loading, lb per sq ft
WS	seat width, inches

FIGURE II.2.2 SUBROUTINE SIZE - OUTPUT CHARACTERISTICS

VARIABLE	DESCRIPTION
B	wingspan, ft
BD	body diameter, ft
BHT	span of horizontal tail, ft
BVT	span of vertical tail, ft
CBARHT	mean aerodynamic chord of horizontal tail, ft
CBARVT	mean aerodynamic chord of vertical tail, ft
CBARW	mean aerodynamic chord of wing, ft
CRCLW	wing chord at wing centerline, ft
CROOTW	wing root chord, ft
ELP	cabin pressure differential, lb per sq in
ELBM	tail boom length, ft
ELF	fuselage length, ft
ELFFC	fuselage length forward of tail boom, ft
ELTH	horizontal tail moment arm, ft
ELTV	vertical tail moment arm, ft
HC	external cabin width, ft
HN	nose cone diameter, ft
LC	cabin length, ft
SF	total fuselage wetted area, sq ft
SHT	area of horizontal tail, sq ft
SN	total nacelle wetted area, sq ft
SVT	area of vertical tail, sq ft.
SW	total wetted area, sq ft

FIGURE II.2.2 SUBROUTINE SIZE - OUTPUT CHARACTERISTICS

VARIABLE	DESCRIPTION
SWF	width of fuselage
SWBM	wetted area of fuselage boom, sq ft
SWPLE	wing leading edge
SWPTE	wing trailing edge sweep angle, rad
TC	thickness to chord ratio of wing
VBARH	dimensionless horizontal tail volume parameter
VBARV	dimensionless vertical tail volume parameter
XARBM	tail boom cross-sectional area, sq ft

GASP - GENERAL AVIATION SYNTHESIS PROGRAM

VOLUME II - GEOMETRY

PART 3 - PROGRAMMER'S MANUAL

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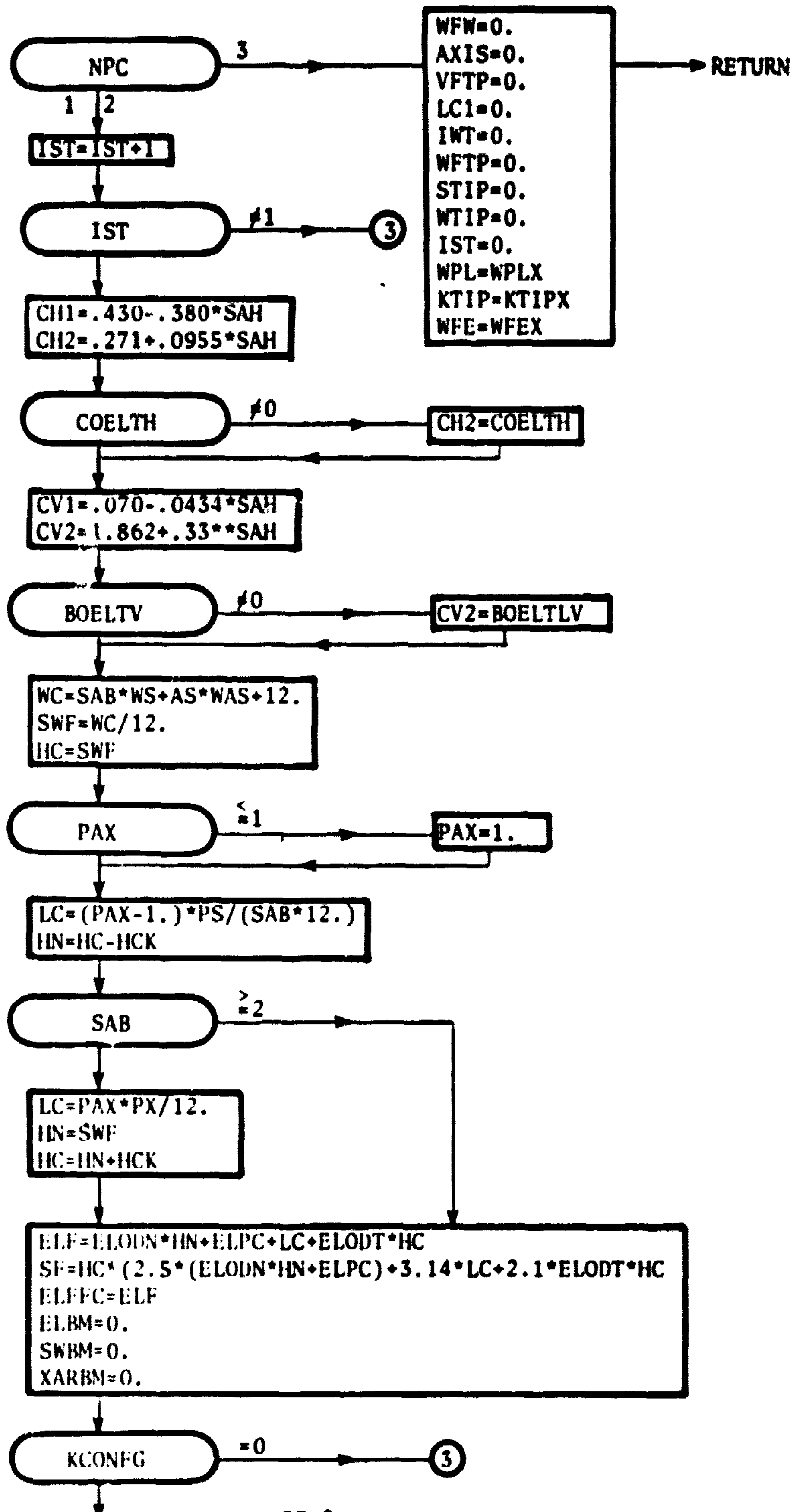
II.3 GEOMETRY MODEL PROGRAMMER'S MANUAL

The geometry module SIZE is the first operational subroutine to be called by MAIN, with NPC = 3. Input data passed from MAIN to SIZE by COMMON and NPC is changed to 2, and the subsequent call to SIZE results in geometric computations which follow the sequence discussed in Part 1 of this volume. No other subroutines are called by SIZE apart from the "utility" program TPALT, whicn provides atmospheric data. Subroutine TPALT and its function have been described in Volume I. As shown in the subsequent flow chart, Figure II.3.1, there exist no iterative loops in SIZE, and for this reason the computational sequence is particularly simple.

The equations employed in subroutine SIZE have been presented in Section II.1. The computer symbols employed in the routine, together with a description of input and output from SIZE have been presented in Section II.2.

FIGURE II.3.1 SUBROUTINE SIZE



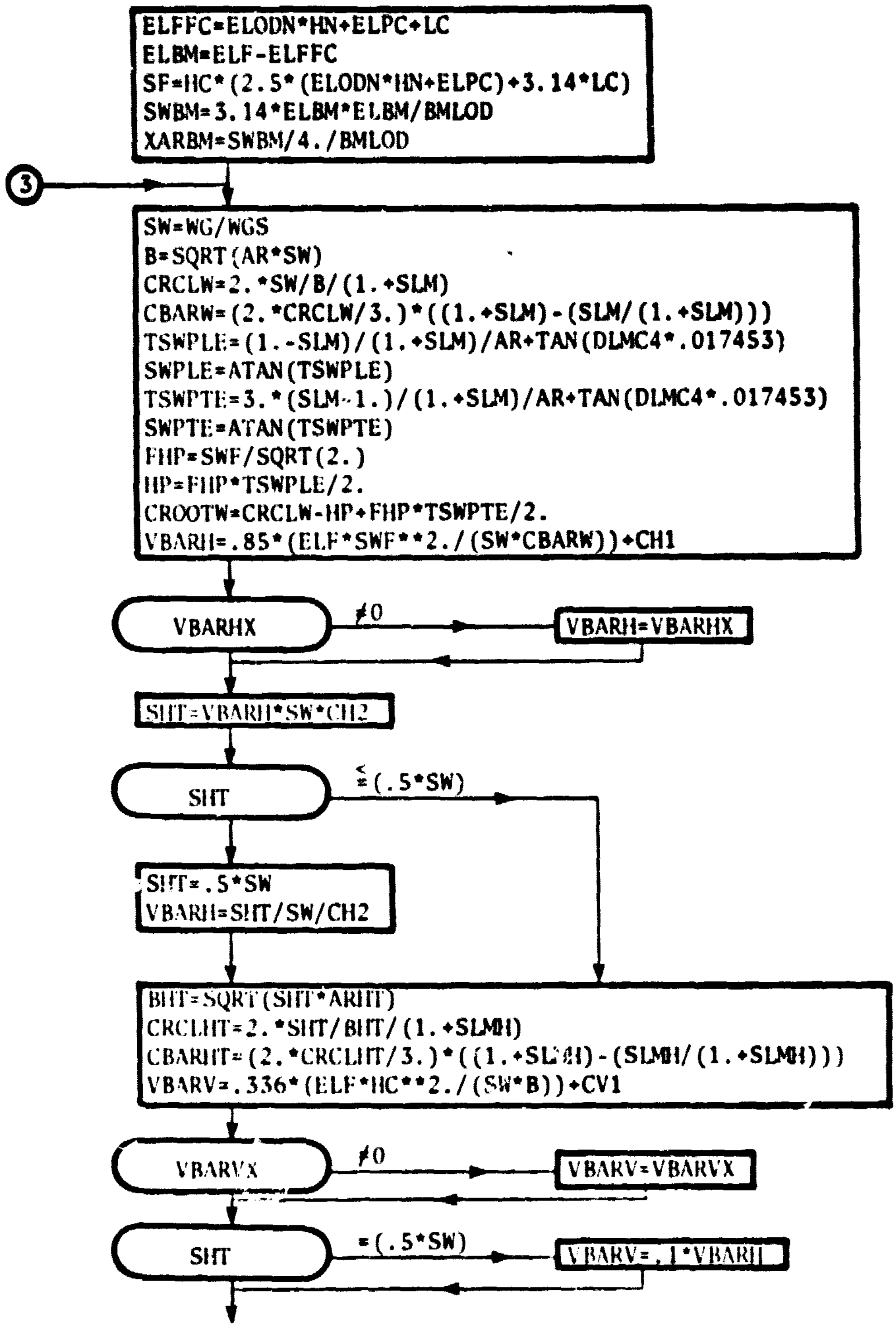

ELFFC=ELODN*HN+ELPC+LC
ELBM=ELF-ELFFC
SF=HC*(2.5*(ELODN*HN+ELPC)+3.14*LC)
SWBM=3.14*ELBM*ELBM/BMLOD
XARBM=SWBM/4./BMLOD
3
SW=WG/WGS
B=SQRT(AR*SW)
CRCLW=2.*SW/B/(1.+SLM)
CBARW=(2.*CRCLW/3.)*((1.+SLM)-(SLM/(1.+SLM)))
TSWPLE=(1.-SLM)/(1.+SLM)/AR+TAN(DLMC4*.017453)
SWPLE=ATAN(TSWPLE)
TSWPTE=3.*(SLM-1.)/(1.+SLM)/AR+TAN(DLMC4*.017453)
SWPTE=ATAN(TSWPTE)
FHP=SWF/SQRT(2.)
HP=FHP*TSWPLE/2.
CROOTW=CRCLW-HP+FHP*TSWPTE/2.
VBARH=.85*(ELF*SWF**2./(SW*CBARW))+CH1
VBARHX
≠0
VBARH=VBARHX
SHT=VBARH*SW*CH2
SHT
≤(.5*SW)
SHT=.5*SW
VBARH=SHT/SW/CH2
BHT=SQRT(SHT*ARHT)
CRCLHT=2.*SHT/BHT/(1.+SLMH)
CBARHT=(2.*CRCLHT/3.)*((1.+SLMH)-(SLMH/(1.+SLMH)))
VBARV=.336*(ELF*HC**2./(SW*B))+CV1
VBARVX
≠0
VBARV=VBARVX
SHT
=(.5*SW)
VBARV=.1*VBARH

FIGURE II.3.1 SUBROUTINE SIZE