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GASP - GENERAL AVIATION SYNTHESIS PROGRAM

NASA-CR-152303

VOLUME III - AERODYNAMICS

PART 1 - THEORETICAL DEVELOPMENT

(NASA-CR-152303-Vol-3-Pt-1) GASP- GENERAL AVIATION SYNTHESIS PROGRAM. VOLUME 3: AERODYNAMICS. PART 1: THEORETICAL DEVELOPMENT (Aerophysics Research Corp., Bellevue, Wash.) 103 p HC A06/MF A01

N81-19090

Unclas G3/05 15991

JANUARY 1978

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center
Moffett Field, California

Under

CONTRACT NAS 2-9352

AEROPHYSICS RESEARCH CORPORATION

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III.1 AERODYNAMICS

The aerodynamic subroutines are concerned with forces and moments as they vary with flight condition and attitude. The main program calls four programs which could broadly be termed aerodynamic in nature, as listed in Table III.1.1. These programs are of lengths indicated in the parentheses and call two others, CLIFT and DRAG, and this volume of the documentation will be concerned with descriptions of all of these seven subroutines.

III.1.1 Subroutine AERO - Equivalent Flat Plate and Wetted Areas

This subroutine is called by CTAER, and is principally concerned with a set of drag coefficients which are found by combining geometric descriptors with experimentally determined aerodynamics.

Drag is assumed to be composed of profile drag, lift-induced drag, and compressibility drag. Profile drag is the most complex portion, and for each airplane component the corresponding drag coefficient takes the form

$$\Delta C_{D_P} = C_K \, C_F \, F(Re)\,(S/S_W) \qquad (III.1.1)$$

where

C_K = geometry-dependent form factor

C_F = Mach number dependent skin friction coefficient at a reference Reynolds number of 10^7

$F(Re)$ = Reynolds number correlation factor

S/S_W = ratio of component area to wing reference area (fuselage and nacelle wetted areas and lifting surface planform areas).

AERO - COMPUTES COMPONENT EQUIVALENT FLAT PLATE AND WETTED AREAS AND PROFILE DRAG (130)

AEROUT - PRINTS AND PLOTS LOW AND HIGH SPEED DRAG POLARS (170)

CLIFT - DETERMINES LIFT COEFFICIENT OR ANGLE-OF-ATTACK (40)

DRAG - DETERMINES DRAG COEFFICIENT (90)

FLAPS - DETERMINES MAXIMUM LIFT COEFFICIENT AND DRAG INCREMENT FOR VARIOUS FLAP TYPES AND FLAP SETTINGS (350)

CTAER - DETERMINES REQUIRED LIFT COEFFICIENT AND DRAG COEFFICIENT (50) IN CRUISE FLIGHT

TABLE III.1.1 - SUBROUTINE STRUCTURE OF AERODYNAMIC CALCULATIONS

III.1.1.1 <u>Form Factors</u>.— Computation of the form factors begins with the equation defining the average thickness to chord ratio for the exposed wing,

$$TC = \frac{[TC_R - S_{WF}/B(TC_R - TC_T)] * T_{ERM} + S_{LM}TC_T}{T_{ERM} + S_{LM}} \qquad \text{(III.1.2)}$$

where

T_{ERM} = $1 - (S_{WF}/B)(1-S_{LM})$

TC_R, TC_T = thickness to chord ratios (root and tip)

S_{WF} = diameter of fuselage at wing, ft

B = wing span, ft

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

In terms of this dimensionless parameter, the wing form factor is

$$C_{KW} = 1.03[2. + 4.\ TC + 240.\ TC^4] \qquad \text{(III.1.3)}$$

Other form factors may also be input and the computed value is overridden in GASP by a positive input value in this and subsequent form factor equations. The corresponding factor for the vertical tail has the same form,

$$C_{KVT} = 2. + 4.\ TC_{VT} + 240.\ TC_{VT}^4 \qquad \text{(III.1.4)}$$

The factor for the horizontal tail is modified by its location (low or high) on the vertical tail; i.e.,

$$C_{KHT} = [1 + .1(1-S_{AH})][2. + 4.TC_{HT} + 240.TC_{HT}^4] \qquad \text{(III.1.5)}$$

where $S_{AH} = 0$ for a low-tail geometry and $S_{AH} = 1$ for a T-tail geometry.

The form factors for the nacelles and tip tanks (if any) are respectively

$$C_{KN} = 1.5[1 + .35/(EL_N/DBAR_N)] \tag{III.1.6}$$

and

$$C_{KTP} = 1. + .0025(AXIS/BXIS) + 60./(AXIS/BXIS)^3 \tag{III.1.7}$$

where

EL_N = length of nacelle, ft

$DBAR_N$ = diameter of nacelle, ft

AXIS = length of tip tank, ft

BXIS = diameter of tip tank, ft

For the fuselage, the corresponding factor is

$$C_{KF} = 1.35[1. + .0025(Z_{LF}/S_{WF}) + 60./(Z_{LF}/S_{WF})^3] \tag{III.1.8}$$

where

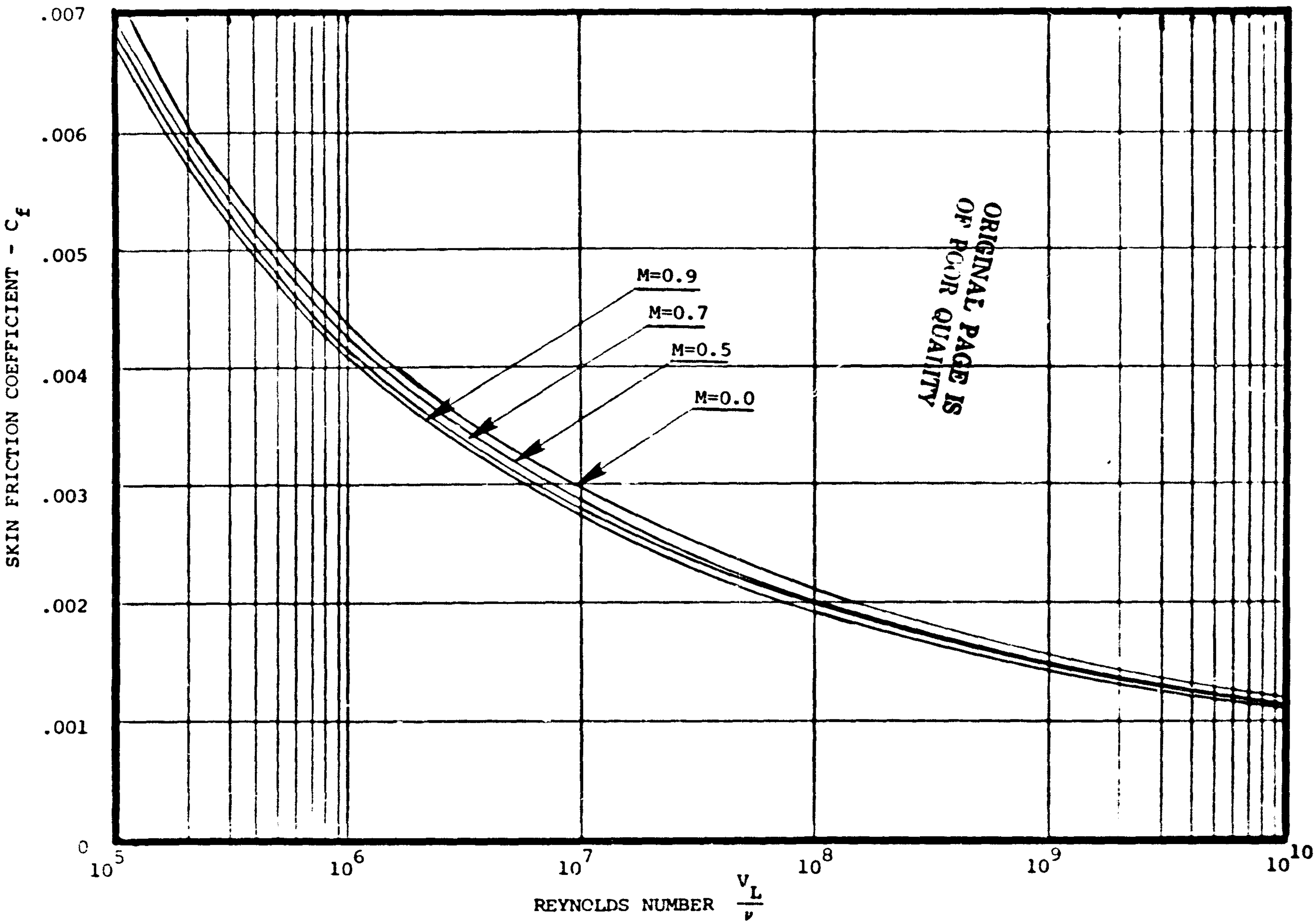
Z_{LF} = fuselage length, ft.

III.1.1.2 Skin Friction Coefficient.— The skin friction coefficient is a function of both Mach number and Reynolds number (Figure III.1.1). It is initially computed at a reference Reynolds number of 10^7. At this Reynolds number its Mach number dependence is approximated by:

$$C_{FIN} = \begin{cases} .002944 - .000176\ E_M; & E_M < .4 \\ .00299 - .0003125\ E_M; & .4 \leq E_M \leq .92 \\ .0027; & E_M > .92 \end{cases} \tag{III.1.9}$$

where E_M is the Mach number. This function varies nearly continuously over the interval .0027 to .002944.

FIGURE III.1.1 REFERENCE SKIN FRICTION COEFFICIENT



Component Mach-dependent skin-friction coefficients at the reference Reynolds number are next defined as equal to C_{FIN}; this definition is effective for wing, nacelle, fuselage, vertical tail, horizontal tail, and tip tank, and they are respectively denoted by C_{DWI}, C_{DNI}, C_{DFI}, C_{DVTI}, C_{DHTI}, and C_{DTIP}.

III.1.1.3 Reynolds Number Correction.—The skin friction coefficient of Section III.1.2 is determined at a reference Reynolds number of 10^7. Effects of component Reynolds number of the skin friction coefficient are incorporated through the Prandtl-Schlichting turbulent flat plate skin friction equation. This results in the Reynolds number correction factor taking the general form of

$$F(R) = \frac{C_{f_{component}}}{C_{f_{Re=10^7}}} = [LOG_{10}(RE_{component})/7]^{-2.6} \qquad \text{(III.1.10)}$$

The component Reynolds number is determined from the Reynolds number per foot (RELI) and a characteristic length. RELI is calculated at the design cruise conditions (HNCRU, EMCRU) and the characteristic length is usually taken in the direction of the airflow.

In the case of the fuselage, we have

$$EL_F = \text{fuselage length } (K_{CONFG} \neq 1)$$

$$EL_{FCC} = \text{fuselage length excluding tail boom } (K_{CONFG} = 1)$$

and thus the fuselage Reynolds number is

$$RF_F = \begin{cases} RE_{LI}\ EL_F, & K_{CONFG} \neq 1 \\ RE_{LI}\ EL_{FFC}, & K_{CONFG} = 1 \end{cases} \qquad \text{(III.1.11)}$$

Similarly, other Reynolds numbers are found as

$$RE_{BM} = RE_{LI} * EL_{BM} \quad \text{(fuselage boom)} \tag{III.1.12}$$

$$RE_{N} = RE_{LI} * EL_{N} \quad \text{(nacelle)} \tag{III.1.13}$$

$$RE_{VT} = RE_{LI} * CBAR_{VT} \quad \text{(vertical tail)} \tag{III.1.14}$$

$$RE_{HT} = RE_{LI} * CBAR_{HT} \quad \text{(horizontal tail)} \tag{III.1.15}$$

$$RE_{TP} = RE_{LI} * AXIS \quad \text{(tip tank)} \tag{III.1.16}$$

where EL_{BM}, . . ., AXIS, are characteristic lengths in the streamwise direction of the indicated aircraft components.

The Reynolds number correction factor for each component then becomes

$$FW_{RE} \quad \text{(wing)}$$

$$FF_{RE} = [LOG_{10}(RE_{F})/7]^{-2.6} \quad \text{(fuselage)} \tag{III.1.17}$$

$$FBM_{RE} = [LOG_{10}(RE_{BM})/7]^{-2.6} \quad \text{(fuselage boom, if } K_{CONFG}=1) \tag{III.1.18}$$

$$FN_{RE} = [LOG_{10}(RE_{N})/7]^{-2.6} \quad \text{(nacelle)} \tag{III.1.19}$$

$$FVT_{RE} = [LOG_{10}(RE_{VT})/7]^{-2.6} \quad \text{(vertical tail)} \tag{III.1.20}$$

$$FHT_{RE} = [LOG_{10}(RE_{HT})/7]^{-2.6} \quad \text{(horizontal tail)} \tag{III.1.21}$$

$$FLT_{RE} = [LOG_{10}(RE_{TP})/7]^{-2.6} \quad \text{(tip tanks)} \tag{III.1.22}$$

III.1.1.4 Profile Drag Coefficient.— The profile drag coefficients of all aircraft components except the wing are obtained by summation,

$$SA_5 = (CK_F\ CD_{FI}\ FF_{RE}\ S_F + DEL_{FE})/S_W$$
$$+ CK_{VT}\ CD_{VTI}\ FVT_{RE}\ S_{VT}/S_W$$
$$+ CK_{HT}\ CD_{HTI}\ FHT_{RE}\ S_{HT}/S_W$$
$$+ CK_N\ CD_{NI}\ FN_{RE}\ S_N/S_W$$
$$+ CK_{TP}\ C_{DTIP}\ FLT_{RE}\ S_{TIP}/S_W + DEL_{CD}$$
$$+ CK_{BM}\ C_{DTIP}\ FBM_{RE}\ S_{WBM}/S_W + GR_{CD} \qquad \text{(III.1.23)}$$

where DEL_{FE} is a fuselage incremental F_e which may be input; DEL_{CD} is an incremental input drag coefficient, and GR_{CD} is the exposed landing gear drag coefficient. This last term is included here only for fixed landing gear configurations ($I_{GEAR} \neq 0$); for retractable gear configurations ($I_{GEAR} = 0$) it is added in subroutine DRAG.

Landing gear drag can be input as an equivalent flat plate area (GRFE) or the default value is computed as a function of gross weight, which is

$$GR_{CD} = (.0032/S_W)W_G^{.8} \qquad \text{(III.1.24)}$$

Wing profile drag is handled in subroutine DRAG; however, the product of two of the factors used in DRAG to compute the wing profile drag are computed in AERO:

$$SA_6 = CKW * FW_{RE} \qquad \text{(III.1.25)}$$

III.1.1.5 Wetted Areas and Flat Plate Areas.— The next set of computations in the subroutine deal with component wetted areas and equivalent flat plate areas. The wetted area expressions are all straightforward except for the wing which is

$$SWET_W = 2S_W - \frac{3(1+S_{LM})}{(S_{LM}{}^2+S_{LM}+1)} \; CBAR_W \; S_{WF} [1 + \frac{S_{WF}}{2B} (S_{LM}-1)] \qquad \text{(III.1.26)}$$

where S_W = wing area, sq ft

S_{WF} = fuselage diameter at wing, ft

S_{LM} = taper ratio of wing

B = wing span, ft

The wing wetted area of Equation (III.1.26) is derived in Appendix IIIA.

The six component flat plate areas are listed next; for example, for the wing (W),

$$FE_W = S_W \; CD_{WI} \; CK_W \; FW_{RE} \qquad \text{(III.1.27)}$$

where the four terms on the right have been defined. This function has the units of area and is proportional to the drag. The remaining five components are those associated with fuselage, vertical tail, horizontal tail, nacelles and tip tanks. The sum of these coefficients is then expressed as

$$FE = FE_W + FE_F + FE_{VT} + FE_{HT} + FE_N + FE_{TP} + DLTAFE \qquad \text{(III.1.28)}$$

where the last term is

$$DLTAFE = DEL_{CD} * S_W \qquad \text{(III.1.29)}$$

III.1.1.6 Concluding Computations.— The Oswald efficiency factor, used to compute induced drag, is computed by

$$SEE = [1.035 + 1.19\ AR(CD_{PW}/COS^2(RLM_{C4}) + CD_{PO})]^{-1} \qquad (III.1.30)$$

where $CD_{PO} = (FE-FE_W)/S_W$, wing-free profile drag coefficient

$CD_{PW} = FE_W/S_W$, wing profile drag coefficient

The coefficient multiplying C_L^2 in the induced drag equation is next defined as

$$SA_7 = 1./(PI * SEE * AR) \qquad (III.1.31)$$

This coefficient is reduced if the aircraft carries tip tanks b[illegible]use of the effective increase in wing aspect ratio; i.e., in t[illegible]is case,

$$SA_7 = SA_7/(1+.5\ B_{XIS}/B) \qquad (III.1.32)$$

where B_{XIS} has been defined in Equation (III.1.7)

For fixed landing gear ($J_{GEAR} \neq 0$), FE is incremented by GRFE as given in Equations (III.1.28)

$$FE = FE + GRFE \qquad (III.1.33)$$

III.1.1.7 Compressibility Drag Parameters.--The wing geometry enters into the next calculations with the specification of the tangent of the quarter chord sweep angle,

$$T = \tan(R_{LMC4}) \qquad (III.1.34)$$

Following this is the parameter depending on the taper ratio S_{LM},

$$YA_{LEO5} = (1 - S_{LM})/(1+S_{LM}) \qquad \text{(III.1.35)}$$

and sweep angles

$$DLM_{PS} = ATAN[T - 4/AR(X_{CPS} - .25)YA_{LEO5}] * RTOD \qquad \text{(III.1.36)}$$

$$DLM_{TCX} = ATAN[T - 4/AR(X_{CTCMX} - .25)YA_{LEO5}] * RTOD \qquad \text{(III.1.37)}$$

where

X_{CPS} = wing minimum pressure point in fraction of wing chord

X_{CTCMX} = wing maximum thickness point in fraction of wing chord
= .35 for conventional airfoils
= .40 for supercritical airfoils

These points enter into the computation of one of the empirical compressibility parameters.

$$SA_2 = -.33(.65 - X_{CPS})[1 + .0033(4.*DLM_{PS}-3.*DLM_{TCX})] \qquad \text{(III.1.38)}$$

The sweep angle of the wing leading edge is then

$$RLM_{LE} = ATAN[T + YA_{LEO5}/AR] \qquad \text{(III.1.39)}$$

and this is followed by the definition

$$F_K + [1+YA_{LEO5}/AR + 4\ S_{LM}^2]^{-1} \qquad \text{(III.1.40)}$$

Three more of the compressibility drag parameters are then defined as follows:

$$SA_1 = [1 + .033(4.*DLM_{PS} - 3.*DLM_{TCX})]$$

$$* [1. - 1.4*TC - .06(1. - S_{CPS})] - .0368 \qquad \text{(III.1.41)}$$

$$SA_3 = [1.5 - 2.*F_K^2 * SIN^2(RLM_{LE})]\ TC^{5/3} \qquad \text{(III.1.42)}$$

and

$$SA_4 = .75 * TC \qquad \text{(III.1.43)}$$

III.1.2 Subroutine AEROUT -
Drag Polar Computation and Plots

While this is an apparently long subroutine, the major part of it is concerned with the graphical presentation of routine lift-drag relationships. Thus, low speed and cruise polars are computed by calls to the subroutines CLIFT and DRAG using as input the Mach number and certain gross geometric characteristics of the aircraft. The coefficients of lift and drag are then plotted with angle of attack as the independent parameter in the usual drag polar format. That is, either the lift coefficient is specified and the angle of attack and drag coefficient are found, or the angle of attack is specified, and both lift and drag coefficients are found. In either case, C_L is then plotted on the vertical axis as the dependent variable with C_D as the independent variable.

If the input flag NPC is greater than 1, the aircraft is in a cruise configuration, and the computations between statements 1 and 50 deal with the determination of the drag coefficient as both lift coefficient and Mach number are independently varied. The outer loop varies C_L from .1 to .5, and at each value the inner loop varies the Mach number X_{EM} from .5 to .85. For each combination (C_L, X_{EM}) the subroutines CLIFT, DRAG return the quantities

ACD(I, J) = drag coefficient (C_L, X_{EM})

ZLOD = lift to drag ratio

CL_{ALPH} = lift curve slope, per rad.

ALPHA = angle of attack, deg.

If the input flag NPC = 2, the angle of attack is the independent variable at ten values from -2 degrees to 16 degrees, and Mach is constant at .15. For each value, the subroutines CLIFT and DRAG return lift and drag coefficients in the three flight conditions,

I_L = 1: low speed cruise configuration

I_L = 2: gear up take-off configuration

I_L = 3: gear up approach configuration

The lift and drag arrays are then

ACL1(I_L, K) = lift coefficient (I_L, ALPHA)

ACD1(I_L, K) = drag coefficient (I_L, ALPHA)

The final portion of the subroutine is concerned with the plotting of the drag polars. First, the drag coefficient is plotted versus Mach number for eight constant values of lift coefficient. These correspond to the cruise configuration. Finally, the lift drag polar is drawn at low Mach number in the three flight conditions defined by the indicator I_L.

III.1.2.1 Subroutine CLIFT - Wing-Alone Lift Coefficient.— This subrout·ne relates the lift coefficient and angle of attack of the wing alone. Either the lift coefficient or the angle of attack can be input, and the other is determined, for the appropriate cruise, take-off or approach, and landing configuration. The input flag I_{LIFT} takes one of six values, reflecting these various possibilities; i.e.,

I_{LIFT} = 1: Compute C_L at cruise from ALPHA

= 2: Compute C_L at take-off from ALPHA

= 3: Compute C_L at approach from ALPHA

= 4: Compute ALPHA at cruise from C_L

= 5: Compute ALPHA at take-off from C_L

= 6: Compute ALPHA at approach from C_L

The lift coefficient and angle of attack are linearly related by the slope CL_{ALPH}. Lift increments are those due to flap deflection (DEL_{CL}) and to a multiplier for ground-effect (KCL_{GE}). These are set equal to 0 and 1, respectively, at the start of the subroutine. The first computation is that for the lift-curve slope,

$$CL_{ALPH} = PI * AR/(1 + \sqrt{1 + C_1 C_2} \qquad \text{(III.1.44)}$$

where

$$C_1 = AR/[2\ COS(RLM_{C4})]^2 \qquad \text{(III.1.45)}$$

$$C_2 = 1 - [EM * COS(RLM_{C4})]^2 \qquad \text{(III.1.46)}$$

AR = aspect ratio of wing

RLM_{C4} = quarter chord sweep angle, rad

EM = flight Mach number

In the cruise configuration, neither flap effect nor ground effect is significant, and I_{LIFT} = 1 or 4. When I_{LIFT} = 1, ALPHA is input, and the cruise lift coefficient is given by

$$CL_{OGE} = CL_{ALPH}(ALPHA - ALPHLO)(.0174533) + DEL_{CL} \qquad (III.1.47)$$

where

ALPHA = angle of attack, deg (input)

ALPHLO = zero lift angle of attack, deg (input)

This will be the lift coefficient returned unless CL_{OGE} exceeds CL_{MAX} = 2. In this case, the maximum angle of attack is computed as

$$ALPHA = ALPHLO + (CL_{MAX} - DEL_{CL})/(.01745 * CL_{ALPH}) \qquad (III.1.48)$$

and the lift coefficient returned is

$$C_L = KCL_{GE}\, CL_{ALPH}(.01745)(ALPHA - ALPHLO) + DEL_{CL} \qquad (III.1.49)$$

When I_{LIFT} = 4, and the cruise lift coefficient is input, the program computes,

$$CL_{OGE} = (CL - DEL_{CL})/CKL_{GE} + DEL_{CL} \qquad (III.1.50)$$

where the right side reduces to CL, since KCL_{GE} = 1 and DEL_{CL} = 0. Then, if this is less than CL_{MAX}, the corresponding angle of attack is given by

$$ALPHA = ALPHLO + (CL - DEL_{CL})/(KCL_{GE}\ CL_{ALPH}\ .01745) \qquad (III.1.51)$$

If I_{LIFT} = 2 or 5, the take-off configuration requires consideration of both flaps and ground effect and of the parameter HOB. This is the altitude of the aircraft mac as measured in wing spans, and it enters into the computation of the factor

$$KCL_{GE} = 1.005 + C_3[.00211 - .0003(AR - 3)] \qquad (III.1.52)$$

where

$$C_3 = \exp\ [5.2(1 - HOB)] \qquad (III.1.53)$$

For typical aspect ratios, this equation shows that CKL_{GE} varies between 1.005 and 1.5, approximately, with the larger values occurring at low altitude (HOB = 0).

If I_{LIFT} = 2, and angle of attack is input, the lift coefficient is again found using Equation (III.1.47). Otherwise I_{LIFT}=5, and the angle of attack is again computed according to Equation (III.1.51), where DEL_{CL}=DCL_{TO} and CL_{MAX} = $CLMX_{TO}$ are appropriate to the take-off configuration.

If I_{LIFT} = 3 or 6, as for the approach configuration, the computations use different values for the quantities,

$$DEL_{CL} = DCL_{LD} \qquad (III.1.54)$$

$$CL_{MAX} = CLMX_{LD} \qquad (III.1.55)$$

but otherwise the same as for the take-off configuration.

III.1.2.2 Subroutine DRAG - Total Aircraft Drag Coefficient.— This subroutine is concerned with the total aircraft drag coefficient at a given flight condition and configuration. Profile drag, induced drag, and compressibility drag contributions are found, and ground effects, flap deflection effects and landing gear effects are included when appropriate. These flight conditions are distinguished by the calling parameter I_{DRAG}, as defined below.

I_{DRAG}	Flight Condition
1	Cruise, gear up
2	Take-off, gear down
3	Landing, gear down
4	Cruise, gear down
5	Take-off flaps down, gear up
6	Landing flaps down, gear up
7	Cruise, gear down
8	Approach flaps, gear up

Other input call parameters are the Mach number EM, dimensionless height above ground, HOB, and lift coefficient, C_L, and return quantities are drag divergence Mach number EM_D and drag coefficient C_D.

In the "clean" configuration (IDRAG = 1), the aircraft drag coefficient is expressed as

$$C_D = \underbrace{SA_5 + SA_6}_{\text{Profile}} CD_{WI} + \underbrace{CK_W \; DEL_{CDM}}_{\text{Compressibility}} + \underbrace{SA_7 C_L^2}_{\text{Induced}}$$

where

SA_5 = profile drag of all components except the wing (excludes landing gear if retractable) (from AERO)

SA_6 = $CK_W \cdot FW_{RE}$

= wing form factor x Reynolds number correction factor (see AERO)

CD_{WI} = wing skin friction coefficient

DEL_{CDM} = compressibility term (see below)

SA_7 = $1/\pi$ ARe (from AERO)

The wing profile drag may be expressed as a function of lift coefficient by multiplying the wing reference skin friction coefficient (CD_{WI} = CFIN, from AERO) by an additional correction factor, CDCDR, which is a function of lift coefficient. Values for CDCDR, along with corresponding table values of lift coefficient, CLS, must be input by the user. If CDCDR is <u>not</u> input, it is assumed to be 1.0 for all lift coefficients.

The correction factor CDCDR represents the ratio of the actual clean wing profile drag at some lift coefficient to the profile drag of the wing at the angle of attack for minimum profile drag. Typical values for CDCDR are illustrated in Figure III.1.2. Also illustrated in a set of values for CDCDR which would be representative of a <u>laminar flow</u> wing. Values less than 1.0 are appropriate in the "drag bucket" since the skin friction coefficient is computed assuming fully turbulent flow (see AERO).

The compressibility drag term DEL_{CDM}, is given by

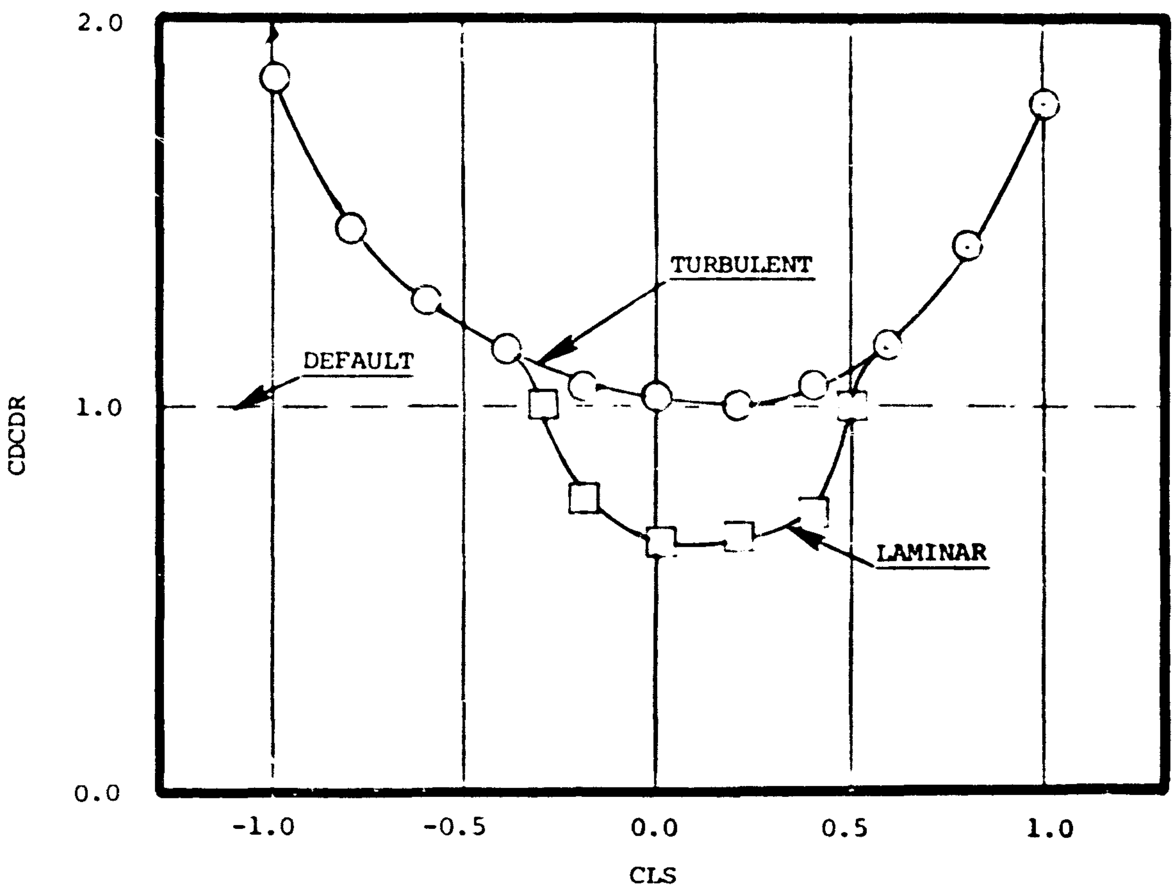


FIGURE III.1.2 TWO-DIMENSIONAL WING PROFILE DRAG MODEL

$$DEL_{CDM} = \begin{cases} 10\ (EM-EM_D)^3, \text{ if } EM \quad EM_D \\ 0, \text{ otherwise} \end{cases} \qquad \text{(III.1.56)}$$

where
$$EM_D = SA_1 + SA_2C_L + .08\ SD_{FAX} \qquad \text{(III.1.57)}$$

$$= \text{drag divergence Mach number}$$

The factors SA_1 and SA_2 are computed in AERO. SC_{FAX} is a factor which may be input (as SC_{FAC}) to shift the drag divergence Mach number of the airfoil, Figure (III.1.3)

For $I_{DRAG} = 2$, flaps and landing gear are down, and the drag coefficient is expressed as the sum of five terms,

$$C_D = SA_5 + SA_6CD_{WI} + DEL_{CDF} + DEL_{CDG}$$

$$+ SA_7K_{CDIGE}(C_L - SIGMA * DEL_{CL})^2/VDEL_6 \qquad \text{(III.1.58)}$$

where

DEL_{CDF} = parasite drag coefficient increment due to trailing edge flaps, from FLAPS

DEL_{CDG} = parasite drag increment due to landing gear, equal to GR_{CD}, as found in AERO

SIGMA = induced drag correction factor, from FLAPS

DEL_{CL} = incremental lift due to flaps, from FLAPS

$VDEL_6$ = wing efficiency correction factor due to change in spanwise lift caused by flap deflection, from FLAPS

and
$$K_{CDIGE} = 1.111 + 5.55 * HOB - [29.8(HOB + .02)^2 + .817]^{1/2} \qquad \text{(III.1.59)}$$

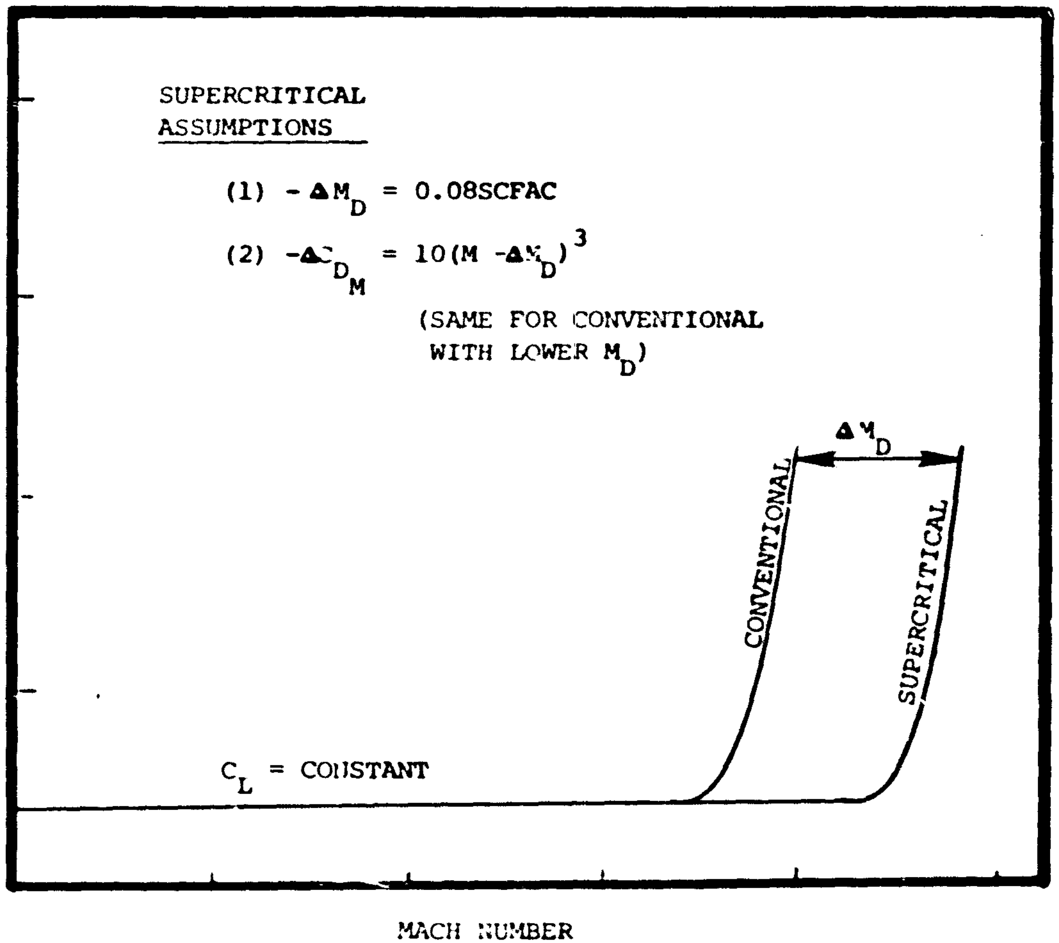


FIGURE III.1.3 - SCHEMATIC MODEL OF SUPERCRITICAL AERODYNAMICS

This last expression is to be used only when in ground effect (HOB < .88, approximately) since the next line of the subroutine sets $K_{CDIGE} = 1$, if this function is greater than 1.

The final lines of DRAG involve the contribution of the nacelle drag

$$C_D = C_D + C_{DNAC} \qquad \text{(III.1.60)}$$

where C_{DNAC} is defined in subroutine ENGSZ when KNAC = 1.

III.1.3 Subroutine CTAER - Cruise Aerodynamics

The cruise-drag computation, as indicated in Table III.1.1, is performed in the 50-card subroutine CTAER, which itself calls on AERO, CLIFT, and DRAG. Each of these subroutines has already been described in previous pages of this section, while CTAER itself is concerned only with details of the computation.

The cruise drag is found as a function of cruise Mach number and altitude which are specified. The subroutine finds the angle of attack required to balance lift and weight. The drag (or thrust required) is found at this equilibrium flight condition.

The cruise lift coefficient is given as a function of angle of attack in subroutine CLIFT, while the drag coefficient is obtained by calling AERO and DRAG, which combine several drag components as described in prior sections of this chapter.

The cruise weight option is specified by the indicator IDC, such that is IDC = 1, the weight W is input through the UNIV common block. Otherwise, the ratio of cruise weight to design gross weight (RW_{CRTO}) and gross weight together imply W:

$$W = WG_{TO} * RW_{CRTO} \qquad \text{(III.1.61)}$$

At statement 6, the subroutine TPALT provides various physical characteristics of the atmosphere as functions of the geometric altitude, H_N.

The static pressure, P_O, speed of sound, ASONO, and velocity V_O, are found in the required units, for the input values of altitude and Mach number, and the lift coefficient required for cruise is calculated as

$$C_{LREQ} = W/(.7\ S_{REF}\ P_O\ S_{MN}^2) \qquad \text{III.1.62)}$$

where S_{MN} is the Mach number. The subroutine CLIFT then returns the angle of attack A_D required in this cruise configuration.

The subroutines AERO and DRAG then return the corresponding drag coefficient, C_D, following which the cruise lift and drag are found as

$$ZL = .7\ C_L\ S_{MN}^2\ S_{REF} \qquad (\text{III.1.63})$$

$$DRG = ZL/ZLQD \qquad (\text{III.1.64})$$

where their ratio is $ZLQD = C_L/C_D$.

III.1.4 Subroutine FLAPS -

Flap Aerodynamic, Geometric, and Weight Characteristics

This subroutine is called by the main program and by two others (APPFLP and RGBAL) and it calls only the utility programs related to the current flight conditions and to interpolation of tabular data. The major portion of the subroutine is developed from a technical paper published by K. L. Sanders in May 1969, in the Journal of the Society of Aeronautical Weights Engineers. The purpose of the subroutine is the computation of aerodynamic, geometric, and weight characteristics of wing high-lift devices. A major output is the maximum lift coefficient C_{LMAX} of the aircraft in the take-off or landing configuration. Parasite drag increments due to flap deflection are also found, as are flap areas and weights.

Aerodynamic lift and drag data for a reference or baseline wing are known for various types of high-lift devices, and the program is chiefly concerned with the computation of correction factors, as applied to the reference wing configuration. Seven different flap types may be simulated as indicated by the input variable JFLTYP:

JFLTYP = 1, plain
= 2, split
= 3, single slotted
= 4, double slotted
= 5, triple slotted
= 6, Fowler
= 7, double slotted Fowler

The first third of the program listing is devoted to common card statements, comments and input data tabulations. This is followed by the GO TO statement depending on the input flag NPC. These options are briefly described as

NPC = 2: Compute sensitivity factors leading to lift, drag characteristics for specific choice of flap

NPC = 4: Compute flap lift and drag as flap deflection varied by subroutine APPFLF

III.1.4.1 Computation of Airplane Geometry Lift and Drag Correction Factors. The basic standard wing has both flaps and leading edge slats, neither of which is deflected in the reference configuration. The reference wing is assumed to have a thickness ratio of .10, and an aspect ratio of 12. It is unswept and untapered, and has a trailing edge flap chord ratio of .3 and a leading edge slat chord ratio of .15, both of which extend over the whole span. The reference Reynolds number and Mach number are 6×10^6 and 0 respectively. The maximum airplane lift coefficient is expressed as the sum of four terms,

$$C_{LMAX} = [R_{CLAMX} V_{LAM1} V_{LAM2} + DCL_{MTE} V_{LAM3} \cdot \cdot \cdot V_{LAM8}$$

$$+ DCL_{MLE} V_{LAM9} \cdot \cdot \cdot V_{LAM12}] V_{LAM13} V_{LAM14} + DEL_{CLF} \qquad \text{(III.1.65)}$$

where R_{CLMAX} = input reference maximum lift coefficient for basic wing

DCL_{MTE} = input trailing edge flap lift increment for flap type at optimum flap deflection

DCL_{MLE} = input leading edge slat lift increment for leading edge type at optimum leading edge deflection

DEL_{CLF} = fuselage lift increment

V_{LAMI} = sensitivity to variations from reference values for flaps and slats, I = 1 to 14 (correction factors)

The first two correction factors relate to the wing aspect ratio and thickness, and the next six (V_{LAM3} to V_{LAM8}) correct for flap geometry and deflection and for wing sweep. Similarly, V_{LAM9} to V_{LAM12} are used to account for variations in slat geometry and deflection, and the last two, V_{LAM13} and V_{LAM14}, correct for Reynolds number and Mach number deviations from their reference values.

These correction factors are determined by successive calls to the interpolation routine ITRLN and BIV. For example, for V_{LAM1}:

CALL ITRLN(AARW, ALAM1, AR, VLAM1, NARW)

where AARW = input array of wing aspect ratios from 0 to 20, NARW in number

ALAM1 = corresponding input array of sensitivities of maximum lift coefficient to aspect ratio, NARW in number

AR = actual input value of wing aspect ratio (COMMON/UNIV/)

VLAM1 = sensitivity of clean wing maximum lift coefficient to wing aspect ratio, AR

NARW = number of data points in table AARW vx. ALAM1

Subsequent calls to ITRLN and BIV generate corrections for the following effects

V_{LAM2} = sensitivity of clean wing C_{LMAX} to wing thickness to chord ratio

V_{LAM3} = sensitivity of flap clean wing C_{LMAX} to wing aspect ratio

V_{LAM4} = sensitivity of flap clean wing C_{LMAX} slope to wing thickness to chord ratio. This is a function of flap type

V_{LAM5} = sensitivity of flap clean wing C_{LMAX} to wing flap to chord ratio (function of flap type)

V_{LAM6} = sensitivity of flap clean wing C_{LMAX} to wing flap deflection (function of flap type)

V_{LAM7} = sensitivity of flap clean wing C_{LMAX} to wing flap span

V_{LAM8} = sensitivity of flap clean wing C_{LMAX} to wing sweep angle

$$= \cos^3(SWPQC) \qquad (III.1.66)$$

V_{LAM9} = sensitivity of slat clean wing C_{LMAX} to slat chord

$$= 6.65 * C_{LEOC} \qquad (III.1.67)$$

V_{LAM10} = sensitivity of clean wing C_{LMAX} to slat deflection angle

V_{LAM11} = sensitivity of slat clean wing C_{LMAX} to slat span

V_{LAM12} = sensitivity of slat clean wing C_{LMAX} to leading edge sweepback

$= \cos^3(SWPLE - 5/57.29)$ (III.1.68)

C_{LMAX} is computed at the unaccelerated stall speed of the airplane corresponding to C_{LMAX}. This is accomplished by an iteration on stall speed: at each stall speed the Reynolds number (V_{LAM13}) and Mach number (V_{LAM14}) correction factors are determined. Using these factors C_{LMAX} is computed and based on this C_{LMAX} a new stall speed is calculated. The iteration continues until the stall speed converges.

The incremental lift due to trailing edge devices is given by:

$$DCL = DCLMTE\ V_{LAM3} \ldots V_{LAM8}\ V_{LAM13}\ V_{LAM14}$$

Further computations deal with the modifications to the drag coefficient, as implied by the following factors:

V_{DEL1} = sensitivity of flap C_{DMIN} to flap chord ratio (functions of flap size

V_{DEL2} = sensitivity of flap C_{DMIN} to flap angle, function of flap type

V_{DEL3} = sensitivity of flap C_{DMIN} to partial flap span

V_{DEL4} = sensitivity of flap C_{DMIN} to flap hinge line sweepback

$= \cos(SWP_{FHL})$ (III.1.69)

V_{DEL5} = sensitivity of C_{DMIN} to fuselage width to span ratio,

$= 1. - FWOB$ (III.1.70)

V_{DEL6} = sensitivity of span efficiency factor to flap angle

Sensitivities not followed by equations are determined by interpolation of tabular input data, as was done for the lift coefficient increments. The result of combining these expressions is the incremental drag coefficient

$DCD = DCD_{OTE}\ V_{DEL1} \ldots V_{DEL5}$, incremental parasitic drag coefficient, due to trailing edge devices

The empirical flap efficiency factors, $SIGM_{TO}$ and $SIGM_{LD}$ are determined as functions of flap deflection for the take-off (IFLAP = 1) and landing (IFLAP = 2) configurations respectively. This relationship is illustrated in Figure III.1.4)

III.1.4.2 Flap Weight Estimation. The flap weight is assumed to be a function of the flap type, flap area, and design flap airspeed. The flap area (ratioed to the wing area) is computed from the wing geometry:

$$S_{FLAPS} = (CF_{OC} * Z * B)[2 - (L - TR_{WING})(FW_{OB} + BTE_{OB})]$$
$$[BTE_{OB} - FW_{OB} - B_{ENGOB}]/(2 * S) \qquad \text{(III.1.71)}$$

where Z = root chord at wing centerline, ft.

CF_{OC} = ratio, flap chord to wing chord

BTE_{OB} = ratio, flap span to wing span

FW_{OB} = ratio, body diameter at quarter chord to wing span

B_{ENGOB} = ratio, total engine diameter to wing span, for wing mounted engines

The design airspeed of the flaps is assumed to be

$$V_{FLAP} = 1.8\ V_{STALL} \qquad \text{(III.1.72)}$$

where V_{STALL} is the stall speed in knots corresponding to C_{LMAX} in the landing configuration.

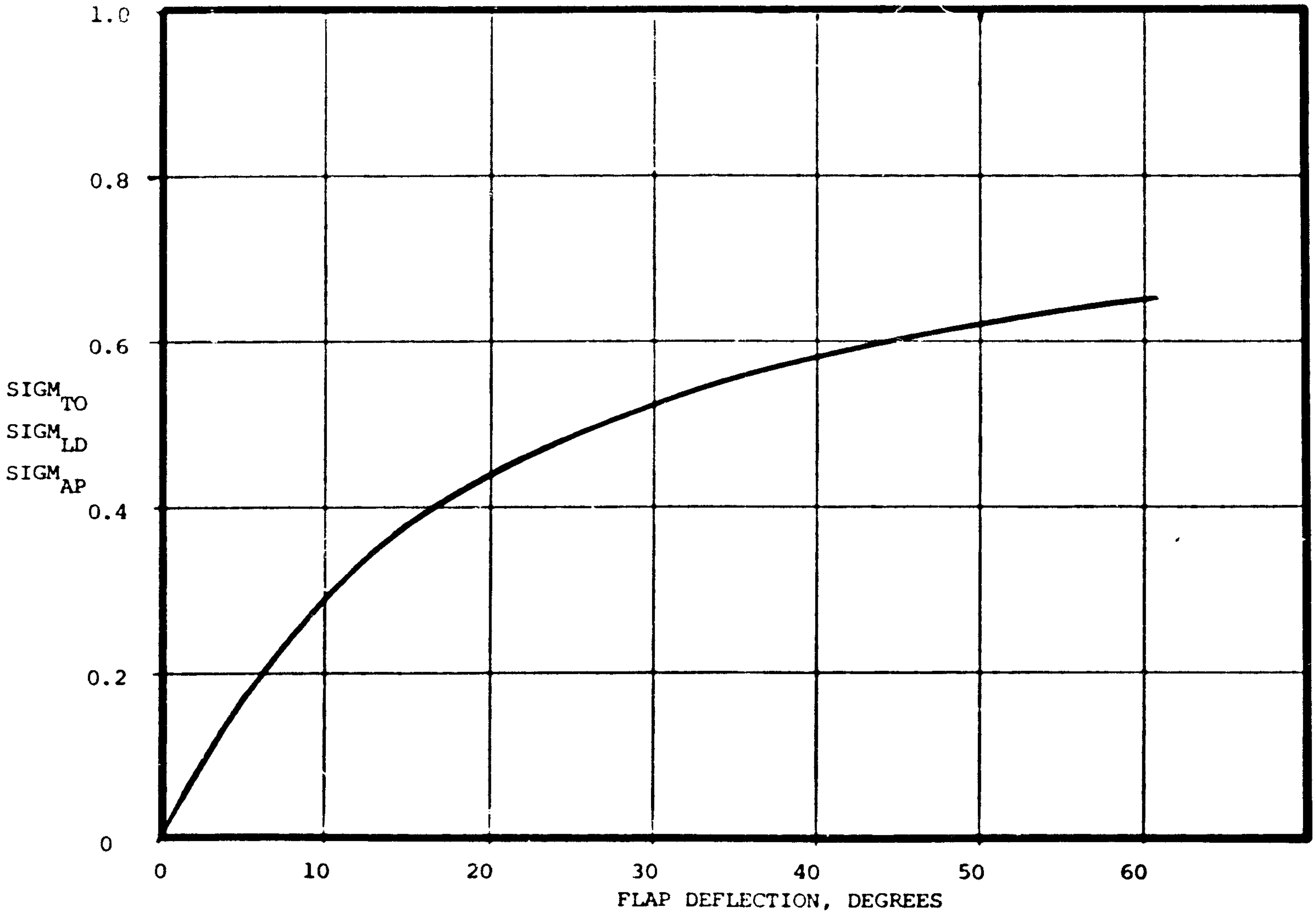


FIGURE III.1.4 EMPIRICAL FLAP EFFICIENCY FACTOR

Flap weights are represented as one of the following functions, depending on the flap type, $J_{FLTYP} = 1$ to 7.

$J_{FLTYP} = 1$; Plain Flaps

$$W_{FLAP} = WC_{FLAP}(V_{FLAP}/100.)^2 \; S_{FLAP}(FLAP_N)^{-.5} \qquad \text{(III.1.73)}$$

$J_{FLTYP} = 2$; Split flaps

$$W_{FLAP} = \begin{cases} .369 \; WC_{FLAP} \; S_{FLAP} \; V_{FLAP}^{.2733} & V_{FLAP} \leq 160 \\ (WC_{FLAP} \; S_{FLAP}/45180.)V_{FLAP}^{2.195} & V_{FLAP} > 160 \end{cases} \qquad \text{(III.1.74)}$$

$J_{FLTYP} = 3,4,5$: Single, double or triple slotted flaps

$$W_{FLAP} = WC_{FLAP} \; S_{FLAP} \; (V_{FLAP}/100.)^2 \; FLAP_N^{.5} \qquad \text{(III.1.75)}$$

$J_{FLTYP} = 6, 7$: Fowler or double slotted Fowler flaps

$$W_{FLAP} = WC_{FLAP} \; S_{FLAP}^{1.19}(V_{FLAP}/100.)^{2.38} \; FLAP_N^{-.595} \qquad \text{(III.1.76)}$$

where WC_{FLAP} = [.62, 1.0, .733, 1.2, 1.32, .633, .6781] = variation with J_{FLTYP} of flap weight factor or may be input

$S_{FLAP} = S_{FLAPS} * S$ = flap area

$FLAP_N$ = 1. = number of flap segments per wing panel

The weight of the leading edge devices is given by the function:

$$W_{LED} = 3.28 \; S_{LE}^{1.13} \qquad \text{(III.1.77)}$$

where S_{LE} is the leading edge slat area and the total weight of "high-lift devices" is the sum

$$W_{HLDEV} = W_{FLAP} + W_{LED} \tag{III.1.78}$$

III.1.4.3 Allowable Flap Reflection on Approach. The final section of FLAPS is used only during engine sizing when FLAPS is called by APPFLP with NPC = 4. FLAPS computes the incremental flap lift and drag coefficients and C_{LMAX} corresponding to an approach flap angle specified by APPFLP. Since engine sizing occurs only after the flap characteristics have already been determined, it is not necessary to recompute most of the correction factors (VLAM, VDEL), and thus these sections of the program are bypassed when NPC = 4. Only the factors which are explicit functions of flap deflection are recomputed (VLAM6, VDEL2, VDEL6). In addition, an empirical flap efficiency factor, SIGMAP, is determined from the flap angle specified by APPFLP.

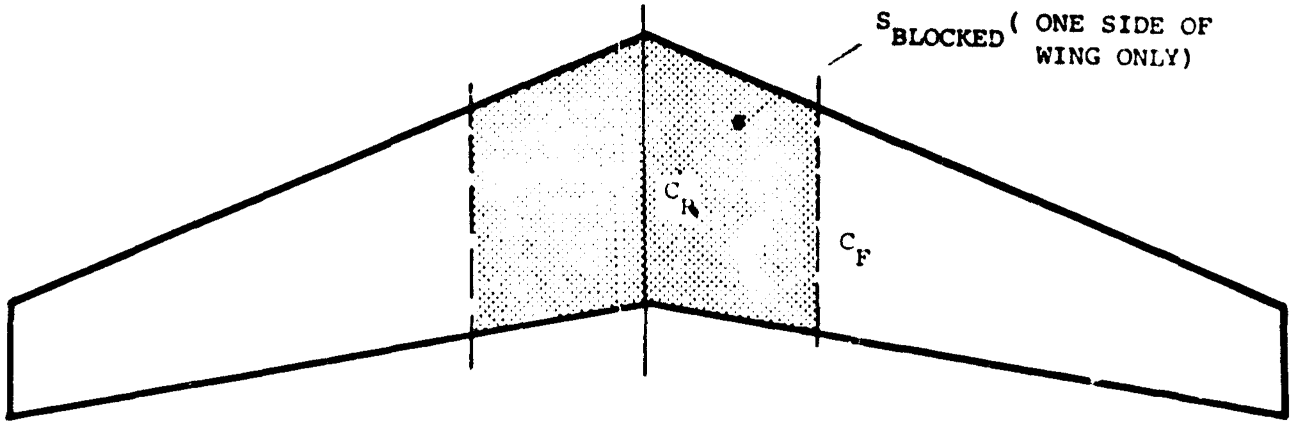
III.1.4.4 Subroutine APPFLP. This subroutine determines an approach flap deflection by calling FLAPS with NPC = 4 such that the corresponding approach lift coefficient is a specified fraction of the landing lift coefficient. The FAA regulation 25.121 requires that the approach stall speed cannot exceed 1.1 times the landing stall speed, and this implies a specific flap deflection; i.e.,

$$C_{LMXAP} = C_{LMXLD}/1.1^2 = .83\ C_{LMXLD}$$

where AP and LD denote "approach" and "landing" values, respectively. The landing value of C_{LMAX} has been previously computed by the program, and subroutine APPFLP returns the flap deflection DFLAP, as found by numerical interpolation, that provides the appropriate approach C_{LMAX}.

APPENDIX III.A

WING WETTED AREA DERIVATION



The exposed wing wetted area is

$$SWET_W = 2S_W - 2S_{BLOCKED}$$

where it is assumed that the fuselage completely blocks the area shaded. Now

$$S_{BLOCKED} = 2\left(\frac{C_R + C_F}{2}\right) S_{WF}$$

and for a wing with single taper

$$C_F = C_R - \frac{S_{WF}}{B} (C_R - C_T)$$

substituting

$$S_{BLOCKED} = 2 \frac{[C_R + C_R - \frac{S_{WF}}{B}(C_R - C_T)]}{2}$$

$$= 2 C_R S_{WF} (1 + \frac{S_{WF}}{2B} (\lambda - 1)$$

Now

$$\bar{C} = \frac{2}{3} C_R (1 + \lambda - \frac{\lambda}{1+\lambda})$$

so that

$$S_{BLOCKED} = 2\left[\frac{3}{2}\,\frac{\bar{C}\;S_{WF}}{(1+\lambda-\dfrac{\lambda}{1+\lambda}}\;(1+\frac{S_{WF}}{2B}\;(\lambda-1)\right]$$

$$S_{BLOCKED} = \frac{\frac{3}{2}\;\bar{C}\;S_{WF}\;(1+\lambda)}{\lambda+1\;+\lambda(\lambda+1)\;-\lambda}\;[1+\frac{S_{WF}}{2B}\;(\lambda-1)]$$

$$= 2\left[\frac{3}{2}\;\bar{C}\;S_{WF}\;\frac{(1+\lambda)}{\lambda+1+\lambda^2+\lambda-\lambda}\;[1+\frac{S_{WF}}{2B}\;(\;-1)]\right]$$

$$= 2\left[\frac{3}{2}\;\bar{C}\;S_{WF}\;\frac{(1+\lambda)}{\lambda^2+\lambda+1}\;[1+\frac{S_{WF}}{2B}\;(\lambda-1)]\right]$$

therefore

$$S_{WET_W} = 2S_W - 3\bar{C}S_{WF}\;\frac{(1+\lambda)}{\lambda^2+\lambda+1}\left[1+\frac{S_{WF}}{2B}\;(\lambda-1)\right]$$

GASP - GENERAL AVIATION SYNTHESIS PROGRAM

VOLUME III - AERODYNAMICS

PART 2 - USER'S MANUAL

JANUARY 1978

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center
Moffett Field, California

Under

CONTRACT NAS 2-9352

AEROPHYSICS RESEARCH CORPORATION

III.2 AERODYNAMICS MODEL USER'S MANUAL

The aerodynamics subroutines are called in the following order, in the typical application of program MAIN:

1. FLAPS - Lift and drag dependence on wing geometry
2. CTAER - Cruise lift and drag computation
3. AEROUT - Drag polar variation with flight condition

As described in earlier sections of this volume, subroutines CLIFT and DRAG are also called by CTAER and AEROUT, and these various subroutines may be separated from one another by a number of other programs which are described in other volumes of this study.

The aerodynamic input parameters are very large in number because of the large number of geometrically and operationally independent possibilities in aircraft design. In this user's manual, the input and output quantities of each subroutine are listed, with their appropriate units, in alphabetic order. Subroutines covered in this manner are

Table III.2.1 - Subroutine AERO Input

III.2.2 - Subroutine AERO Output

III.2.3 - Subroutine AEROUT Input

III.2.4 - Subroutine AEROUT Output

III.2.5 - Surboutine CLIFT Input

III.2.6 - Subroutine CLIFT Output

III.2.7 - Subroutine DRAG Input

III.2.8 - Subroutine DRAG Output

III.2.9 - Subroutine CTAER Input

III.2.10 - Subroutine CTAER Output

Table III.2.11 - Subroutine FLAPS Input

III.2.12 - Subroutine FLAPS Output

III.2.13 - Subroutine APPFLP Input

III.2.14 - Subroutine APPFLP output

TABLE III.2.1 SUBROUTINE AERO - INPUT

VARIABLE	DESCRIPTION
AR	aspect ratio
AXIS	length of tip tank, ft
B	Wing span, ft
BXIS	diameter of tip tank, ft
CBARHT	mean aerodynamic chord of horizontal tail, ft
CBARVT	mac of vertical tail, ft
CBARW	mac of wing, ft
DBARN	average nacelle diameter, ft
DELCD	drag coefficient increment
DELFE	incremental effective flat plate area of fuselage, sq ft
DLMC4	quarter chord sweep of wing, deg.
DLSWSW	incremental wetted area/wing area
ELBM	length of tail boom, ft
ELF	fuselage length, ft
ELFFC	fuselage length minus tail boom length, ft
ELN	nacelle length, ft
IGEAR	landing gear configuration
KCONFG	fuselage configuration
KNAC	nacelle drag estimation flag (0, 1, or 2)
RELI	Reynolds number per foot
SAH	relative position of horizontal tail position
SCFAC	factor on shift of drag divergence Mach number for super-critical airfoil
SF	fuselage wetted area

TABLE III.2.1 SUBROUTINE AERO - INPUT

VARIABLE	DESCRIPTION
SHT	horizontal tail planform area, sq ft
SLM	taper ratio of wing
SMN	Mach number
SN	nacelle wetted area, sq ft
STIP	tip tank wetted area, sq ft
SVT	vertical tail planform area, sq ft
SW	wing planform area, sq ft
SWBM	tail boom wetted area, sq ft
SWF	fuselage width, ft
TC	average thickness to chord ratio of wing
TCHT	thickness to chord ratio of horizontal tail
TCVT	thickness to chord ratio of vertical tail
WG	gross weight, lb

TABLE III.2.2 SUBROUTINE AERO - OUTPUT

VARIABLE	DESCRIPTION
CBARF	aerodynamic cleanliness coefficient
CDNI	skin friction coefficient of nacelle
CFIN	skin friction coefficient at Re = 10^7
CKF	form factor of fuselage
CKHT	form factor of horizontal tail
CKN	form factor of nacelle
CKTP	form factor of tip tank
CKVT	form factor of vertical tail
CKW	form factor of wing
CKWX	form factor of wing
DLTAFE	incremental equivalent flat plate area, sq ft
EM	Mach number
FE	total equivalent flat plate area, sq ft
FEF	fuselage equivalent flat plate area, sq ft
FEHT	horizontal equivalent flat plate area, sq ft
FEN	nacelle equivalent flat plate area, sq ft
FETP	tip tank equivalent flat plate area, sq ft
FEVT	vertical tail equivalent flat plate area, sq ft
FEW	wing equivalent flat plate area, sq ft
GRCD	landing gear drag coefficient
GRFE	incremental landing gear equivalent flat plate array, sq ft
SA1-4	compressibility drag factors
SA5, 6	profile drag parameters

TABLE III.2.2 SUBROUTINE AERO - OUTPUT

VARIABLE	DESCRIPTION
SA7	induced drag parameter
SCFAX	supercritical airfoil parameter (SCFAC)
SEE	Oswald efficiency factor
SWET	total wetted area, sq ft
SWETF	fuselage wetted area, sq ft
SWETH	horizontal tail wetted area, sq ft
SWETIC	increment in wetted area, sq ft
SWETV	vertical tail wetted area, sq ft
SWETW	wing wetted area, sq ft
XCKN	form factor of nacelle

TABLE III.2.3 SUBROUTINE AEROUT - INPUT

VARIABLE	DESCRIPTION
ACL	array of lift coefficients
ALPHLO	zero lift angle of attack, deg
AM	array of Mach numbers
AR	aspect ratio
CLALPH	lift curve slope, per rad
DLMC4	quarter chord sweep angle, deg.
EMCRU	cruise Mach number
HOB	altitude in wing spans
NPC	= 1, calculate only low speed polar
	= 2, calculate cruise polar and low speed polar
	= 3, calculate only cruise polar
	= 4, calculate and plot both polars

TABLE III.2.4 SUBROUTINE AEROUT - OUTPUT

VARIABLE	DESCRIPTION
AACD	array of drag coefficients
AACD1	array of drag coefficients
AACL	array of lift coefficients
ACD	array of drag coefficients
ACD1	array of drag coefficients
ACL1	array of lift coefficients
EM	Mach number
CLOD	array of lift to drag ratios

TABLE III.2.5 SUBROUTINE CLIFT - INPUT

VARIABLE	DESCRIPTION
ALPHA	angle of attack, deg
ALPHLO	zero lift angle of attack, deg
AR	aspect ratio
CL	lift coefficient
CLMXLD	maximum lift coefficient in landing configuration
CLMXTO	maximum lift coefficient in takeoff configuration
DCLLD	landing lift coefficient increment
DCLTO	takeoff lift coefficient increment
DLMC4	quarter chord sweep angle, deg
EM	free stream Mach number
HOB	altitude measured in wing spans
ILIFT	= 1, 2, 3 - compute CL from ALPHA
	= 4, 5, 6 - compute ALPHA from CL

TABLE III.2.6 SUBROUTINE CLIFT - OUTPUT

VARIABLE	DESCRIPTION
ALPHA	angle of attack, deg.
CL	lift coefficient
CLALPH	lift curve slope, per rad

TABLE III.2.7 SUBROUTINE DRAG - INPUT

VARIABLE	DESCRIPTION
ACDCDR	array of ratio of wing profile drag coefficient to minimum drag
ACLS	array of lift coefficients, dimension KWCD
CDNAC	nacelle drag coefficient
CFIN	skin friction coefficient at RE = 10 million
CKWX	wing form factor
CL	lift coefficient
DCDAPP	drag coefficient increment in approach configuration
DCDLD	drag coefficient increment in landing configuration
DCDTO	drag coefficient increment in takeoff configuration
DCLAPP	lift coefficient increment in approach configuration
DCLLD	lift coefficient increment in landing configuration
DCLTO	lift coefficient increment in takeoff configuration
EM	Mach number
GRCD	drag coefficient of landing gear
HOB	altitude in wing spans
IDRAG	= 1 to 8, flight condition at which drag is calculated
KNAC	= 0, nacelle drag accounted for in engine performance
	= 1, nacelle drag part of aero drag, computed when engine sized
	= 2, nacelle drag part of aero drag, based on input nacelle size
KWCD	number of points in wing profile drag table
SA1-7	1 to 4, compressibility drag factors
	5 and 6, profile drag parameters

TABLE III.2.7 SUBROUTINE DRAG - INPUT

VARIABLE	DESCRIPTION
	7, induced drag parameter
SCFAX	supercritical airfoil parameter
SIGMAP	empirical induced-drag correction factor, approach configuration
SIGMLD	empirical induced-drag correction factor, landing configuration
SIGMTO	empirical induced-drag correction factor, take-off configuration
VDEL6A	efficiency factor correction factor for approach flaps
VDEL6L	efficiency factor correction factor for landing flaps
VDEL6T	efficiency factor correction factor for take-off flaps

TABLE III.2.8 SUBROUTINE DRAG - OUTPUT

VARIABLE	DESCRIPTION
CD	drag coefficient
EMD	drag rise Mach number

TABLE III.2.9 SUBROUTINE CTAER - INPUT

VARIABLE	DESCRIPTION
AD	angle of attack, degrees
ALPHLO	zero lift angle of attack, deg
AR	aspect ratio
CLALPH	lift curve slope, per rad
DLMC4	quarter chord sweep angle, deg
FPMN	Mach number, used in fixed pitch propeller option
H	altitude, ft
IDC	reference area flag
RWCRTX	ratio of cruise weight to design gross weight
SW	wing area, sq ft
WG	gross weight at take-off, lb
WGS	wing loading, lb per sq ft

TABLE III.2.10 SUBROUTINE CTAER - OUTPUT

VARIABLE	DESCRIPTION
DRG	cruise drag, lb
PO	static pressure, lb per sq ft
RELI	Reynolds number per ft
W	current aircraft weight, lb
ZL	cruise lift, lb
ZLQD	lift to drag ratio in cruise

TABLE III.2.11 SUBROUTINE FLAPS - INPUT

VARIABLE	DESCRIPTION
AARW	array of wing aspect ratio
ABFOB	array of flap span to wing span ratios
ABLEOB	array of leading edge slat span to wing span ratios
ABTEOB	array of trailing edge device span to wing span ratios
ACFOC	array of flap chord to wing chord ratios
ACROBL	array of root chord to body length ratios
ADCDOT	array of flap-induced drag coefficients
ADCLTE	array of flap-induced lift coefficients
ADELCL	array of lift coefficient increments
ADELFD	array of flap deflections, deg
ADELTO	array of optimum flap deflections for different flap typ
ADEL1	array of flap chord correction on drag (JFLTYP $>$ 2)
ADEL1Y	array of flap chord correction on drag (JFLTYP $\leq$ 2)
ADEL2	array of flap angle correction on drag
ADEL3	array of flap span correction on drag
ADEL6	array of flap angle correction of Oswald efficiency facto
AFWOB	array of wing/body diameter ratios for fuselage drag increment
ALAM1	sensitivity of maximum wing lift coefficient to aspect ratio
ALAM2	sensitivity of maximum wing lift coefficient to thickness to chord ratio
ALAM3	sensitivity of maximum flap lift coefficient to aspect ratio
ALAM4	ensitivity of maximum flap lift coefficient to thicknes to chord ratio (JFLTYP $>$ 2)

TABLE III.2.11 SUBROUTINE FLAPS - INPUT

VARIABLE	DESCRIPTION
ALAM4X	sensitivity of maximum flap lift coefficient to thickness to chord ratio (JFLTYP $\leq$ 2)
ALAM5	sensitivity of maximum flap lift coefficient to flap chord to chord ratio (JFLTYP $\geq$ 6)
ALAM5X	sensitivity of maximum flap lift coefficient to flap chord to chord ratio (JFLTYP = 3, 4, 5)
ALAM5Y	sensitivity of maximum flap lift coefficient to flap chord to chord ratio (JFLTYP = 1, 2)
ALAM6	sensitivity of maximum flap lift coefficient to flap angle (JFLTYP $\geq$ 6)
ALAM6X	sensitivity of maximum flap lift coefficient to flap angle (JFLTYP = 3, 4, 5)
ALAM6Y	sensitivity of maximum flap lift coefficient to flap angle (JFLTYP = 1, 2)
ALAM7	sensitivity of maximum flap lift coefficient to flap span
ALAM10	sensitivity of maximum slat lift coefficient to slat deflection
ALAM11	sensitivity of maximum slat lift coefficient to slat span
ALAM13	sensitivity of maximum lift coefficient to Reynolds number
ALAM14	sensitivity of maximum lift coefficient to Mach number
ALTFLP	altitude at which flaps are retracted, ft
AMNW	array of wing Mach numbers
AR	wing aspect ratio
ARDELF	array of ratios of flap deflection to optimum deflection angle
ARDELL	array of ratios of leading edge slat deflection to optimum deflection angle

TABLE III.2.11 SUBROUTINE FLAPS - INPUT

VARIABLE	DESCRIPTION
ARNW	array of Reynolds numbers for Reynolds number correction on C_{LMAX}
ASIGMA	array of induced drag correction factors
ASLM	array of taper ratios in table
ATCW	array of thickness ratios in table
AWCFLP	array of weight coefficients for different flap types
B	wing span, ft
BENGOB	fraction of span blanketed by wing mounted engine
BTEOB	trailing edge flap span divided by wing span
CBARW	mean aerodynamic chord of wing, ft
CFOC	flap chord divided by wing chord
CLEOC	leading edge flap chord divided by wing chord
CRCLW	
CROOTW	wing root chord, ft
DLMC4	quarter chord sweep angle, deg
ELF	fuselage length, ft
IFLAP	= 1 or 2; takeoff or approach configuration
JFLTYP	= 1 to 7, plain, split, slotted, etc., flap type
RCLMAX	reference maximum lift coefficient
SIGMAP	induced drag correction factor, approach configuration
SIGMLD	induced drag correction factor, landing configuration
SIGMTO	induced drag correction factor, takeoff configuration
SLM	wing taper ratio
SWF	fuselage width, ft

TABLE III.2.11 SUBROUTINE FLAPS - INPUT

VARIABLE	DESCRIPTION
SWPLE	leading edge sweep angle, deg
SWPTE	trailing edge sweep angle, deg
TC	wing average thickness to chord ratio
WGS	wing loading in cruise, lb per sq ft

TABLE III.2.12 SUBROUTINE FLAPS - OUTPUT

VARIABLE	DESCRIPTION
CLMXAP	maximum lift coefficient in approach configuration
CLMXLD	maximum lift coefficient in landing configuration
CLMXTO	maximum lift coefficient in takeoff configuration
DCDAPP	drag increment in approach configuration
DCDLD	drag increment in landing configuration
DCDOTE	drag increment due to trailing edge flap
DCDTO	drag increment in takeoff configuration
DCLAPP	lift increment in approach configuration
DCLLD	lift increment in landing configuration
DCLMTE	lift increment due to trailing edge flap
DCLTO	lift increment in takeoff configuration
DELFD	flap deflection, deg
DELTEO	optimum flap deflection, deg
DFLPLD	landing flap deflection, deg
VDEL6A	efficiency correction factor for approach flaps
VDEL6L	efficiency correction factor for landing flaps
VDEL6T	efficiency correction factor for takeoff flaps
VSTALL	stall velocity, kts
WCFLAP	flap weight trend coefficient
WLED	weight of leading edge device, lb
WFLAP	weight of flaps, lb
WHLDEV	weight of high lift devices, lb.

TABLE III.2.13 SUBROUTINE APPFLP - INPUT (TURBOFAN)

VARIABLE	DESCRIPTION
CLMXAP	maximum lift coefficient, approach configuration
CLMXLD	maximum lift coefficient, landing configuration
DELFDX	maximum flap deflection, deg.

TABLE III.2.14 SUBROUTINE APPFLP - OUTPUT

VARIABLE	DESCRIPTION
DFLAP	approach flap deflection, deg
IOK	= 0, computation diverges = 1, computation converges

GASP - GENERAL AVIATION SYNTHESIS PROGRAM

VOLUME III - AERODYNAMICS

PART 3 - PROGRAMMER'S MANUAL

JANUARY 1978

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center
Moffett Field, California

Under

CONTRACT NAS 2-9352

AEROPHYSICS RESEARCH CORPORATION

III.3 PROGRAMMERS MANUAL FOR AERODYNAMIC ROUTINES

The function of the aerodynamic routines has been outlined in Volume III.1. Detailed flow charts and subroutine outlines are presented in the present volume. A list of inputs and outputs by the subroutine are available in Volume III.2.

III.3.1 Subroutine AERO -

Flat Plate and Wetted Areas, Profile Drag

The function of this subroutine is the computation of equivalent flat plate areas, wetted areas, and profile drag for the basic aircraft in the cruise configuration.

Figure III.3.1 presents a detailed flow chart of subroutine AERO. Calculations performed are described in Volume III.1 in the following sections:

III.1.1 - Flat Plate and Wetted Areas

III.1.1.1- Form Factors

III.1.1.2- Skin Friction Coefficient

III.1.1.3- Reynold's Number Correction

III.1.1.4- Profile Drag Coefficient

III.1.1.5- Wetted Areas and Flat Plate Areas

III.1.1.6- Concluding Computations

Equations (III.1.1) to (III.1.43) can readily be identified in the detailed flow chart of this subroutine

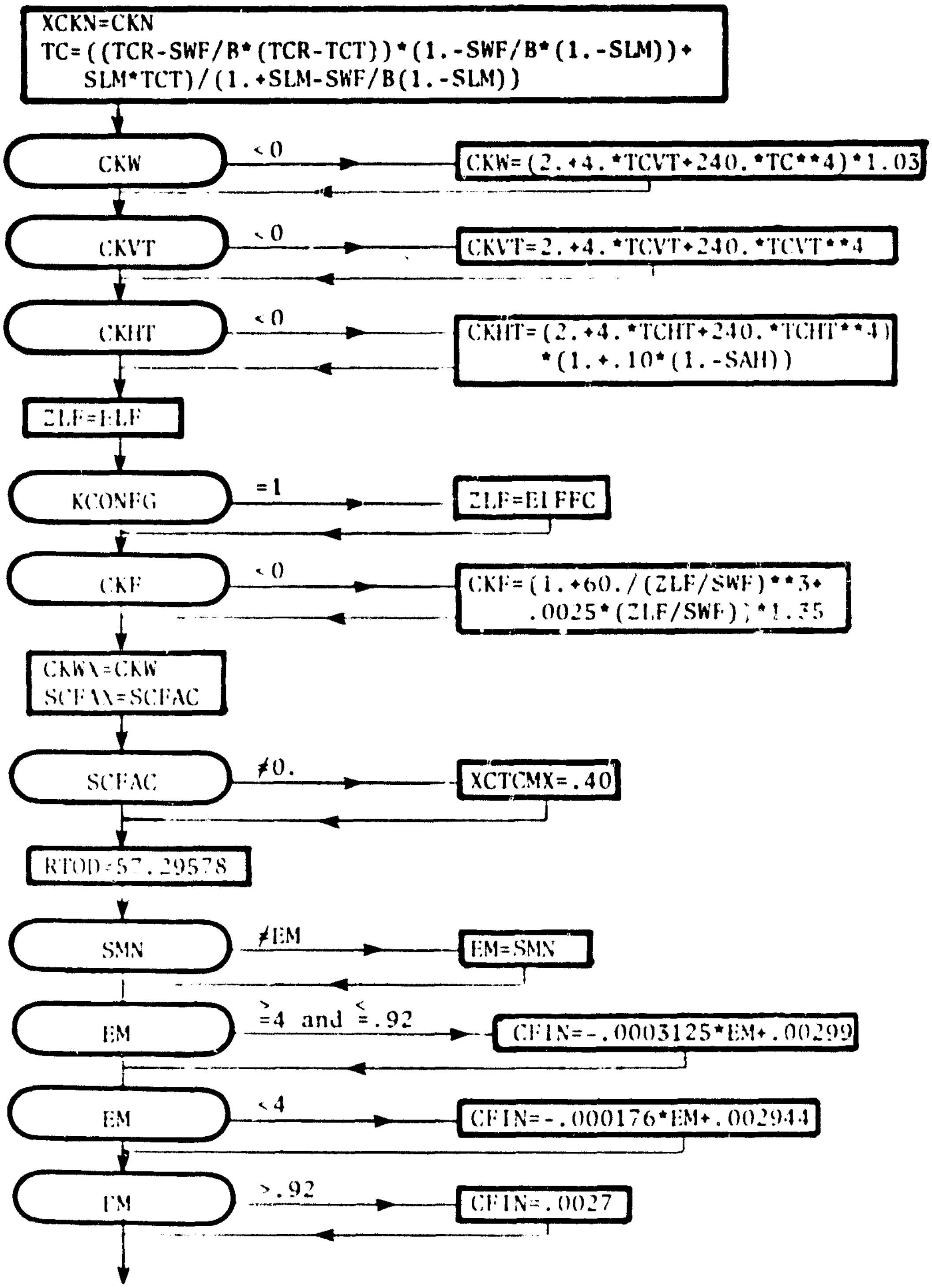
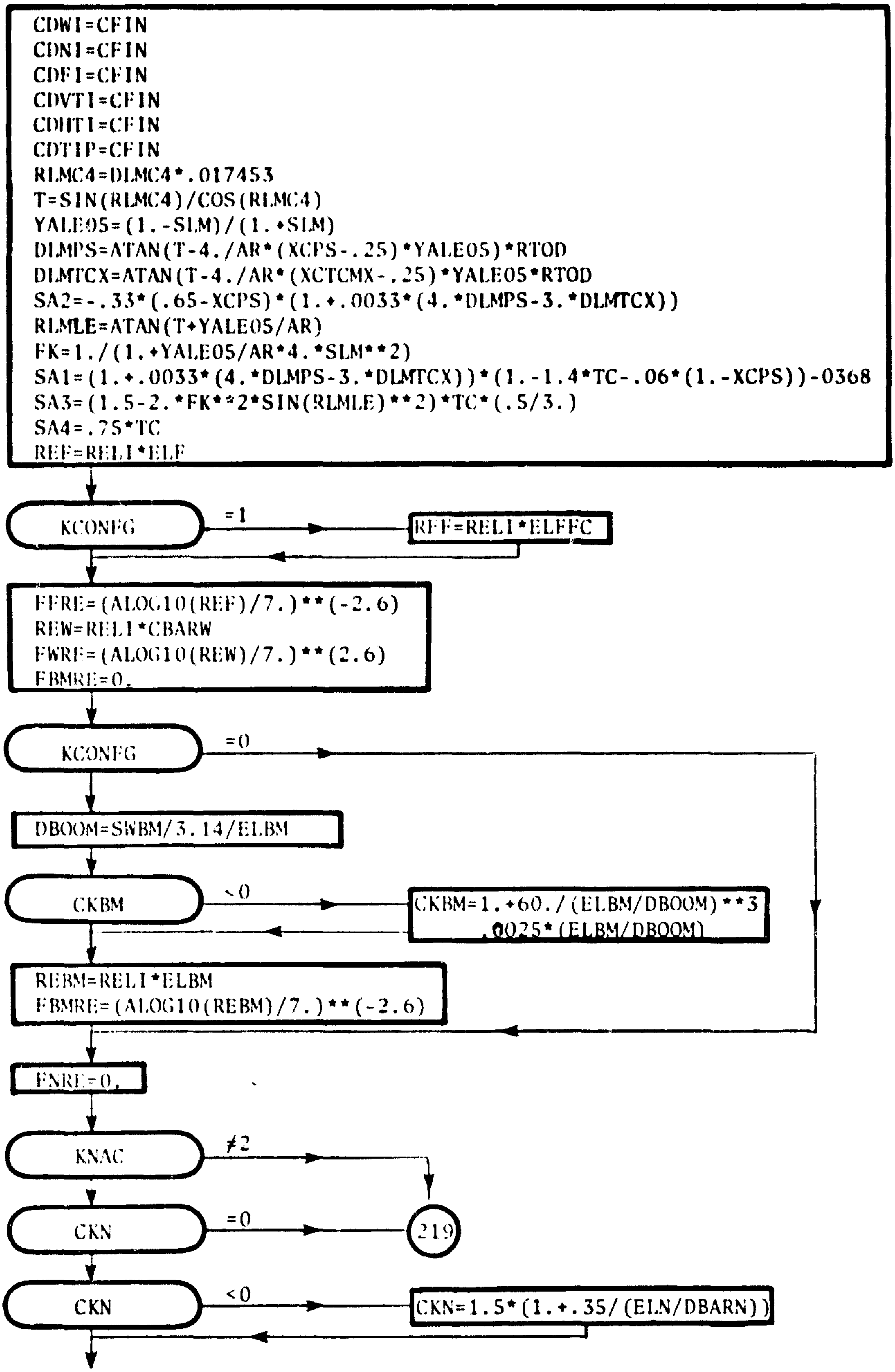
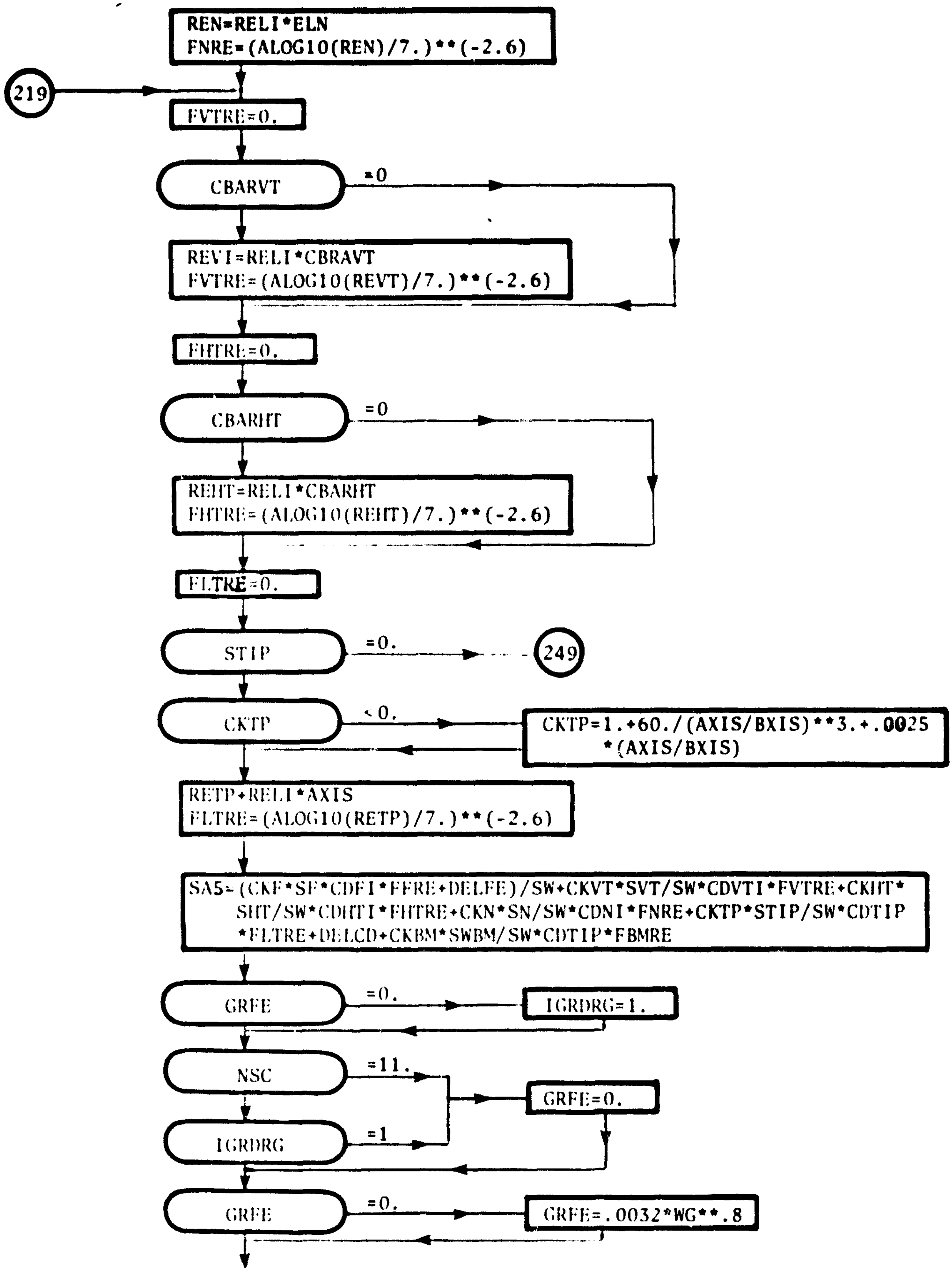
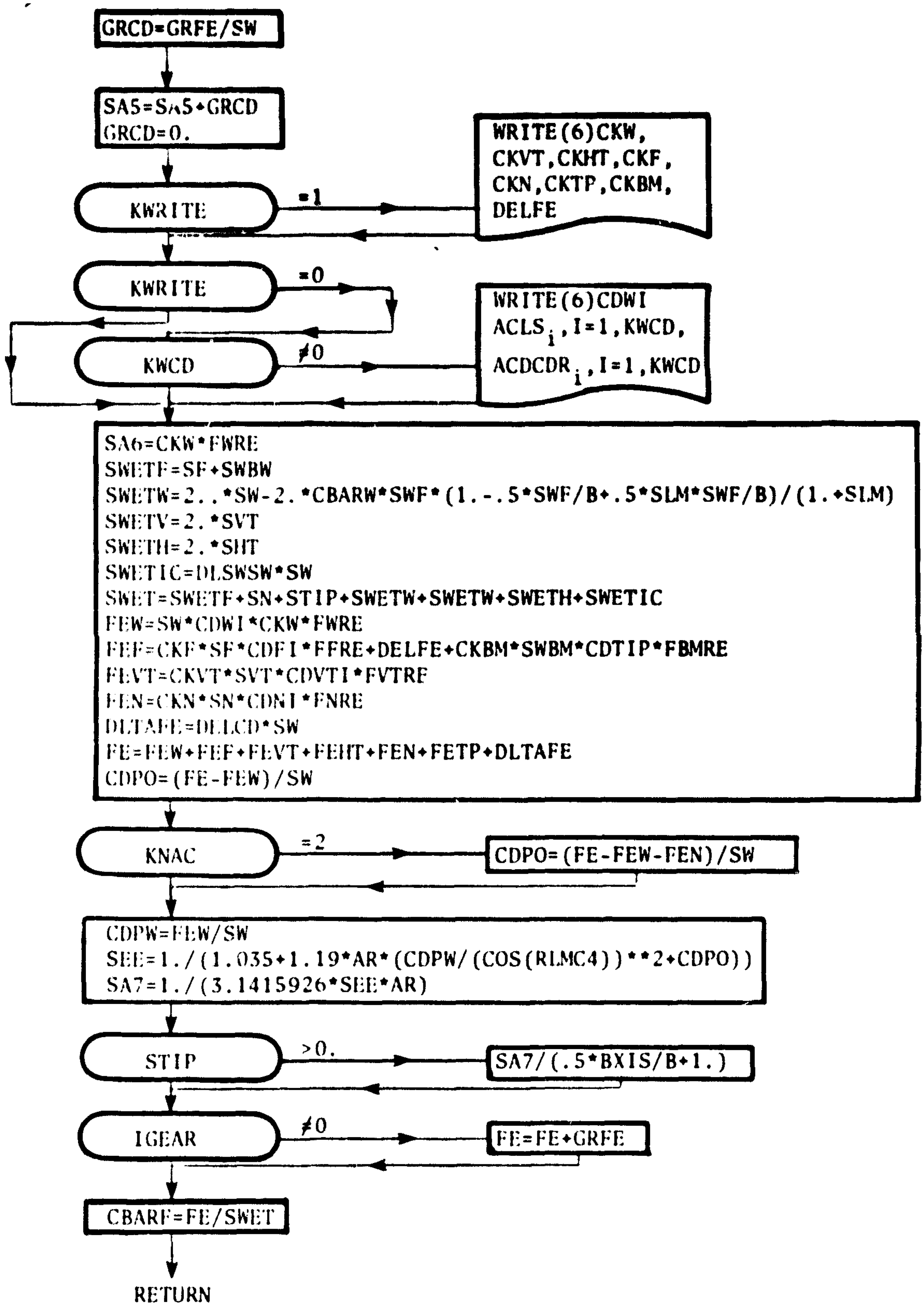


FIGURE III.3.1 - DETAILED FLOW CHART, SUBROUTINE AERO


CDWI=CFIN
CDNI=CFIN
CDFI=CFIN
CDVTI=CFIN
CDHTI=CFIN
CDTIP=CFIN
RLMC4=DLMC4*.017453
T=SIN(RLMC4)/COS(RLMC4)
YALE05=(1.-SLM)/(1.+SLM)
DLMPS=ATAN(T-4./AR*(XCPS-.25)*YALE05)*RTOD
DLMTCX=ATAN(T-4./AR*(XCTCMX-.25)*YALE05*RTOD
SA2=-.33*(.65-XCPS)*(1.+.0033*(4.*DLMPS-3.*DLMTCX))
RLMLE=ATAN(T+YALE05/AR)
FK=1./(1.+YALE05/AR*4.*SLM**2)
SA1=(1.+.0033*(4.*DLMPS-3.*DLMTCX))*(1.-1.4*TC-.06*(1.-XCPS))-0368
SA3=(1.5-2.*FK**2*SIN(RLMLE)**2)*TC*(.5/3.)
SA4=.75*TC
REF=RELI*ELF
KCONFG
=1
REF=RELI*ELFFC
FFRE=(ALOG10(REF)/7.)**(-2.6)
REW=RELI*CBARW
FWRE=(ALOG10(REW)/7.)**(2.6)
FBMRE=0.
KCONFG
=0
DBOOM=SWBM/3.14/ELBM
CKBM
<0
CKBM=1.+60./(ELBM/DBOOM)**3
.0025*(ELBM/DBOOM)
REBM=RELI*ELBM
FBMRE=(ALOG10(REBM)/7.)**(-2.6)
FNRE=0.
KNAC
≠2
CKN
=0
219
CKN
<0
CKN=1.5*(1.+.35/(ELN/DBARN))


REN=RELI*ELN
FNRE=(ALOG10(REN)/7.)**(-2.6)
219
FVTRE=0.
CBARVT
=0
REVT=RELI*CBRAVT
FVTRE=(ALOG10(REVT)/7.)**(-2.6)
FHTRE=0.
CBARHT
=0
REHT=RELI*CBARHT
FHTRE=(ALOG10(REHT)/7.)**(-2.6)
FLTRE=0.
STIP
=0.
249
CKTP
<0.
CKTP=1.+60./(AXIS/BXIS)**3.+.0025
*(AXIS/BXIS)
RETP+RELI*AXIS
FLTRE=(ALOG10(RETP)/7.)**(-2.6)
SA5=(CKF*SF*CDFI*FFRE+DELFE)/SW+CKVT*SVT/SW*CDVTI*FVTRE+CKHT*
SHT/SW*CDHTI*FHTRE+CKN*SN/SW*CDNI*FNRE+CKTP*STIP/SW*CDTIP
*FLTRE+DELCD+CKBM*SWBM/SW*CDTIP*FBMRE
GRFE
=0.
IGRDRG=1.
NSC
=11.
GRFE=0.
IGRDRG
=1
GRFE
=0.
GRFE=.0032*WG**.8


GRCD=GRFE/SW
SA5=SA5+GRCD
GRCD=0.
KWRITE
=1
WRITE(6)CKW,
CKVT,CKHT,CKF,
CKN,CKTP,CKBM,
DELFE
KWRITE
=0
WRITE(6)CDWI
ACLS_i,I=1,KWCD,
ACDCDR_i,I=1,KWCD
KWCD
≠0
SA6=CKW*FWRE
SWETF=SF+SWBW
SWETW=2..*SW-2.*CBARW*SWF*(1.-.5*SWF/B+.5*SLM*SWF/B)/(1.+SLM)
SWETV=2.*SVT
SWETH=2.*SHT
SWETIC=DLSWSW*SW
SWET=SWETF+SN+STIP+SWETW+SWETW+SWETH+SWETIC
FEW=SW*CDWI*CKW*FWRE
FEF=CKF*SF*CDFI*FFRE+DELFE+CKBM*SWBM*CDTIP*FBMRE
FEVT=CKVT*SVT*CDVTI*FVTRE
FEN=CKN*SN*CDNI*FNRE
DLTAFE=DLLCD*SW
FE=FEW+FEF+FEVT+FEHT+FEN+FETP+DLTAFE
CDPO=(FE-FEW)/SW
KNAC
=2
CDPO=(FE-FEW-FEN)/SW
CDPW=FEW/SW
SEE=1./(1.035+1.19*AR*(CDPW/(COS(RLMC4))**2+CDPO))
SA7=1./(3.1415926*SEE*AR)
STIP
>0.
SA7/(.5*BXIS/B+1.)
IGEAR
≠0
FE=FE+GRFE
CBARF=FE/SWET
RETURN

III.3.2 Subroutine AEROUT - Drag Polars

Subroutine AEROUT prints and plots low and high speed drag polars using subroutines CLIFT and DRAG to determine angle-of-attack or lift coefficient and drag coefficient. Standard system graphics routines are employed to prepare plots including

Subroutine	PLOTS	- Plot Initializer
	PLOT	- Plotting Routine
	LINAXS	- Linear Axis
	SYMBOL	- Symbol Drawer
	SPLINE	- Spline Fit
	NUMBER	- Number Drawer
	RSTR	- System Restoration

A detailed flow chart for subroutine AEROUT is presented in Figure III.3.2. A discussion of this routine's function is presented in Section III.1.2.

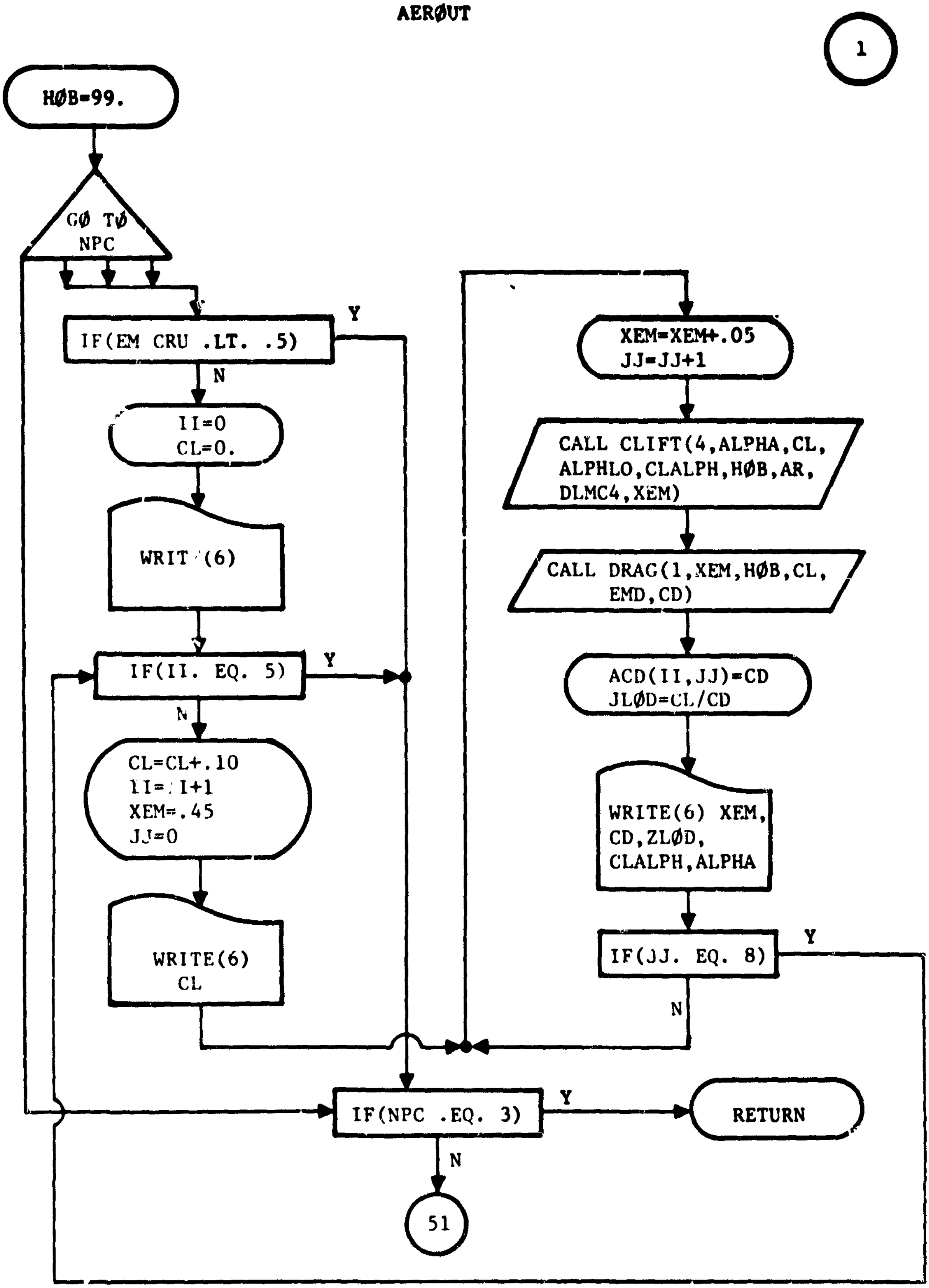
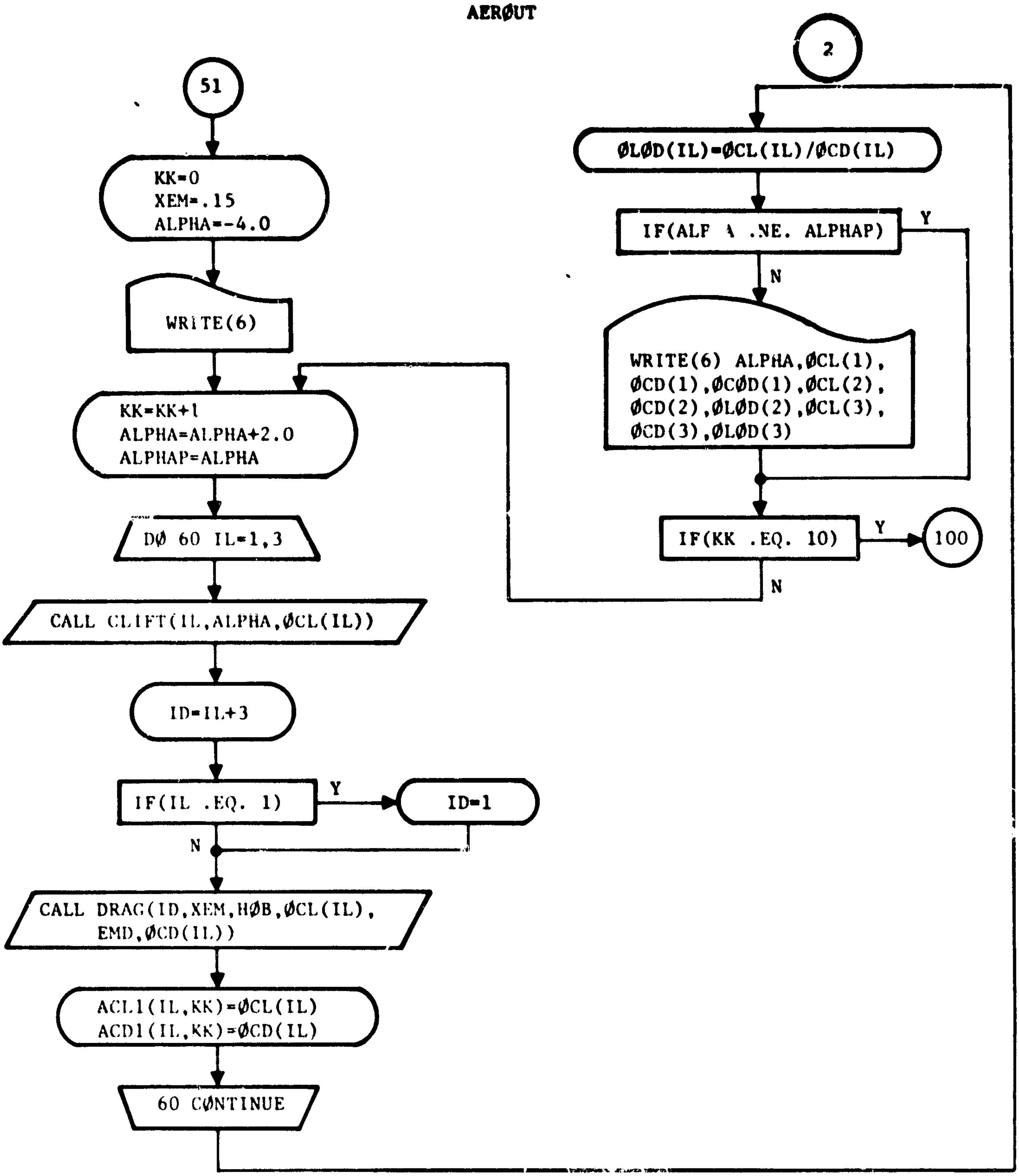
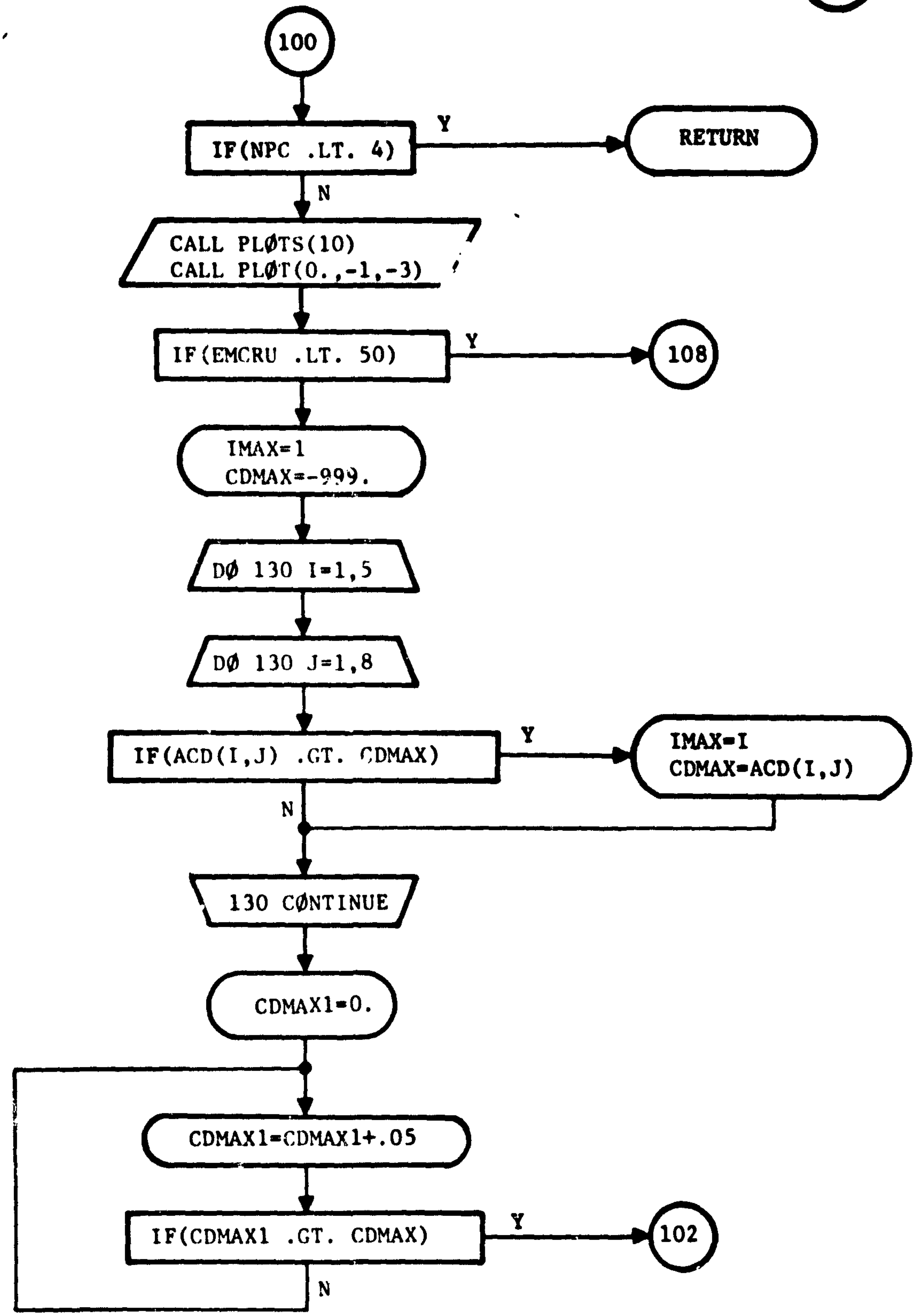


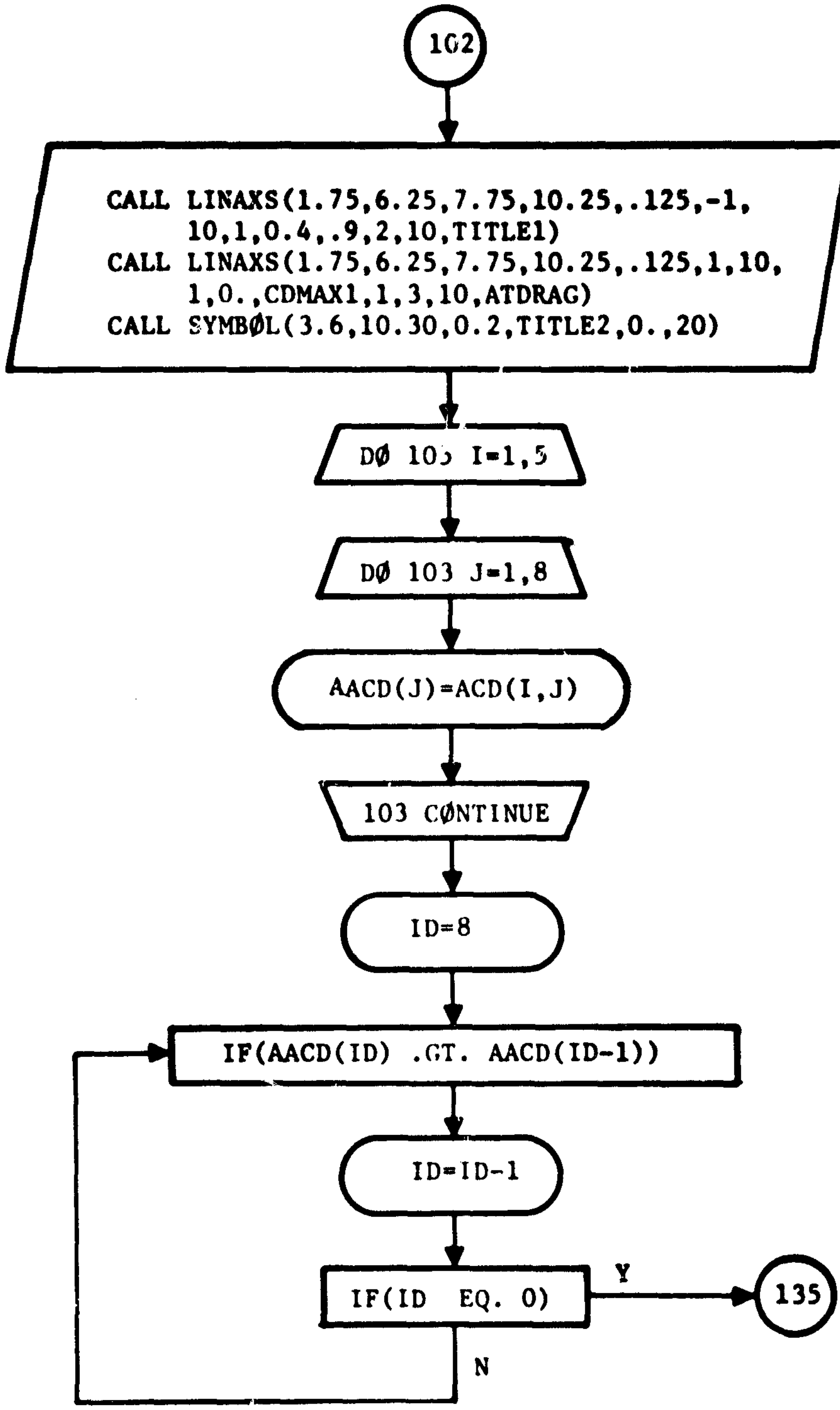
FIGURE III.3.2 - DETAILED FLOWCHART, SUBROUTINE AEROUT

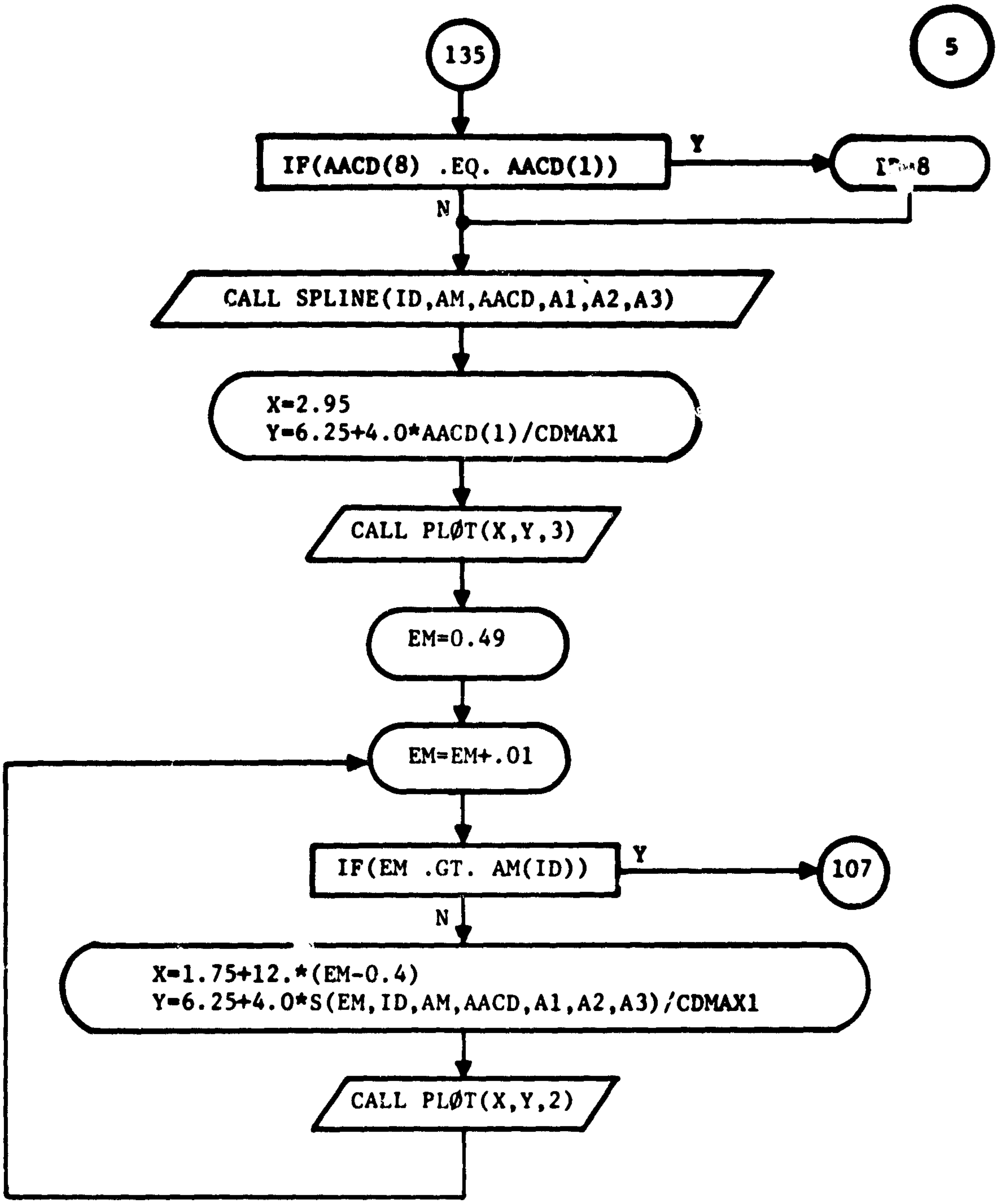
AERØUT

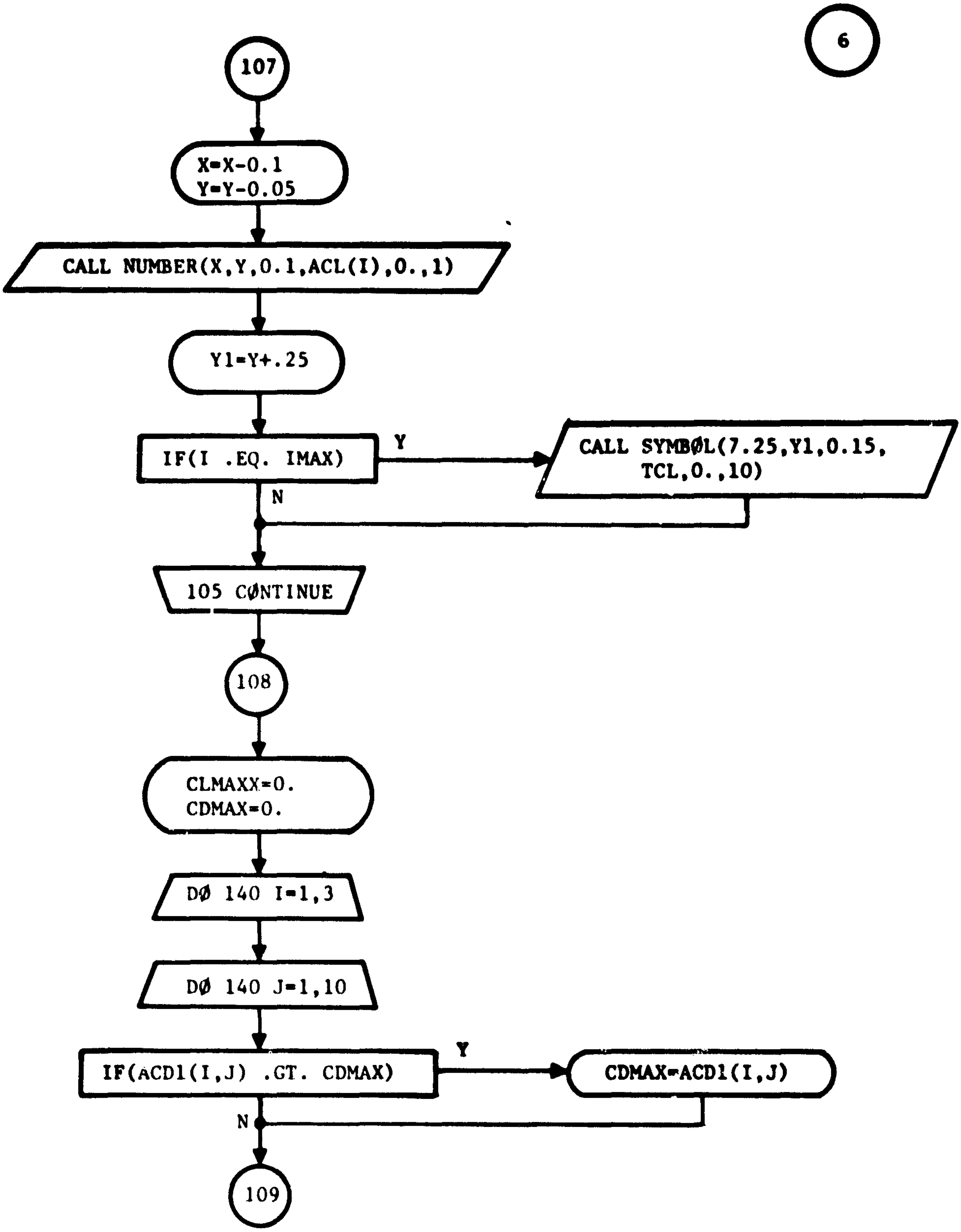


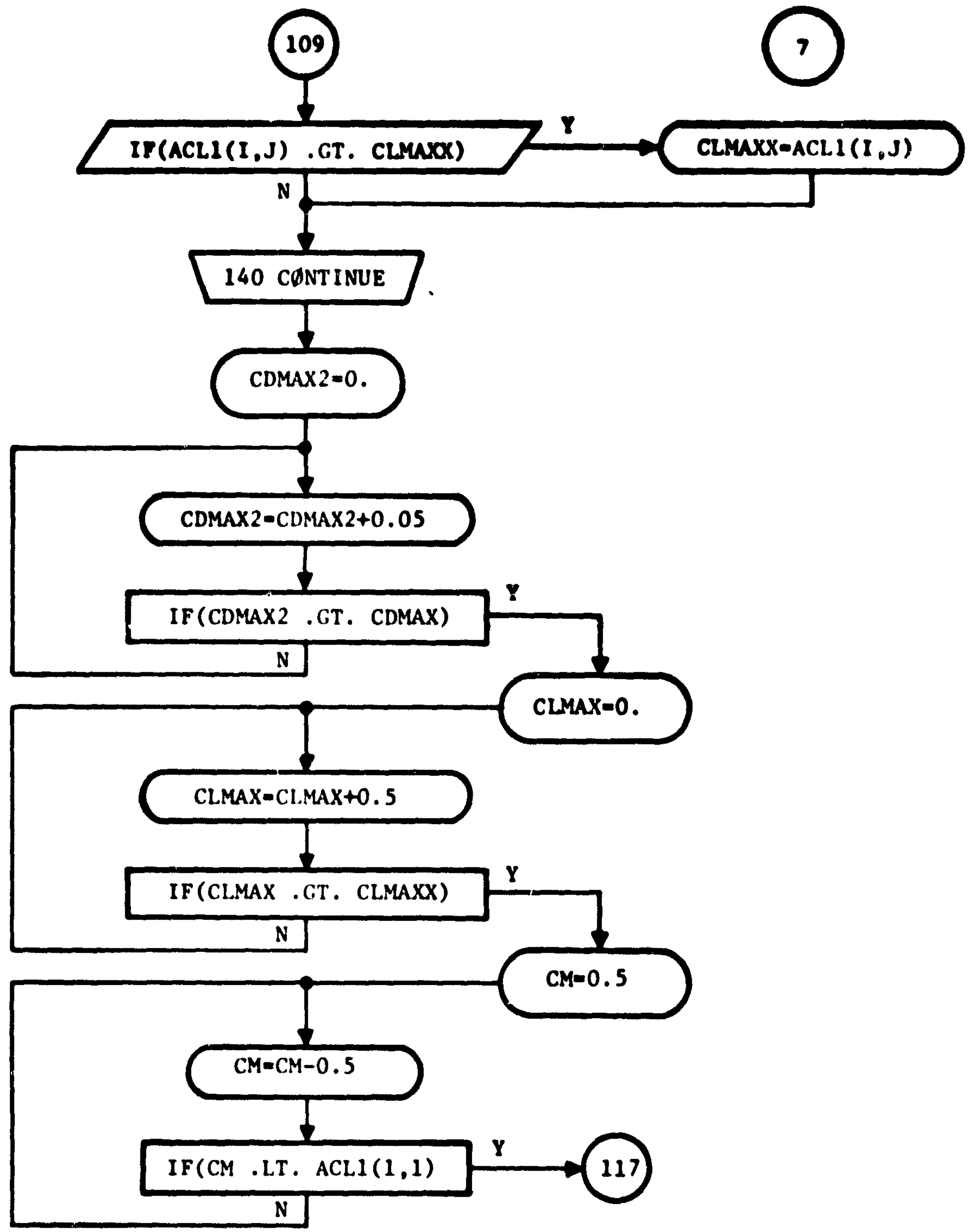
51
KK=0
XEM=.15
ALPHA=-4.0
WRITE(6)
KK=KK+1
ALPHA=ALPHA+2.0
ALPHAP=ALPHA
DØ 60 IL=1,3
CALL CLIFT(IL,ALPHA,ØCL(IL))
ID=IL+3
IF(IL .EQ. 1)
Y
ID=1
N
CALL DRAG(ID,XEM,HØB,ØCL(IL),
EMD,ØCD(IL))
ACL1(IL,KK)=ØCL(IL)
ACD1(IL,KK)=ØCD(IL)
60 CØNTINUE
2
ØLØD(IL)=ØCL(IL)/ØCD(IL)
IF(ALF A .NE. ALPHAP)
Y
N
WRITE(6) ALPHA,ØCL(1),
ØCD(1),ØCØD(1),ØCL(2),
ØCD(2),ØLØD(2),ØCL(3),
ØCD(3),ØLØD(3)
IF(KK .EQ. 10)
Y
100
N

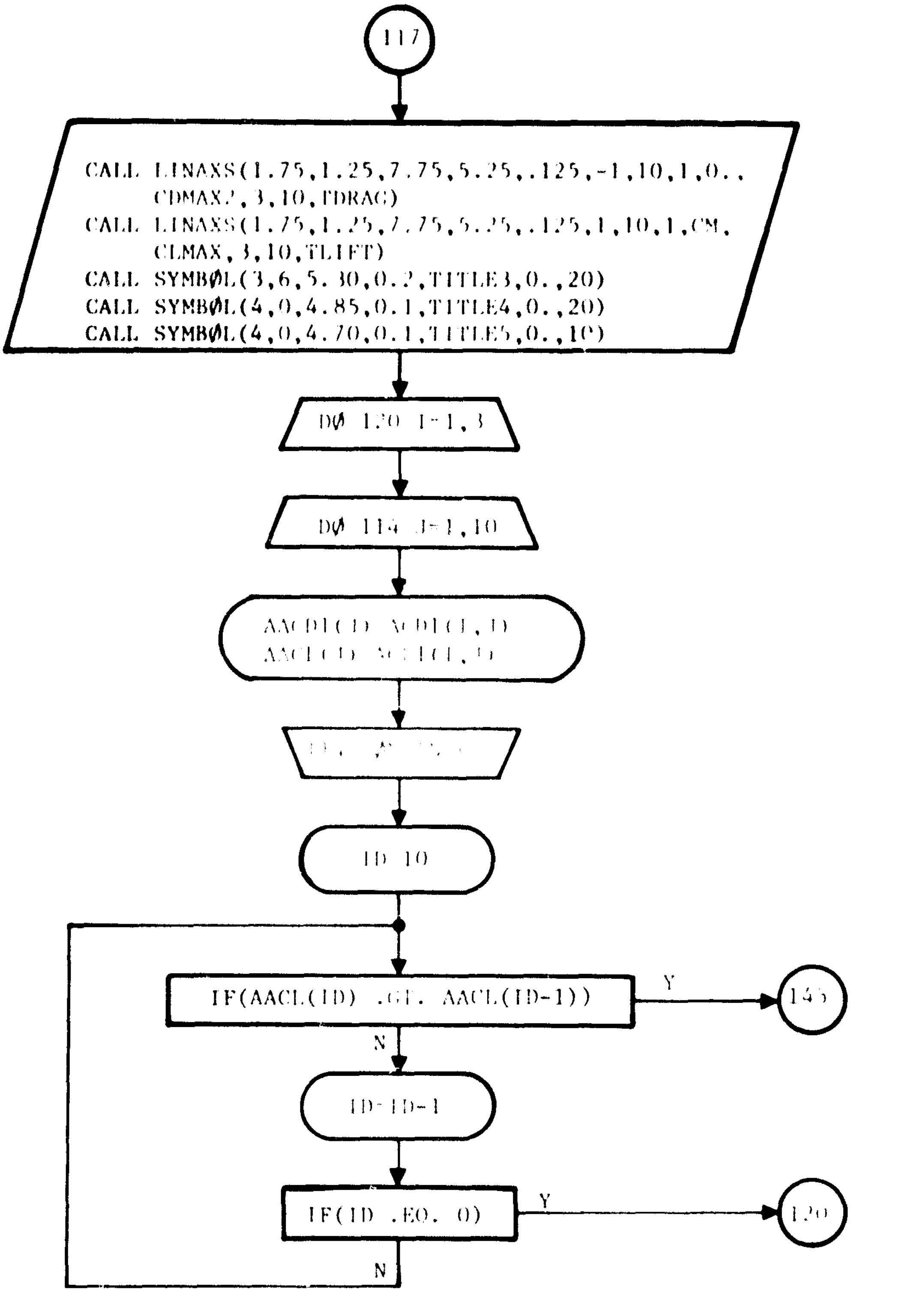

100
IF(NPC .LT. 4)
Y
RETURN
N
CALL PLØTS(10)
CALL PLØT(0.,-1,-3)
IF(EMCRU .LT. 50)
Y
108
IMAX=1
CDMAX=-999.
DØ 130 I=1,5
DØ 130 J=1,8
IF(ACD(I,J) .GT. CDMAX)
Y
IMAX=I
CDMAX=ACD(I,J)
N
130 CØNTINUE
CDMAX1=0.
CDMAX1=CDMAX1+.05
IF(CDMAX1 .GT. CDMAX)
Y
102
N


102
CALL LINAXS(1.75,6.25,7.75,10.25,.125,-1,
10,1,0.4,.9,2,10,TITLE1)
CALL LINAXS(1.75,6.25,7.75,10.25,.125,1,10,
1,0.,CDMAX1,1,3,10,ATDRAG)
CALL SYMBØL(3.6,10.30,0.2,TITLE2,0.,20)
DØ 105 I=1,5
DØ 103 J=1,8
AACD(J)=ACD(I,J)
103 CØNTINUE
ID=8
IF(AACD(ID) .GT. AACD(ID-1))
ID=ID-1
IF(ID EQ. 0)
Y
135
N


135
5
IF(AACD(8) .EQ. AACD(1))
Y
N
CALL SPLINE(ID,AM,AACD,A1,A2,A3)
X=2.95
Y=6.25+4.0*AACD(1)/CDMAX1
CALL PLØT(X,Y,3)
EM=0.49
EM=EM+.01
IF(EM .GT. AM(ID))
Y
107
N
X=1.75+12.*(EM-0.4)
Y=6.25+4.0*S(EM,ID,AM,AACD,A1,A2,A3)/CDMAX1
CALL PLØT(X,Y,2)


6
107
X=X-0.1
Y=Y-0.05
CALL NUMBER(X,Y,0.1,ACL(I),0.,1)
Y1=Y+.25
IF(I .EQ. IMAX)
Y
CALL SYMBØL(7.25,Y1,0.15,
TCL,0.,10)
N
105 CØNTINUE
108
CLMAXX=0.
CDMAX=0.
DØ 140 I=1,3
DØ 140 J=1,10
IF(ACD1(I,J) .GT. CDMAX)
Y
CDMAX=ACD1(I,J)
N
109


109
7
IF(ACL1(I,J) .GT. CLMAXX)
Y
CLMAXX=ACL1(I,J)
N
140 CØNTINUE
CDMAX2=0.
CDMAX2=CDMAX2+0.05
IF(CDMAX2 .GT. CDMAX)
Y
N
CLMAX=0.
CLMAX=CLMAX+0.5
IF(CLMAX .GT. CLMAXX)
Y
N
CM=0.5
CM=CM-0.5
IF(CM .LT. ACL1(1,1)
Y
117
N



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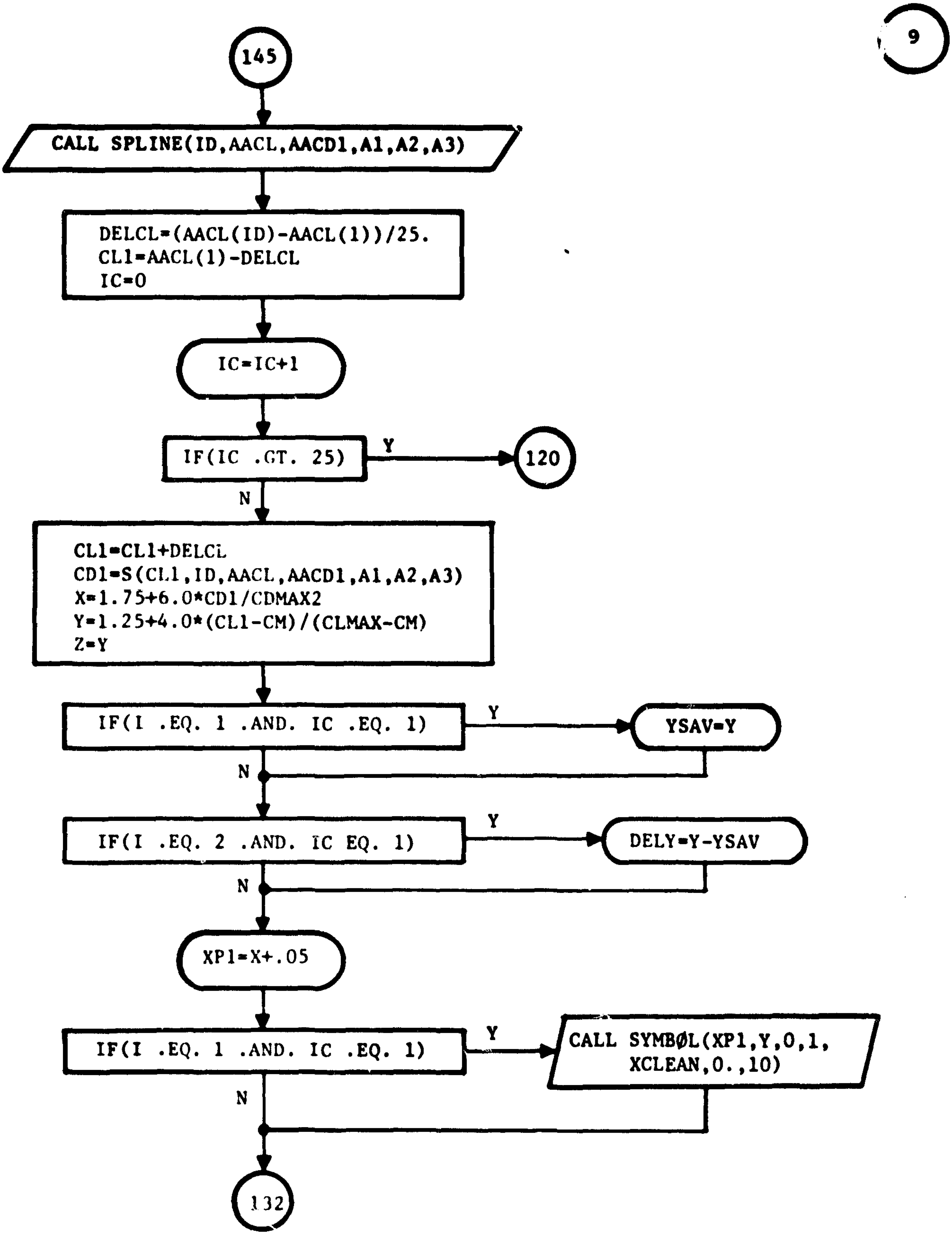
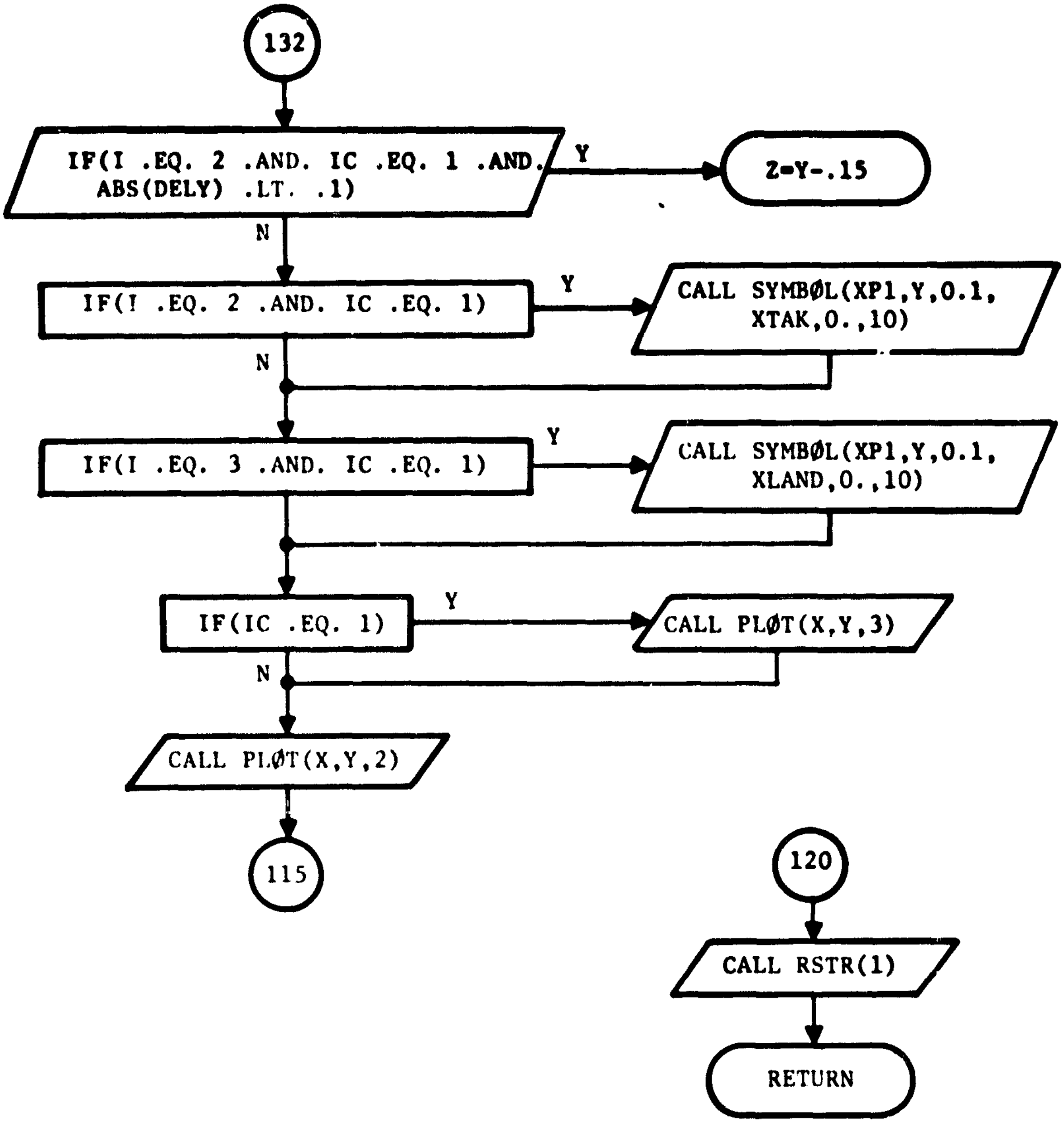
OF POOR QUALITY


9
145
CALL SPLINE(ID,AACL,AACD1,A1,A2,A3)
DELCL=(AACL(ID)-AACL(1))/25.
CL1=AACL(1)-DELCL
IC=0
IC=IC+1
IF(IC .GT. 25)
Y
120
N
CL1=CL1+DELCL
CD1=S(CL1,ID,AACL,AACD1,A1,A2,A3)
X=1.75+6.0*CD1/CDMAX2
Y=1.25+4.0*(CL1-CM)/(CLMAX-CM)
Z=Y
IF(I .EQ. 1 .AND. IC .EQ. 1)
Y
YSAV=Y
N
IF(I .EQ. 2 .AND. IC EQ. 1)
Y
DELY=Y-YSAV
N
XP1=X+.05
IF(I .EQ. 1 .AND. IC .EQ. 1)
Y
CALL SYMBØL(XP1,Y,0,1,
XCLEAN,0.,10)
N
132


132
IF(I .EQ. 2 .AND. IC .EQ. 1 .AND. ABS(DELY) .LT. .1)
Y
Z=Y-.15
N
IF(I .EQ. 2 .AND. IC .EQ. 1)
Y
CALL SYMBØL(XP1,Y,0.1, XTAK,0.,10)
N
IF(I .EQ. 3 .AND. IC .EQ. 1)
Y
CALL SYMBØL(XP1,Y,0.1, XLAND,0.,10)
IF(IC .EQ. 1)
Y
CALL PLØT(X,Y,3)
N
CALL PLØT(X,Y,2)
115
120
CALL RSTR(1)
RETURN

III.3.3 Subroutine APPFLP - Flap Application Routine

This subroutine controls the flap setting calculation using subroutine FLAPS to compute lift associated with a given flap setting and ITRMHW to iterate for the desired flap setting. When convergence cannot be obtained, flaps are set to the landing position. Refer to Section III.1.3.4 for additional details. A flow chart for subroutine APPFLP is presented in Figure III.3.3.

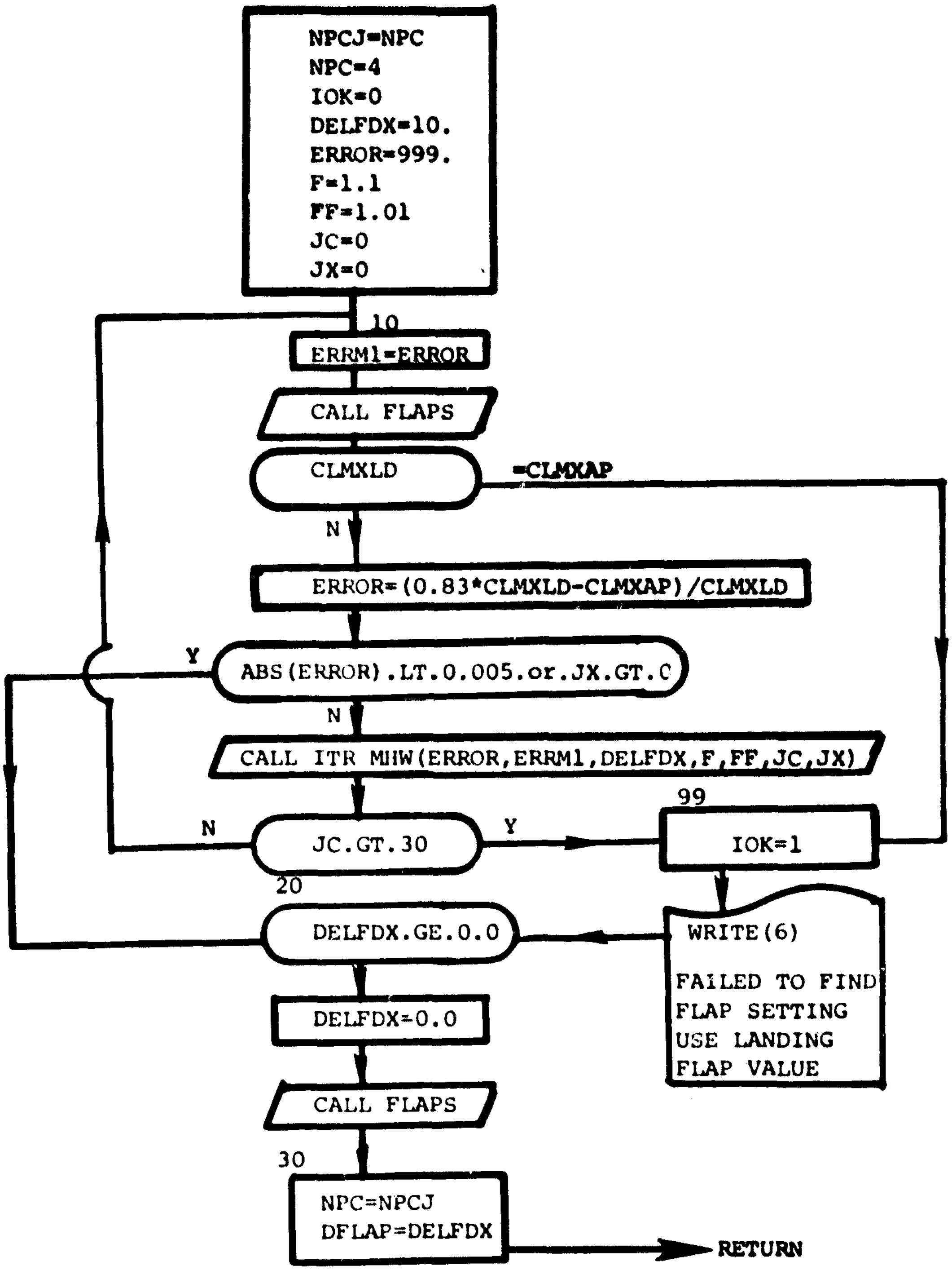


FIGURE III.3.3
DETAILED FLOW CHART, SUBROUTINE APPFLP

III.3.4 Subroutine CLIFT -

Wing Alone Lift Coefficient

This subroutine computes wing alone lift coefficient at a given angle-of-attack. Methodology is described in Section III.1.2.1 of this report. A detailed flow chart of the calculations is presented in Figure III.3.4. Equations III.1.54 to III.1.65 of the referenced section can readily be identified in the flow chart.

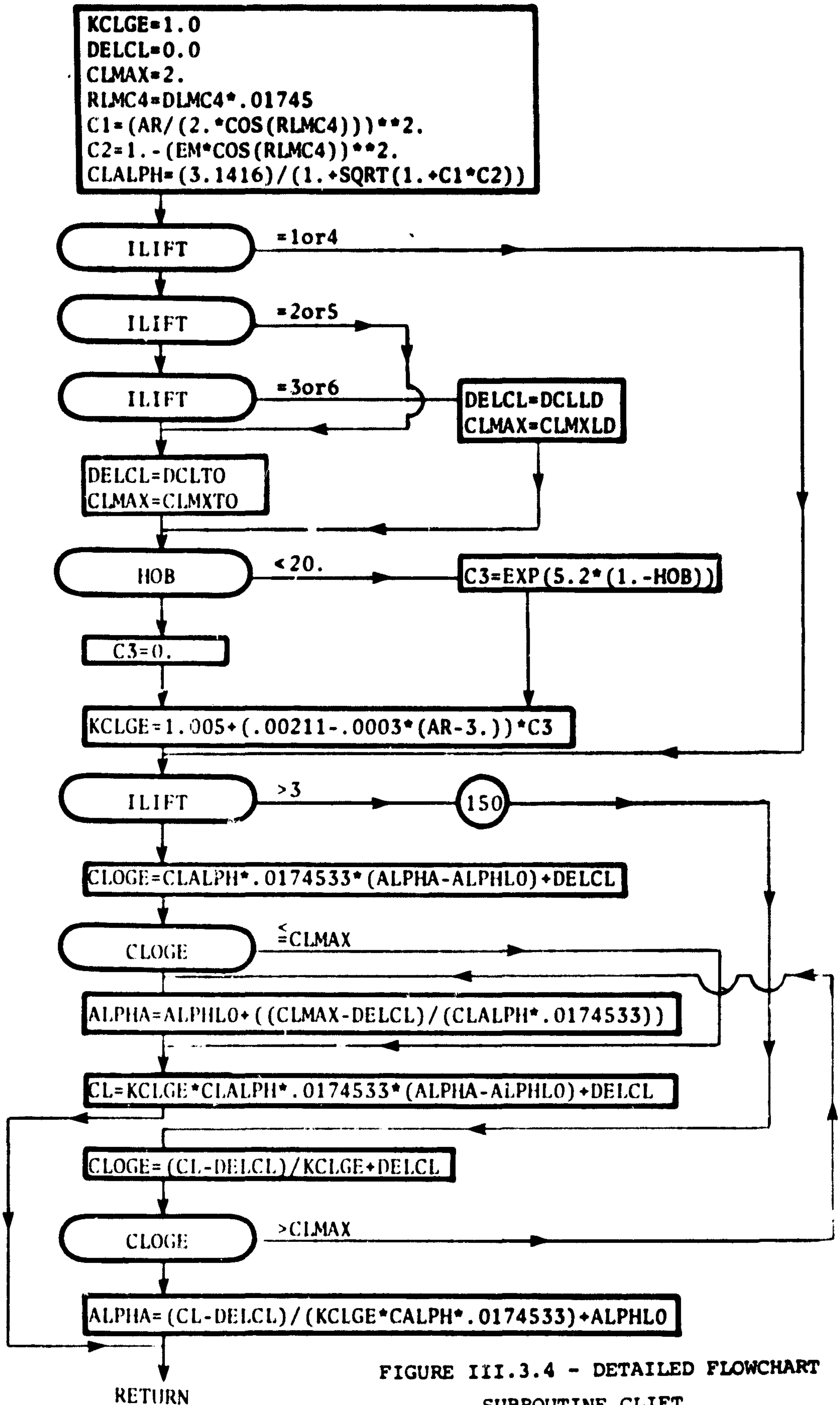


FIGURE III.3.4 - DETAILED FLOWCHART

SUBROUTINE CLIFT

III.3.5 Subroutine CTAER -

Lift and Drag in Cruise Flight

This subroutine determines lift coefficient to support the aircraft in cruise flight together with the associated drag coefficient. Subroutine CTAER employs subroutine TPALT to obtain atmospheric properties in the cruise flight condition. Subroutine CLIFT provides lift coefficient; subroutine AERO provides profile drag, and subroutine DRAG computes induced drag and compressibility drag. The computations of subroutine CTAER are discussed in some detail in Section III.1.3 and Equations (III.1.71) to (III.1.74) of that section can be identified in the detailed flow chart of Figure III.3.5.

CTAER

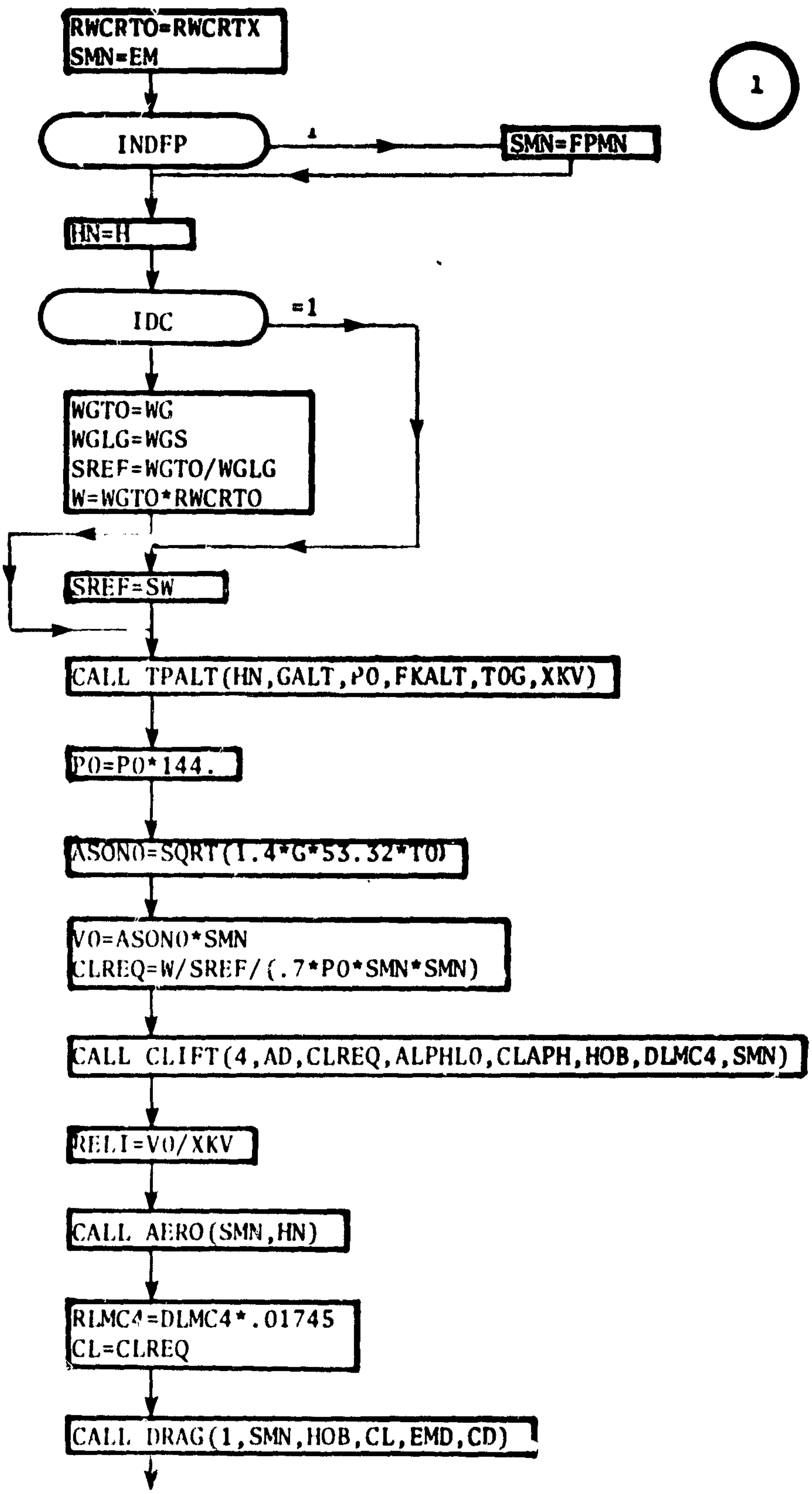
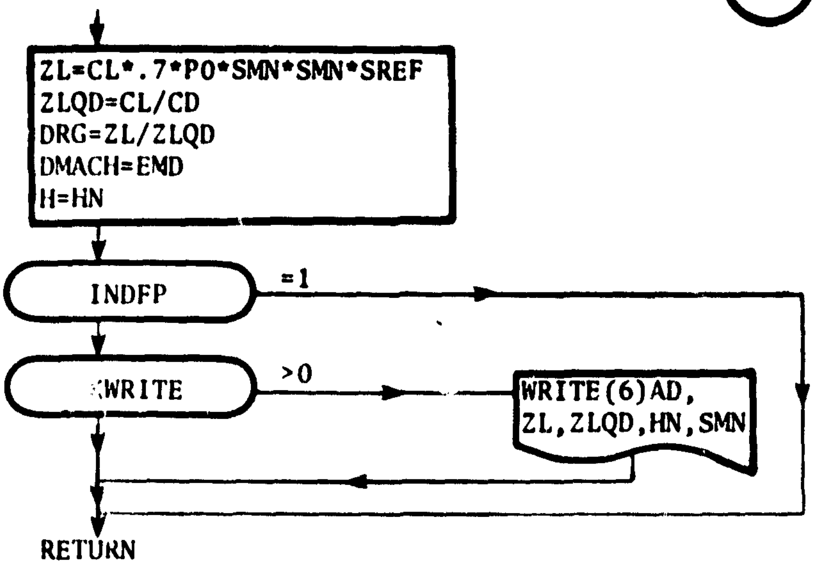


FIGURE III.3.5 - DETAILED FLOW CHART SUBROUTINE CTAER


ZL=CL*.7*PO*SMN*SMN*SREF
ZLQD=CL/CD
DRG=ZL/ZLQD
DMACH=EMD
H=HN
INDFP
=1
KWRITE
>0
WRITE(6)AD,
ZL,ZLQD,HN,SMN
RETURN

III.3.6 Subroutine DRAG -

Induced and Compressibility Drag

Subroutine DRAG computes the total aircraft drag coefficient with or without flaps deployed. The methodology is presented in Section III.1.2.2 of this report. Flight condition is selected through the indicator IDRAG. Equations (III.1.66) to (III.1.70) can be identified in the detailed flow chart of Figure III.3.6. Several of the coefficients appearing in these equations are obtained by interpolation in tabulated values using subroutine ITRLN which is the only subroutine called by DRAG.

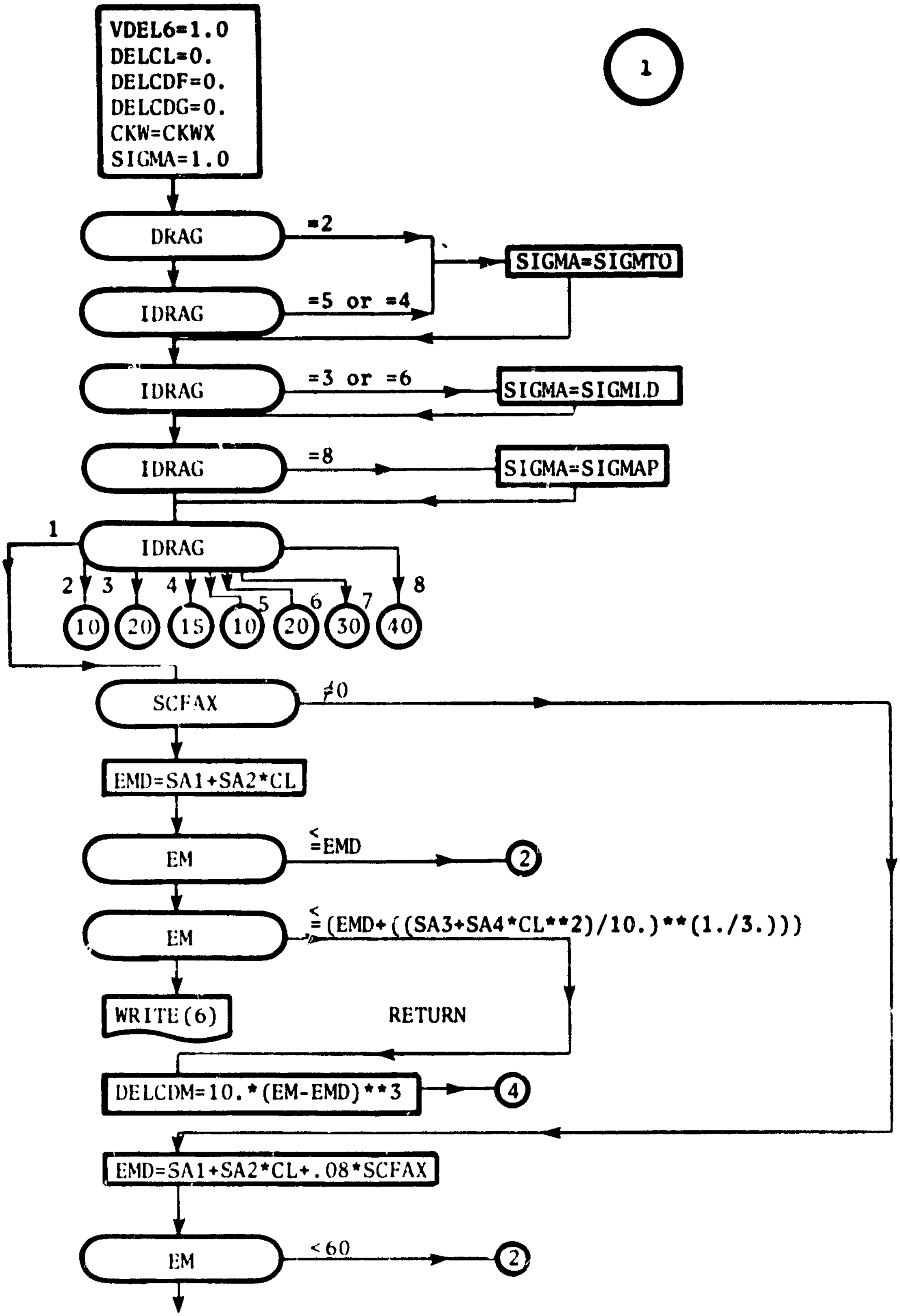
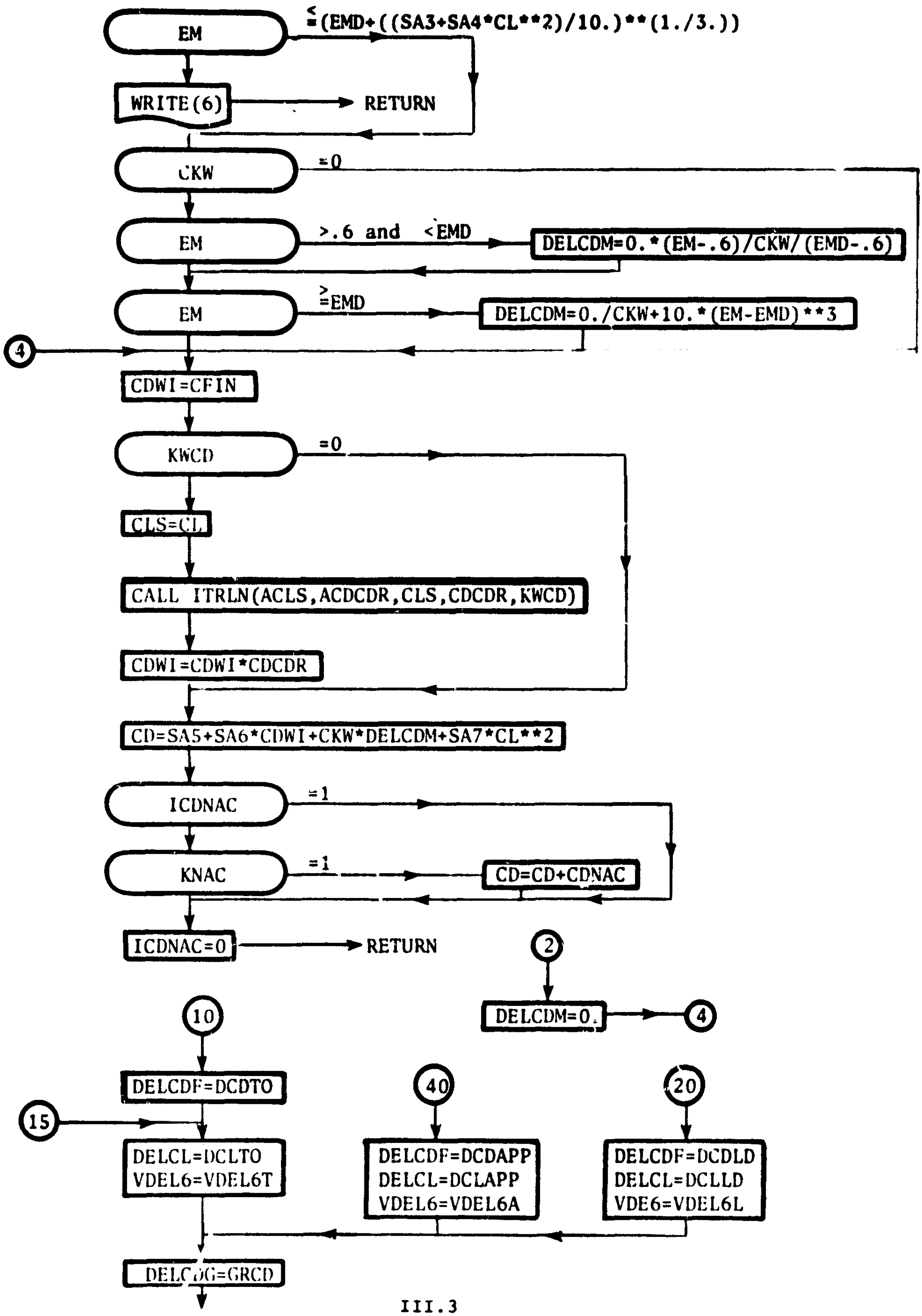


FIGURE III.3.6 - DETAILED FLOWCHART SUBROUTINE DRAG

DRAG

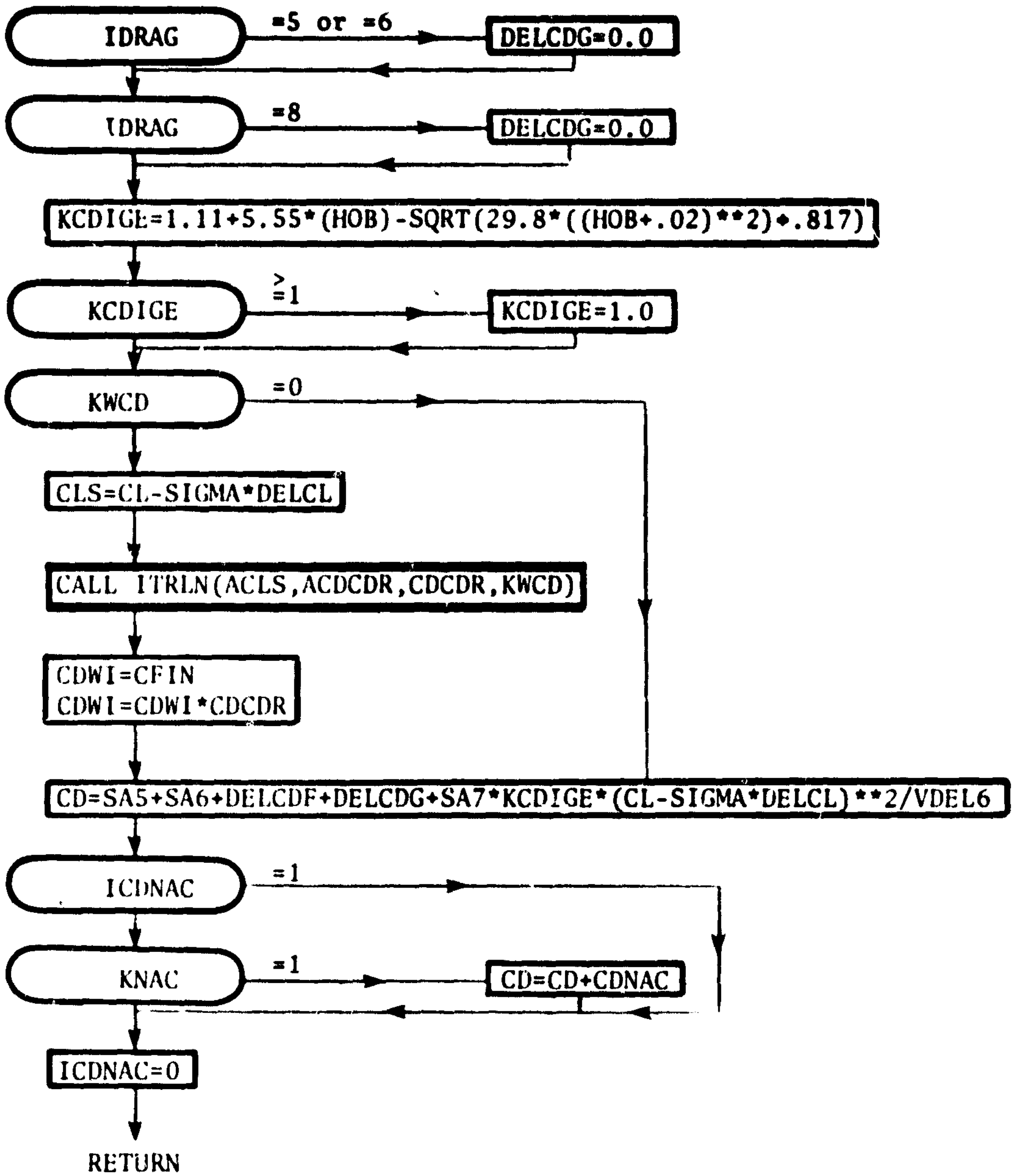
2



EM
≤ (EMD+((SA3+SA4*CL**2)/10.)**(1./3.))
WRITE(6)
RETURN
CKW
=0
EM
>.6 and <EMD
DELCDM=0.*(EM-.6)/CKW/(EMD-.6)
EM
≥EMD
DELCDM=0./CKW+10.*(EM-EMD)**3
4
CDWI=CFIN
KWCD
=0
CLS=CL
CALL ITRLN(ACLS,ACDCDR,CLS,CDCDR,KWCD)
CDWI=CDWI*CDCDR
CD=SA5+SA6*CDWI+CKW*DELCDM+SA7*CL**2
ICDNAC
=1
KNAC
=1
CD=CD+CDNAC
ICDNAC=0
RETURN
2
DELCDM=0.
4
10
DELCDF=DCDTO
15
DELCL=DCLTO
VDEL6=VDEL6T
40
DELCDF=DCDAPP
DELCL=DCLAPP
VDEL6=VDEL6A
20
DELCDF=DCDLD
DELCL=DCLLD
VDE6=VDEL6L
DELCDG=GRCD

DRAG

3


IDRAG
=5 or =6
DELCDG=0.0
IDRAG
=8
DELCDG=0.0
KCDIGE=1.11+5.55*(HOB)-SQRT(29.8*((HOB+.02)**2)+.817)
KCDIGE
≥1
KCDIGE=1.0
KWCD
=0
CLS=CL-SIGMA*DELCL
CALL ITRLN(ACLS,ACDCDR,CDCDR,KWCD)
CDWI=CFIN
CDWI=CDWI*CDCDR
CD=SA5+SA6+DELCDF+DELCDG+SA7*KCDIGE*(CL-SIGMA*DELCL)**2/VDEL6
ICDNAC
=1
KNAC
=1
CD=CD+CDNAC
ICDNAC=0
RETURN

III.3.7 Subroutine FLAPS - Flap Characteristics Routine

Subroutine FLAPS computes flap lift and drag increments for several flap types using the methods outlined in Section III.1.4.1. The routine also has the ability to compute flap weight characteristics by the method of Section III.1.4.2.

A detailed flow chart for subroutine FLAPS is presented in Figure III.3.7. The first two-and-one-half pages of this routine are mainly concerned with computation of the factors VLAM1 to VLAM14 (Section III.1.4.1) which enter into the maximum lift coefficient computation. These factors are obtained by table look-ups using subroutine ITRLN. This is followed by computation of the flap efficiency factors on Pages 3 and 4 of the detailed flow chart. Page 5 of the flow chart primarily computes flap weights and geometrical characteristics. When NPC = 4, the routine transfers directly to the bottom of Page 6 at Statement 150 where allowable approach flap characteristics are determined.

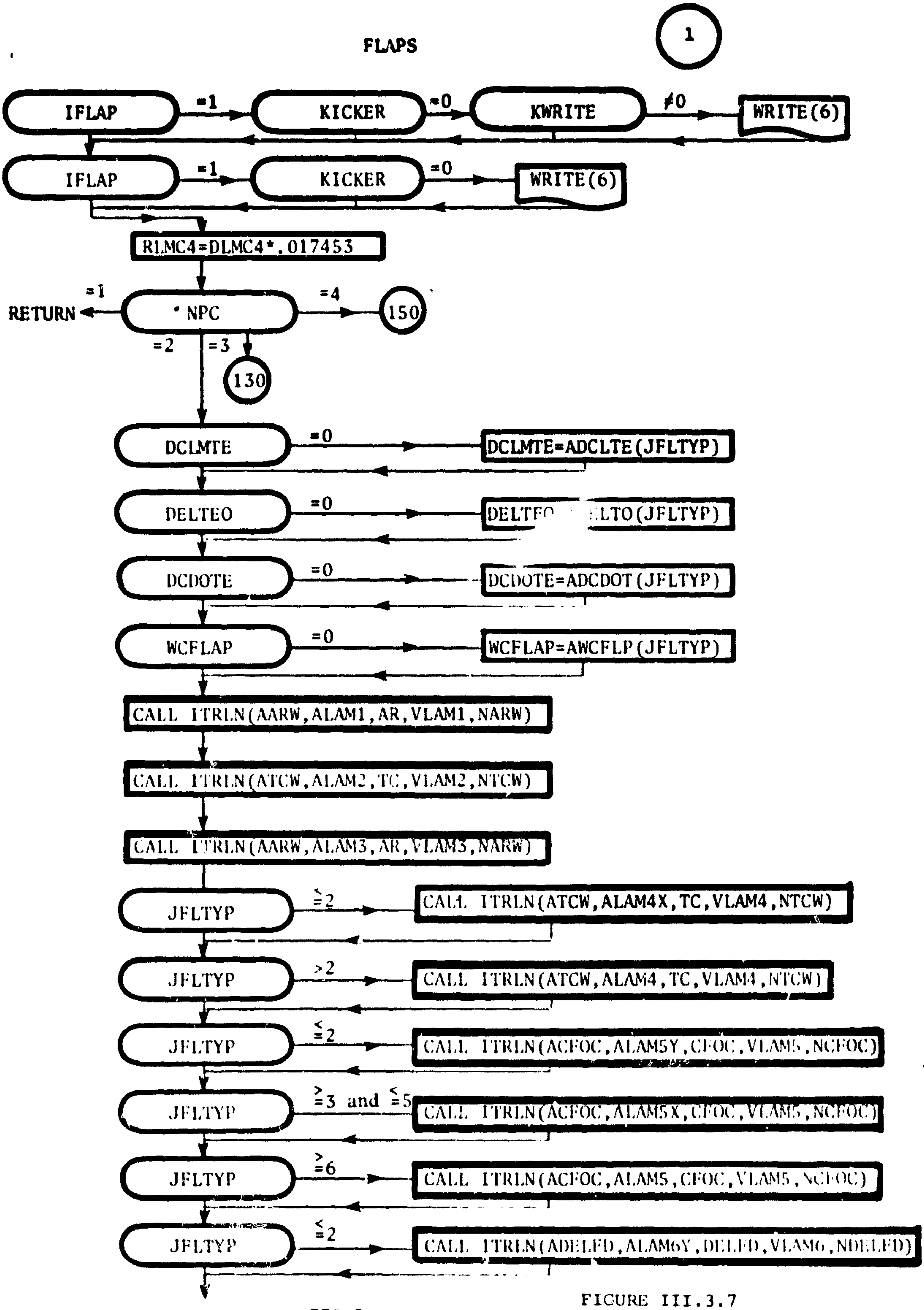
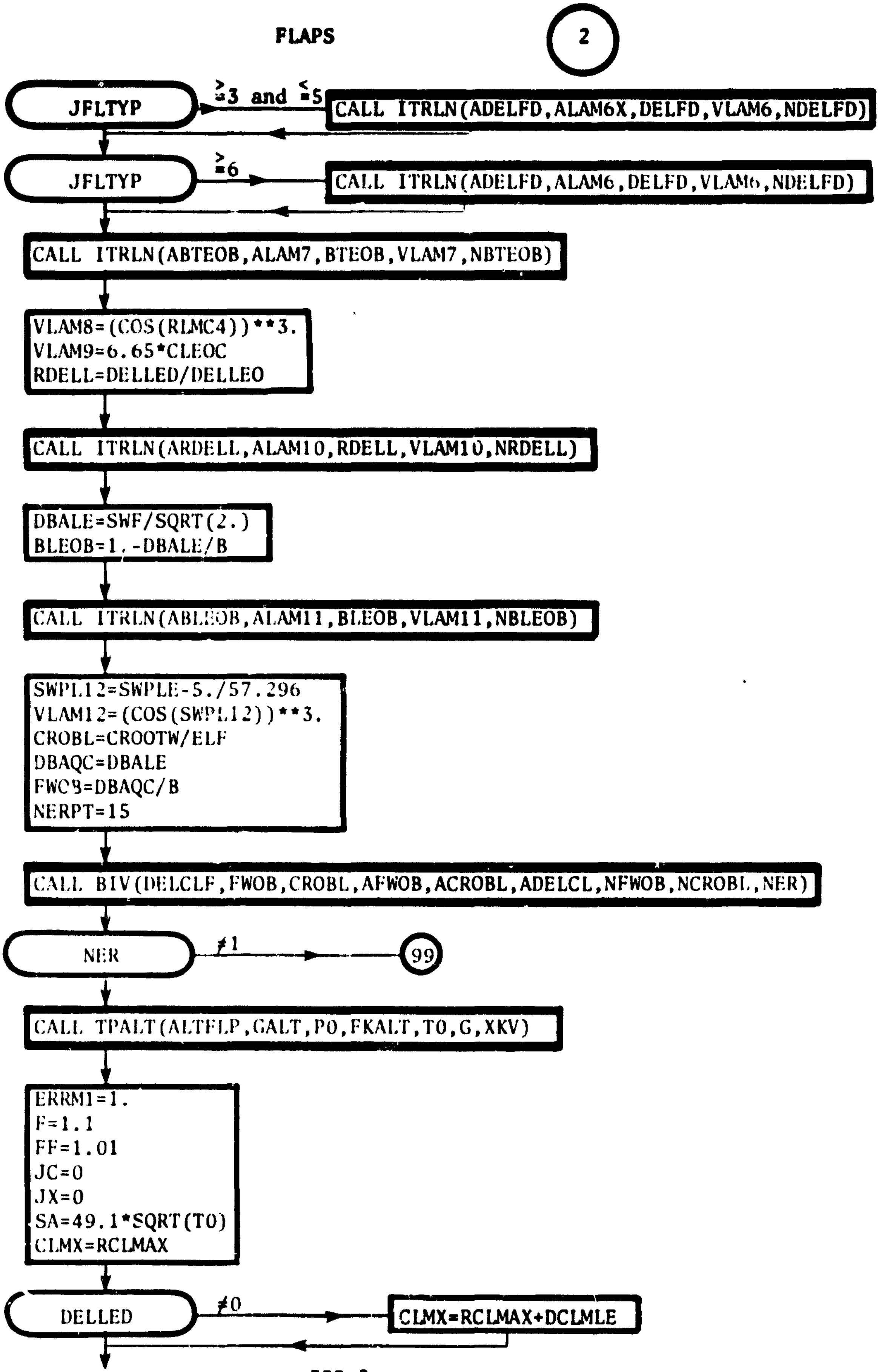
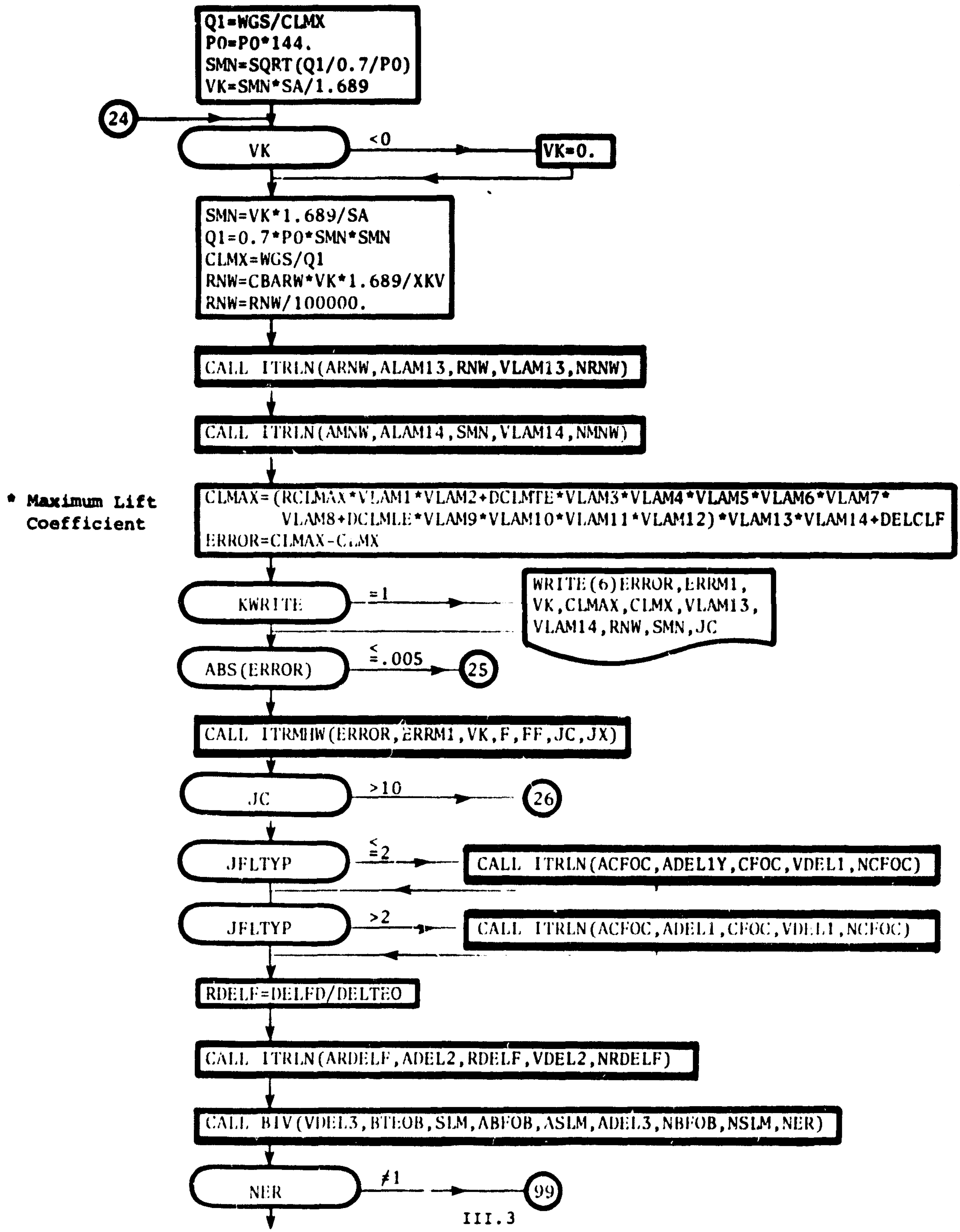


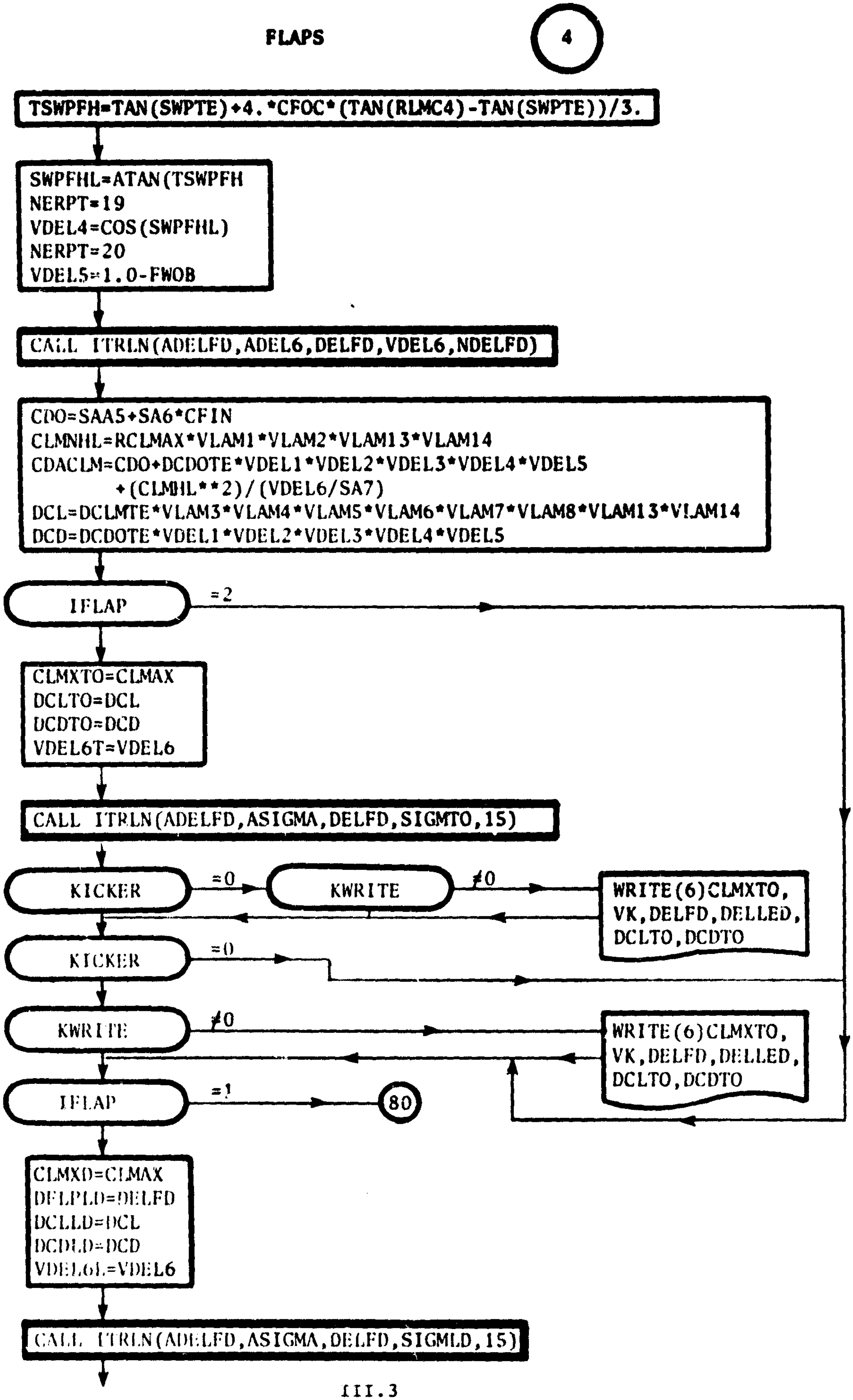
FIGURE III.3.7

DETAILED FLOWCHART SUBROUTINE FLAPS

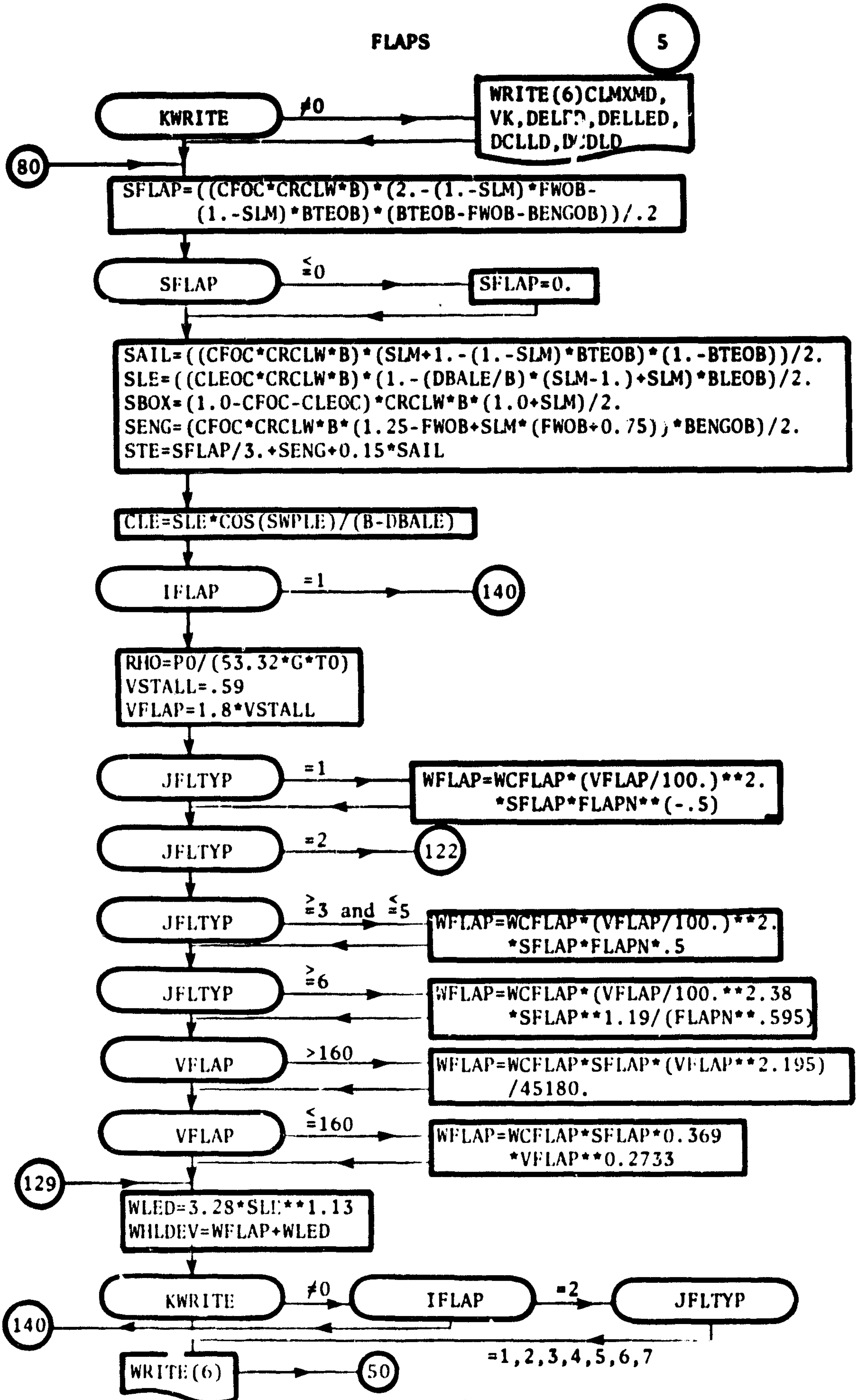

FLAPS
2
JFLTYP
≥3 and ≤5
CALL ITRLN(ADELFD,ALAM6X,DELFD,VLAM6,NDELFD)
JFLTYP
≥6
CALL ITRLN(ADELFD,ALAM6,DELFD,VLAM6,NDELFD)
CALL ITRLN(ABTEOB,ALAM7,BTEOB,VLAM7,NBTEOB)
VLAM8=(COS(RLMC4))**3.
VLAM9=6.65*CLEOC
RDELL=DELLED/DELLEO
CALL ITRLN(ARDELL,ALAM10,RDELL,VLAM10,NRDELL)
DBALE=SWF/SQRT(2.)
BLEOB=1.-DBALE/B
CALL ITRLN(ABLEOB,ALAM11,BLEOB,VLAM11,NBLEOB)
SWPL12=SWPLE-5./57.296
VLAM12=(COS(SWPL12))**3.
CROBL=CROOTW/ELF
DBAQC=DBALE
FWOB=DBAQC/B
NERPT=15
CALL BIV(DELCLF,FWOB,CROBL,AFWOB,ACROBL,ADELCL,NFWOB,NCROBL,NER)
NER
≠1
99
CALL TPALT(ALTFLP,GALT,P0,FKALT,T0,G,XKV)
ERRM1=1.
F=1.1
FF=1.01
JC=0
JX=0
SA=49.1*SQRT(T0)
CLMX=RCLMAX
DELLED
≠0
CLMX=RCLMAX+DCLMLE


Q1=WGS/CLMX
PO=PO*144.
SMN=SQRT(Q1/0.7/PO)
VK=SMN*SA/1.689
24
VK
<0
VK=0.
SMN=VK*1.689/SA
Q1=0.7*PO*SMN*SMN
CLMX=WGS/Q1
RNW=CBARW*VK*1.689/XKV
RNW=RNW/100000.
CALL ITRLN(ARNW,ALAM13,RNW,VLAM13,NRNW)
CALL ITRLN(AMNW,ALAM14,SMN,VLAM14,NMNW)
* Maximum Lift Coefficient
CLMAX=(RCLMAX*VLAM1*VLAM2+DCLMTE*VLAM3*VLAM4*VLAM5*VLAM6*VLAM7*VLAM8+DCLMLE*VLAM9*VLAM10*VLAM11*VLAM12)*VLAM13*VLAM14+DELCLF
ERROR=CLMAX-CLMX
KWRITE
=1
WRITE(6)ERROR,ERRM1,VK,CLMAX,CLMX,VLAM13,VLAM14,RNW,SMN,JC
ABS(ERROR)
≤.005
25
CALL ITRMHW(ERROR,ERRM1,VK,F,FF,JC,JX)
JC
>10
26
JFLTYP
≤2
CALL ITRLN(ACFOC,ADEL1Y,CFOC,VDEL1,NCFOC)
JFLTYP
>2
CALL ITRLN(ACFOC,ADEL1,CFOC,VDEL1,NCFOC)
RDELF=DELFD/DELTEO
CALL ITRLN(ARDELF,ADEL2,RDELF,VDEL2,NRDELF)
CALL BIV(VDEL3,BTEOB,SLM,ABFOB,ASLM,ADEL3,NBFOB,NSLM,NER)
NER
≠1
99

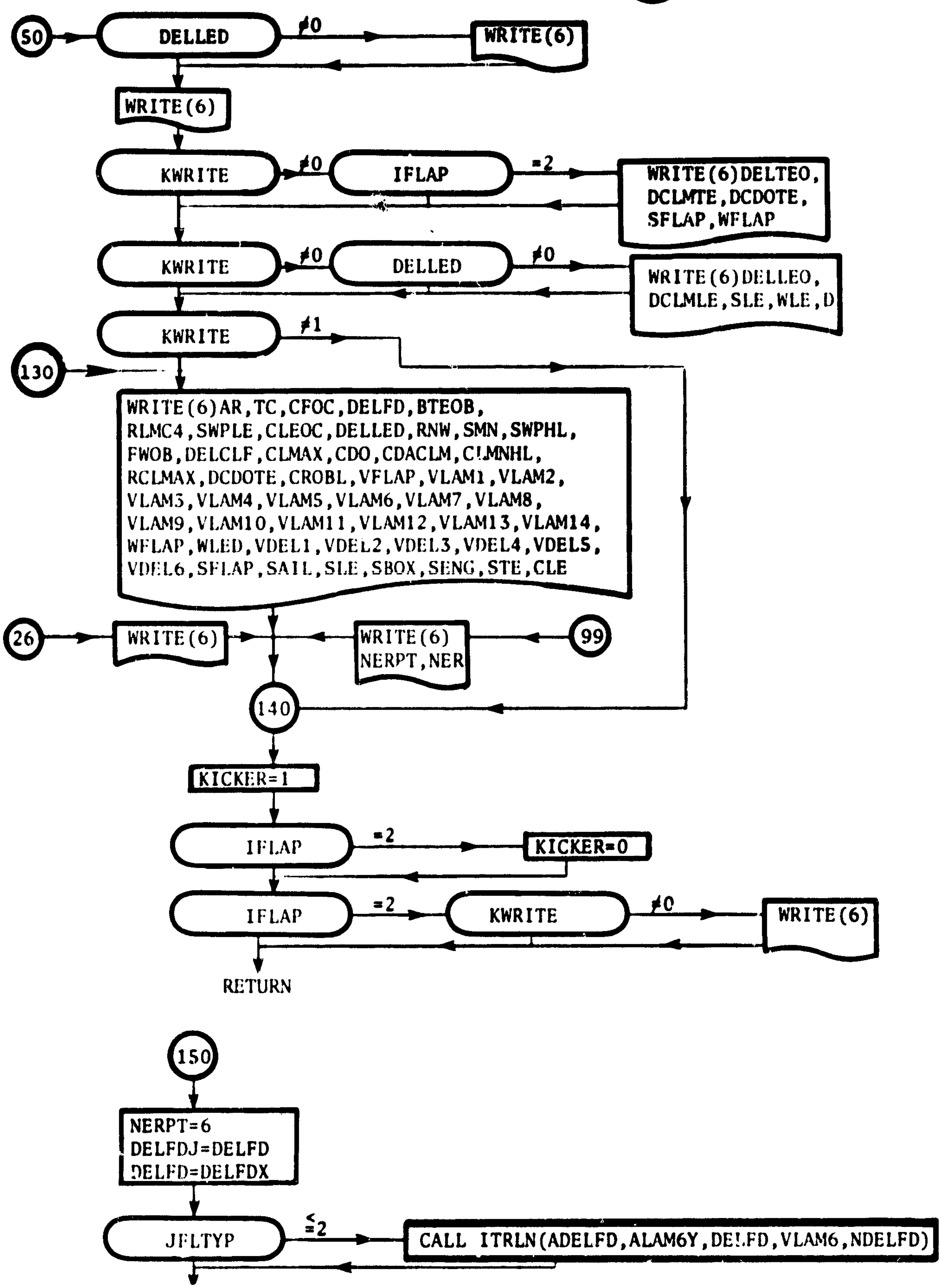
FLAPS


4
TSWPFH=TAN(SWPTE)+4.*CFOC*(TAN(RLMC4)-TAN(SWPTE))/3.
SWPFHL=ATAN(TSWPFH
NERPT=19
VDEL4=COS(SWPFHL)
NERPT=20
VDEL5=1.0-FWOB
CALL ITRLN(ADELFD,ADEL6,DELFD,VDEL6,NDELFD)
CDO=SAA5+SA6*CFIN
CLMNHL=RCLMAX*VLAM1*VLAM2*VLAM13*VLAM14
CDACLM=CDO+DCDOTE*VDEL1*VDEL2*VDEL3*VDEL4*VDEL5
+(CLMHL**2)/(VDEL6/SA7)
DCL=DCLMTE*VLAM3*VLAM4*VLAM5*VLAM6*VLAM7*VLAM8*VLAM13*VLAM14
DCD=DCDOTE*VDEL1*VDEL2*VDEL3*VDEL4*VDEL5
IFLAP
=2
CLMXTO=CLMAX
DCLTO=DCL
DCDTO=DCD
VDEL6T=VDEL6
CALL ITRLN(ADELFD,ASIGMA,DELFD,SIGMTO,15)
KICKER
=0
KWRITE
≠0
WRITE(6)CLMXTO,
VK,DELFD,DELLED,
DCLTO,DCDTO
KICKER
=0
KWRITE
≠0
WRITE(6)CLMXTO,
VK,DELFD,DELLED,
DCLTO,DCDTO
IFLAP
=1
80
CLMXD=CLMAX
DELPLD=DELFD
DCLLD=DCL
DCDLD=DCD
VDEL6L=VDEL6
CALL ITRLN(ADELFD,ASIGMA,DELFD,SIGMLD,15)

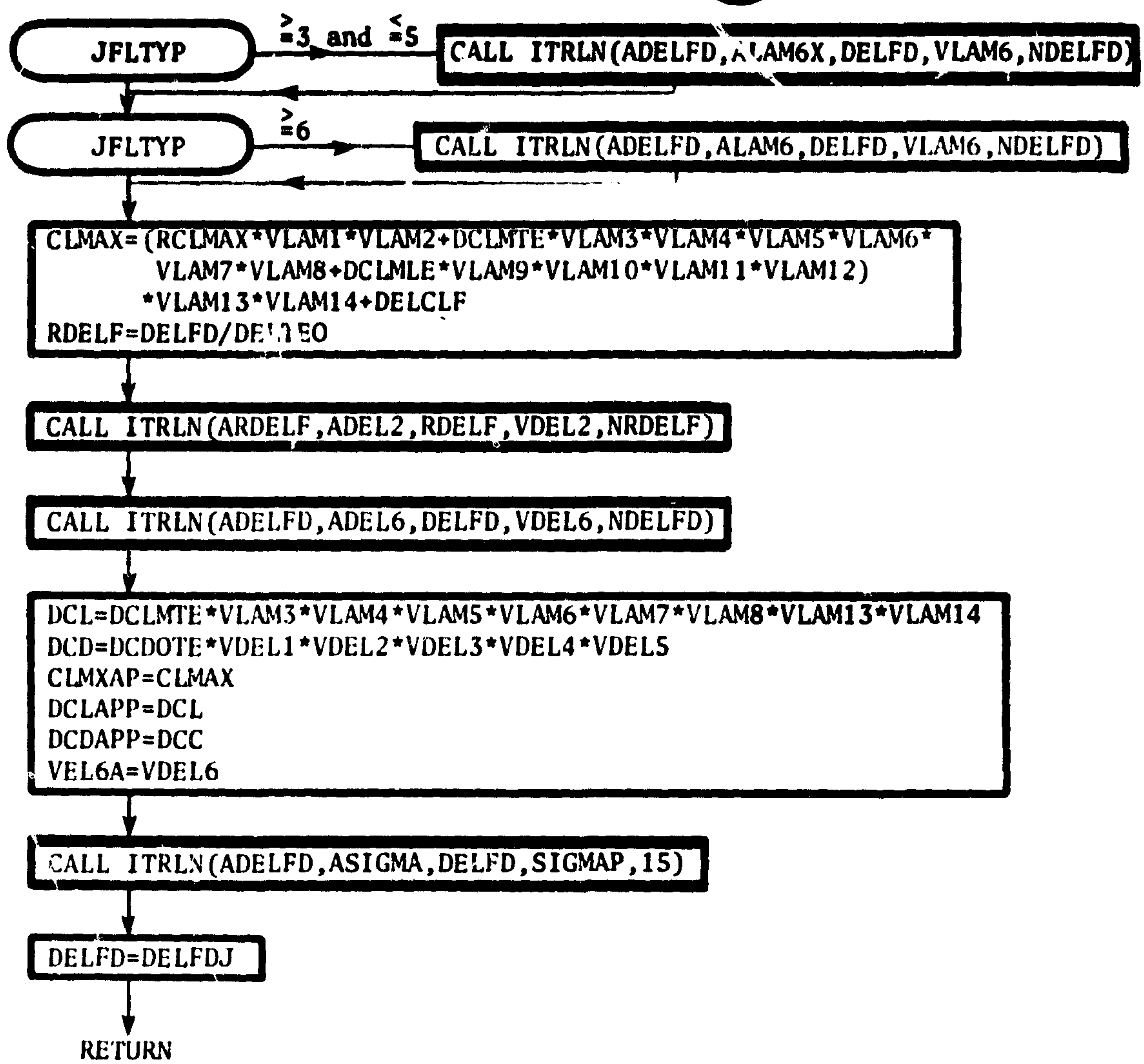
FLAPS



5
KWRITE
≠0
WRITE(6)CLMXMD,
VK,DELLED,
DCLLD,
80
SFLAP=((CFOC*CRCLW*B)*(2.-(1.-SLM)*FWOB-
(1.-SLM)*BTEOB)*(BTEOB-FWOB-BENGOB))/.2
SFLAP
≤0
SFLAP=0.
SAIL=((CFOC*CRCLW*B)*(SLM+1.-(1.-SLM)*BTEOB)*(1.-BTEOB))/2.
SLE=((CLEOC*CRCLW*B)*(1.-(DBALE/B)*(SLM-1.)+SLM)*BLEOB)/2.
SBOX=(1.0-CFOC-CLEOC)*CRCLW*B*(1.0+SLM)/2.
SENG=(CFOC*CRCLW*B*(1.25-FWOB+SLM*(FWOB+0.75))*BENGOB)/2.
STE=SFLAP/3.+SENG+0.15*SAIL
CLE=SLE*COS(SWPLE)/(B-DBALE)
IFLAP
=1
140
RHO=P0/(53.32*G*T0)
VSTALL=.59
VFLAP=1.8*VSTALL
JFLTYP
=1
WFLAP=WCFLAP*(VFLAP/100.)**2.
*SFLAP*FLAPN**(-.5)
JFLTYP
=2
122
JFLTYP
≥3 and ≤5
WFLAP=WCFLAP*(VFLAP/100.)**2.
*SFLAP*FLAPN*.5
JFLTYP
≥6
WFLAP=WCFLAP*(VFLAP/100.**2.38
*SFLAP**1.19/(FLAPN**.595)
VFLAP
>160
WFLAP=WCFLAP*SFLAP*(VFLAP**2.195)
/45180.
VFLAP
≤160
WFLAP=WCFLAP*SFLAP*0.369
*VFLAP**0.2733
129
WLED=3.28*SLE**1.13
WHLDEV=WFLAP+WLED
KWRITE
≠0
IFLAP
=2
JFLTYP
140
=1,2,3,4,5,6,7
WRITE(6)
50


50
DELLED
≠0
WRITE(6)
WRITE(6)
KWRITE
≠0
IFLAP
=2
WRITE(6)DELTEO,
DCLMTE,DCDOTE,
SFLAP,WFLAP
KWRITE
≠0
DELLED
≠0
WRITE(6)DELLEO,
DCLMLE,SLE,WLE,D
KWRITE
≠1
130
WRITE(6)AR,TC,CFOC,DELFD,BTEOB,
RLMC4,SWPLE,CLEOC,DELLED,RNW,SMN,SWPHL,
FWOB,DELCLF,CLMAX,CDO,CDACLM,CLMNHL,
RCLMAX,DCDOTE,CROBL,VFLAP,VLAM1,VLAM2,
VLAM3,VLAM4,VLAM5,VLAM6,VLAM7,VLAM8,
VLAM9,VLAM10,VLAM11,VLAM12,VLAM13,VLAM14,
WFLAP,WLED,VDEL1,VDEL2,VDEL3,VDEL4,VDEL5,
VDEL6,SFLAP,SAIL,SLE,SBOX,SENG,STE,CLE
26
WRITE(6)
WRITE(6)
NERPT,NER
99
140
KICKER=1
IFLAP
=2
KICKER=0
IFLAP
=2
KWRITE
≠0
WRITE(6)
RETURN
150
NERPT=6
DELFDJ=DELFD
DELFD=DELFDX
JFLTYP
≤2
CALL ITRLN(ADELFD,ALAM6Y,DELFD,VLAM6,NDELFD)

7


JFLTYP
≥3 and ≤5
CALL ITRLN(ADELFD,ALAM6X,DELFD,VLAM6,NDELFD)
JFLTYP
≥6
CALL ITRLN(ADELFD,ALAM6,DELFD,VLAM6,NDELFD)
CLMAX= (RCLMAX*VLAM1*VLAM2+DCLMTE*VLAM3*VLAM4*VLAM5*VLAM6*
VLAM7*VLAM8+DCLMLE*VLAM9*VLAM10*VLAM11*VLAM12)
*VLAM13*VLAM14+DELCLF
RDELF=DELFD/DELFEO
CALL ITRLN(ARDELF,ADEL2,RDELF,VDEL2,NRDELF)
CALL ITRLN(ADELFD,ADEL6,DELFD,VDEL6,NDELFD)
DCL=DCLMTE*VLAM3*VLAM4*VLAM5*VLAM6*VLAM7*VLAM8*VLAM13*VLAM14
DCD=DCDOTE*VDEL1*VDEL2*VDEL3*VDEL4*VDEL5
CLMXAP=CLMAX
DCLAPP=DCL
DCDAPP=DCC
VEL6A=VDEL6
CALL ITRLN(ADELFD,ASIGMA,DELFD,SIGMAP,15)
DELFD=DELFDJ
RETURN

C-2