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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

\[ \Delta C_{D_p} = C_K C_F F(\text{Re})(S/S_W) \]  

(III.1.1)

where

- \( C_K \) = geometry-dependent form factor
- \( C_F \) = Mach number dependent skin friction coefficient at a reference Reynolds number of \( 10^7 \)
- \( F(\text{Re}) \) = 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).
**TABLE III.1.1 - SUBROUTINE STRUCTURE OF AERODYNAMIC CALCULATIONS**
III.1.1.1 Form Factors.— Computation of the form factors begins with the equation defining the average thickness to chord ratio for the exposed wing,

\[
TC = \frac{[TC_R - S_{WF}/B(TC_R - TC_T)] \cdot T_{ERM} + S_{LM} TC_T}{T_{ERM} + S_{LM}}
\]

(III.1.2)

where

\[
T_{ERM} = 1 - (S_{WF}/B)(1 - S_{LM})
\]

\[
TC_R, TC_T = \text{thickness to chord ratios (root and tip)}
\]

\[
S_{WF} = \text{diameter of fuselage at wing, ft}
\]

\[
B = \text{wing span, ft}
\]

\[
S_{LM} = \text{taper ratio (tip chord/root chord)}
\]

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

\[
C_{KW} = 1.03[2 + 4. TC + 240. TC^4]
\]

(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,

\[
C_{KV} = 2 + 4. TC_{VT} + 240. TC_{VT}^4
\]

(III.1.4)

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

\[
C_{KH} = [1 + .1(1 - S_{AH})][2 + 4. TC_{HT} + 240. TC_{HT}^4]
\]

(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

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

and

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

where

\[ EL_N = \text{length of nacelle, ft} \]
\[ DBAR_N = \text{diameter of nacelle, ft} \]
\[ AXIS = \text{length of tip tank, ft} \]
\[ BXIS = \text{diameter of tip tank, ft} \]

For the fuselage, the corresponding factor is

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

where

\[ Z_{LF} = \text{fuselage length, ft}. \]

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:

\[ C_{FIN} = \begin{cases} .002944 - .000176 E_M; & E_M \leq .4 \\ .00299 - .0003125 E_M; & .4 \leq E_M \leq .92 \\ .0027; & E_M > .92 \end{cases} \] (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

SKIN FRICTION COEFFICIENT - $C_f$

REYNOLDS NUMBER $\frac{\nu}{L}$

$M=0.9$
$M=0.7$
$M=0.5$
$M=0.0$

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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

$$F(R, \phi) = \frac{C_f}{C_{fRe=10^7}} = \left[ \log_{10}(RE_{component}) / 7 \right]^{-2.6}$$

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

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

and thus the fuselage Reynolds number is

$$RF_F = \left\{ \begin{array}{ll}
RELI & EL_F, K_{CONFIG} = 1 \\
RELI & EL_{FCC}, K_{CONFIG} = 1
\end{array} \right\}$$

III.1.1
Similarly, other Reynolds numbers are found as

\[
\begin{align*}
\text{RE}_{BM} &= \text{RE}_{LI} \times \text{EL}_{BM} \quad \text{(fuselage boom)} \\
\text{RE}_{NI} &= \text{RE}_{LI} \times \text{EL}_{N} \quad \text{(nacelle)} \\
\text{RE}_{VT} &= \text{RE}_{LI} \times \text{CBAR}_{VT} \quad \text{(vertical tail)} \\
\text{RE}_{HT} &= \text{RE}_{LI} \times \text{CBAR}_{HT} \quad \text{(horizontal tail)} \\
\text{RE}_{TP} &= \text{RE}_{LI} \times \text{AXIS} \quad \text{(tip tank)}
\end{align*}
\]

(III.1.12) (III.1.13) (III.1.14) (III.1.15) (III.1.16)

where \( \text{EL}_{BM}, \ldots, \text{AXIS}, \) are characteristic lengths in the streamwise direction of the indicated aircraft components.

The Reynolds number correction factor for each component then becomes

\[
\begin{align*}
\text{FW}_{RE} &= \text{(wing)} \\
\text{FF}_{RE} &= [\log_{10} (\text{RE}_F)/7]^{-2.6} \quad \text{(fuselage)} \\
\text{FBM}_{RE} &= [\log_{10} (\text{RE}_{BM})/7]^{-2.6} \quad \text{(fuselage boom, if } K_{\text{CONFIG}} = 1) \\
\text{FN}_{RE} &= [\log_{10} (\text{RE}_N)/7]^{-2.6} \quad \text{(nacelle)} \\
\text{FVT}_{RE} &= [\log_{10} (\text{RE}_{VT})/7]^{-2.6} \quad \text{(vertical tail)} \\
\text{FHT}_{RE} &= [\log_{10} (\text{RE}_{HT})/7]^{-2.6} \quad \text{(horizontal tail)} \\
\text{FLT}_{RE} &= [\log_{10} (\text{RE}_{TP})/7]^{-2.6} \quad \text{(tip tanks)}
\end{align*}
\]

(III.1.17) (III.1.18) (III.1.19) (III.1.20) (III.1.21) (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,
\[
SA_5 = \frac{(CK_F CD_{PI} FF_{RE} S_F + DEL_{FE})}{SW} + CK_{VT} CD_{VTI} FVT_{RE} S_{VT}/SW
+ CK_{HT} CD_{HTI} FHT_{RE} S_{HT}/SW
+ CK_N CD_{NI} FN_{RE} S_N/SW
+ CK_{TP} CD_{TIP} FLT_{RE} S_{TIP}/SW + DEL_{CD}
+ CK_{BM} CD_{BM} FBM_{RE} S_{WBM}/SW + GR_{CD}
\]

(III.1.23)

where \(\text{DEL}_{FE}\) is a fuselage incremental \(F_e\) which may be input; \(\text{DEL}_{CD}\) 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 (\(IGEAR \neq 0\)); for retractable gear configurations (\(IGEAR = 0\)) it is added in subroutine DRAG.

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

\[
GR_{CD} = \frac{(0.0032/S_w)^{0.8}}{W_G}
\]

(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:

\[
SA_6 = CKW * FW_{RE}
\]

(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

$$\text{SWET}_W = 2S_W - \frac{3(1+S_{LM})}{(S_{LM}^2+S_{LM}+1)} \text{CBAR}_W S_{WF}^{11} + \frac{S_{WF}}{2B} (S_{LM} - 1)$$ \quad (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 ($W$),

$$\text{FE}_W = S_W \ C_D \ C_K \ C_F \ W \ R_E$$ \quad (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

$$\text{FE} = \text{FE}_W + \text{FE}_F + \text{FE}_{VT} + \text{FE}_{HT} + \text{FE}_N + \text{FE}_{TP} + \text{DLTAFE}$$ \quad (III.1.28)

where the last term is

$$\text{DLTAFE} = \text{DEL}_{CD} \ast S_W$$ \quad (III.1.29)
III.1.1.6 Concluding Computations.—The Oswald efficiency factor, used to compute induced drag, is computed by

\[
\text{SEE} = \left[1.035 + 1.19 \frac{\text{AR}(\text{CD}_{PW}/\cos^2(\text{RLM}_{C4}) + \text{CD}_{PO})}{\text{AR}}\right]^{-1} \tag{III.1.30}
\]

where \(\text{CD}_{PW} = \frac{\text{FE}_{W}}{S_{W}}\), wing-free profile drag coefficient

\(\text{CD}_{PO} = \frac{\text{FE}_{W}}{S_{W}}\), wing profile drag coefficient

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

\[
\text{SA}_7 = \frac{1}{(\pi \times \text{SEE} \times \text{AR})} \tag{III.1.31}
\]

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

\[
\text{SA}_7 = \frac{\text{SA}_7}{(1.5 \frac{B_{XIS}}{B})} \tag{III.1.32}
\]

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

For fixed landing gear (\(\text{GR}_\text{GEAR} = 0\)), \(\text{FE}\) is incremented by \(\text{GR}_\text{FE}\) as given in Equations (III.1.28)

\[
\text{FE} = \text{FE} + \text{GR}_\text{FE} \tag{III.1.33}
\]

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,

\[
T = \tan(R_{LMC4}) \tag{III.1.34}
\]

III.1
10
Following this is the parameter depending on the taper ratio $S_{LM}$,

$$Y_{A_{LE05}} = \frac{(1 - S_{LM})}{(1 + S_{LM})}$$  \hspace{1cm} (III.1.35)

and sweep angles

$$D_{LM_{PS}} = \tan^{-1}\left[\frac{T - 4/AR(X_{CPS} - .25)Y_{A_{LE05}}}{RTOD}\right]$$  \hspace{1cm} (III.1.36)

$$D_{LM_{TCX}} = \tan^{-1}\left[\frac{T - 4/AR(X_{CTCMX} - .25)Y_{A_{LE05}}}{RTOD}\right]$$  \hspace{1cm} (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.

$$S_{A_2} = -.33(0.65 - X_{CPS})\left[1 + 0.0033(4.*D_{LM_{PS}} - 3.*D_{LM_{TCX}})\right]$$  \hspace{1cm} (III.1.38)

The sweep angle of the wing leading edge is then

$$R_{LM_{LE}} = \tan^{-1}\left[\frac{T + Y_{A_{LE05}}}{AR}\right]$$  \hspace{1cm} (III.1.39)

and this is followed by the definition

$$F_{K} = \left[1 + Y_{A_{LE05}} + 4S_{LM}^{-1}\right]$$  \hspace{1cm} (III.1.40)

Three more of the compressibility drag parameters are then defined as follows:
\[ SA_1 = [1 + .033(4*DLM_{PS} - 3*DLM_{TCX})] \]
\[ \times [1 - 1.4*TC - .06(1 - S_{CPS})] - .0368 \quad (III.1.41) \]

\[ SA_3 = [1.5 - 2.0F_k^2 \frac{1}{2}(RLM_{LE})] TC^{5/3} \quad (III.1.42) \]

and

\[ SA_4 = .75 * TC \quad (III.1.43) \]

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

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

$$ZLOD = \text{lift to drag ratio}$$

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

$$\text{ALPH}^a = \text{angle of attack, deg.}$$

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

$$ACL1(I_L, K) = \text{lift coefficient } (I_L, \text{ALPHA})$$

$$ACD1(I_L, K) = \text{drag coefficient } (I_L, \text{ALPHA})$$

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 CL1FT - Wing-Alone Lift Coefficient.— This subroutine 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.,

\[
I_{LIFT} = 1: \text{ Compute } C_L \text{ at cruise from } \text{ALPHA} \\
= 2: \text{ Compute } C_L \text{ at take-off from } \text{ALPHA} \\
= 3: \text{ Compute } C_L \text{ at approach from } \text{ALPHA} \\
= 4: \text{ Compute } \text{ALPHA} \text{ at cruise from } C_L \\
= 5: \text{ Compute } \text{ALPHA} \text{ at take-off from } C_L \\
= 6: \text{ Compute } \text{ALPHA} \text{ at approach from } C_L
\]

The lift coefficient and angle of attack are linearly related by the slope \( C_{L, \text{ALPHA}} \). Lift increments are those due to flap deflection \( (\Delta C_L) \) and to a multiplier for ground-effect \( (K_{CL, \text{GE}}) \). 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,

\[
C_{L, \text{ALPHA}} = \pi \cdot \text{AR}/(1 + \sqrt{1 + C_1 C_2}) \quad (\text{III.1.44})
\]

where

\[
C_1 = \text{AR}/(2 \cos(\text{RLM}_{C4}))^2 \quad (\text{III.1.45})
\]

\[
C_2 = 1 - (\text{EM} \cdot \cos(\text{RLM}_{C4}))^2 \quad (\text{III.1.46})
\]

\[
\text{AR} = \text{aspect ratio of wing}
\]

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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

$$CL_{OGE} = CL_A LPH (\alpha - \alpha_{LH}) (0.0174533) + \Delta CL$$

where:

$\alpha$ = angle of attack, deg (input)

$\alpha_{LH}$ = 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

$$\alpha = \alpha_{LH} + (CL_{MAX} - \Delta CL) / (0.0174533 * CL_A LPH)$$

and the lift coefficient returned is

$$CL = KCL_{GE} CL_A LPH (0.0174533) (\alpha - \alpha_{LH}) + \Delta CL$$

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

$$CL_{OGE} = (CL - \Delta CL) / KCL_{GE} + \Delta CL$$

where the right side reduces to $CL$, since $KCL_{GE} = 1$ and $\Delta CL = 0$.

Then, if this is less than $CL_{MAX}$, the corresponding angle of attack is given
by

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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

$$K_{CL} = 1.005 + C_3 \{1.00211 - 0.0003(AR - 3)\}$$

where

$$C_3 = \exp [5.2(1 - HOB)]$$

For typical aspect ratios, this equation shows that $K_{CL}$ 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 (111.1.47). Otherwise $I_{LIFT} = 5$, and the angle of attack is again computed according to Equation (111.1.51), where $D_{CL} = D_{CL_{TO}}$ and $C_{L_{MAX}} = C_{L_{MAX_{TO}}}$ 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,

$$D_{CL} = D_{CL_{LD}}$$

$$C_{L_{MAX}} = C_{L_{MAX_{LD}}}$$

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.

<table>
<thead>
<tr>
<th>$I_{DRAG}$</th>
<th>Flight Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cruise, gear up</td>
</tr>
<tr>
<td>2</td>
<td>Take-off, gear down</td>
</tr>
<tr>
<td>3</td>
<td>Landing, gear down</td>
</tr>
<tr>
<td>4</td>
<td>Cruise, gear down</td>
</tr>
<tr>
<td>5</td>
<td>Take-off flaps down, gear up</td>
</tr>
<tr>
<td>6</td>
<td>Landing flaps down, gear up</td>
</tr>
<tr>
<td>7</td>
<td>Cruise, gear down</td>
</tr>
<tr>
<td>8</td>
<td>Approach flaps, gear up</td>
</tr>
</tbody>
</table>

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

In the "clean" configuration ($I_{DRAG} = 1$), the aircraft drag coefficient is expressed as

$$Cd = SA_5 + SA_6 \frac{CD}{WI} + CW \frac{DEL}{CDM} + SA_7 C_L$$

Profile Compressibility Induced
where

\[
SA_5 = \text{profile drag of all components except the wing (excludes landing gear if retractable) (from AERO)}
\]

\[
SA_6 = CK_W \cdot FW_{RE}
\]

= wing form factor x Reynolds number correction factor

(see AERO)

\[
CD_{WI} = \text{wing skin friction coefficient}
\]

\[
DEL_{CDM} = \text{compressibility term (see below)}
\]

\[
SA_7 = \frac{1}{\pi} \text{AR}_{e} \text{ (from AERO)}
\]

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 not 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 laminar flow 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
The factors $S_{A1}$ and $S_{A2}$ are computed in AERO. $S_{C_{FAX}}$ is a factor which may be input (as $S_{C_{FAC}}$) 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,

$$C_{D} = S_{A5} + S_{A6} C_{W1} + \text{DEL}_{CDF} + \text{DEL}_{CDG}$$

$$+ S_{A7} K_{CDIGE} (C_{L} - \Sigma \text{DEL}_{CL})^{2}/V\text{DEL}_{6}$$  \hspace{1cm} (III.1.58)

where

$\text{DEL}_{CDF}$ = parasite drag coefficient increment due to trailing edge flaps, from FLAPS

$\text{DEL}_{CDG}$ = parasite drag increment due to landing gear, equal to $G_{R_{CD}}$, as found in AERO

$\Sigma$ = induced drag correction factor, from FLAPS

$\text{DEL}_{CL}$ = incremental lift due to flaps, from FLAPS

$V\text{DEL}_{6}$ = wing efficiency correction factor due to change in span-wise lift caused by flap deflection, from FLAPS

and

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

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SUPERCRITICAL ASSUMPTIONS

(1) $\Delta M_D = 0.08 SCFAC$

(2) $-\Delta \phi_D = 10 (M - \Delta N_D)^3$

(SAME FOR CONVENTIONAL WITH LOWER $M_D$)

$C_L = \text{CONSTANT}$

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 \( K_{\text{CDIGE}} = 1 \), if this function is greater than 1.

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

\[
C_D = C_D + C_{\text{DNAC}}
\]

where \( C_{\text{DNAC}} \) 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 AKED, 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 if IDC = 1, the weight \( W \) is input through the UNIV common block. Otherwise, the ratio of cruise weight to design gross weight \( (RW_{\text{CETO}}) \) and gross weight together imply \( W \):

\[
W = \frac{W_G}{W_G} \times RW_{\text{CETO}}
\]

\[\text{(III.1.61)}\]
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

\[
C_{LREQ} = W/(.7 S_{REF} P_o S_{MN}^2)
\]  

where \( S_{MN} \) is the Mach number. The subroutine CLIFT then returns the angle of attack \( \alpha_D \) 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

\[
ZL = .7 C_L S_{MN}^2 S_{REF}
\]

\[
DRG = ZL/ZLQD
\]

where their ratio is \( ZLQD = \frac{C_L}{C_D} \).

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

III.1
lift coefficient $C_{L_{MAX}}$ 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 $6 \times 10^6$ and 0 respectively. The maximum airplane lift coefficient is expressed as the sum of four terms,

$$C_{L\text{MAX}} = R_{CL\text{MAX}} V_{LAM1} V_{LAM2} + DCL_{MTE} V_{LAM3} \cdots V_{LAM8}$$

$$+ DCL_{MLE} V_{LAM9} \cdots V_{LAM12} V_{LAM13} V_{LAM14} + DEL\text{CLF}$$

(III.1.65)

where

$R_{CL\text{MAX}}$ = 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

$DEL\text{CLF}$ = 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 $V_{LAM1}$:

III.1
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

\[ V_{LAM2} = \text{sensitivity of clean wing } C_{L_{\text{MAX}}} \text{ to wing thickness to chord ratio} \]

\[ V_{LAM3} = \text{sensitivity of flap clean wing } C_{L_{\text{MAX}}} \text{ to wing aspect ratio} \]

\[ V_{LAM4} = \text{sensitivity of flap clean wing } C_{L_{\text{MAX}}} \text{ slope to wing thickness to chord ratio. This is a function of flap type} \]

\[ V_{LAM5} = \text{sensitivity of flap clean wing } C_{L_{\text{MAX}}} \text{ to wing flap to chord ratio (function of flap type)} \]

\[ V_{LAM6} = \text{sensitivity of flap clean wing } C_{L_{\text{MAX}}} \text{ to wing flap deflection (function of flap type)} \]

\[ V_{LAM7} = \text{sensitivity of flap clean wing } C_{L_{\text{MAX}}} \text{ to wing flap span} \]

\[ V_{LAM8} = \text{sensitivity of flap clean wing } C_{L_{\text{MAX}}} \text{ to wing sweep angle} \]

\[ = \cos^3(\text{SWPQ}) \]  \hspace{1cm} (III.1.66)

\[ V_{LAM9} = \text{sensitivity of slat clean wing } C_{L_{\text{MAX}}} \text{ to slat chord} \]

\[ = 6.65 \times C_{\text{LEOC}} \]  \hspace{1cm} (III.1.67)
\[ V_{\text{LAM10}} = \text{sensitivity of clean wing } C_{\text{LMAX}} \text{ to slat deflection angle} \]
\[ V_{\text{LAM11}} = \text{sensitivity of slat clean wing } C_{\text{LMAX}} \text{ to slat span} \]
\[ V_{\text{LAM12}} = \text{sensitivity of slat clean wing } C_{\text{LMAX}} \text{ to leading edge sweepback} = \cos^3(\text{SWPLE} - 5/57.29) \] (III.1.68)

\[ C_{\text{LMAX}} \] is computed at the unaccelerated stall speed of the airplane corresponding to \( C_{\text{LMAX}} \). This is accomplished by an iteration on stall speed: at each stall speed the Reynolds number \( (V_{\text{LAM13}}) \) and Mach number \( (V_{\text{LAM14}}) \) correction factors are determined. Using these factors \( C_{\text{LMAX}} \) is computed and based on this \( C_{\text{LMAX}} \) 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:

\[ \text{DCL} = \text{DCLMTE} \ V_{\text{LAM3}} \ldots V_{\text{LAM8}} \ V_{\text{LAM13}} \ V_{\text{LAM14}} \]

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

\[ V_{\text{DEL1}} = \text{sensitivity of flap } C_{\text{DMIN}} \text{ to flap chord ratio (functions of flap size)} \]
\[ V_{\text{DEL2}} = \text{sensitivity of flap } C_{\text{DMIN}} \text{ to flap angle, function of flap type} \]
\[ V_{\text{DEL3}} = \text{sensitivity of flap } C_{\text{DMIN}} \text{ to partial flap span} \]
\[ V_{\text{DEL4}} = \text{sensitivity of flap } C_{\text{DMIN}} \text{ to flap hinge line sweepback} = \cos(\text{SWP}_{\text{FHL}}) \] (III.1.69)
\[ V_{\text{DEL5}} = \text{sensitivity of } C_{\text{DMIN}} \text{ to fuselage width to span ratio,} = 1. - \text{FWOB} \] (III.1.70)
\[ V_{\text{DEL6}} = \text{sensitivity of span efficiency factor to flap angle} \]
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

\[
\text{DCD} = \text{DCD}_{\text{OTE}} \cdot \frac{V_{\text{DEL}}}{V_{\text{DEL5}}}, \text{ incremental parasitic drag coefficient, due to trailing edge devices}
\]

The empirical flap efficiency factors, \( \text{SIGM}_{\text{TO}} \) and \( \text{SIGM}_{\text{LD}} \), 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:

\[
S_{\text{FLAPS}} = (C_{\text{OC}} \cdot Z \cdot B)[2 - (L - T_{\text{WING}})(F_{\text{OB}} + B_{\text{TOB}})]
\]

\[
[B_{\text{TOB}} - F_{\text{OB}} - B_{\text{ENGOB}}] / (2 * S)
\]

(III.1.71)

where

- \( Z \) = root chord at wing centerline, ft.
- \( C_{\text{OC}} \) = ratio, flap chord to wing chord
- \( B_{\text{TOB}} \) = ratio, flap span to wing span
- \( F_{\text{OB}} \) = ratio, body diameter at quarter chord to wing span
- \( B_{\text{ENGOB}} \) = ratio, total engine diameter to wing span, for wing mounted engines

The design airspeed of the flaps is assumed to be

\[
V_{\text{FLAP}} = 1.8 V_{\text{STALL}}
\]

(III.1.72)

where \( V_{\text{STALL}} \) is the stall speed in knots corresponding to \( C_{\text{LMAX}} \) 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, $J_{\text{FLTYF}} = 1$ to 7.

1. **$J_{\text{FLTYF}} = 1$; Plain Flaps**

   \[ W_{\text{FLAP}} = W_{\text{CFLAP}} (V_{\text{FLAP}}/100.)^2 S_{\text{FLAP}} (FLAP_N)^{-0.5} \]  \hspace{1cm} (III.1.73)

2. **$J_{\text{FLTYF}} = 2$; Split Flaps**

   \[ W_{\text{FLAP}} = \begin{cases} 
   0.369 W_{\text{CFLAP}} S_{\text{FLAP}} V_{\text{FLAP}}^{2.733} & V_{\text{FLAP}} \leq 160 \\
   (W_{\text{CFLAP}} S_{\text{FLAP}}/45180.) V_{\text{FLAP}}^{2.195} & V_{\text{FLAP}} > 160 
   \end{cases} \]  \hspace{1cm} (III.1.74)

3. **$J_{\text{FLTYF}} = 3, 4, 5$; Single, double or triple slotted flaps**

   \[ W_{\text{FLAP}} = W_{\text{CFLAP}} S_{\text{FLAP}} (V_{\text{FLAP}}/100.)^2 FLAP_N^{0.5} \]  \hspace{1cm} (III.1.75)

4. **$J_{\text{FLTYF}} = 6, 7$; Fowler or double slotted Fowler flaps**

   \[ W_{\text{FLAP}} = W_{\text{CFLAP}} S_{\text{FLAP}}^{1.19} (V_{\text{FLAP}}/100.)^{2.38} FLAP_N^{-.595} \]  \hspace{1cm} (III.1.76)

where $W_{\text{CFLAP}} = [0.62, 1.0, 0.733, 1.2, 1.32, 0.633, 0.678]$ = variation with $J_{\text{FLTYF}}$ of flap weight factor or may be input

$S_{\text{FLAP}} = S_{\text{FLAPS}} \times S$ = flap area

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

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

\[ W_{\text{LED}} = 3.28 S_{\text{LE}}^{1.13} \]  \hspace{1cm} (III.1.77)
where $S_{LE}$ is the leading edge slat area and the total weight of "high-lift devices" is the sum

$$W_{HLDEV} = W_{FLAP} + W_{LED} \quad (III.1.78)$$

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 $C_{L_{MAX}}$ 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 ($V_{LAM}$, $V_{DEL}$), and thus these sections of the program are bypassed when NPC = 4. Only the factors which are explicit functions of flap deflection are recomputed ($V_{LAM6}$, $V_{DEL2}$, $V_{DEL6}$). 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.,

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

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 $C_{LMAX}$.

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APPENDIX III.A

WING WETTED AREA DERIVATION

The exposed wing wetted area is

\[ \text{SWET}_W = 2S_W - 2S_{BLOCKED} \]

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

\[ C_F = C_R - \frac{S_{WF}}{B} \cdot (C_R - C_T) \]

substituting

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

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

Now

\[ \bar{C} = \frac{2}{3} C_R (1 + \lambda - \frac{\lambda}{1+\lambda}) \]
so that

\[ S_{\text{BLOCKED}} = 2 \left[ \frac{3}{2} c \frac{S_{\text{WF}}}{(1+\lambda)} \frac{(1+\lambda)}{1+\lambda} (1 + \frac{S_{\text{WF}}}{2B} (\lambda - 1)) \right] \]

\[ S_{\text{BLOCKED}} = \frac{3}{2} c \frac{S_{\text{WF}}}{\lambda + 1 + \lambda(\lambda + 1) - \lambda} \left[ 1 + \frac{S_{\text{WF}}}{2B} (\lambda - 1) \right] \]

\[ = 2 \left[ \frac{3}{2} c \frac{S_{\text{WF}}}{\lambda + 1 + \lambda(\lambda + 1) - \lambda} \left[ 1 + \frac{S_{\text{WF}}}{2B} (\lambda - 1) \right] \right] \]

therefore

\[ S_{\text{WET}} = 2S_{\text{WF}} - 3cS_{\text{WF}} \frac{(1+\lambda)}{\lambda^2 + \lambda + 1} \left[ 1 + \frac{S_{\text{WF}}}{2B} (\lambda - 1) \right] \]
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

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<td>------------------------</td>
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### TABLE III.2.11 SUBROUTINE FLAPS - INPUT

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</tr>
<tr>
<td>AWCFLP</td>
<td>array of weight coefficients for different flap types</td>
</tr>
<tr>
<td>B</td>
<td>wing span, ft</td>
</tr>
<tr>
<td>BENGOB</td>
<td>fraction of span blanketed by wing mounted engine</td>
</tr>
<tr>
<td>BTEOB</td>
<td>trailing edge flap span divided by wing span</td>
</tr>
<tr>
<td>CBARW</td>
<td>mean aerodynamic chord of wing, ft</td>
</tr>
<tr>
<td>CFOC</td>
<td>flap chord divided by wing chord</td>
</tr>
<tr>
<td>CLLEAC</td>
<td>leading edge flap chord divided by wing chord</td>
</tr>
<tr>
<td>CRCLW</td>
<td>wing root chord, ft</td>
</tr>
<tr>
<td>CRROOTW</td>
<td>quarter chord sweep angle, deg</td>
</tr>
<tr>
<td>DLLG4</td>
<td>fuselage length, ft</td>
</tr>
<tr>
<td>IFLAP</td>
<td>= 1 or 2; takeoff or approach configuration</td>
</tr>
<tr>
<td>JFLTYF</td>
<td>= 1 to 7, plain, split, slotted, etc., flap type</td>
</tr>
<tr>
<td>RCMAX</td>
<td>reference maximum lift coefficient</td>
</tr>
<tr>
<td>SIGMAP</td>
<td>induced drag correction factor, approach configuration</td>
</tr>
<tr>
<td>SIGMLD</td>
<td>induced drag correction factor, landing configuration</td>
</tr>
<tr>
<td>SIGMTO</td>
<td>induced drag correction factor, takeoff configuration</td>
</tr>
<tr>
<td>SLM</td>
<td>wing taper ratio</td>
</tr>
<tr>
<td>SWF</td>
<td>fuselage width, ft</td>
</tr>
</tbody>
</table>

TABLE III.2.11 SUBROUTINE FLAPS - INPUT
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWPLE</td>
<td>leading edge sweep angle, deg</td>
</tr>
<tr>
<td>SWPTE</td>
<td>trailing edge sweep angle, deg</td>
</tr>
<tr>
<td>TC</td>
<td>wing average thickness to chord ratio</td>
</tr>
<tr>
<td>WGS</td>
<td>wing loading in cruise, lb per sq ft</td>
</tr>
<tr>
<td>VARIABLE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>CLMXAP</td>
<td>maximum lift coefficient in approach configuration</td>
</tr>
<tr>
<td>CLMXLD</td>
<td>maximum lift coefficient in landing configuration</td>
</tr>
<tr>
<td>CLMXTO</td>
<td>maximum lift coefficient in takeoff configuration</td>
</tr>
<tr>
<td>DCDAPP</td>
<td>drag increment in approach configuration</td>
</tr>
<tr>
<td>DCDLD</td>
<td>drag increment in landing configuration</td>
</tr>
<tr>
<td>DCDOTE</td>
<td>drag increment due to trailing edge flap</td>
</tr>
<tr>
<td>DCDTO</td>
<td>drag increment in takeoff configuration</td>
</tr>
<tr>
<td>DCLAPP</td>
<td>lift increment in approach configuration</td>
</tr>
<tr>
<td>DCLLD</td>
<td>lift increment in landing configuration</td>
</tr>
<tr>
<td>DCLMTE</td>
<td>lift increment due to trailing edge flap</td>
</tr>
<tr>
<td>DCLUDO</td>
<td>lift increment in takeoff configuration</td>
</tr>
<tr>
<td>DDFLD</td>
<td>flap deflection, deg</td>
</tr>
<tr>
<td>DELTD0</td>
<td>optimum flap deflection, deg</td>
</tr>
<tr>
<td>DSSLPLD</td>
<td>landing flap deflection, deg</td>
</tr>
<tr>
<td>VDELGA</td>
<td>efficiency correction factor for approach flaps</td>
</tr>
<tr>
<td>VDELGL</td>
<td>efficiency correction factor for landing flaps</td>
</tr>
<tr>
<td>VDELOUT</td>
<td>efficiency correction factor for takeoff flaps</td>
</tr>
<tr>
<td>VSTALL</td>
<td>stall velocity, kts</td>
</tr>
<tr>
<td>WCFLAP</td>
<td>flap weight trend coefficient</td>
</tr>
<tr>
<td>WLED</td>
<td>weight of leading edge device, lb</td>
</tr>
<tr>
<td>WFLAP</td>
<td>weight of flaps, lb</td>
</tr>
<tr>
<td>WHELDEV</td>
<td>weight of high lift devices, lb.</td>
</tr>
<tr>
<td>VARIABLE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>CLMXAP</td>
<td>maximum lift coefficient, approach configuration</td>
</tr>
<tr>
<td>CLMXLD</td>
<td>maximum lift coefficient, landing configuration</td>
</tr>
<tr>
<td>DELFDX</td>
<td>maximum flap deflection, deg.</td>
</tr>
</tbody>
</table>
### TABLE III.2.14 SUBROUTINE APPFLP - OUTPUT

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFLAP</td>
<td>approach flap deflection, deg</td>
</tr>
<tr>
<td>IOK</td>
<td>= 0, computation diverges</td>
</tr>
<tr>
<td></td>
<td>= 1, computation converges</td>
</tr>
</tbody>
</table>
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
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
AERO

\[ \begin{align*}
CDWI &= \text{CFIN} \\
CDNI &= \text{CFIN} \\
CDFI &= \text{CFIN} \\
CDTI &= \text{CFIN} \\
CDTI &= \text{CFIN} \\
CDTIP &= \text{CFIN} \\
RLMC4 &= \text{DLMC4} \cdot 0.017453 \\
T &= \sin (\text{RLMC4}) / \cos (\text{RLMC4}) \\
\text{YALE05} &= (1. - \text{SLM}) / (1. \cdot \text{SLM}) \\
\text{DLMPS} &= \text{ATAN}(T - 4. / \text{AR} \cdot (\text{XCPS} - 0.25) \cdot \text{YALE05}) \cdot \text{RTOD} \\
\text{DLMTCX} &= \text{ATAN}(T - 4. / \text{AR} \cdot (\text{XCTCMX} - 0.25) \cdot \text{YALE05}) \cdot \text{RTOD} \\
\text{SA2} &= -0.33 \cdot (0.65 - \text{XCPS}) \cdot (1. + 0.033 \cdot (4. \cdot \text{DLMPS} - 3. \cdot \text{DLMTCX})) \\
\text{RLMLE} &= \text{ATAN}(T \cdot \text{YALE05} / \text{AR}) \\
\text{FK} &= 1. / (1. + \text{YALE05} / \text{AR} \cdot 4. \cdot \text{SLM} \cdot 2) \\
\text{SA1} &= (1. + 0.033 \cdot (4. \cdot \text{DLMPS} - 3. \cdot \text{DLMTCX})) \cdot (1. - 1.4 \cdot \text{TC} - 0.06 \cdot (1. - \text{XCPS})) - 0.368 \\
\text{SA3} &= (1.5 - 2. \cdot \text{FK} \cdot 2 \cdot \text{SIN}(\text{RLMLE}) \cdot 2) \cdot \text{TC} \cdot (0.5 / 3.) \\
\text{SA4} &= 0.75 \cdot \text{TC} \\
\text{REF} &= \text{RELI} \cdot \text{ELF}
\end{align*} \]

\[
\begin{align*}
\text{KCONFIG} &= 1 \\
\text{REF} &= \text{RELI} \cdot \text{ELF} \\
\text{FFRF} &= (\text{ALOG10}(\text{REF}) / 7.) \cdot (2.6) \\
\text{REW} &= \text{RELI} \cdot \text{CBARW} \\
\text{FWRF} &= (\text{ALOG10}(\text{REW}) / 7.) \cdot (2.6) \\
\text{FBMRE} &= 0. \\
\text{KCONFIG} &= 0 \\
\text{DBOOM} &= \text{SWBM} / 3.14 / \text{ELBM} \\
\text{CKBM} &= \text{CKBM} + 0.60 \cdot (\text{ELBM} / \text{DBOOM}) \cdot 0.025 \cdot (\text{ELBM} / \text{DBOOM}) \\
\text{REBM} &= \text{RELI} \cdot \text{ELBM} \\
\text{FBMRE} &= (\text{ALOG10}(\text{REBM}) / 7.) \cdot (2.6) \\
\text{FSRF} &= 0. \\
\text{KNAC} &= 2 \\
\text{CKN} &= 0 \\
\text{CKN} &= 219 \\
\text{CKN} &= \text{CKN} + 1.5 \cdot (1. + 0.35 / (\text{EIN} / \text{DBARN}))
\end{align*}
\]
III.3
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
- PLCT - 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
51

KK = 0
XEM = .15
ALPHA = -4.0

WRITE(6)

KK = KK + 1
ALPHA = ALPHA + 2.0
ALPHAP = ALPHA

DO 60 IL = 1, 3

CALL CLIFT(IL, ALPHA, CL(IL))

ID = IL + 3

IF(IL .EQ. 1) Y
ID = 1

N

CALL DRAG(ID, XEM, XUB, CL(IL), EMD, CD(IL))

ACL(IL, KK) = CL(IL)
ACD(IL, KK) = CD(IL)

60 CONTINUE
AEROUT

100

IF(NPC .LT. 4)

Y

RETURN

N

CALL PLOTS(10)
CALL PLOT(0.,-1,-3)

IF(EMCRU .LT. 50)

Y

108

IMAX=1
CDMAX=-999.

DO 130 I=1,5

DO 130 J=1,8

IF(ACD(I,J) .GT. CDMAX)

Y

IMAX=I
CDMAX=ACD(I,J)

N

130 CONTINUE

CDMAX1=0.

CDMAX1=CDMAX1+.05

IF(CDMAX1 .GT. CDMAX)

Y

102

N

III.3

10
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 SYMBOL(3.6,10.30,0.2,TITLE2,0.,20)

DO 103 I=1,5

DO 103 J=1,8

AACD(J)=ACD(I,J)

103 CONTINUE

ID=8

IF(AACD(ID) .GT. AACD(ID-1))

ID=ID-1

IF(ID EQ. 0) Y 135

III.3

11
AEROUT

135

IF(AACD(8) .EQ. AACD(1))

N

CALL SPLINE(ID, AM, AACD, A1, A2, A3)

X = 2.95
Y = 6.25 + 4.0 * AACD(1) / CDMAX1

CALL PLOT(X, Y, 3)

EM = 0.49

EM = EM + 0.01

IF(EM .GT. AM(ID))

Y

107

N

X = 1.75 + 12.0 * (EM - 0.4)
Y = 6.25 + 4.0 * S(EM, ID, AM, AACD, A1, A2, A3) / CDMAX1

CALL PLOT(X, Y, 2)

III.3

12
CALL NUMBER(X,Y,0.1,ACL(I),0.,1)

Y1=Y+.25

IF(I.EQ.IMAX)

CALL SYMBOL(7.25,Y1,0.15,TCL,0.,10)

105 CONTINUE

108

CLMAXX=0.
CDMAX=0.

D0 140 I=1,3

D0 140 J=1,10

IF(ACD1(I,J).GT.CDMAX)

CDMAX=ACD1(I,J)
IF(ACL1(I,J) .GT. CLMAX)  

109  

N  

IF(CDMAX2 .GT. CDMAX)  

140 CONTINUE  

CDMAX2 = 0.  

CDMAX2 = CDMAX2 + 0.05  

IF(CDMAX2 .GT. CDMAX)  

N  

CLMAX = 0.  

CLMAX = CLMAX + 0.5  

IF(CLMAX .GT. CLMAXX)  

N  

CM = 0.5  

CM = CM - 0.5  

IF(CM .LT. ACL1(1,1))  

117  

Y  

CLMAXX = ACL1(I,J)  

Y  

N
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)

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)

IF(I .EQ. 2 .AND. IC .EQ. 1)

XP1=X+.05

IF(I .EQ. 1 .AND. IC .EQ. 1)

CALL SYMBOL(XP1,Y,0,1,
XCLEAN,0.,10)
IF(I .EQ. 2 .AND. IC .EQ. 1 .AND. ABS(DELY) .LT. 1)

CALL SYMBOL(XP1,Y,0.1,XTAK,0.,10)

CALL SYMBOL(XP1,Y,0.1,XLAND,0.,10)

IF(IC .EQ. 1)

CALL PLOT(X,Y,3)

CALL PLOT(X,Y,2)

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.
APPFLP

NPCJ=NPC
NPC=4
IOK=0
DELFDX=10.
ERROR=999.
F=1.1
FF=1.01
JC=0
JX=0

10
ERRM1=ERROR
CALL FLAPS
CLMXLDD

N

ERROR=(0.83*CLMXD-CLMXP)/CLMXLDD

Y
ABS(ERROR).LT.0.005.or.JX.GT.C

N
CALL ITR MHW(ERROR,ERROR1,DELFDX,F,FF,JC,JX)

JX.GT.30

20
DELFDX.GE.0.0

Y

NPC=NPCJ
DFLAP=DELFDX

RETURN

WRITE(6)
FAILED TO FIND
FLAP SETTING
USE LANDING
FLAP VALUE

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.
KCLGE=1.0
DELCL=0.0
CLMAX=2.
RLMC4=DLMC4*.01745
C1= (AR/(2.*COS(RLMC4)))**2.
C2=1.- (EM*COS(RLMC4))**2.
CLALPH=(3.1416)/(1.+SQRT(1.+C1*C2))

ILIFT =1 or 4

ILIFT =2 or 5

ILIFT =3 or 6

DELCL=DCLLD
CLMAX=CLMXLD

DELCL=0CLTO
CLMAX=CLMTLO

HOB

<20.

C3=EXP(5.2*(1.-HOB))

C3=0.

KCLGE=1.005+(.00211-.0003*(AR-3.)*C3)

ILIFT >3

ILIFT

CLOGE=CLALPH*.0174533*(ALPHA-ALPHLO)+DELCL

CLOGE <=CLMAX

ALPHA=ALPHLO+((CLMAX-DELCL)/(CLALPH*.0174533))

CL=KCLGE*CLALPH*.0174533*(ALPHA-ALPHLO)+DELCL

CLOGE=(CL-DELCL)/KCLGE+DELCL

CLOGE >CLMAX

ALPHA=(CL-DELCL)/(KCLGE*CLALPH*.0174533)+ALPHLO

RETURN

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.
FIGURE III.3.5 - DETAILED FLOW CHART SUBROUTINE CTAER
CTAER

ZL=CL*.7*PO*SMN*SMN*SREF
ZLQD=CL/CD
DRG=ZL/ZLQD
DMACH=EMD
H=HN

INDFP

WRITE

WRITE(6)AD,
ZL,ZLQD,HN,SMN

RETURN

III.3
24
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.
DRAG

VDEL6=1.0
DELC=0.
DELCDF=0.
DELCDG=0.
CKW=CKWX
SIGMA=1.0

DRAG

=2

SIGMA=SIGMATO

IDRAG

=5 or =4

SIGMA=SIGMA1D

IDRAG

=3 or =6

SIGMA=SIGMAP

IDRAG

=8

SIGMA=SIGMAP

SCFAX

EMD=SA1+SA2*CL

EM

≤EMD

EM

≤(EMD+((SA3+SA4*CL)**2)/10.)*((1./3.))

WRITE(6)

RETURN

DELCDM=10.*(EM-EMD)**3

EMD=SA1+SA2*CL+.08*SCFAX

EM

<60

FIGURE III.3.6 - DETAILED FLOWCHART SUBROUTINE DRAG

III.3

26
DRAG

\[ \delta = \left( EM + \frac{(SA3 + SA4 \cdot CL \cdot 2)}{10.} \right) \cdot (1/3) \]

\[ \text{WRITE}(6) \rightarrow \text{RETURN} \]

\[ \text{CKW} = 0 \]

\[ EM > 0.6 \text{ and } < EM \]

\[ \text{DELCDM} = 0 \cdot \frac{(EM - 0.6)}{CKW} \]

\[ EM \geq EM \]

\[ \text{DELCDM} = \frac{0}{CKW + 10 \cdot (EM - EM)^{3}} \]

\[ CDWI = CFIN \]

\[ \text{KWCD} = 0 \]

\[ CLS = CL \]

\[ \text{CALL ITRLN(ACL,ACDC,CLS,CD,KWCD)} \]

\[ CDWI = CDWI \cdot CD \]

\[ CD = SA5 + SA6 \cdot CDWI + CKW \cdot \text{DELCDM} + SA7 \cdot CL \cdot 2 \]

\[ \text{ICDANAC} = 1 \]

\[ \text{KNAC} = 1 \]

\[ CD = CD + \text{CDNAC} \]

\[ \text{ICDANAC} = 0 \rightarrow \text{RETURN} \]

\[ \text{DELCDF} = \text{DCD0} \]

\[ \text{DELCDF} = \text{DCDAPP} \]

\[ \text{DELCDF} = \text{DCDLD} \]

\[ \text{DELC1L} = \text{DCL0} \]

\[ \text{VDEL6} = \text{VDEL6T} \]

\[ \text{DELC1L} = \text{DCLAPP} \]

\[ \text{VDEL6} = \text{VDEL6A} \]

\[ \text{DELC1L} = \text{DCL0D} \]

\[ \text{VDEL6} = \text{VDEL6L} \]

\[ \text{DELC10G} = \text{GRCD} \]

III. 3

27
DRAG

IF IDRAG = 5 or 6
   DELCDG = 0.0
ENDIF

IF IDRAG = 8
   DELCDG = 0.0
ENDIF

KCDIGE = 1.11 + 5.55 * (HOB) - SQRT(29.8 * ((HOB + .02)^2) + .817)

IF KCDIGE >= 1
   KCDIGE = 1.0
ENDIF

IF KWCD = 0
   CLS = CL - SIGMA * DELCL
ENDIF

CALL ITRI.N(ACL.S, ACDCR, CDCR, KWCD)

CDWI = CFIN
CDWI = CDWI * CDCR

CD = SA5 + SA6 + DELCDF + DELCDG + SA7 * KCDIGE * (CL - SIGMA * DELCL)^2 / VDEL6

IF ICNAC = 1
   CD = CD + CDNAC
ENDIF

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 $VLAM_1$ to $VLAM_4$ (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.
FLAPS

IFLAP = 1

KICKER = 0

KWRITE = #0

WRITE(6)

IFLAP = 1

KICKER = 0

WRITE(6)

RETURN

NPC

= 1

= 4

= 3

= 2

= 130

= 150

DCLMTE = 0

DCLMTE = ADCLTE(JFLTY)

DELTEO = 0

DELTEO = DELTO(JFLTY)

DCDOT = 0

DCDOT = ADCDOT(JFLTY)

WCFLAP = 0

WCFLAP = AWCFLP(JFLTY)

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

CALL ITRLN(ATCW, ALAM2, TC, VLAM2, NTCW)

CALL ITRLN(AARW, ALAM3, AR, VLAM3, NARW)

JFLTY

< 2

CALL ITRLN(ATCW, ALAM4X, TC, VLAM4, NTCW)

JFLTY

< 2

CALL ITRLN(ATCW, ALAM4, TC, VLAM4, NTCW)

JFLTY

< 2

CALL ITRLN(ACFOC, ALAM5Y, CFOC, VLAM5, NCFOC)

JFLTY

< 3 and < 5

CALL ITRLN(ACFOC, ALAM5X, CFOC, VLAM5, NCFOC)

JFLTY

< 6

CALL ITRLN(ACFOC, ALAM5, CFOC, VLAM5, NCFOC)

JFLTY

< 2

CALL ITRLN(ADELF, ALAM6Y, DELF, VLAM6, NDELF)
FLAPS

JFLYP ≥ 3 and ≥ 5

CALL ITRLN(ADELFD, ALAM6X, DELFD, VLAM6, NDELF)

JFLYP ≥ 6

CALL ITRLN(ADELFD, ALAM6, DELFD, VLAM6, NDELF)

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
FWC9 = DBAQC / B
NERPT = 15

CALL BIV(DELXL, FWOB, CROBL, AFWOB, ACROBL, ADELCL, NFWOB, NCROBL, NER)

NER #1 99

CALL TPALT(ALTFIL, GALT, PO, FKALT, T0, G, XKV)

ERRMI = 1.
F = 1. 1
FF = 1. 01
JC = 0
JX = 0
SA = 49. 1 * SQRT(T0)
CLMX = RCLMAX

DELEDD #0

CLMX = RCLMAX + DCLMLE

III. 3

31
\[ Q_1 = \frac{WGS}{CLMX} \]
\[ P_0 = P_0 \times 144. \]
\[ SMN = \sqrt{Q_1 / 0.7 / P_0} \]
\[ VK = SMN \times SA / 1.689 \]

\[ VK < 0 \quad \rightarrow \quad VK = 0. \]

\[ SMN = VK \times 1.689 / SA \]
\[ Q_1 = 0.7 \times P_0 \times SMN \times SMN \]
\[ CLMX = WGS / Q_1 \]
\[ RNW = CBARW \times VK \times 1.689 / XKV \]
\[ RNW = RNW / 100000. \]

\[ CALL \ ITRLN(ARNW, ALAM13, RNW, VLAM13, NRNW) \]

\[ CALL \ ITRLN(AMNW, ALAM14, SMN, VLAM14, NMNW) \]

\[ CLMAX = (RCLMAX \times VLAM1 \times VLAM2 + DCLMTE \times VLAM3 \times VLAM4 \times VLAM5 \times VLAM6 \times VLAM7 \times VLAM8 + DCLMTE \times VLAM9 \times VLAM10 \times VLAM11 \times VLAM12) \times VLAM13 \times VLAM14 + DELCLF \]
\[ ERROR = CLMAX - CLMX \]

\[ KWRITE = 1 \]
\[ ABS(\text{ERROR}) \leq 0.005 \]

\[ CALL \ ITTRMW(\text{ERROR}, \text{ERRM1}, VK, F, FF, JC, JX) \]

\[ JC > 10 \]

\[ JFLTYP \leq 2 \]
\[ CALL \ ITRLN(ACFOC, ADEL1, CFOC, VDEL1, NCFOC) \]

\[ JFLTYP > 2 \]
\[ CALL \ ITRLN(ACFOC, ADEL1, CFOC, VDEL1, NCFOC) \]

\[ RDELF = DELFD / DELTEO \]

\[ CALL \ ITRLN(ARDELF, ADEL2, RDELF, VDEL2, NRDELF) \]

\[ CALL \ BTIV(VDEL3, BTIVOB, SLM, AFOB, ASLM, ADEL3, NFOB, NSLM, NER) \]

\[ NER \neq 1 \]

\[ III.3 \]

\[ 32 \]
FLAPS

TSWPFH = TAN(SWPTE) * 4 * CFOC * (TAN(RLMC4) - TAN(SWPTE)) / 3.

SWPFH = ATAN(TSWPFH)
NERPT = 19
VDEL4 = COS(SWPFH)
NERPT = 20
VDEL5 = 1.0 - FWOB

CALL ITRLN(ADELFD, ADEL6, DELFD, VDEL6, NDELFD)

CDO = SAA5 + SA6 * CFIN
CLMNHL = RCLMAX * VLAM1 * VLAM2 * VLAM13 * VLAM14
CDACL = CDO + DCDOTE * VDEL1 * VDEL2 * VDEL3 * VDEL4 * VDEL5
+ (CLMNHL**2) / (VDEL6/S7)
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

IFLAP = 1

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CLMXD = CLMAX
DELFLD = DELFD
DCLLD = DCL
DCDL, D = DCD
VDEL6L = VDEL6

CALL ITRLN(ADELFD, ASIGMA, DELFD, SIGMLD, 15)