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A COMPUTATIONAL SYSTEM FOR AERODYNAMIC DESIGN AND ANALYSIS OF SUPERSONIC AIRCRAFT

Part 3 - Computer Program Description

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16. Abstract

An integrated system of computer programs has been developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. Interactive graphics are optional at the user's request.

The description of the design and analysis system is broken into three parts, covered in three separate documents:

Part 1—General Description and Theoretical Development
Part 2—User's Manual
Part 3—Computer Program Description

This part contains schematics of the program structure and describes the individual overlays and subroutines.

These three documents supersede NASA contractor reports CR-2520, CR-2521, and CR-2522, which described an earlier version of the system.

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A COMPUTATIONAL SYSTEM FOR AERODYNAMIC DESIGN AND ANALYSIS OF SUPERSONIC AIRCRAFT

PART 3 - COMPUTER PROGRAM DESCRIPTION

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1.0 SUMMARY

An integrated system of computer programs has been developed for the design and analysis of supersonic configurations.

The system consists of an executive driver and seven basic computer programs including a plot module, which are used to build up the theoretical force coefficients of a selected configuration.

Documentation of the system has been broken into three parts:

Part 1 - General Description & Theoretical Development
Part 2 - User's Manual
Part 3 - Computer Program Description

This part, the computer program description, contains schematics of the program structure and written descriptions of the individual overlays and subroutines.

These three documents supersede NASA contractor reports CR-2520, CR-2521, and CR-2522 which described an earlier version of the system.

Interactive graphics for use with the system are optional, employing the NASA-LRC CRT display and associated software.

The computer program is written in FORTRAN IV for a SCOPE or KRONOS operating system. It is designed for the CDC 6600 series of computers and is overlay structured. The system requires approximately 115000_8 (octal) central memory words and uses eight disc files in addition to the input and output files.

2.0 DISCUSSION

A schematic of the design and analysis system overlay structure is shown in figure 2.0-1. The system is a single overlaid program, with the executive driver as the main overlay and the basic programs as primary overlays. The basic programs manipulate input (geometry module), draw a picture of the configuration (plot module), or perform design or analysis calculations.

The format of the computer program documentation is to present schematics or block diagrams of the major program structure, together with subroutine descriptions, for each module developed under the design and analysis system contract. The plot and far-field wave drag modules are not included in this procedure, since they are described in other NASA documentation (references 1 and 2).

The description of the overlay structure follows the convention of labeling overlays with octal numbers, but calling them with their decimal equivalents.

A typical test case and associated program output is given in the User's Manual (part 2).

File Usage

File usage in the system is assigned as follows:

1	basic geometry storage
2	interface file
3	restart data
5	card input
6	output
9, 10, 11, 12	storage files for far-field wave drag module
9, 11, 12	storage files for plot module

Program Structure

A block diagram of the design and analysis system is shown in figure 2.0-2. The largest element of the system with the NASA-LRC graphics software attached occurs with the geometry display module loaded, and is approximately 115000_8. A "stripped" version of the system (graphics software excluded) would have its largest core requirement with the wing design module loaded, and would be approximately 77000_8.

These core sizes are for an absolute version of the program.

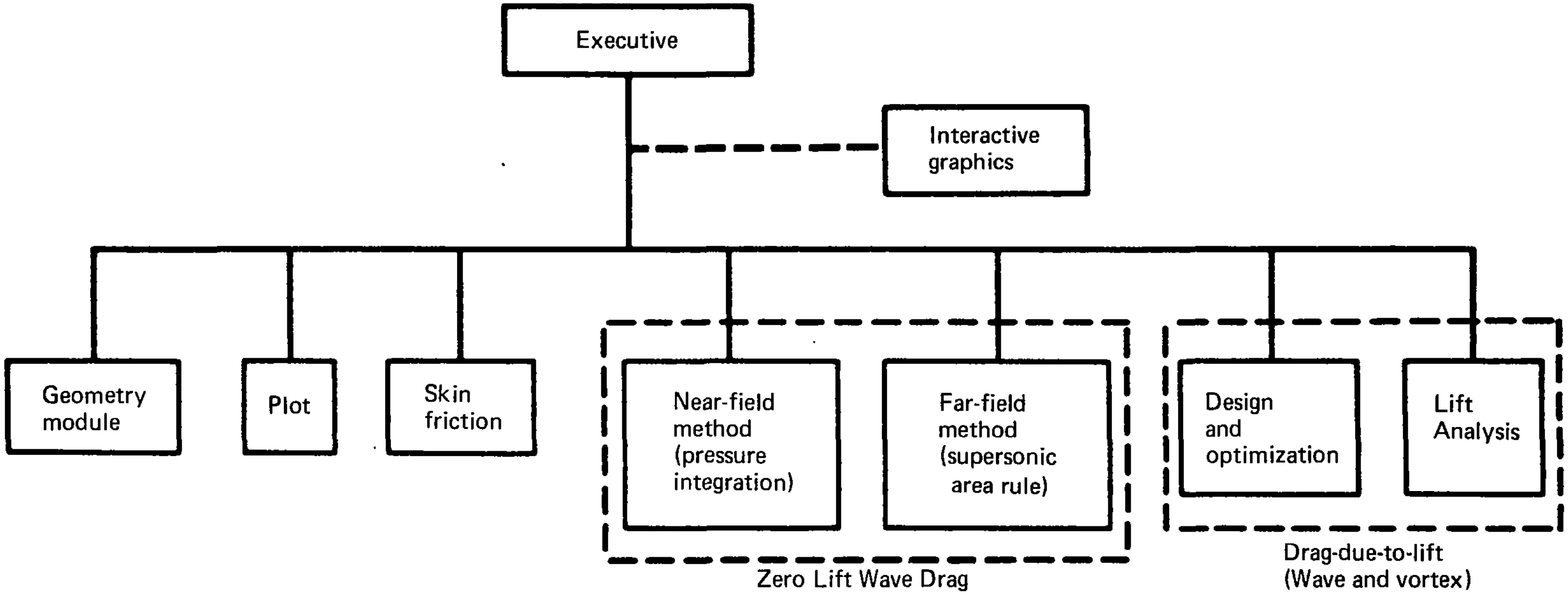
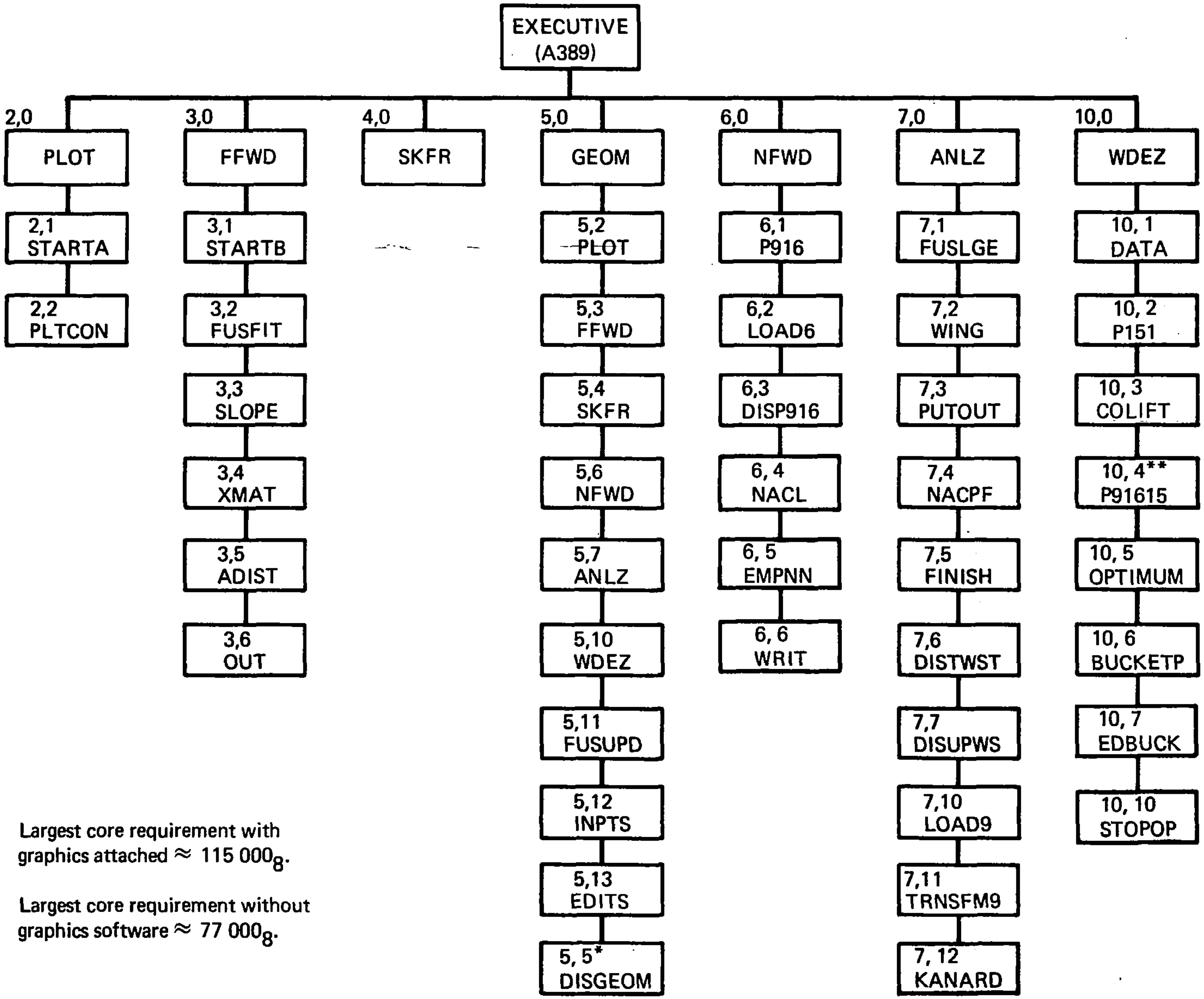


FIGURE 2.0-1.—INTEGRATED SUPERSONIC DESIGN AND ANALYSIS SYSTEM



* Largest core requirement with graphics attached ≈ 115 000_8.

** Largest core requirement without graphics software ≈ 77 000_8.

FIGURE 2.0-2.—SYSTEM OVERLAY STRUCTURE

2.1 EXECUTIVE MODULE

The executive level (0,0 overlay) is used to read executive control cards and request execution of the basic programs (primary overlays) as instructed. The executive cards are described in the user's manual (part 2) and summarized under subroutine CHECKIN (page 6).

Program A389A00

PURPOSE: To read program executive cards and call primary overlays.

METHOD: A389A00 is the program name assigned to the executive level (A389, 0, 0). It reads executive cards, calls subroutine CHECKIN to find the corresponding overlay number, calls the geometry module to read or sort input, then calls the appropriate primary overlay for problem execution.

CRT is a special executive card used only to turn on (or off) the graphics routines as described in the user's manual.

INPUT: Executive cards (see user's manual)

SUBROUTINES CALLED: CHECKIN

Program CHECKIN

PURPOSE: To identify primary overlay number corresponding to executive card.

METHOD: The overlay number for the different primary overlays is determined by variable PROG, in common block/SAV1/. CHECKIN sets the value of IPRG by finding the executive card word corresponding to PROG. The correspondence is:

EXECUTIVE CARD (PROG)	IPRG
PLØT	2
FFWD	3
SKFR	4
GEØM	5
NFWD	6
ANLS	7
WDES	8
FSUP	9
WGUP	10

USE: CALL CHECKIN

INPUT: Variable PROG in common block SAV1

SUBROUTINES CALLED: None

Function TBLU1
Integer Function LOOKUP

PURPOSE: To perform linear or second order interpolation from one-dimensional array.

METHOD: TBLU1 and the associated integer function LOOKUP are general purpose interpolation routines, for either linear or second order interpolation. The program call is:

Z = TBLU1 (X, XX, Y, MD, N)

where

X	independent variable
XX	array containing independent variable
Y	array containing dependent variable
MD	code defining interpolation type 1 = linear 2 = second order
N	number of variables in array XX or Y
Z	dependent variable (answer)

Array XX must be monotonically increasing.

USE: Z =TBLU1 (X, XX, Y, MD, N)

INPUT: As described above

SUBROUTINES CALLED: TBLU1 calls associated subroutine LOOKUP

2.2 GEOMETRY MODULE

The geometry module is primary overlay 5. It contains subprograms to read, store, or display the configuration geometry, and to set up the input for the other basic programs. A schematic of the geometry module is shown in Figure 2.2-1.

Program PDPACK

PURPOSE: To route geometry handling requests from the executive to geometry routines, based on executive control cards.

METHOD: Program PDPACK is the primary level of the geometry module. It is entered from the executive to store, add, or change input data; to update wing camber surface or fuselage basic geometry; or to enter the interface routines to set up input data for the other modules. A schematic of PDPACK is shown in figure 2.2-2.

The executive control cards corresponding to variables in PDPACK are as follows:

EXECUTIVE CARD	PDPACK VARIABLE	PRINCIPAL PROGRAMS OR SUBROUTINES CALLED
GEØM NEW	IFIRST=0	EDITS
GEØM	IFIRST=1	INPTS, EDITS
PLØT	IPRG=2	INPTS, GEØMPLT
FFWD	IPRG=3	INPTS, GEØM80
SKFR	IPRG=4	INPTS, GEØM158
NFWD	IPRG=6	INPTS, GEØM916
ANLZ	IPRG=7	INPTS, GEØM201
WDEZ	IPRG=8	INPTS, GEØM253
FSUP	IPRG=9	INPTS, FUSUPD
WGUP	IPRG=10	INPTS, NEWCAM

Configuration geometry is read from cards in program EDITS and stored on tape 1 when the geometry module is not in core. Program INPTS retrieves the geometry from tape 1 when the geometry module is called. Subroutines WRGEØM and PRINTG write the configuration geometry on tape 1 for storage or print the geometry onto the output tape, respectively.

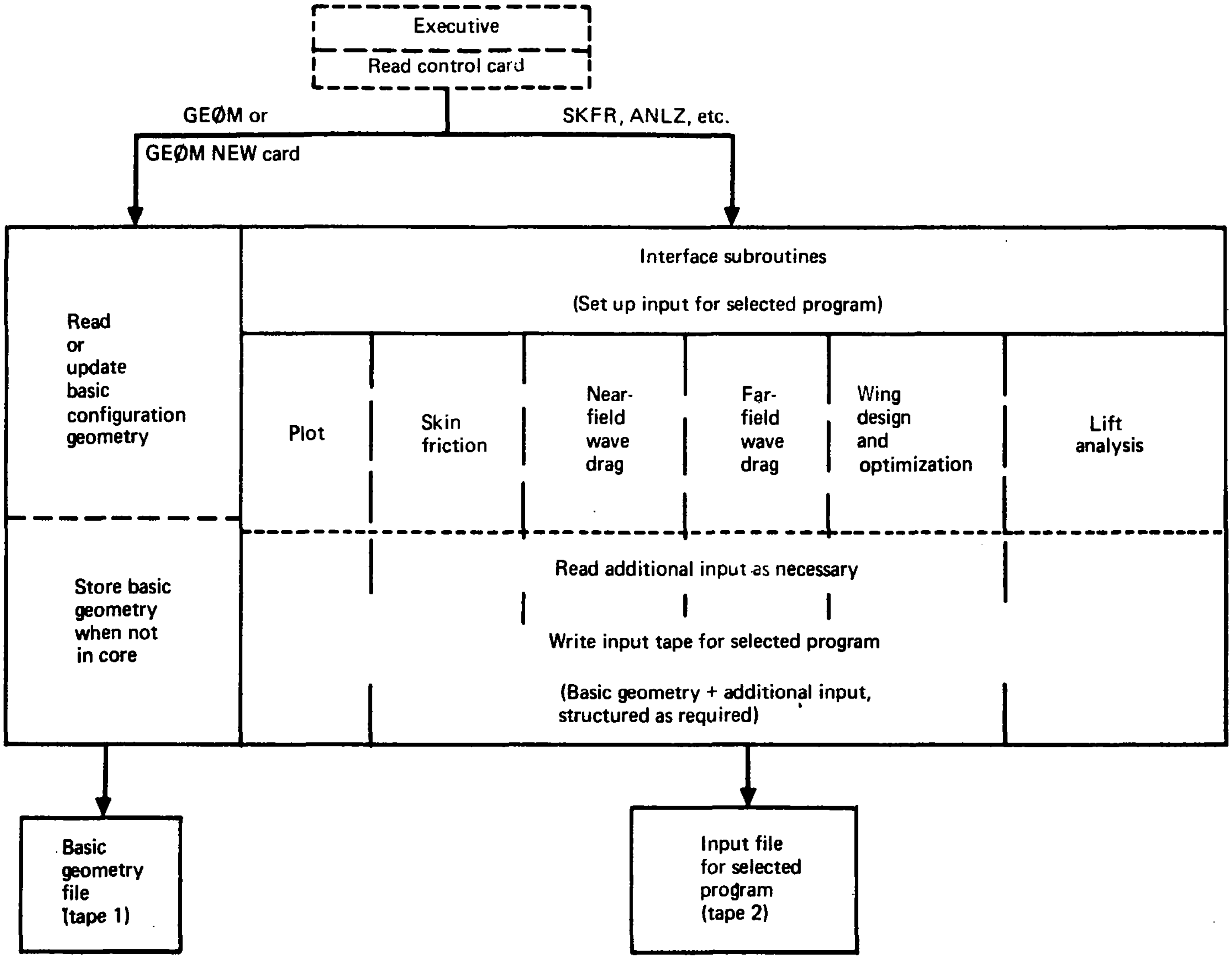


FIGURE 2.2-1.—SCHEMATIC OF GEOMETRY MODULE

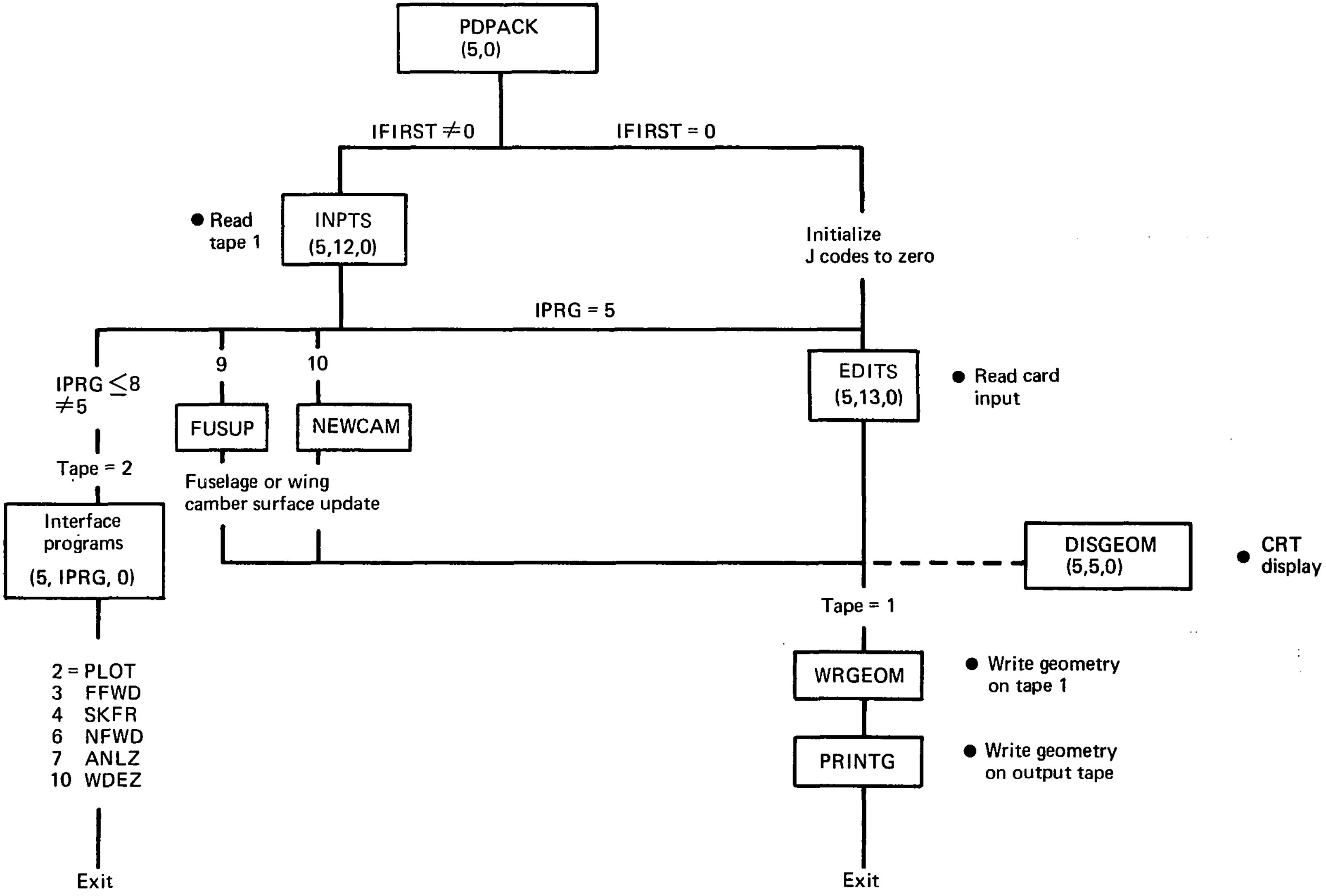


FIGURE 2.2-2.—PROGRAM PDPACK SCHEMATIC

The interface programs write data onto tape 2, which becomes the input tape for the individual basic modules.

USE: CALL OVERLAY (GEOM, 5, 0, 0)

INPUT: Executive card variables listed above.

SUBROUTINES CALLED: See schematic on page 10 .

Subroutine WRGEØM

PURPOSE: To write geometry data onto tape 1 for storage, or onto tape 2 for plot program or far-field wave drag program.

METHOD: Subroutine WRGEØM uses the input format of the NASA-LRC plot program and is used to write the basic geometry data onto tape 1 when the geometry module leaves core, or to write the geometry data onto the interface tape (2) as a part of the plot or far-field wave drag program interfaces.

USE: CALL WRGEØM

INPUT: Configuration geometry (see user's manual)

SUBROUTINES CALLED: None

Subroutine ZPØD

PURPOSE: To calculate the Z distance between the nacelle centerline and the local wing camber surface.

METHOD: The basic configuration geometry input (read in EDITS) allows the nacelles to be input with either of two Z dimensions: in the Z system of the configuration coordinates, or with Z measured to the local wing camberline. Subroutine ZPØD is used, regardless of which Z definition is input, to calculate the other definition and store it in the basic geometry.

If the nacelle origin is forward or aft of the wing planform, the Z distance is measured from the wing leading edge or trailing edge (whichever is closer) at the same Y station.

As a special case, ZPØD is also used to compute the distance between the fuselage centerline and the wing camber line at the side of the fuselage (in program GEØM916).

USE: CALL ZPØD(NN)

INPUTS:

NN	Nacelle origin index
PØDØRG	Nacelle origin data
XAF, WAFØRG, WAFØRD, TZRD	Wing definition (planform, thickness, camberline)

SUBROUTINES CALLED: None

Subroutine PRINTG

PURPOSE: To write configuration geometry onto output tape (6).

METHOD: After configuration geometry is read or changed, subroutine PRINTG is used to write the current geometry definition. In the case where the fuselage or wing camber surface is updated (executive cards FSUP or WGUP), only the fuselage or camber surface is output. This is controlled by variable ISKIP1 (=98 for fuselage only, =99 for camber surface only).

USE: CALL PRINTG

INPUT: Geometry definition (see user's manual)
ISKIP1

SUBROUTINES CALLED: None

Subroutine NEWCAM

PURPOSE: To interpolate a wing camber surface for basic geometry definition (TZØRD) from wing design or analysis definition (WZØRD)

METHOD: The camber surface definition generated or used by the wing design or analysis modules, called WZØRD, may be different from the basic geometry definition (TZØRD). This can happen either because the definition is being created by the design program, or because the analysis program input option for WZØRD was used. NEWCAM linearly interpolates for TZØRD from WZØRD, and is called by program PDPACK if executive card WGUP is read. NEWCAM is also automatically called by the analysis program interface if the WZØRD option is used.

USE: CALL NEWCAM (FACTØR)

INPUT:

FACTØR	Multiplier used to scale camber surface ordinates, if desired.
NØPCT, P, JBYMAX, Y, WZØRD, IFZC	Camber surface definition WZØRD contained in common block /CAMBER/
XAF, WAFØRG, TZØRD	Camber surface definition (TZØRD) of basic geometry contained in common block /WING/

SUBROUTINES CALLED: INTERP

Subroutine INTERP

PURPOSE: To interpolate two-dimensional array.

METHOD: INTERP is used to linearly interpolate WZØRD definition (used in conjunction with subroutine NEWCAM).

USE: CALL INTERP (A, Ø, N, X, Y, M)

INPUT

A	First array location for abscissa values
Ø	First array location for ordinate values
N	Number of values in A and Ø arrays
X	Array of abscissa for ordinate outputs
Y	Array of calculated ordinates
M	Number of values in X and Y arrays output

SUBROUTINES CALLED: None

Program GEØMPLT

PURPOSE:	To write input tape for PLOT module.
METHOD:	GEØMPLT is the interface program between the executive and the PLOT module, entered when the executive card PLØT is read. The interface reads the plot title card and configuration codes, then uses WRGEØM to write the corresponding basic geometry data onto tape 2 (the program input tape). GEØMPLT then reads the plot view cards and writes them onto tape 2.
USE:	CALL ØVERLAY (GEOM, 5, 2, 0)
INPUT:	See user's manual for input description
SUBROUTINES CALLED:	WRGEØM

Program GEØM80

PURPOSE:	To write input tape for far-field wave drag module.
METHOD:	GEØM80 is the interface program between the executive and the far-field wave drag program, entered when the executive card FFWD is read. The interface reads a title card and the configuration codes, then uses WRGEØM to write the corresponding basic geometry data onto tape 2. GEØM80 then reads the case and restraint cards (if used) and writes them onto tape 2.
USE:	CALL ØVERLAY (GEOM, 5, 3, 0)
INPUT:	See user's manual for input description
SUBROUTINES CALLED:	WRGEØM

Program GEØM158

PURPOSE:	To write input tape for skin friction module.
METHOD:	GEØM158 is the interface program between the executive and the skin friction drag module, entered when the executive card SKFR is read. It reads title information, flight conditions, and configuration data, and structures those inputs together with basic geometry to write the input tape (2) for the skin friction module.

USE: CALL OVERLAY (GEOM, 5, 4, 0)

INPUT: See user's manual for input description

SUBROUTINES CALLED: None

Program GEOM916

PURPOSE: To write input tape for near-field wave drag module.

METHOD: GEOM916 is the interface program between the executive and the near-field wave drag module, entered when the executive card NFWD is read. It reads title information, Mach number, etc., and structures those inputs together with basic geometry to write the input tape (2) for the near-field wave drag module.

The near-field program considers the configuration to be uncambered; the wing and fuselage have thickness but have a flat mean-line. Wing height in the side of the fuselage is preserved, however, being the distance from the fuselage centerline to the wing at the side of the fuselage. In GEOM916, the wing height dimensions are computed by a special use of ZPOD, in which the fuselage centerline is treated as a nacelle origin in a series of calculations.

The nacelle Z dimension used in the near-field program is the distance from the local wing camberline.

USE: CALL OVERLAY (GEOM, 5, 6, 0)

INPUT: See user's manual for input description.

SUBROUTINES CALLED: ZPOD, NEWAREA

Subroutine NEWAREA

PURPOSE: To check for and remove "steps" in input fuselage area definition corresponding to inlet or exit stream tubes.

METHOD: The basic geometry fuselage definition allows for input of the fuselage in four segments. If the first cross-section of segment 2 is input at the same X station as the last cross-section of segment 1, and the cross-sectional areas of the two inputs are different, then the far-field wave drag program extends a streamtube to account for the area "step", so that no area discontinuity occurs in the wave drag calculations. This can occur, also, between other segments. The near-field wave drag fuselage calculations cannot accommodate an area step at a fuselage station other than the first or last. If one occurs, subroutine NEWAREA removes the step by collapsing the fuselage to a solid body having the same area growth.

NEWAREA also reduces the fuselage area definition to 50 values in X, Ƶ and area if more than 50 total values were input in all fuselage segments, since the near-field program allows only 50 points.

USE: CALL NEWAREA (X, Ƶ, A, L)

INPUT:

X	Output array of fuselage X values for analysis program.
Ƶ	Output array of fuselage camberline Ƶ values.
A	Output array of fuselage cross-sectional areas.
L	Number of values in X, Ƶ, or A arrays
/BØDY/	Common block containing fuselage basic geometry definition.

SUBROUTINES CALLED: None

Program GEØM201

PURPOSE: To write input tape for lift analysis module.

METHOD: GEØM201 is the interface program between the executive and the lift analysis module, entered when the executive card ANLƵ is read. It reads title information, Mach number, etc., and structures those inputs together with basic geometry to write the input tape (2) for the lift analysis module.

The lift analysis interface allows the wing camber surface to be read as the WƵØRD definition, or passed in through common block /CAMBER/, in addition to the basic geometry definition. If WZØRD is used, the basic geometry is automatically updated by means of subroutines NEWCAM and WRGEØM.

In addition, since the lift analysis program logic does not permit step discontinuities in fuselage area between the most forward and aft X stations, subroutine NEWAREA is used to prepare the fuselage cross-sectional area definition. (NEWAREA is described in connection with GEØM916).

The nacelle origin Z dimension is the vertical distance to the local wing camber line.

USE: CALL ØVERLAY (GEOM, 5, 7, 0)

INPUT: See user's manual for input description

SUBROUTINES CALLED: NEWAREA, NEWCAM, WRGEØM

Program GEØM253

PURPOSE: To write input tape for wing design module.

METHOD: GEØM253 is the interface between the executive and the wing design module, entered when the executive card WDEZ is read. It reads title information, Mach number, loadings data, etc., and structures those inputs together with basic geometry to write the input tape (2) for the wing design module.

The wing design program may employ pressure fields generated by the near-field wave drag module or analysis module. The existence of these pressure fields is tested in the corresponding common blocks. This involves the codes BØDCPX, BØDUPX, and CPNACX. The actual use of these pressure fields is controlled by input of the corresponding loading numbers.

The nacelle Z origin is the vertical dimension to the local wing camber surface.

The restart data deck is substantial. Logic for this part of the interface is copied from the wing design program input.

USE: CALL ØVERLAY (GEOM, 5, 8, 0)

INPUT: See user's manual for input description

SUBROUTINES CALLED: RDWRT,RDWRTE

Subroutine RDWRT,RDWRTE

PURPOSE: To read input data cards and write the data on the interface file (2) in the format specified.

METHOD: If subroutine RDWRT is called, data is read using FORMAT(10F7.0) and written using FORMAT(10F10.4). If subroutine RDWRTE is called, data is read and written using FORMAT(4E20.13).

USE:
```
CALL RDWRT(NUM)
CALL RDWRTE(NUM)
```

INPUT: NUM Number of data values to transmit.

SUBROUTINES CALLED: None

Program FUSUPD

PURPOSE: To update the fuselage definition in the basic geometry to the optimum area distribution generated by the far-field wave drag program.

METHOD: The far-field wave drag program contains a fuselage optimization feature, which area-rules the fuselage subject to input constraints. FUSUPD uses the optimized definition to update the basic fuselage geometry, and is accessed by means of the executive card FSUP.

FSUP first reads the value of ØPHOW, which controls the optimization interpolation. (ØPHØW = -, interpolate at original fuselage X stations; ØPHØW= +, interpolate at 50 equally spaced X stations). It then changes the basic geometry definition to the optimum body area distribution, contained in common block/ØPBOD/. The original fuselage Z definition is preserved. Fuselage perimeters are proportioned to the new area distribution.

USE: CALL ØVERLAY (GEOM, 5, 9, 0)

INPUT:
OPHØW Interpolation code
XØP Optimum fuselage definition. XØP = X
AØP array, AØP = area array, JØP =
JØP number of XØP or AØP values.

SUBROUTINES
CALLED: TBLU1

Program INPTS

PURPOSE: To read basic geometry data from tape into core.

METHOD: Program INPTS is used to reread the configuration basic geometry back into core when the geometry module is accessed. INPTS uses the same format as program WRGEØM, which was used to store the basic geometry on tape 1.

USE: CALL ØVERLAY (GEOM, 5, 10, 0)

INPUT: Tape 1

SUBROUTINES
CALLED: None

Program EDITS

PURPOSE: To read configuration geometry from cards.

METHOD: Program EDITS is used to read the configuration geometry from cards, and is accessed by either the GEØM NEW or GEØM executive cards. (GEØM NEW zeroes all the configuration J1, J2, etc., codes, so that EDITS reads all new data; GEØM preserves all existing codes, so that new geometry read replaces or adds to existing geometry read by INPTS).

The input format of program EDITS is basically that if the NASA-LRC plot program, with a few additional input variables added as noted in the user's manual.

USE: CALL ØVERLAY (GEOM, 5, 11, 0)
INPUT: See user's manual for input description
SUBROUTINES
CALLED: SPØD

2.3 SKIN FRICTION MODULE

The skin friction module is primary overlay 4. Its principal subprograms calculate the wetted areas of the configuration, and then the skin friction drag for a series of input flight conditions. A schematic of the skin friction module is shown in figure 2.3-1.

Program TEA-158A

PURPOSE:	To read configuration data, flight conditions, and calculate wetted areas and lengths to be used in skin friction drag calculations.
METHOD:	Program first reads all input data, which consists of configuration geometry and either Mach number-altitude or Mach number-Reynolds number flight conditions. For each configuration component, the corresponding wetted areas and reference lengths are computed. In the case of the wing or canard(s) or fin(s), the parts are broken into strips to permit more accuracy in determining an average skin friction coefficient. (The wing is broken into approximately 50 strips, canard or fin into 10 strips.) The wetted areas and references lengths are passed to subroutine DRAG for the skin friction coefficient calculations.
USE:	CALL OVERLAY (SKFR, 4, 0)
INPUT:	Input is read from the interface tape (2), set up by the skin friction interface program in the geometry module.
SUBROUTINES CALLED:	DRAG

Subroutine DRAG

PURPOSE:	To calculate configuration skin friction coefficients and print answers for all input flight conditions.
METHOD:	Given the set of configuration wetted areas and input flight conditions, the skin friction coefficients for each component are computed and summed to obtain the total skin friction drag. If

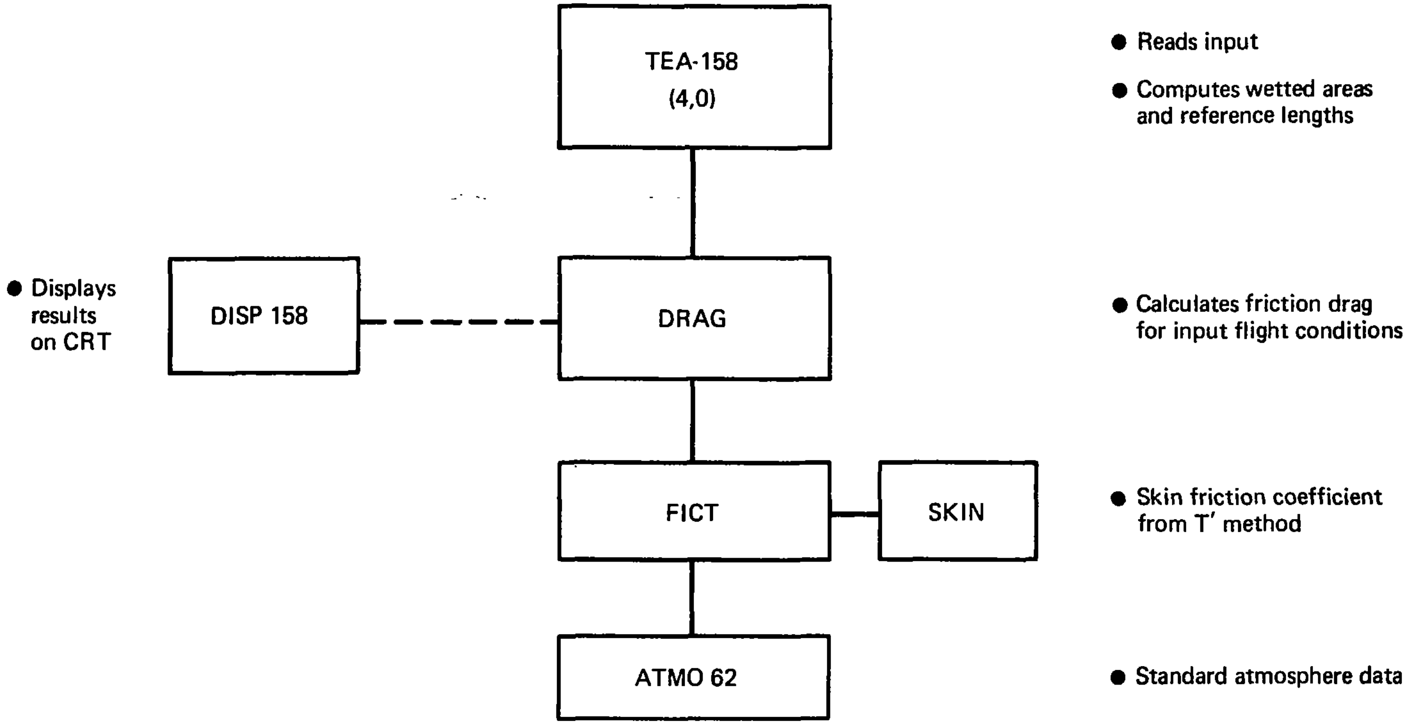


FIGURE 2.3-1.—SKIN FRICTION MODULE SCHEMATIC

the graphics routines are activated, the friction drag coefficients are also printed on the CRT.

USE: CALL DRAG

INPUT: Input is passed in common blocks from program TEA-158A

PRINCIPAL VARIABLES: Same as program TEA-158A, plus:

SCAM	Scale factor to convert configuration reference lengths to feet for use in subroutine FICT
SREF	Wing reference area
SWETT	Total configuration wetted area
CDFT	Total skin friction drag coefficient
AM, AL, DELT, SCAMØD	Mach number - altitude flight condition input AM = Mach number, AL = altitude (feet), DELT = temperature deviation from standard (°F), SCAMØD = input scale factor.
AM, RNPFL, SCAMØD, TØTEM	Mach number - Reynolds number condition input. RNPFL = Reynolds number per foot/1,000,000 TØTEM = total temperature (°Rankine)
SWETRB FUSL SWETB	Fuselage wetted area Fuselage reference length Fuselage wetted area corrected for overlap areas of wing, fin(s), and canard(s)
AREAJ WINGL LCOUNT SWETW	Planform area of a wing strip Length of wing strip Total number of wing strips (nominally 50) total wing wetted area
TSWTNA TPØDL SWETNA NPØD	Wetted area of nacelle(s) at first input origin, corresponding length, total wetted area for all nacelles Number of nacelle origins
SWTFN CHDFN NFIN	Planform area of a fin strip (10 total strips), corresponding strip length, number of fins
TSWTC TCCAN NCAN	Planform area of canard strip Corresponding strip length Number of canards

SWETXP RLXP NXTPT	Wetted area of an arbitrary configuration part, corresponding reference length, number of arbitrary parts.

OUTPUT: Output consists of flight conditions, wetted area and skin friction coefficient buildups, total skin friction drag coefficient and configuration wetted area.

SUBROUTINES CALLED: FICT, DISP158

Subroutine FICT

PURPOSE: To calculate the turbulent skin friction drag coefficient for a given reference length, Mach number, Reynolds number, and total temperature.

METHOD: The skin friction coefficient is calculated from the T' method described in the aerodynamic theory document (part 1).

USE: CALL FICT (AMX, ALX, EEL, C)

INPUT:

AMX	Mach number
ALX	Altitude, feet
EEL	Reference length

PRINCIPAL VARIABLES:

TI	Total temperature, degrees Rankine
SCAM	Scale factor to convert input reference length to feet
RI	Free stream Reynolds number

OUTPUT:

C	Skin friction coefficient

SUBROUTINES CALLED: ATM062, SKIN

Subroutine ATMO62

PURPOSE: To provide standard atmospheric data

METHOD: Program uses 1962 standard altitude definition (reference 3).

USE: CALL ATM062 (Z, TEMP, SIGMA, AX)

INPUT:	Z	Geometric altitude, feet
OUTPUT:	TEMP	Temperature, degrees centigrade
	SIGMA	Density ratio
	AX	Speed of sound, knots
SUBROUTINES CALLED:	None	

Subroutine SKIN

PURPOSE: To iterate for skin friction coefficient.

METHOD: Program is used to solve the Karman-Schoenherr equation

using $$\frac{.242}{\sqrt{CF}} = \log_{10} (CF * REY)$$

value for CF. Solution is iterative, and is satisfied when successive iterations agree within .0001 per cent. A maximum of 50 iterations is allowed.

USE: CALL SKIN (REY, CF)

INPUT:	REY	Reynolds number
OUTPUT:	CF	Skin friction coefficient
SUBROUTINES CALLED:	None	

ERROR RETURN: Program uses 50th iteration for CF if convergence does not occur, and prints error message.

2.4 NEAR-FIELD WAVE DRAG MODULE

The near-field wave drag module is primary overlay 6. It contains principal subprograms to calculate the near-field pressure data and drag coefficients and to display the calculated results. Schematics of the principal program structure are given in figures 2.4-1, 2.4-2, and 2.4-3.

Program TEA-356

PURPOSE: Near-field wave drag primary overlay

METHOD: Program TEA-356 is the primary level of the near-field wave drag program. It calls the input overlay and contains the Mach number loop which calls the calculation overlays and the graphics display (overlay 3).

USE: CALL ØVERLAY (NFWD, 6, 0, 0)

INPUT: Executive card NFWD

SUBROUTINES CALLED: Overlays 6,1 to 6,6 and primary level subroutines

Subroutine NBØDY

PURPOSE: To calculate the Whitham F(y) function for an arbitrary body of revolution, then compute surface pressure distribution, wave drag, and wetted area.

METHOD: Subroutine NBØDY first computes the Whitham F(y) function, according to the Stieltjes integral formulation. The equations used are summarized in the theoretical document (part 1). The F(y) function is computed at TNCUT+1 X-stations (where TNCUT is an input in the main program, usually 50). To remove minor irregularities in the final F(y) function, extra points are inserted between each of the X-stations, F(y) is computed there also, and a five point smoothing formula applied.

The F(y) function is also computed at X-stations downstream of the last body station, to define the "tail" on the F(y) function which is needed in the area-balancing technique for pressure coefficient. The loop for the F(y) equations begins at statement 60, which results in the unsmoothed F(y) array stored in TFY, with corresponding y values in BTØ, JFY total values. After smoothing and extending the F(y) function aft of the body, the final F(y)

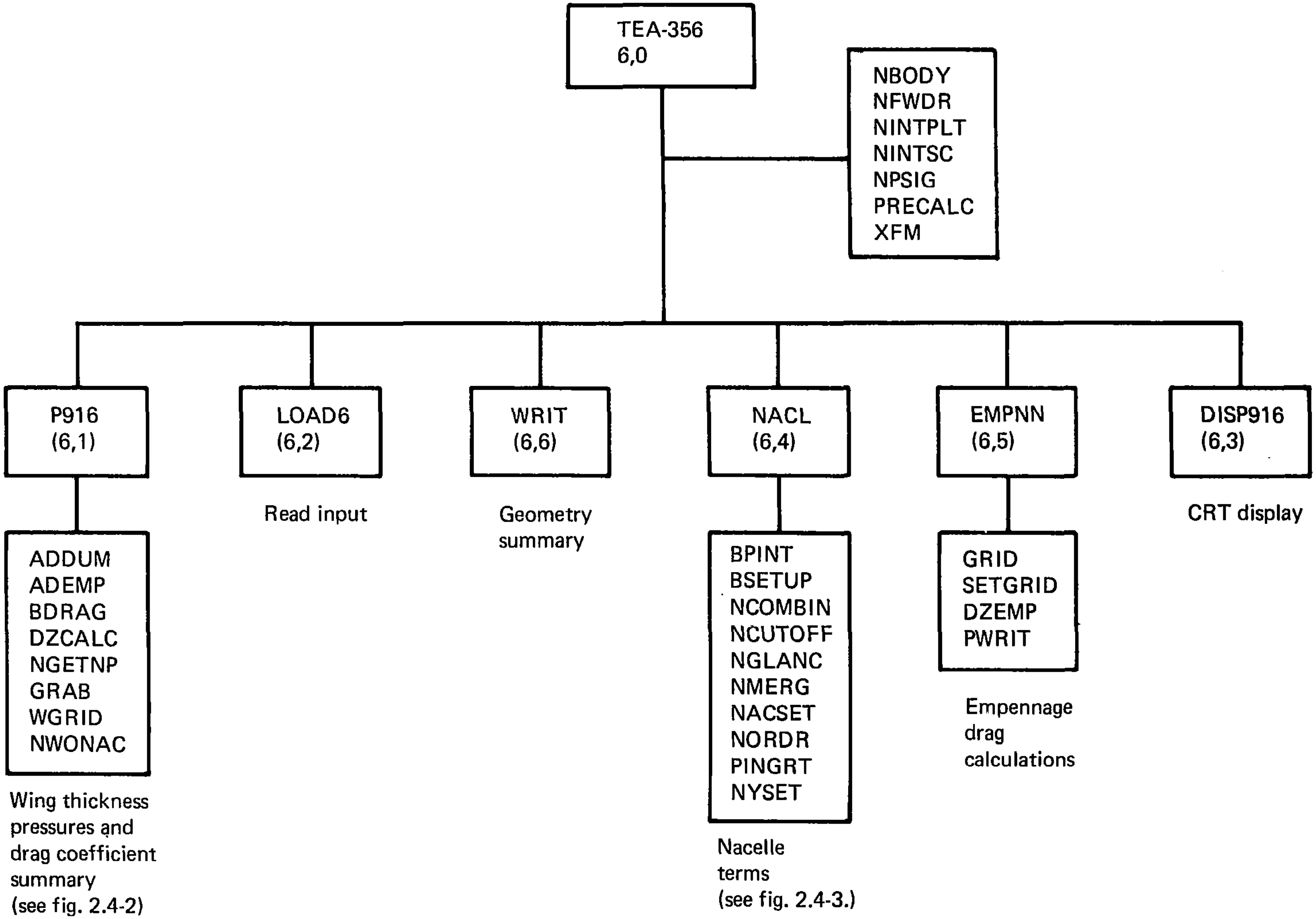


FIGURE 2.4-1.—NEAR-FIELD WAVE DRAG MODULE SCHEMATIC

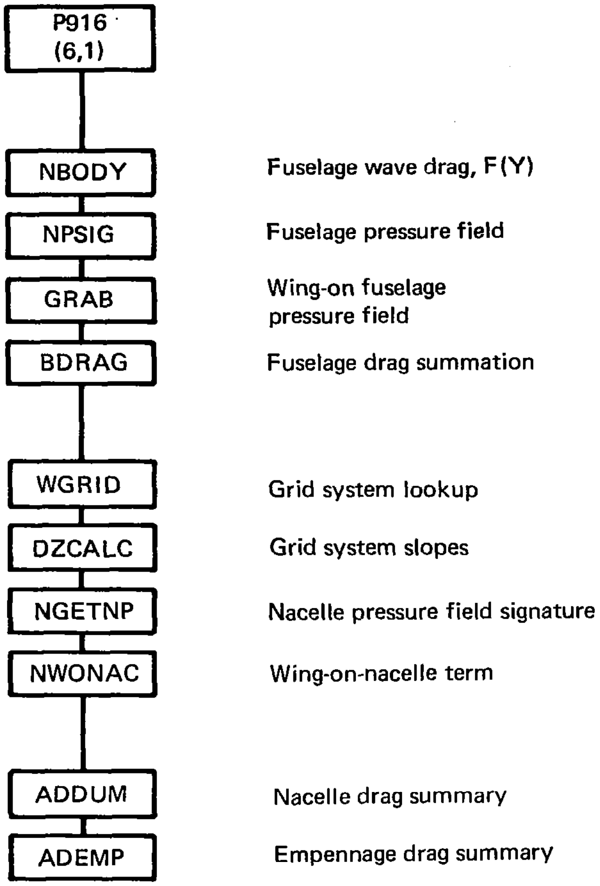
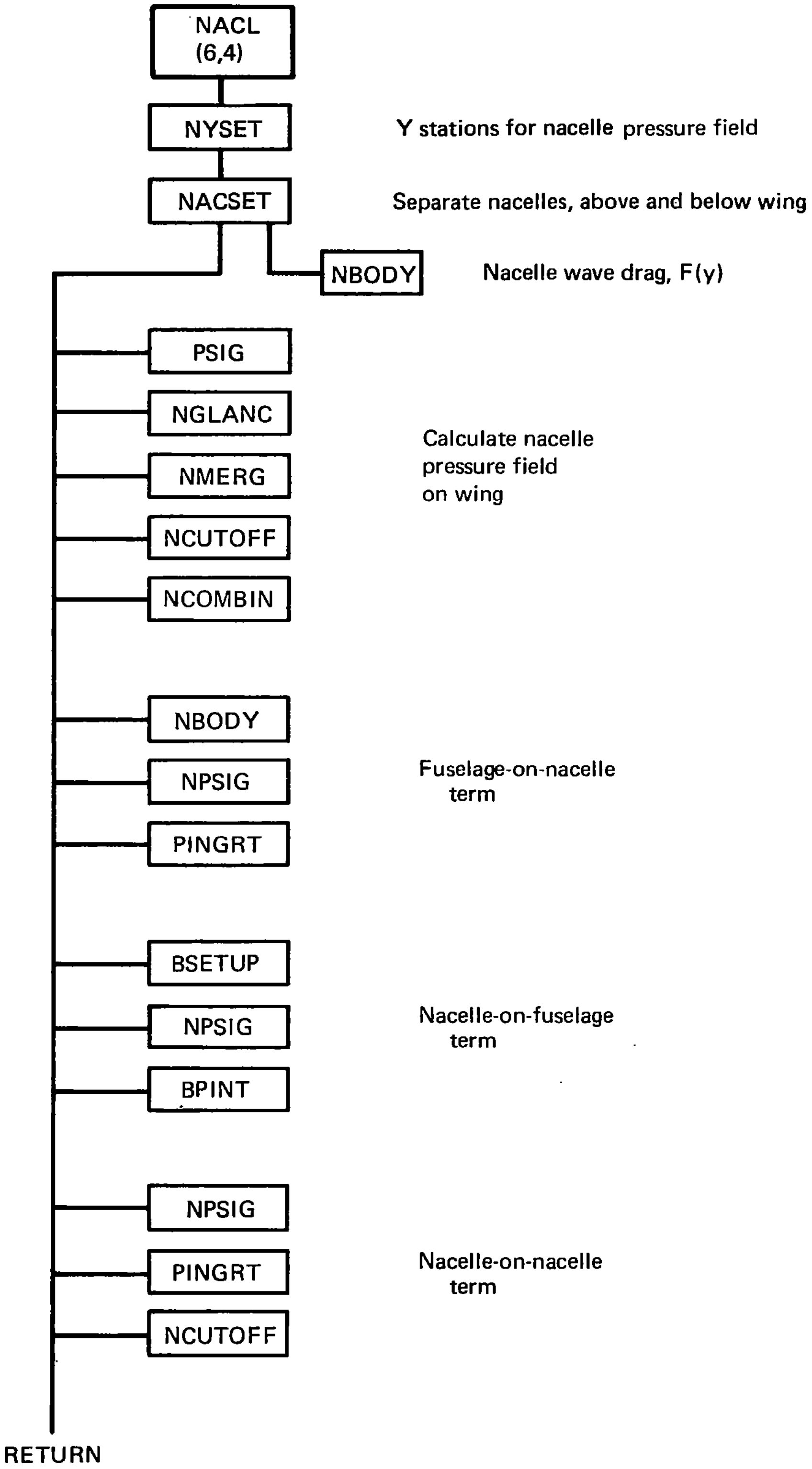


FIGURE 2.4-2.—WING THICKNESS PRESSURES AND DRAG SUMMARY SCHEMATIC



Y stations for nacelle pressure field

Separate nacelles, above and below wing

Nacelle wave drag, F(y)

Calculate nacelle pressure field on wing

Fuselage-on-nacelle term

Nacelle-on-fuselage term

Nacelle-on-nacelle term

FIGURE 2.4-3.—NACELLE TERMS SCHEMATIC

function is stored in TFTAU, with corresponding y values in TTAU, JST0 total values.

The body surface pressure calculations loop starts at D0 330, using the equations given in the theory document (part 1). The body is again broken into TNCUT+1 segments, and the resulting thickness pressures stored in TCPBY, with corresponding X values in TXCPBY. The wetted area calculation and the integration of the thickness pressures to get wave drag is performed in loop D0 340.

Subroutine NB0DY will handle bodies having open front or aft ends, but assumes smooth geometry in-between.

USE: CALL NBODY (TXB, TRB, TNXB, TNCUT, TTAU, TFTAU, JST0, WAVE, SNWET)

INPUT:

TXB	Body definition. TXB = x array,
TRB,	TRB = radii array, TNXB values in
TNXB	X or radius.
TNCUT	Number of body segments in F(y) and thickness pressure calculations
TTAU	F(y) function. TTAU = y,
TFTAU,	TFTAU = F(y), JST0 values in y or
JST0	F(y).
WAVE	$\int C_p \, dA$ = wave drag/q
SNWET	Wetted area of body, assuming circular cross-sections

SUBROUTINES CALLED: TBLU1

Subroutine NFWDR

PURPOSE: To calculate influence coefficient function for wing thickness pressure calculations.

METHOD: NFWDR calculates R function for a selected grid element according to equation given in theory document (Part 1).

USE: CALL NFWDR (NS1, DELTN1, DELTN2, AN1)

INPUT:

NS1	X distance from field point element
DELTN1	lateral distances from field point
DELTN2	element, $\beta y \pm .5$
AN1	R function

SUBROUTINES CALLED: None

Subroutine NINTPLT

PURPOSE: To generate a detailed definition of the tilted F(y) function for a selected right-running leg.

METHOD: Subroutine NPSIG identifies all right-running legs of the tilted F(y) function. NINTPLT is used to enrich the definition for use in later interpolations. The selected leg may either be a "base" leg, or a leg that possibly contains an area-balancing solution. The maximum number of points used to enrich the leg definition is 300. The enriched definitions end up in the following arrays:

	Base leg	Other leg
Tilted F(y)	BT0	CT0
F(y)	BFTAU	CFTAU
Integrated area under tilted F(y)	BAREA	CAREA

USE: CALL NINTPLT (SUM, TPRE, FPRE, NL, NR, NSET, TFTAU)

INPUT:

SUM	Area under tilted F(y) function corresponding to left end of leg
TPRE,FPRE	Value of tilted Y, (F(y) at left end of leg
NL, NR	Storage index of tilted F(y) array (arrays TT0 = tilted y, TFTAU = F(y)
NSET	Index for leg definition 1 = base leg 2 = succeeding leg
TFTAU	F(y) array

SUBROUTINES CALLED: None

Subroutine NINTSC

PURPOSE: To locate the wing-fuselage intersection and compute corresponding exposed wing wetted area.

METHOD: The wing-fuselage intersection code is controlled by input ANYB0D. If positive, ANYB0D defines the inboard end of the wing for purposes of the thickness definition, whether a fuselage is present or not. If ANYBOD is negative, the intersection of the wing and fuselage is calculated by solving for the point at which each constant per cent chord meanline of the wing crosses through the fuselage surface (assuming the fuselage to be circular).

The wing-fuselage intersection is stored in common block /WBINT/.

WX	X location of intersection
WY,WZ,WT	Corresponding Y,Z, and thickness values

USE: CALL NINTSC (WSW)

INPUT: WSW Exposed wing wetted area

SUBROUTINES CALLED: TELU1

Subroutine NPSIG

PURPOSE: To calculate the near-field pressure signature for a body of revolution at a given distance from the body.

METHOD: Given an F(y) function, Mach number, and radial distance from the body, NPSIG is used to calculate the resultant pressure signature. The method is described in the aerodynamic theory document (part 1).

The basic steps in the calculation sequence are as follows:

1. The tilted F(y) function is constructed from the input F(y) function, and the running sum of area under the tilted F(y) function computed. (The input function is defined by arrays TTAU, TFTAU and the tilted function by TT0, TFTAU, with the area corresponding to TT0 in TAREA).

2. The bow shock position is identified by the left-most value of TT0 for which TAREA = 0. (Interpolation of the TAREA array is used for accuracy.)

3. The tilted F(y) function remaining after the bow shock is located is searched to identify all right-running legs.

4. All right-running legs are compared for common TAREA values, which would identify possible shock wave locations. (Again, interpolation is used to enrich the TAREA definition, using subroutine NINTPLT.)

5. Valid shock wave solutions are identified, based on the left-most criteria described in the theory document.

6. The resulting tilted and area-balanced F(y) function is converted to pressure coefficient by means of the multiplier CØNST and stored in arrays BTØ and CTØ (x and pressure coefficient). The BTØ and CTØ arrays are cut off if x becomes greater than input value YED.

USE: CALL NPSIG (TTAU, TFTAU, JSTØ, R, YED)

INPUT:

TTAU	F(y) definition, Y = TTAU array,
TFTAU	F(y) = TFTAU array, JSTØ values
JSTØ	
R	Radial distance from body centerline
YED	Largest x-value of interest for pressure signature

SUBROUTINES CALLED: NINTPLT, TBLU1

Subroutine XFM

PURPOSE: To convert input planform geometry to program grid system.

METHOD: The wing planform is represented in the near-field wave drag program as a set of recilinear elements, described in the theory document (part 1). Given the number of semi-span rows (TNØN) used to define the right-hand wing, XFM interpolates the planform definition at the mid-point of each semi-span row for the leading edge and trailing edge x value. These x values are converted to program scale (by means of RATIØ = Ywing-tip * BETA/TNØN) and stored in arrays TXLE and TXTE, with XLEØ and XTEØ defining the wing centerline grid points.

Storage of wing pressure coefficients and surface slopes uses a space-conserving technique: The leading edge of a spanwise element row is stored immediately after the trailing edge of the adjacent inboard row. The index array for the row storage is JZ, which totals the number of elements stored up to the leading edge of a selected row. The allowable total number of elements representing the right hand wing is 2750; if this total is exceeded for a given value of TN0N, the program reduces TN0N until the 2750 limit is not exceeded.

USE: CALL XFM

INPUT: Input geometry in common blocks

SUBROUTINES CALLED: TBLU1

Subroutine PRECALC

PURPOSE: To precalculate a standard set of R values for thickness pressure calculations.

METHOD: PRECALC sets up an array of R values for grid elements up to 20 units forward or laterally from any field point element (to save time in recalculating often-used values). The resulting array is stored in common block /RSAVE/.

USE: CALL PRECALC

INPUT: None

SUBROUTINES CALLED: NFWDR

Program P916

PURPOSE: To perform thickness pressure calculations in near-field wave drag module.

METHOD: Program P916 is the main program of the near-field wave drag module. It solves for the thickness pressure distribution on the surface of an arbitrary wing-fuselage-nacelle configuration, and integrates the pressures over the surface to obtain wave drag.

The equations used in the thickness pressure solution are given in the theory document (part 1). A consistent nomenclature is used, as possible, between the theory equations and the Fortran variable names.

The principal program logic is as follows:

1) Calculate fuselage pressure field acting on wing. This is done for each selected semi-span station (TYB2) in loop DO 130. The resultant fuselage pressure field is stored in PBWG, which is printed in loop DO 150.

2) Calculate wing thickness pressure field. This is done for the selected semi-span stations in loop DO 830. The semi-span element row is NSTAR and the associated x elements are LSTAR. For each NSTAR and LSTAR, the upstream region of integration contains elements located at N and LVAR. The local wing slopes are DZDX, contained in array TZC. The loop DO 450 performs the influence function times slope calculation described in the theory document. The velocity potential (PHI) is then calculated, and differenced to get pressure coefficient (CP).

   After all pressure coefficients are calculated at a given semi-span station, they are smoothed in loop 710, resulting in CPAVG. Calculation of the drag terms (pressure times wing slope) employs these variables names:

DBWG	fuselage pressure acting on wing
DAVG	wing thickness pressure
DNAC	nacelle pressure acting on wing.

3) Interpolate wing thickness pressures for output. This is done at the selected semi-span stations in loop DO 770. The wing thickness pressures are then output in loop DO 840. At the same time, the common block containing the wing thickness pressures, /PLIM/, is completed to make it self-sufficient for use in other modules, where:

FYB2	per cent semi-span array, MYFR values
TNMPC	per cent chord array, NMPC values
VAR(X,Y)	thickness pressure array

   The wing thickness pressure plus fuselage pressure field is then summed and output in loop DO 860.

4) Integrate drag terms spanwise to get total wing drag. This is done in loop DO 900.

5) Calculate wing thickness pressure on nacelle volume term (subroutine NW0NAC.)

6) Calculate fuselage pressure drag plus wing thickness pressure on fuselage drag terms. This is done in subroutine BDRAG and results in drag terms DBD and DW0B, respectively.

7) Convert drag terms to coefficient form, output wing section drag coefficients, nacelle drag coefficients, and final drag summary. This is done starting at loop D0 920, using the following nomenclature:

YB2	semi-span fraction
CHORD	local wing chord
CAS	wing section drag coefficient
BEF	section drag of fuselage on wing
CNACS	section drag of nacelle on wing
CINT	sum of CAS, BEF, CNACS
DFR	fraction of total wing drag occuring at YB2
CDAVG	wing thickness drag coefficient
CDB	fuselage thickness drag coefficient
CDBOW	interference drag coefficient of fuselage on wing
CDWOB	interference drag coefficient of nacelle on wing
CDTOT	total drag coefficient

The nacelle drag coefficient summary is printed in subroutine ADDUM. Empennage drags are printed in subroutine ADEMP.

USE: CALL 0VERLAY (NFWD, 6, 1, 6HRECALL)

INPUT: MK Mach number index variable (from overlay 6, 0). Configuration data from overlay 6, 2.

SUBROUTINES CALLED: See schematic, figure 2.4-2.

Subroutine ADDUM

PURPOSE: To sum nacelle drag terms, convert them to coefficient form (based on wing reference area) and write them onto the output file.

METHOD: Program NACL generates all nacelle thickness drag terms except for the wing on nacelle and nacelle on wing terms. These are saved in common block /NDRAG/ and printed by ADDUM when the main program (P916) writes the final drag summary. The drag coefficient nomenclature is as follows:

TNISOL	isolated nacelle wave drag coefficient
TFB0N	interference drag coefficient of fuselage on nacelles
TFN0B	interference drag coefficient of nacelle on fuselage
TNN0N	interference drag of other nacelles on nacelle
TFIMAG	"image" drag coefficient of nacelle on itself
TF0IMG	"image" drag coefficient of other nacelles
TDW0N	interference drag coefficient of wing on nacelles

USE: CALL ADDUM (SUMM)

INPUT: SUMM Sum of nacelle drag coefficients

SUBROUTINES CALLED: None

Subroutine ADEMP

PURPOSE: To write and sum empennage drag terms.

METHOD: Program EMPNN computes thickness pressure distribution and wave drag of canard(s) or fin(s), and stores drag coefficients in common block /EMPDRG/. Subroutine ADEMP is used to output the drag coefficients.

USE: CALL ADEMP (SUME)

INPUT: SUME Sum of empennage drag coefficients.

SUBROUTINES CALLED: None

Subroutine BDRAG

PURPOSE: To integrate fuselage thickness pressures over fuselage to get wave drag, and calculate wing-on-fuselage interference drag term.

METHCD: The fuselage is broken into TNCUT lengthwise strips, and 5 radial segments (per half section) per strip. The fuselage thickness pressures and wing pressures acting on the carry-over region covered by the fuselage are integrated over the fuselage segments. Wing pressures are transferred aft along Mach lines to obtain the point of application on the fuselage.

USE: CALL BDRAG (TNCUT)

INPUT:

TNCUT	Number of fuselage strips. (Set at 50 in main program).
TNMPC, TPWE, NMPC	Wing pressure field extended along fuselage centerline. TPWE = pressure coefficient array, TNMPC = X array, NMPC = number cf pressure coefficient values
/PLIM/	Common block containing wing thickness pressures
TXCPBY, TCPBY, NCPB	Fuselage thickness pressure array TXCPBY = X, TCPBY = pressure coefficient, NCPB values

SUBROUTINES CALLED: GRAB, TBLU1

Subroutine DZCALC

PURPOSE: To calculate wing slopes for all grid elements representing wing planform.

METHOD: The wing thickness definition is contained in common block /THICK/, consisting of the array TZØRD (thickness profile), TPCT (per cent chord array, NØPCT values). The Y stations corresponding to TZØRD are the planform input stations, in array YLED, DZCALC first interpolates the TZØRD array linearly at the midpoint of each semi-span element, storeing the results in AZC. The AZC array is then interpolated chordwise to obtain the dz/dx slope for each element, storing the slopes in TZC. The chordwise interpolation may be either linear or quadratic depending upon an input code. (The TZC storage scheme is described under subroutine TRNSFM.)

Inboard of the wing side-of-body Y value (input ANYBØD, if ANYBØD = +), the wing slopes are set to zero.

USE: CALL DØCALC

INPUT: Wing planform, thickness, ANYBØD (described above).

SUBROUTINES CALLED: TELU1

Subroutine NGETNP

PURPOSE: To interpolate a nacelle pressure signature at a given wing semi-span station, for use in calculating nacelle-on-wing interference drag.

METHOD: The nacelle pressure field, TCPN, is a two-dimensional array (for per cent chord and span). The wing program, P916, performs wing thickness pressure calculations at selected span stations. It is convenient to have a one-dimensional array, versus X only at that span station, for use in interpolating nacelle pressures for the nacelle-on-wing interference drag.

NGETNP interpolates TCPN to obtain the required pressure signature, which is stored in TXNCW (per cent chord) and TCPNCW (pressure coefficient).

USE: CALL NGETNP(YB2)

INPUT:

YB2	Semi-span fraction
/NPF/	nacelle pressure field definition common block.

SUBROUTINES CALLED: None

Subroutine GRAB

PURPOSE: To interpolate pressure coefficient at a given planform location from the wing thickness pressure table or fuselage-on-wing interference pressure table.

METHOD: Linear interpolation for pressure coefficient from a two-dimensional array.

USE: CALL GRAB (X, Y, XCP, JTELL)

INPUT:

X	X coordinate on wing planform
Y	Y coordinate on wing planform

XCP	Interpolated pressure coefficient
JTELL	Variable to select interpolation array 1 = wing thickness pressure 2 = fuselage-on-wing pressure
VAR	Wing thickness pressure array
PBWG	Fuselage-on-wing pressure array

SUBROUTINES USED: None

Subroutine NW0NAC

PURPOSE: To calculate buoyancy effect of wing thickness pressures acting on nacelle.

METHOD: The wing-on-nacelle interference drag term, consisting of wing thickness pressures acting on the nacelle area distribution, is computed in NW0NAC. Wing thickness pressures are transferred aft along Mach lines to a series of nacelle first runs. The resulting interference drag terms, C_dA, are stored in array, TDW0N, with storage index corresponding to the nacelle origin number.

USE: CALL NW0NAC

INPUT: Wing thickness pressure definition (VAR),configuration geometry passed in through common blocks.

SUBROUTINES CALLED: TBLUI

Subroutine WGRID

PURPOSE: To define wing grid system data.

METHOD: WGRID is a utility routine, identifying wing grid element data at a selected spanwise element row.

USE: CALL WGRID (JBY, XLE, STE, LLE, LTE, ALE, ATE)

INPUT:

JBY	selected element row
XLE	wing leading edge coordinate
XTE	wing trailing edge coordinate
LLE	leading edge element
LTE	trailing edge element
ALE	leading edge element function (at LLE)
ATE	trailing edge element fraction (at LTE)

SUBROUTINES CALLED: None

Program NACL

PURPOSE: To calculate pressure field of nacelles and associated drag terms.

METHOD: NACL is a major overlay of NFWD, which is used to calculate the nacelle thickness pressures, and all nacelle interference terms except the wing-on-nacelle and nacelle-on-wing terms. A schematic of the program is shown in Figure 2.4-3. The calculation sequence is as follows:

1. Construct the pressure field of the nacelles acting on the wing. To do this, a series of wing semi-span stations is set up (in NYSET). The program then calculates the composite pressure signature from all nacelles acting at those Y stations, for nacelles first below the wing, then for nacelles above the wing (if any). Either glance or wrap nacelle pressure field option may be used.

   The nacelle pressure field is shrunk to 20 X and pressure coefficient values at each y station, stored in common block NPF:

TXPN	x array, per cent chord
TCPN	pressure coefficient array
TYP	y semi-span stations (per cent), NYP values

2. Calculate composite pressure signatures and interference drag terms between nacelles or between nacelles and fuselage. The composite pressure signatures are applied to the area growth of the affected component to get the drag force.

3. "Image" effects of the nacelles are calculated. If the nacelle is located next to the wing, the pressure signature from itself reflects off the wing and back onto the generating nacelle. Similarly, the reflected signature from other nacelles may cause an interference drag. Drag interference due to reflected pressure signatures are calculated separately from the direct effects under (2).

USE: CALL OVERLAY (NFWD, 6, 4,0)

INPUT: Configuration geometry, passed to NACL in common blocks.

SUBROUTINES CALLED: See schematic, figure 2.4-3.

Subroutine BPINT

PURPOSE: To integrate the nacelle(s) pressure signature over fuselage surface to obtain interference drag.

METHOD: The composite nacelle pressure signature (contained in XVAL, CPVAL, JNEXT values) is applied to the fuselage area distribution obtained in subroutine BSETUP. The process is repeated for each nacelle origin. The integral of Cp* area is called BFORCE.

USE: CALL BPINT (ZNAC, BFORCE, JNEXT)

INPUT:

ZNAC	Nacelle vertical deminsion, relative to wing
BFORCE	Resulting pressure force
JNEXT	Number of values in nacelle pressure signature

SUBROUTINES CALLED: TBLU1

Subroutine BSETUP

PURPOSE: To calculate fuselage area growth for use in integrating nacelle-on-fuselage interference drag term.

METHOD: The fuselage is broken into 3 pieces: forebody, mid-body region (wing part), and aft body. The mid-body region covers the X interval of the wing-fuselage intersection.

Each fuselage piece is broken into 50 segments, and the area growth associated with each segment stored in an array (for use later in subroutine BPINT). The arrays are:

FBX, FBDA	forebody X and area
BMX	mid-body X
BMDAU	area growth above wing
BMDAL	area growth below wing

ABX, ABDA aft-body X and area

USE: CALL BSETUP

INPUT: Fuselage geometry contained in /FUSLG/
wing-fuselage intersection contained in
/WBINT/

SUBROUTINES CALLED: TBLU1

Subroutine NC0MBIN

PURPOSE: To combine two nacelle pressure fields, for nacelles located above and below the wing, into a single composite pressure field.

METHOD: If nacelles are located both above and below the wing, subroutine NACL generates two nacelle pressure fields: TCPDN (nacelles below) and TCPN (nacelles above). NC0MBIN sums these two nacelle pressure fields, to use in computing the thickness pressure interference drag. The resulting pressure field is stored in TXPN (per cent chord array) and TCPN (pressure coefficient array), with NYP semi-span per cents contained in TYP

USE: CALL NC0MBIN

INPUT: Nacelle pressure fields described above

SUBROUTINES CALLED: TBLU1

Subroutine NCUT0FF

PURPOSE: To delete portions of a nacelle pressure field.

METHOD: In constructing nacelle pressure signatures at an arbitrary distance from the generating body, subroutine NACL calls NCUT0FF to delete parts of the signature intercepted (or not reflected) by intermediate configuration components. The pressure signature is contained in BT0 AND CT0 (x and pressure coefficients, respectively).

USE: CALL NCUT0FF (X1, X2)

INPUT: X1,X2 Bounding values of X, between which the pressure coefficients are set to zero.

SUBROUTINES CALLED: TBLU1

Subroutine NGLANC

PURPOSE: To perform cutoff of nacelle pressure signature according to glance feature of nacelle pressure field.

METHOD: If the "glance" option of calculating the nacelle pressure field is used, this subroutine calculates what part of a pressure signature from a selected nacelle acting at a given spanwise station should be deleted. The approximation is made that the pressure signature propagates along Mach lines for this calculation.

If deletion of part of the signature is required, subroutine NCUT0FF is called.

USE: CALL NGLANC (Y, YNAC, BETA)

INPUT:

Y	Y station on wing
YNAC	Y station of nacelle generating pressure signature
BETA	Mach number parameter, $\sqrt{M^2-1}$

SUBROUTINES CALLED: NCUT0FF

Subroutine NMERG

PURPOSE: To create a single composite pressure signature from multiple superimposed signatures.

METHOD: The nacelle pressure field in NACL at a given Y station is built up from contributions from all nacelles. The pressure signature from a single nacelle is contained in arrays BT0 and CT0 (x and pressure coefficient), NW values of each. The composite signature becomes XVAL and CPVAL, with JNEXT values of each.

All values of the new pressure signature are retained, and are merged with any previous values in XVAL and CPVAL, except that the merged pressure signature is cut off aft of an input X value (XTE). In addition, the location of the bow shock of all pressure signatures in CPVAL is saved (in TSX, NWHAT values).

USE: CALL NMERG (JNEXT, NWHAT, XTE)

INPUT:

JNEXT	Number of values in composite CPVAL array
NWHAT	Number of combined pressure signatures
XTE	Aft-most X value of interest

SUBROUTINES CALLED: TBLU1

Subroutine NACSET

PURPOSE: To separate nacelles into those above or below wing, write nacelle geometry, and calculate nacelle wave drag, wetted area, and F(y) function.

METHOD: NACSET is used for general bookkeeping involving the nacelles, and is called by NACPF. It scans the nacelle origins and separates them into those below and above the wing. It prints the nacelle input, and then zeroes the tables used to sum the nacelle interference drag terms. It then calls subroutine NB0DY to calculate the nacelle F(y) function, wave drag, and wetted areas.

If all nacelles have the same goemetry, NACSET calculates the nacelle F(y) only once, and shifts it appropriately for other nacelle origins.

USE: CALL NACSET

INPUT: Nacelle data in common blocks

SUBROUTINES CALLED: NB0DY

Subroutine N0RDR

PURPOSE: To arrange an arbitrary set of numbers into a monotonically increasing array.

METHOD: The nacelle bow shock locations contained in TSX (NWHAT values) are in random order. For interpolation by TBLUI, they must be in monotonically increasing order, and cannot be double-valued. NØRDR is used to rework TSX as required.

USE: CALL NØRDR (TSX, NWHAT)

INPUT:

TSX	Array of bow shock X locations
NWHAT	Number of values in TSX array

SUBROUTINES CALLED: None

Subroutine PINGRT

PURPOSE: To integrate pressure field over surface of nacelle.

METHOD: Given a pressure signature defined by the XVAL, CPVAL arrays, PINGRT is used to integrate the signature as a buoyancy field over a nacelle area distribution.

USE: CALL PINGRT (J, FØRCE, JNEXT)

INPUT:

J	Index value of nacelle origin
FØRCE	Resultant pressure drag term, $\int C_p dA$
JNEXT	Number of values in XVAL or CPVAL array

SUBROUTINES CALLED: TBLU1

Subroutine NYSET

PURPOSE: To set up semi-span Y values for calculation of nacelle pressure field.

METHOD: A set of Y stations on the right hand wing are identified in NYSET for use in defining the nacelle pressure field. This set of Y stations consists of the semi-span Y values used in the wing thickness pressure calculations (contained in TYB2) plus extra stations immediately inboard and outboard of each nacelle centerline.

The set of Y values is arranged in monotonically increasing order by calling subroutine NØRDR. The resulting array is TYP, with NYP values.

USE: CALL NYSET

INPUT: Configuration gemmetry passed in through common blocks

SUBROUTINES CALLED: N0RDR

Program L0AD6

PURPOSE: To read input geometry for near-field wave drag module.

METHOD: L0AD6 reads the input set up by the near-field program interface in the geometry module.

USE: CALL 0VERLAY (NFWD, 6, 2, 0)

INPUT: See input instructions in user's manual.

SUBROUTINES CALLED: TBLUI

Program EMPNN

PURPOSE: To calculate thickness pressures and drag coefficients for canard(s) or fin(s).

METHOD: EMPNN selects empennage surfaces in turn and computes thickness pressures and drag coefficients utilizing the same logic as wing solution (program P916), except interference terms with remainder of configuration are neglected.

USE: CALL OVERLAY (NFWD, 6, 5, 0)

INPUT: Empennage geometry data and basic configuration data contained in common blocks.

SUBROUTINES CALLED: GRID, SETGRID, DZEMP, NFWDR, TBLU1, PWRIT

Subroutine DZEMP

PURPOSE: To calculate surface slopes of canard or fin.

METHOD: DZEMP calculates surface slopes of canard or fin for all grid elements defining the surface. Slopes of grid elements inboard of the side-of-body

	station are set to zero. Method parallels that of subroutine DZCALC for wing.
USE:	Call DZEMP
INPUT:	Configuration geometry in common blocks
SUBROUTINES CALLED:	GRID, TBLU1

Subroutine GRID

PURPOSE:	To define empennage grid system data.
METHOD:	GRID is a utility routine, to define grid element data at a selected spanwise element row.
USE:	CALL GRID (JBY, XLE, XTE, LLE, LTE, ALE, ATE)
INPUT:	See description under subroutine WGRID
SUBROUTINES CALLED:	None

Subroutine SETGRID

PURPOSE:	To set up grid system for selected canard or fin.
METHOD:	Given an identified empennage part (defined in common block /EPLAN/), SETGRID sets up the corresponding grid element system. Method parallels that of routine XFM for wing.
USE:	CALL SETGRID
INPUT:	Configuration data in common blocks.
SUBROUTINES CALLED:	TBLU1, GRID

Subroutine PWRIT

PURPOSE:	To write out pressure distribution of canard or fin.
METHOD:	Common block /DINT/ contains thickness pressure array (ECPE) of canard or fin. PWRIT is called to output the data.

USE: CALL PWRIT

INPUT: Configuration and pressure data in common blocks.

SUBROUTINE CALLED: None

Program WRIT

PURPOSE: To write out input data

METHOD: WRIT is used to write the input and pertinent program data onto the output file.

USE: `CALL ØVERLAY (NFWD, 6, 6, 0)`

INPUT: Configuration data in common blocks.

SUBROUTINES CALLED: None.

2.5 WING DESIGN AND OPTIMIZATION MODULE

The wing design and optimization module is primary overlay 8. It contains secondary overlays to calculate:

- The flat wing solution for the input planform and Mach number
- Carry-over pressure distribution on wing inboard of side-of-fuselage station.
- The wing shape and force characteristics for a given loading
- The optimum combination of loadings for least drag, subject to imposed constraints.

A schematic of the wing design and optimization module is shown in figure 2.5-1. Major logic of the optimization coding is shown in figure 2.5-2.

Program TEA-253

PURPOSE:	To call the calculation overlays of the wing camber design program and to call the interactive graphics displays (if used).
METHOD:	Standard FORTRAN statements
USE:	Call OVERLAY (A389, 8, 0)
INPUT:	Input is in DATA OVERLAY (WDEZ, 10, 1)

Subroutine FOLLOW

PURPOSE:	To provide diagnostic information which identifies the entry to and departure from each secondary overlay of the wing camber design program.
METHOD:	Standard FORTRAN statements.
USE:	Call FOLLOW (I, J)
INPUT:	The parameters I and J in the calling statement. I is the secondary overlay number. If J is 1, then overlay I is being entered; if J is 2, then overlay I is being departed.

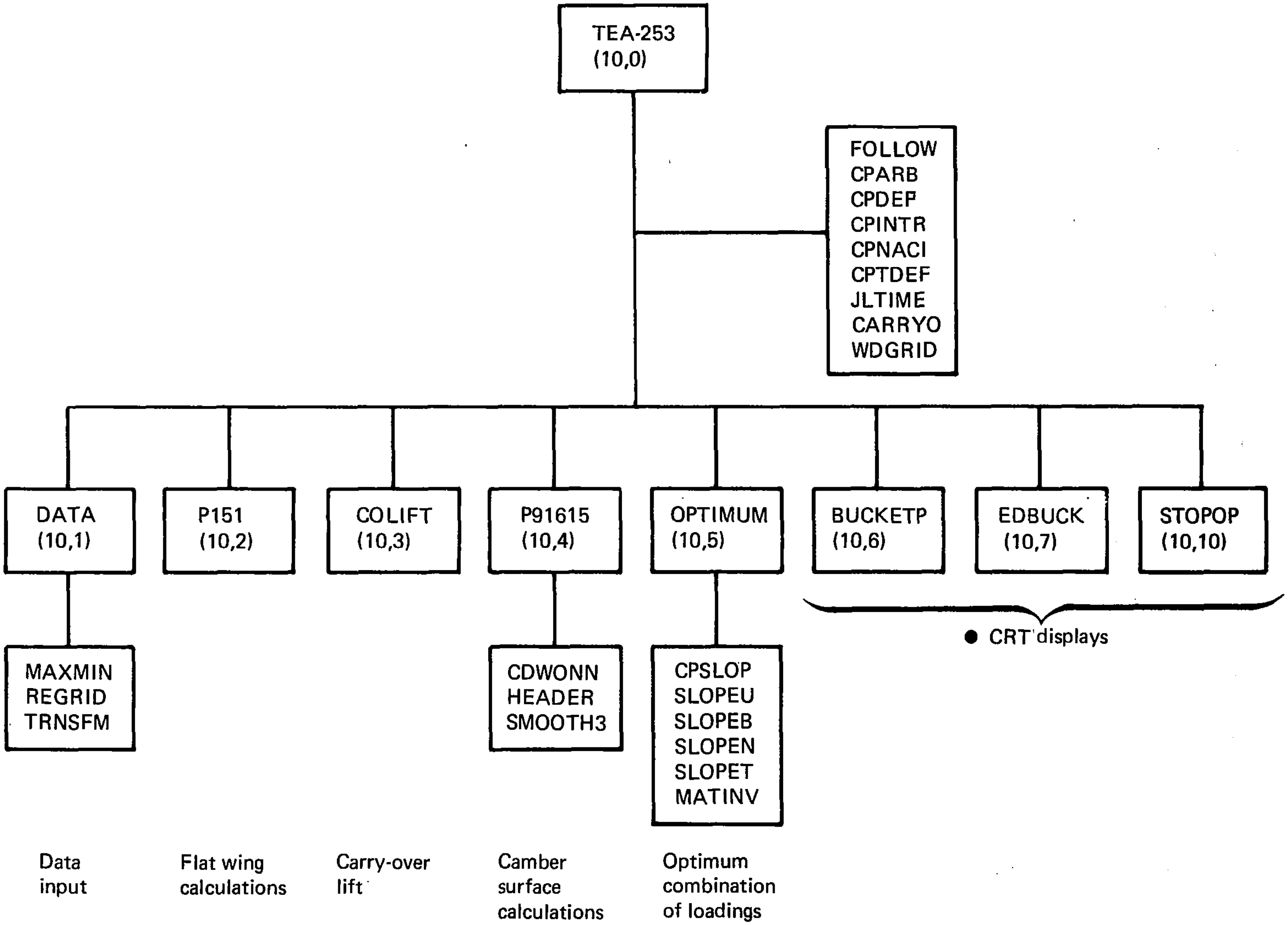


FIGURE 2.5-1.—WING DESIGN AND OPTIMIZATION MODULE

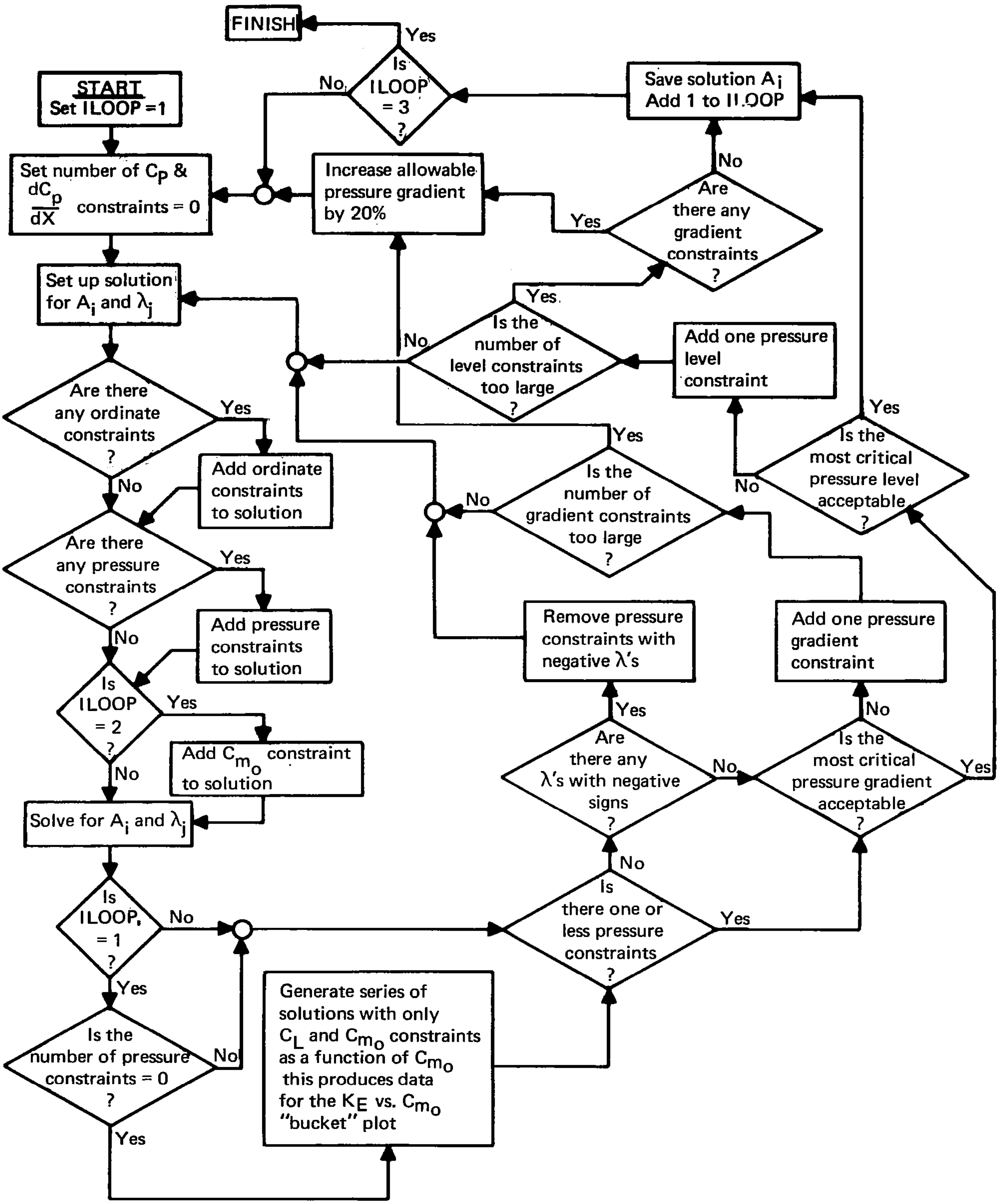


FIGURE 2.5-2.—MAJOR LOGIC OF OPTIMIZATION CODING IN WING DESIGN MODULE

Function CPARB

PURPOSE: To define lifting pressure coefficient in the arbitrarily defined planform region for component loading 11.

METHOD: At a given span station, linear interpolation is used to establish the chordwise coordinate of the arbitrary region's leading edge. Then, Cp is proportional to distance aft of this location.

USE: CP = CPARB (XF, YF, CHORD)

INPUT:

XF	the chordwise and spanwise location on the wing planform in fractions of local chord and semispan at which pressure coefficient is to be provided.
YF	
CHORD	local wing chord at span station YF.

In addition, a definition of the arbitrary region is passed through COMMON/BLOCK4/.

PRINCIPAL VARIABLES:

CPARB	the lifting pressure coefficient in the arbitrarily defined region.
XARB	chordwise and spanwise coordinates of points defining the arbitrary region.
YARB	

Subroutine CPDEF

PURPOSE: To define lifting pressure coefficient as a function of chordwise and spanwise planform location for each of the seventeen component loadings; further, to also define this pressure coefficient for an optimum combination of loadings.

METHOD: Lifting pressure coefficients for loadings 1-11 are defined by analytical expressions and for loadings 12-17 by linear interpolation in tables as a function of chordwise and spanwise planform location. If a wing-body configuration is being designed, then lifting pressure coefficient within the body is obtained by interpolation within the body carry-over tables as a function of planform location (using function CARRY0).

USE: CALL CPDEF (DX, BETAY, CHORD, KCPT, IFLAG)

INPUT:

DX	is distance aft of leading edge in

	program units.
BETAY	is the product of the Mach number factor ($\sqrt{M^2-1}$) and spanwise distance from the centerline in program units.
CHORD	is wing chord in program units at span station BETAY.
KOPT	is the index for the loading number table LOADNO.
IFLAG	is a parameter which offers the option of deleting the contribution to lifting Cp of the three configuration-dependent loadings. This option is used during camber surface calculations which use lifting pressures, but not during calculation of wing surface pressures.

Input is also provided through the use of common blocks.

PRINCIPAL VARIABLES:

AI	a table of loading factors computed by program OPTIMUM in OVERLAY (WDEZ, 10, 5), one for each of the component loadings, that defines the optimum combination of loadings.
CPBODL	a table of lifting pressure coefficient acting on the wing and created by nonsymmetric body volume distribution.
CPBUPW	a table of lifting pressure coefficients acting on the wing and created by the body upwash flow field.
CPDEF	lifting pressure coefficient (lower surface Cp - upper surface Cp).
FLOAD	a table of scaling factors set in program P151 which produces component loading lift coefficients of order 1.0.
LOADNO	a table of component loading numbers with index KOPT that are input data in program DATA.
NLOADS	the number of component loadings
PCARRY	a table of lifting pressure coefficient in the body carry-over region computed by C0LIFT.
XBODUP YBODUP	the chordwise and spanwise tables corresponding to the body upwash loading table CPBUPW, in units of percent of local chord and percent of local span, respectively.

XCPBOD YCPBOD	the chordwise and spanwise tables corresponding to the body buoyancy loading CPBODL, in units of percent of local chord and percent of local span, respectively.
YS0B	span station of the side of body.

SUBROUTINES CALLED: CPARB, CPINTR, CPNACI, CARRY0

Function CPINTR

PURPOSE: This program interpolates linearly in chordwise and spanwise directions for pressure distributions not defined in COMMON blocks.

METHOD: Chordwise linear interpolation is used first for two span stations bracketing the span station of interest; then, linear spanwise interpolation is used.

USE: CP = CPINTR (XF, YF, X, Y, CP, NX, NY, NXMAX, NYMAX)

INPUT:

XF YF	the chordwise and spanwise coordinates of the point on the planform for which pressure coefficient is to be found, in fractions of local chord and of semispan, respectively.
X Y	tables of chordwise and spanwise locations at which pressure coefficient CP is defined. NX and NY values, respectively, are defined and NXMAX and NYMAX, respectively, are the maximum values of NX and NY.
CP	a two-dimensional array of pressure coefficients.

PRINCIPAL VARIABLES:

CPINTR	interpolated value of pressure coefficient.

Function CPNACI

PURPOSE: To interpolate linearly both chordwise and spanwise for lift pressures due to nacelles that are defined in COMMON. The chordwise locations at which nacelle pressures are defined vary from span station to span station.

METHOD: The span stations bracketing the desired span station are located first. Linear interpolation chordwise is completed at these two span stations for the desired chordwise location, and finally, spanwise interpolation is carried out at the desired chordwise location.

USE: CP = CPNACI (XF, YF)

INPUT:

XF YF	chordwise and spanwise locations on the wing planform in fractions of local chord and semispan, respectively.

In addition, the nacelle pressure field CP and the spanwise and chordwise locations at which it is defined, Y and X, are defined by COMMON NPF.

PRINCIPAL VARIABLES:

CP	a two-dimensional table of nacelle pressure field defined in the analysis program.
CPNACI	interpolated value of the nacelle pressure coefficient.
X	a two-dimensional table of chordwise locations corresponding on a one-to-one basis with the CP table.
Y	a one-dimensional table of semispan stations corresponding to the spanwise variations of both X and CP.

Function CPTDEF

PURPOSE: To interpolate linearly both chordwise and spanwise for pressure coefficient due to wing thickness and defined in COMMON.

METHOD: Linear interpolation is carried out chordwise at the two span stations bracketing the desired span station, and is followed by linear spanwise interpolation.

USE: CPT = CPTDEF (XF, YF)

INPUT:

XF YF	chordwise and spanwise stations on the wing planform in fractions of local chord and semispan, respect-

ively.

In addition, the wing thickness pressures are defined in a two-dimensional array CPT in COMMON block PLIM; the chordwise locations X and spanwise locations Y corresponding to the elements in CPT are also defined in COMMON.

PRINCIPAL VARIABLES: All defined above.

Subroutine JLTIME

PURPOSE: To print out time since job began execution and to print out the time increment since the immediately preceding call to this subroutine.

METHOD: Interrogate the system timing subroutine SECOND.

USE: CALL JLTIME

INPUT: None

OUTPUT: Time increment and time mentioned above, both in decimal seconds.

SUBROUTINE CALLED: SECOND

Function CARRYØ

PURPOSE: To compute lifting pressure coefficient within the body carry-over region by interpolation within the tabular data provided by CØLIFT as a function of planform location.

METHOD: Linear interpolation chordwise and spanwise.

USE: CP = CARRYØ (DX, BY, CHØRD, KØPT)

INPUT:

DX	is distance aft of the leading edge in program units.
BY	is the product of the Prandtl-Glauert Mach number parameter and the spanwise distance from the centerline, in program units.
CHØRD	is wing chord in program units at span

	station BY.
KØPT	is the index for the loading number in table LØADNØ.

Input is also provided by the use of common blocks.

Subroutine WDGRID

PURPOSE: To define wing grid system.

METHOD: WDGRID is a utility routine to identify the grid elements defining the wing planform at a selected spanwise element row.

USE: CALL WDGRID (JBY, XLE, XTE, LLE, LTE, ALE, ATE)

INPUT:

JBY	selected spanwise element row
XLE	wing leading edge coordinate at JBY
XTE	wing trailing edge coordinate
ILE	wing leading edge element
LTE	wing trailing edge element
ALE	element fraction at leading edge
ATE	element fraction at trailing edge

Program DATA

PURPOSE: To read input data for the wing design module.

METHOD: Program DATA reads the input data (set up by the wing design interface in the geometry module), and writes it out according to the print code set in the input. The wing grid system is also established (in subroutine TRNSFM).

USE: CALL ØVERLAY (WDEZ, 8, 1)

INPUT: See User's Manual

SUBROUTINES CALLED: TRNSFM, MAXMIN, REGRID, JLTIME

Subroutine MAXMIN

PURPOSE: To identify and print both the maximum and the minimum elements in a two-dimensional array.

METHOD: Standard FORTRAN library subroutines.

USE: CALL MAXMIN (A, NX, NY, NXMAX, NYMAX)

INPUT:

A	a two-dimensional array with maximum dimensions NXMAX and NYMAX containing (NX)(NY) values to be searched for maximum and minimum.

OUTPUT:

THEMAX	The maximum element of A
THEMIN	The minimum element of A.

Subroutine REGRID

PURPOSE: To define grid system data when the RESTART option is used.

METHOD: When the RESTART option is used, all basic loading data is input from cards (or tape) and grid system calculations normally made (which will be needed) are bypassed. REGRID sets up the appropriate arrays, which include the wing chord at each of the spanwise calculation stations, and the per cent chord and per cent wing length associated with each grid element along those spanwise stations.

USE: CALL REGRID

INPUT: COMMON block BLOCK1 is used to input a definition of the wing planform and the associated parameters required to define the Mach box grid system.

Subroutine TRNSFM

PURPOSE: To convert input data to program units and set up wing grid system.

METHOD: The wing is represented in the program by a set of rectilinear elements, with the number of semi-span element rows given by input TNØN. TRNSFM interpolates the planform at the centerline of each element row to define the leading edge and trailing edge values, converts them to program scale (using RATIØ = Ywing tip*BETA/TNØN), and stores them in arrays TXLE and TXTE. Special values XLEØ and XTEØ define the wing centerline leading edge and trailing edge.

If the parabolic apex option is selected in the input (YSNØØT>0.), the wing leading edge out to YSNØØT is altered to a parabolic shape.

If a fuselage is input with side-of-fuselage station greater than 0., the grid system element row (NSØB) corresponding to the side-of-fuselage station is identified. TRNSFM then checks to see that NSØB is included in the spanwise camberline row array (TJBYS), adding it if necessary.

USE: CALL TRNSFM

INPUT: A definition of the wing planform in physical units is passed to TRNSFM by COMMON block BLOCK1 and block SNOOT.

SUBROUTINES CALLED: TBLU1

Program P151

PURPOSE: To calculate the flat wing loading; and to set normalizing factors for component loadings 1-10 so that their lift coefficients will be approximately 1.0.

METHOD: The method of the flat wing solution is essentially the same as described for the lift analysis module (using the equations given in the theory document, part 1), except that only the wing is present (no fuselage, nacelles, etc). The wing is scanned from front to back and centerline to right hand wing tip, computing the pressure coefficients (CP) for all field point elements (LSTAR, NSTAR). The 9-point smoothing equation is applied after all pressure coefficients are calculated.

The lifting pressure distribution is calculated over the surface of the wing to obtain lift coefficient (SCL9), drag coefficient (SCD9), dCm/dCL (DCMCL) and drag-due-to-lift factor (KF), based on input reference geometry.

For the given planform, normalizing factors (array FLØAD) are then calculated which will produce a lift coefficient of approximately unity when used with each of the analytically defined basic loadings (1-10) in program P91615.

USE: CALL ØVERLAY (WDEZ, 8, 2, 0)

INPUT: Configuration data in common blocks

SUBROUTINES CALLED: JLTIME

Program CØLIFT

PURPOSE: To calculate carry-over lift distribution in fuselage region.

METHOD: CØLIFT creates a definition of the carry-over lift distribution for all selected loadings, to be applied to the wing planform region covered by the fuselage (if there is one). The calculation procedure utilizes the analysis form of the lifting pressure solution (described in the lifting analysis program writeup) for spanwise element rows inside the side-of-body station. The resultant carry-over lift distributions are stored in array PCARRY. Carry-over lift distributions are not computed for the configuration dependent loadings (loadings 15, 16, and 17) since those are already of the carry-over type.

CØLIFT also integrates lift distributions to get drag, lift, and pitching moment of loadings acting on fuselage, which are stored in common block /FUSCX/.

USE: CALL ØVERLAY (WDEZ, 8, 3,0)

INPUT:

NSØB	side-of-body element row
TXB, TZB	fuselage camber shape
BØDCL(I)	carry-over lift of I-th loading acting on fuselage.
BØDCM(I)	carry-over drag of I-th loading
BØDCM(I)	carry-over pitching moment of Ith loading
PCARRY (I,M,NYS)	carry-over pressure distribution due to I-th loading. NYS spanwise rows given in array KYS, M chordwise percentages given in array SXPC.
USEBØD	logical flag (carry-over lift calculated if USEBØD = TRUE)

SUBROUTINES CALLED: CPDEF, JLTIME, TBLU1, WDGRID

OVERLAY (WDEZ, 10, 4)
Program P91615

PURPOSE: To calculate the aerodynamic characteristics of a specified lift loading and the camber surface required to support it. Both component loadings and combinations of component loadings are handled. If requested, all data for the RESTART option are punched in this program.

METHOD: Program P91615 solves for the camber surface required to support a specified loading and the associated force coefficients, using the equations given in the theory document (part 1). The program is actually used in two ways:

1) To calculate the force coefficients and interference drag characteristics of a set of basic loadings.
2) To calculate the camber surface for an optimum combination of loadings.

The program code used to define the usage of P91615 is K0PTI. If K0PTI is greater than the number of basic loadings used, then option (2) above is employed.

Option (1):

In the calculation of the camber surface and force coefficients, a series of semi-span stations are selected in the program input (TJBYS). The program then picks a loading, calculates the required surface slopes for all elements at each TJBYS station, and integrates the slope distribution to obtain the camberline. In these calculations, each element along TJBYS is identified by the nomenclature LSTAR (X) and NSTAR (βy), as described in the theory document. Z ordinates at specified points on the planform are interpolated and saved if Z constraints are to be applied.

After the camberlines and sectional force coefficients of all spanwise stations have been computed, the characteristics are integrated spanwise to obtain lift coefficient (CL), drag coefficient (CD), and pitching moment coefficient (CMAPEX). These are converted to input reference geometry basis and become CLR and CDR, lift and drag coefficients. The pitching moment coefficient is adjusted to the value at zero lift, and becomes CM0R. Drag-due-to-lift factor is labeled $KE = CDR/(CLR)^2$. The interference drag coefficients are stored in array CDI.

After all calculations are completed for a given loading, the force coefficients are stored in array TDRAG, and the process repeated until all loadings have been used.

The force coefficients and interference drag coefficients of all loadings are then converted to the component and interference forms used in the matrix solution described in the theory document, and stored in common blocks to be passed to program ØPTIMUM.

Finally, the RESTART data are written onto tape 3, and also punched into cards, if requested. These data consist of all component and interference drag terms, the configuration-dependent loadings (if used), and grid system data calculated by P91615.

Option (2):

If option 2 was selected, involving the calculation of the wing shape for an optimum combination of loadings, the calculation sequence is the same as if a basic loading was being used. However, the interference characteristics are not required. The resulting camber surface is stored in common block/CAMBER/ in the following form:

TPCT	percent chord array, NØPCT values.
PYB2	semi-span array, JBYMAX values.
TZØRD(x,y)	camber surface Z/C values, in per cent.
IFZC	1, to denote Z/C in per cent.

The camber surface will also be punched into cards, if requested in the program input.

USE: CALL OVERLAY (WDEZ, 8, 4)

INPUT: All input is handled by COMMON blocks, which pass the required data from DATA.

SUBROUTINES CALLED: CDWONN, CPDEF, CPINTR, CPNACI, CPTDEF, HEADER, JLTIME, SMØØTH3, TBLU1

Function CDWONN

PURPOSE: To calculate the axial force acting on nacelles due to the wing-lift flow-field.

METHOD: The wing lower surface lifting pressures are projected downward in a vertical plane and aft along Mach lines to the nacelle locations where their product with nacelle incremental frontal area is numerically integrated to produce a nacelle axial force.

USE: CDN = CDWONN(KØPT)

INPUT: KØPT component loading index.

In addition, wing planform information is passed to CDWONN by COMMON block BLOCK1 and nacelle geometry is passed by block BLOCK11.

PRINCIPAL VARIABLES:

CPTERM	wing lower surface pressure coefficient due to wing lift only.
XLEN XTEN CRDN	longitudinal coordinates of the wing leading and trailing edges at the nacelle span station, and the corresponding wing chord.
RNAC XNAC	two-dimensional arrays defining nacelle radius as a function of nacelle longitudinal station. The first parameter is the nacelle number index.
XYZ	a two-dimensional array specifying the coordinates of each of the nacelles' forward-most point. The first parameter is the nacelle number index, and the second parameter defines the coordinate being referenced - i.e., first value is X, second is Y, and third iz Z.

SUBROUTINE CALLED: CPDEF

Subroutine HEADER

PURPOSE: To write out loading number and case identification.

METHOD: Standard FORTRAN statements.

USE: CALL HEADER(KØPT)

INPUT: KØPT component loading index.

In addition, the loading number index, loading name, and case identification are passed via COMMON statements.

OUTPUT: Titling information for each component loading prior to its aerodynamic and camber analysis.

Subroutine SMOOTH3

PURPOSE: To apply 3-point smoothing to a selected range of elements within a one-dimensional array.

METHOD: Each element to be smoothed is replaced according to the following algorithum:

$$y_i \to \frac{1}{4}(y_{i-1} \quad 2y_i + y_{i+1})$$

where y_{i-1} and y_{i+1} are the immediate neighbors of y_i before smoothing. If y_i is the first element in the array to be smoothed, then

$$y_i = \frac{1}{3}(2y_i + y_{i+1})$$

and if y_i is the last,

$$y_i = \frac{1}{3}(y_{i-1} + 2y_i)$$

USE: CALL SMOOTH3(A, IFIRST, ILAST, N, NARRAY)

INPUT:

A	the one-dimensional array of data to be smoothed.
IFIRST ILAST	first and last elements in A to be smoothed. All elements between will be smoothed.
N	the number of times the smoothing algorithum is to be applied.
NARRAY	the maximum number of elements in A.

OVERLAY (WDEZ, 10, 5)
Program OPTIMUM

PURPOSE: To define various optimum combinations of lift loadings in terms of their load strength factors A_i.

METHOD: Lagrange's method of undermined multipliers (as described in Part I: Theory), as a function of the aerodynamic characteristics of each of the component loadings and their mutual interferences. In program OPTIMUM, the DO loop on statement 730 (index ILOOP) is used twice only if a constraint on pitching moment coefficient is used. For ILOOP = 1, program OPTIMUM produces a solution for minimum drag with only a lift constraint (this solution also includes constraints on ordinates if they are used); 21 solutions of the drag-due-to-lift factor (KE) and zero lift pitching moment coefficient (CMO) defining the design "bucket" plot; and if requested, a solution for minimum drag with lift coefficient and wing upper surface pressure constraints (this solution also includes constraints on ordinates if they are used). If the wing pressure criteria are satisfied by the first solution, the latter solution is set equal to the first. For ILOOP = 2, program OPTIMUM adds a constraint on pitching moment ccefficient at zero lift to both the solution with lift coefficient constraint and the solution with lift and pressure constraints.

Within the ILOOP loop, the left-hand-side solution matrix AMAT and the right-hand-side solution matrix BMAT are calculated first, corresponding to figure 4.4-4 of the theory document (part I). The left-hand-side matrix is stored in ATEMP for multiplication with the solution as a test of its accuracy; this multiplication should produce the right-hand-side.

Subroutine MATINV is called tc solve for the load strength factors A_i and the Lagrange multipliers, corresponding to the left-hand-side column matrix in figure 3.4-3 of the thecry document. The solution load strength factors A_i are stored in two arrays - the AI array so that the current solution is defined in the wing lifting pressure subroutine CPDEF, and in the TAI array, so that the solution will be defined for program P91615 after program OPTIMUM has been exited. The array TAI has capacity for four sets of load strength factors (under IDUM), corresponding to the four types of available solutions as follows:

IDUM	Lift Constraint	Pitching Moment Constraint	Wing Pressure Constraint(s)
1	yes	no	no
2	yes	yes	no
3	yes	no	yes
4	yes	yes	yes

Lift coefficient CLSOL, drag coefficient CDSOL, and pitching moment coefficient CMOS are computed in program units from the load strength factors and the aerodynamic coefficients of the component loadings. These parameters are then converted to the input reference geometry basis, CLR, CDR, and CMOR, respectively. Values of KE and CMO from previous solutions (if any) for IDUM = 4 are shifted one location toward the rear of the "bucket" plot arrays CKE and CMZERO, and the current solution data are stored in these arrays.

The wing upper surface pressure coefficient CPUS and the corresponding longitudinal gradient DCPDX are calculated next and compared everywhere with the user defined limiting values, CPLIM and CPGLM, respectively. The minimum difference of CPUS - CPLIM is identified (CPMIN) and the maximum difference of DCPDX - CPGLM is identified (GRADM), along with their respective planform locations. This completes the solution corresponding to IDUM = 1 above.

Then, if ILOOP = 1 and if no pressure constraints have been applied, values of KE and CMO are generated by the DO loop on 630 for the "bucket" plot. This solution parallels the one just described, except that a constraint on design pitching moment coefficient at zero lift CMOD is added and is varied through 21 values. The range of values of CMOD depends on design lift coefficient CLDZIN, and is centered on the pitching moment coefficient corresponding to the solution for IDUM = 1, if available, or on zero. Values of CMOD are truncated for plotting convenience.

After the bucket plot data are generated and stored, program OPTIMUM tests to see if pressure constraints on the wing upper surface have been requested and whether they are necessary, if requested. If both tests are positive, then a loop to statement 10 is used to apply constraints on wing pressure. This loop is within the loop on 730 (index = ILOOP). The loop which tests wing upper surface pressure functions as follows. First, the critical pressure gradient is tested to see if it is satisfactory. If it is not, a constraint on pressure gradient is applied at the planform location where the gradient criterion is violated by the greatest margin. At this location, the gradient is constrained to 75 percent of the gradient criterion; this provides a margin to prevent the gradient from exceeding the limit in the immediate vicinity of the constraint. The program then loops to statement 10 and the process is repeated until the overall gradient criterion is satisfied.

The program then tests critical pressure level against its acceptable level. If it is not acceptable, a pressure level constraint is added at the planform location where the pressure level criterion is most strongly violated. The lifting pressure coefficient at the critical planform location is calculated which just meets the upper surface level criterion, and the lifting pressure is constrained to 95 percent of this value. The 95 percent factor provides a margin to prevent the pressure from exceeding the criterion in the immediate vicinity of the constraint location. The program then loops to statement 10, and a new solution is generated.

It has been found that both pressure gradient and pressure level constraints imposed early in the design cycle can become unnecessary, and even undesirable, when later constraints are imposed. This situation can be detected in the solution by noting that the algebraic signs of the pressure-constraint Lagrange multipliers change from positive to negative when the constraints become unnecessary.

The design program takes advantage of this by testing the Lagrange multipliers of the pressure constraints for each solution cycle. If there are unnecessary constraints, they are removed, and the solution cycles back to statement 10 with fewer pressure constraints.

In summary, then, each solution is tested for wing upper surface pressure gradient and pressure level, and for negative pressure constraint Lagrange multipliers. The hierarchy is:

(1) Test for unnecessary pressure constraints
(2) Test most critical pressure gradient.
(3) Test most critical pressure level.

If one of these is violated, appropriate action is taken, and the program loops back to statement 10. Throughout this cyclic process, each solution includes constraints on z ordinates if such constraints have been requested.

It is certainly possible to define wing upper surface pressure criteria which cannot be satisfied, either through input errors or simply through ignorance of, say, wing thickness pressures on the first run of a new configuration in the system. Should this occur, the program will add pressure gradient and/or pressure level constraints until it reaches one of two possible constraint maxima.

One maximum on the number of constraints is imposed by the number of loadings used. The total number of constraints, including those on lift, pitching moment, configuration-dependent loadings, ordinates, and pressure, can at most be equal to the number of loadings. This situation is undesirable for it leaves no degrees of freedom for drag minimization; consequently, this limit has been set so that two degrees of freedom remain free for drag minimization (for small numbers of loading, this is reduced to one).

The second maximum imposed on the number of pressure constraints is dictated by the number of loadings that are free to influence longitudinal pressure gradient. A maximum of ten loadings do so - loadings 2, 5-9, and 11-14. It has been thought desirable to leave one degree of freedom for drag minimization for gradient constraints. For this purpose, the number of permissible gradient constraints is further reduced by one whenever a constraint is imposed on C_{mo} since C_{mo} constraints are satisfied primarily by the same x-dependent loadings used to satisfy gradient criteria.

If the program reaches a pressure constraint maximum, it checks to see if gradient constraints have been imposed. If one or more gradient constraints have been imposed, the program arbitrarily increases the gradient criterion table by 20 percent, and begins anew with no pressure constraints. This process is also cyclic and can be repeated up to 50 times before halting with the solution produced by the last cycle.

If no pressure gradient constraints have been used, the program halts immediately upon reaching one of the two loading maxima.

For ILOOP = 2, a pitching moment constraint is added to the solution, and lift coefficient, ordinate and pressure limiting constraints function as they did for ILOOP = 1. The bucket plot calculations are omitted.

Major logic of the optimization sequence in the wing design module is illustrated in Figure 2.5-2.

USE: CALL OVERLAY (WDEZ, 8, 5)

INPUT: All input is by means of COMMON blocks.

PRINCIPAL VARIABLES:

AI	load strength factor A_i
AMAT	left-hand-side solution matrix
BMAT	right-hand-side solution matrix
CDIJ	interference drag coefficient
CDSOL	solution drag coefficient
CDWON	interference drag coefficient of wing lift acting on nacelles.
CLDZIN	design lift coefficient
CLI	the ith component lift coefficient
CPBODL	lifting pressure coefficient due to unsymmetric body volume distribution
CPBODU	body pressure coefficient acting on the wing upper surface
CPBUPW	lifting pressure coefficient due to the body upwash loading
CPLIMIT	wing upper surface limit pressure coefficient (on input table)
CPNAC	wing lifting pressures due to nacelles
GRADL	the array of maximum longitudinal pressure gradient on the wing upper surface actually used in the wing design module. This array is increased by 20 percent for those solutions having maximum number of pressure constraints, including at least one on gradient.
GTEMP	the array of user-specified maximum pressure gradient. This array is copied into GRADL on entry into OPTIMUM.
MAXNOG	the number of loadings that contribute to longitudinal pressure gradient and that are free to vary.
NCMAX	maximum number of solution constraints
NCPCON	number of pressure coefficient constraints

NGC0N	the number of solution constraints on wing upper surface longitudinal gradient.
NLCON	number of direct solution loading constraints due to use of configuration-dependent loadings
NXCMAX	the maximum number of pressure gradient constraints.
NƵCON	number of ordinate constraints
OPTION	integer array controlling extent of four types of solutions
TAI	up to four sets of load strength factors A_i, corresponding to the four types of solutions.
TBETAY TDXM CHORDT CPLMX	stored parameters which define a solution lifting pressure constraint, namely, spanwise location chordwise location, local chord, and allowable lifting pressure coefficient, respectively.
USEBOY	a logical flag indicating use of body buoyancy loading if true
USEBUP	a logical flag indicating use of body upwash loading if true
USECMC	a logical flag indicating use of pitching moment constraint if true
USECPL	a logical flag indicating use of wing upper surface pressure limiting if true
USEOPT	a logical flag indicating use of wing thickness pressures if true
USENAC	a logical flag indicating use of nacelle buoyancy loading if true
USEƵC	a logical flag indicating use of ordinate constraints if true.
XƵCON YƵCON	longitudinal and lateral planform locations of the ordinate constraints in physical units.
ƵCON	constrained values of ordinate corresponding on a one-to-one basis with XƵCON and YƵCON.
ƵI(17,5)	a two-dimensional array of up to five ordinates for each of the seventeen component loadings.

OUTPUT: Essential output is the set of up to four solution definitions in terms of the loading strength factors A_i. These are passed by COMMON blocks back to the camber surface calculation overlay, OVERLAY (WDEZ, 10, 2). In addition, varying amounts of information about the solutions are printed, depending on the choice of the print control parameter. These are described in more detail for the example case in the User's Manual, part 2.

SUBROUTINES CALLED:	CPDEF, CPINTR, CPNACI, CPSLØP, CPTDEF, JLTIME, MATINV, SLOPET

Subroutine CPSLØP

PURPOSE:	To provide the longitudinal gradient of wing upper surface pressure for component loadings individually and when combined in a solution. This subroutine parallels subroutine CPDEF in structure.
METHOD:	Standard FORTRAN statements.
USE:	CPSLØPE = CPSLØP (DX, BETAY, CHØRD, K)

INPUT:

DX	distance aft of the wing leading edge in program units.
BETAY	the product of the Prandtl-Glauert Mach number parameter and the spanwise distance from the centerline, in program units.
CHØRD	wing chord in program units at span station BETAY.
K	index for the loading number table LØADNO.

Input is also provided by means of COMMON blocks.

SUBROUTINES USED:	CPARB, SLOPEB, SLØPEN, SLOPEU.

Subroutine MATINV

PURPOSE:	To solve a set of linear, simultaneous equations. This is a NASA-LRC library subroutine.
METHOD:	See LRC library.
USE:	CALL MATINV (A, N, B, M, DETERM, IPIVOT, INDEX, NMAX, ISCALE)

Function SLØPEB

PURPOSE:	To provide the longitudinal gradient of the wing upper surface pressure coefficient due to the body-buoyancy configuration loading.

METHOD: Isolation of the body buoyancy contribution to wing upper surface pressure coefficient at the chordwise stations which bracket the input chord station. The gradient is simply the difference of these pressures divided by the difference in longitudinal distance, all at the proper span station.

USE: CPB = SLØPEB (XF, YF, C, J)

Function SLØPEN

PURPOSE: To provide the longitudinal gradient of wing upper surface pressure due to the nacelle pressure distribution when used as a camber loading.

METHOD: As for SLØPEB.

USE: CPN = SLØPEN (XF, YF, C)

INPUT:

XF	chordwise planform location as a fraction of local chord.
YF	spanwise planform location as a fraction of semispan.
C	chord at span station YF.

Tabular input is also provided by the COMMON block NPF.

Function SLØPET

PURPOSE: To provide the longitudinal gradient of wing thickness pressures.

METHOD: As for SLØPEB.

USE: CPT = SLØPET (XF, YF, CHØRD)

INPUT:

XF	chordwise planform location as a fraction of local chord.
YF	spanwise planform location as a function of semispan.
CHØRD	wing chord at span station YF.

Wing thickness pressures are provided in tabular form by array CPT in COMMON block PLIM.

Function SLØPEU

PURPOSE: To provide the longitudinal gradient of the wing upper surface pressure due to the body upwash configuration-dependent loading.

METHOD: As for SLØPEB.

USE: CPU = SLØPEB (XY, YF, C)

INPUT:	XF	chordwise planform location gives as a fraction of local chord.
	YF	spanwise planform location as a fraction of semispan.
	C	wing chord at span station YF.

The loading due to body upwash is provided in array CPBUPW by COMMON block CPBUPW1.

2.6 LIFT ANALYSIS MODULE

The lift analysis program is primary overlay 7. The program is divided into separate elements to read input, transform input into program units, and perform the lifting pressure calculations as shown schematically in figure 2.6-1.

The graphics displays are called as shown in figure 2.6-1.

Program TEA201

PURPOSE: Primary level of lift analysis module

METHOD: TEA201 sets up the calculation sequence for the drag-due-to-lift analysis program. The calculation loops are:

DØ 50 JDØ	Mach number loop, repeated for each Mach number.
DØ 40 MLIMT	Pressure limiting loop. LIMIT angles of attack, if limiting requested.
DØ 30 JCALP	Canard angle of attack loop. Repeated for each canard alpha, if canard is present.

USE: `CALL ØVERLAY (ANLZ, 7, 0, 0)`

INPUT: See user's manual.

SUBROUTINES CALLED: RCALC

Subroutine DUBINT

PURPOSE: To perform double interpolation in array

METHOD: Given a two-dimensional array, DUBINT performs double linear interpolation for an answer at a specified location in array.

USE: `CALL DUBINT (X1, Y1, TX, TY, NX, NY, TBL, MX, MY, ANS)`

INPUT:

X1	X location
Y1	Y location

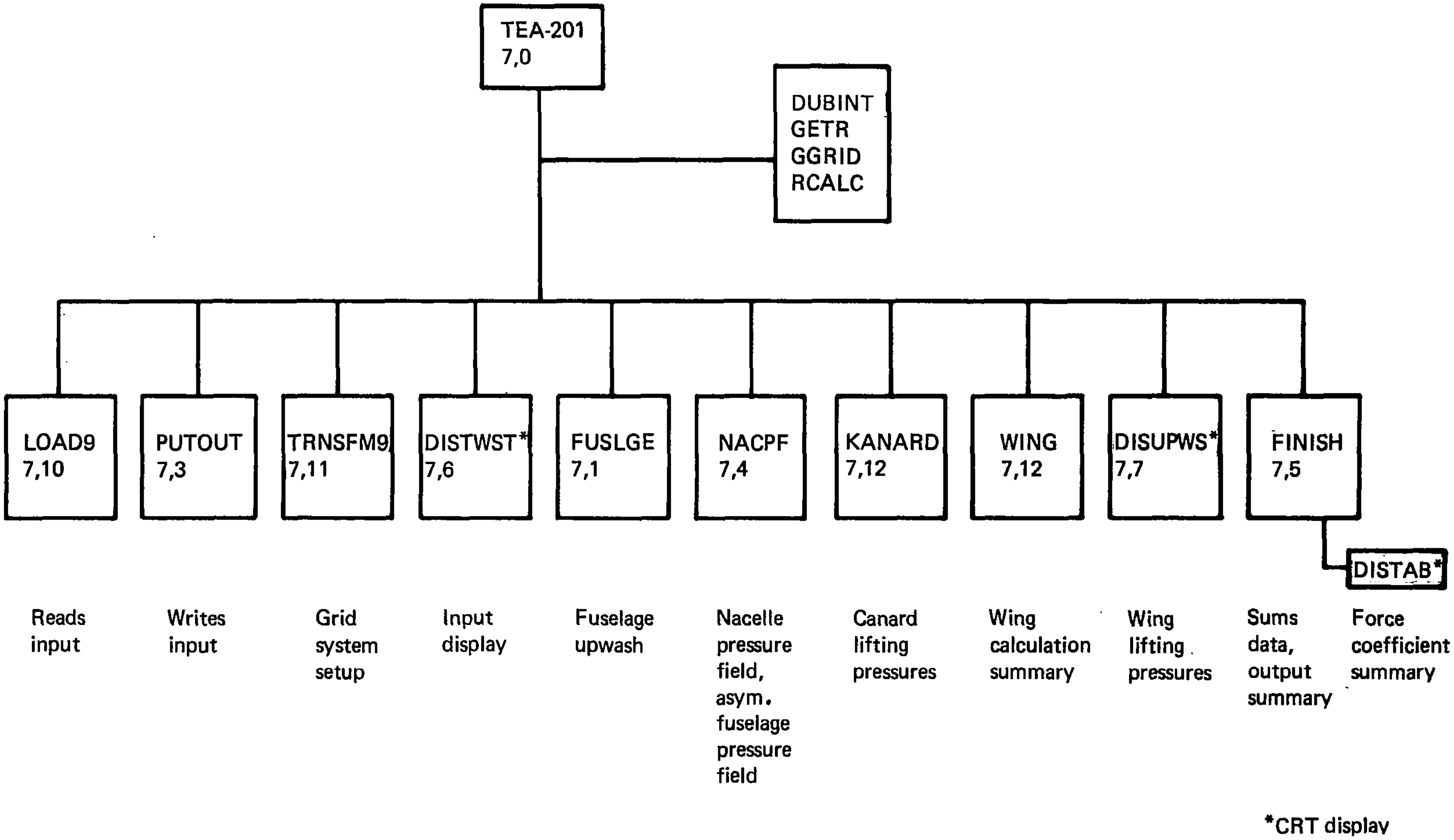


FIGURE 2.6-1.—LIFT ANALYSIS MODULE SCHEMATIC

TX	X array, NX values
TY	Y Array, NY values
TBL	Table being interpolated
MX, MY	Size of TBL in TBL DIMENSION statement
ANS	Interpolated answer at X1, Y1

SUBROUTINES CALLED: None

Subroutine GETR

PURPOSE: To calculate influence factor for specified grid element.

METHOD: Given an element located in the forecone from a selected field point element, GETR provides the corresponding influence factor. (The influence factor equation is discussed in the theory document, part 1).

USE: CALL GETR (LSTAR, LVAR, NDIF, R)

INPUT:

LSTAR	Field point element
LVAR	Specified grid element
NDIF	$\lvert NSTAR - N \rvert$
R	Influence factor

SUBROUTINES CALLED: None

Subroutine GGRID

PURPOSE: To define leading edge and trailing edge data for grid system for specified semi-span element row.

METHOD: Given a wing semi-span station, GGRID defines the leading edge and trailing X values, the corresponding grid elements, and the associated element fractions. GGRID is used for wing, canard or horizontal tail.

USE: CALL GGRID (JBY, XLE, XTE, LLE, LTE, ALE, ATE, NK)

INPUT:

JBY	Semi-span element row
XLE, XTE	Leading and trailing edge X-locations of planform at JBY.
LLE, LTE	Grid elements corresponding to XLE, XTE.
ALE, ATE	Fractions of elements defining plan-

form at LLE, LTE.

NK Code to identify configuration component
1 = Canard
2 = Wing
3 = Horizontal tail

SUBROUTINES CALLED: None

Subroutine RCALC

PURPOSE: To calculate a standard set of influence factors

METHOD: The influence factors used in the lift analysis program are a function only of the relative position of the field point element and the influencing element. RCALC is used to precalculate a standard set of influence factors for use in the program to reduce computer time associated with repeated calculations. The factors are stored in array TRSAVE.

USE: CALL RCALC

INPUT: None

SUBROUTINES CALLED: None

Program FUSLGE

PURPOSE: To calculate upwash field of fuselage and to calculate isolated fuselage force coefficients.

METHOD: Fuselage is used to calculate the wing-fuselage intersection (subroutine INTSEC), then to calculate the isolated fuselage lift distribution and force coefficients using slender body theory, and then to calculate the fuselage upwash field acting in the plane of the wing, canard, or horizontal tail.

The equations used in the fuselage lift distribution and upwash field calculations are given in the theory document (part 1). The fuselage forces in the presence of the wing downwash field are later repeated in subroutine FUSCF under overlay (7,5). The upwash field of canard, wing, or horizontal tail is defined by an array of upwash value at specified chord and semi-span percentages:

	CANARD	WING	TAIL
% Chord	TXUPW	TXPW	TXUPW
Semi-span fraction	TYCCW	TYUPW	TYHTW
Upwash angle	TUPCC	TUPWC	TUPHC
Upwash angle per deg. angle of attack	TUPCF	TUPWF	TUPHF

The upwash angle calculations are performed in subroutine UPWASH.

USE: CALL OVERLAY (ANLZ, 7, 1, 0)

INPUT: Geometry definition contained in common blocks. MLIMT = loop index variable from (7,0) overlay.

SUBROUTINES CALLED: INTSEC, UPWASH

Subroutine INTSEC

PURPOSE: To locate wing-fuselage intersection

METHOD: If input SYMM is less than zero, then the analysis program is to solve for the wing-fuselage intersection in order to define the exposed and "carry-over" wing pieces. INTSEC selects each percent chord line of the wing camber surface definition and locates the intersection between wing and fuselage. The fuselage area distribution is considered to be made up of circular cross-sections in the intersection calculations. The resultant intersection is stored in common block/WBINT/, with X, Y, and Z values in arrays WX, WY, and WZ.

USE: CALL INTSEC.

INPUT: Configuration geometry contained in common blocks.

SUBROUTINES CALLED: TBLU1

Subroutine UPWASH

PURPOSE: To calculate fuselage upwash

METHOD: UPWASH calculates fuselage upwash angle in the plane of the canard, wing, or horizontal tail, using the slender body equations discussed in the theory document (part 1). Upwash angles are computed for a series of percent chord values at selected semi-span stations.

USE: CALL UPWASH (Y, DELX, I, L)

INPUT: Configuration geometry contained in common blocks, plus:

Y	semi-span y station
I	span storage index for upwash array
L	variable defining component 1= canard 2= wing 3= tail

SUBROUTINES CALLED: TBLU1

Program WING

PURPOSE: To calculate lifting pressure distribution on wing.

METHOD: A schematic of WING is shown in figure 2.6-2.

The equations used in calculation of the wing lifting pressures are given in the theory document (part 1). The program scans the wing grid system from front to back (D0 470) and from the centerline to right hand wing tip (D0 450), locating field point elements on the wing or canard. When a field point element (LSTAR, NSTAR) is located, the program (D0 200) computes the upstream influence of elements located in the Mach forecone from LSTAR, NSTAR. The local pressure coefficient (CP) is then computed, with the fuselage upwash added to the local surface slope to obtain the effective element angle of attack. If the field point element is located inside the side-of-fuselage station, the element angle of attack is set to zero. (Either of the two pressure coefficient smoothing options may be used in these calculations, controlled by ut variable SM0G0.) After CP is calculated, p e

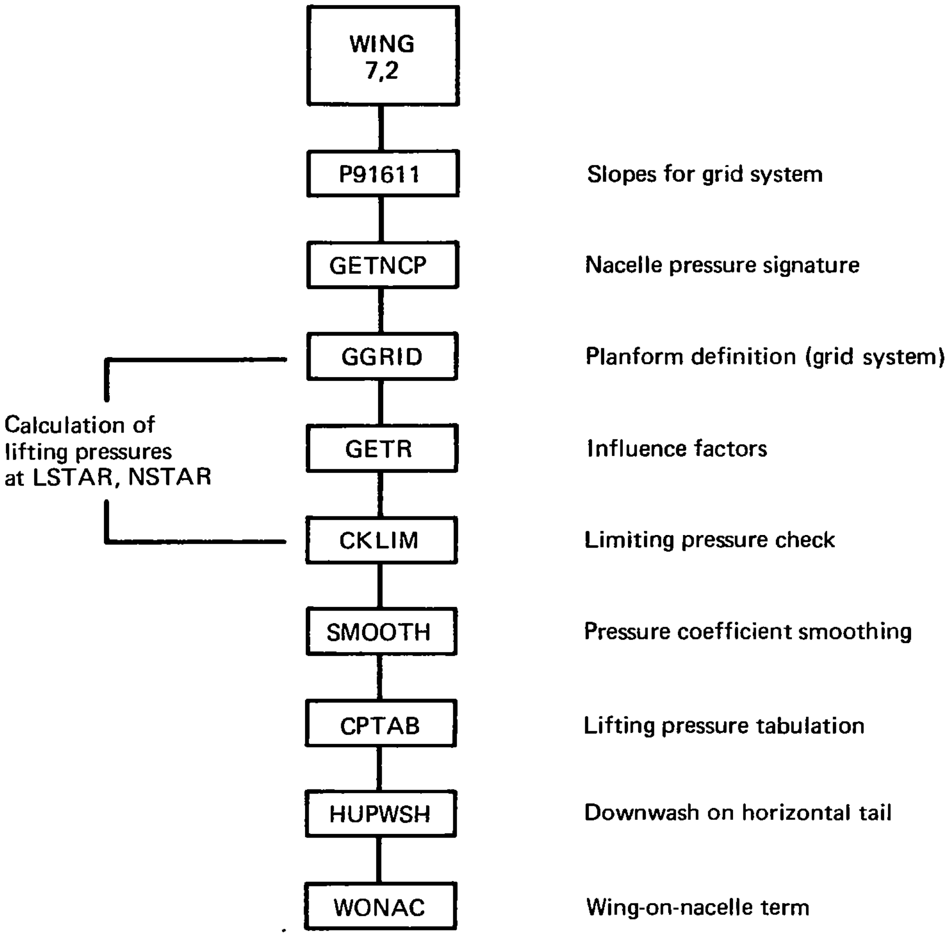


FIGURE 2.6-2.—PROGRAM WING SCHEMATIC

limiting is applied if input LIMIT is greater than zero, using subroutine CKLIM.

After all pressure coefficients are calculated, they are smoothed (DO 630) and integrated over the configuration surface to get lift, drag, and pitching moment. At the same time, the local nacelle pressure coefficients (CPNAC) and asymmetric fuselage volume pressure coefficients (CPASYM) are superimposed. Pressure coeffficients are applied to the wing slopes in the exposed wing area portion, and to the fuselage slopes interior to the side-of-fuselage station.

Corresponding calculations and summations are carried on simultaneously for the flat wing at 1 degree angle of attack. The interference drag term of flat wing pressure coefficients on the cambered wing slopes is also computed. Separate summations carry the nacelle drag, lift, and pitching moment and the configuration streamwise and spanwise lift distributions.

The wing pressure coefficient arrays (TWCP and TWCPF) are then interpolated over the wing planform for the output pressure summary (subroutine CPTAB).

The downwash due to the wing acting in the plane of the horizontal tail is then computed in subroutine HUPWSH. The effect of the wing lifting pressures acting on the nacelle area distribution is computed in subroutine W0NAC.

Program WING is called by two loops in the 7,0 level: the canard angle of attack loop and the pressure limiting angle of attack loop. Both result in changes to the local angle of attack distribution that cannot be handled by superposition.

USE: CALL 0VERLAY (ANLZ, 7, 2, 0)

INPUT: Configuration data in common blocks.

SUBROUTINES CALLED: See schematic, figure 2.6-2.

Subroutine CKLIM

PURPOSE: Checks to see if calculated pressure coefficients violate limiting pressure coefficient.

METHOD: The sum of the wing upper surface lifting pressure coefficient (-.5* calculated lifting pressure coefficient) plus the wing thickness pressure plus the fuselage pressure acting on the wing upper surface is checked against the limiting pressure coefficient. If the summed value, CPCHK, is more negative than the limit, the computed value is reset.

USE: CALL CKLIM (YFR, XPC, CP, CPLIMT, PTEST, CPT)

INPUT: Pressure coefficient arrays in common blocks, plus:

YFR	semi-span wing station
XPC	percent chord
CP	calculated lifting pressure coefficient
CPLIMT	limiting upper surface pressure coefficient
PTEST	indicator variable showing limiting application
CPT	thickness pressure coefficient

SUBROUTINES CALLED: DUBINT

Subroutine CPTAB

PURPOSE: To interpolate wing pressure arrays for output

METHOD: The wing lifting pressure distributions for the grid system are computed in WING. CPTAB is used to interpolate the grid pressure distributions for each semi-span row at selected per cent chord values. The interpolated pressure coefficients are stored in arrays VAR (basic angle of attack) and VAR1 (flat plate solution per degree alpha).

USE: Call CPTAB

INPUT: Configuration data and pressure coefficients in common blocks.

SUBROUTINES CALLED: GGRID, TBLU1

Subroutine GETNCP

PURPOSE:	To interpolate a nacelle pressure signature at a given wing semi-span station, for use in calculating nacelle-on-wing interference drag.
METHOD:	Same as described for subroutine GETNCP for the near-field wave drag program.
USE:	CALL GETNCP (YB2)
INPUT:	YB2 wing semi-span fraction
SUBROUTINES CALLED:	NONE

Subroutine GETUP

PURPOSE:	To perform double interpolation for fuselage upwash angle
METHOD:	GETUP double-interpolates linearly for fuselage upwash angle in arrays TUPWC (upwash at basic fuselage incidence) and TUPWF (upwash per degree fuselage alpha).
USE:	CALL GETUP (XPC, YFR, UPC, UPF)
INPUT:	XPC per cent chord YFR semi-span fraction UPC,UPF upwash angles, radians
SUBROUTINES CALLED:	None

Subroutine HUPWSH

PURPOSE: To compute downwash at tail

METHOD: HUPWSH is used to compute the local downwash acting along the fuselage centerline and in the plane of the horizontal tail. The fuselage asymmetric lifting pressure distribution (if any) is included in the wing lifting pressure definition.

The computed downwash is stored in arrays TWT (basic angle of attack) and TWTF (per degree) for the horizontal tail. Downwash from the canard (if any) is contained in arrays CT and CTF and is added in loop DØ 149. Fuselage downwash is stored in arrays BX (fuselage length fraction), BCC (downwash angle for basic angle of attack) and BCF (per degree).

The wing downwash can be shifted laterally to allow for fuselage closure effects, controlled by inputs FWSH and DYWH.

USE: CALL HUPWSH

INPUT: Configuration geometry and pressure distributions in common blocks

FWSH	wing downwash shift indication (0. = shift, 1.0 = no shift)
DYWH	downwash shift distance (y) (0. = use basic geometry side-of-fuselage increment)

SUBROUTINES CALLED: GGRID, GETR, DUBINT, TBLU1

Subroutine P91611

PURPOSE: To calculate local wing slopes for grid system

METHOD: Subroutine P91611 interpolates the wing camber surface definition for the streamwise slopes of the wing grid system. Interpolation is linear spanwise along constant per cent chord lines, followed by quadratic chordwise. The resultant slopes are stored in array TDZDX.

If wing twist tables or trailing edge flaps are input, the slopes are incremented by the appropriate slopes. Also, the grid element array containing the wing-fuselage intersection (INTN) is identified together with the corresponding fractional element (TNFR).

If the configuration angle of attack is not zero, as may be the case with limiting pressure calculations, all slopes are incremented by alpha.

If input WHUP = 1.0, the camber surface slopes are all zeroed. (This feature is used to generate the wing loading due to fuselage upwash only).

USE: CALL P91611

INPUT: Configuration geometry contained in common blocks

SUBROUTINES CALLED: GGRID, TBLU1

Subroutine SM00TH

PURPOSE: To smooth wing pressure coefficients and sum wing area

METHOD: SM00TH is called by program WING after all wing pressure coefficients have been calculated, to remove irregularities in the calculated values. Either a 9 point or 3 point smoothing equation is applied, depending upon the wing pressure calculation technique used (discussed in the theory document, part 1). The wing area is also calculated, by summing the areas of the individual elements.

USE: CALL SM00TH (AREA9, SM0G0)

INPUT: Configuration data contained in common blocks /SM0TH/, /INDEX/, and pressure data in /PC0EF).

AREA9 (wing area of right hand wing) $\sqrt{M \quad -1}$.

SM0G0 Smoothing technique code

0.= 9 term smoothing
1.= 3 term smoothing

SUBROUTINES CALLED: None

Subroutine W0NAC

PURPOSE: To calculate drag of wing lifting pressures acting on nacelle area distribution

METHOD: W0NAC is used to compute the thrust or drag force due to the wing lifting pressures acting on the nacelle cross-sectional distribution. For this calculation, the lifting pressure is broken into upper and lower surface halves and the proper half used depending upon whether the nacelles are above or below the wing. The pressures are transferred aft along Mach lines from the wing to elemental frustrums describing the nacelle shape.

The drag increments for both the wing pressure distribution at basic incidence and per degree alpha are computed.

USE: CALL W0NAC

INPUT: Configuration geometry and wing pressure field contained in common blocks.

SUBROUTINES CALLED: GGRID, TBLU1

Program PUT0UT

PURPOSE: To print input data

METHOD: PUT0UT is used to write the input and pertinent program data onto the output file.

USE: CALL 0VERLAY (ANLZ, 7, 3, 0)

INPUT: Configuration geometry in common blocks

SUBROUTINES CALLED: None

Program KANARD

PURPOSE: To calculate canard lifting pressures.

METHOD: Program KANARD calculates the canard lifting pressure distribution according to the same logic used for the wing lifting pressures.

USE: Call 0VERLAY (ANLZ, 7, 10, 0)

INPUT: DZDXC canard angle of attack, radians
Configuration data in common blocks.

SUBROUTINES CALLED: GRID, GETR, DUBINT, CANPRES, CONW

Subroutine CANPRES

PURPOSE: To sum pressure distributions over canard for lift, drag, and pitching moment.

METHOD: The canard pressure distributions are calculated in program WING, and stored in arrays TCCP (at input canard alpha) and TCCPF (per degree alpha). CANPRES integrates these to get lift, drag, and pitching moment. Drag is computed by applying the lifting pressure to the exposed canard slopes or the fuselage slopes, as appropriate.

USE: CALL CANPRES

INPUT: Configuration data in common blocks.

SUBROUTINES CALLED: GGRID, TBLU1

Subroutine CØNW

PURPOSE: To calculate downwash from canard on wing, fuselage, and tail.

METHOD: Subroutine CØNW sums the downwash of the canard on fuselage, wing, or tail, using the same influence logic as the basic canard or wing solution, the resulting downwash arrays are:

	Influence at basic angle of attack	Influence per degree alpha
Fuselage	FCC	FCCF
Wing	TCW	TCWF
Hor. Tail	TCT	TCTF

The downwash field can be shifted laterally to follow the side of the fuselage, controlled by program input.

USE: CALL CØNW

INPUT:

TCCP	canard pressure array (basic angle of attack)
TCCPF	canard pressure array per degree alpha.
FCSH	code to shift canard downwash (0. = shift, -1. = no shift)
DYCW	downwash shift magnitude at wing

(0 = use basic geometry distance from canard root to wing root)

DYCH downwash shift magnitude at tail (0 = use basic geometry distance from canard root to tail root).

SUBROUTINES CALLED: GGRID, GETR, TBLU1

Program NACPF

PURPOSE: To calculate pressure fields acting on the wing due to nacelles and asymmetric fuselage volume.

METHOD: This overlay calculates the pressure fields due to nacelles and asymmetric fuselage volume acting on the wing. A schematic of the overlay is given in figure 2.6-3.

The program initially calculates the asymmetric fuselage pressure distribution by calling subroutines SEGRT and SPLIT, using the fuselage representation described in the theory document.

The nacelle pressure field is next calculated. A series of semi-span Y stations are selected, and the composite pressure signature due to all nacelles is computed; first for all nacelles below the wing, then for all nacelles above the wing. If there are nacelles both above and below the wing, a single nacelle lifting pressure definition is calculated in subroutine CØMBINE.

The basic program format is the same as the NACPF subroutine described in the near-field wave drag program, except that the nacelle and fuselage interference terms are not computed in the analysis program version. In addition, there is an optional feature in the analysis program version to permit calculation of the nacelle pressure field at a Mach number other than free stream (to account for local Mach number effects, using input TMLØC). The resulting pressure field is afterwards referenced to free stream dynamic pressure.

The following subroutines associated with NACPF are the same as those previously described in the near-field wave drag program: CØMBINE, CUTØFF, GLANCE, INTPLT, MERGE, NSETUP, ØRDER, PSIG. (Slightly

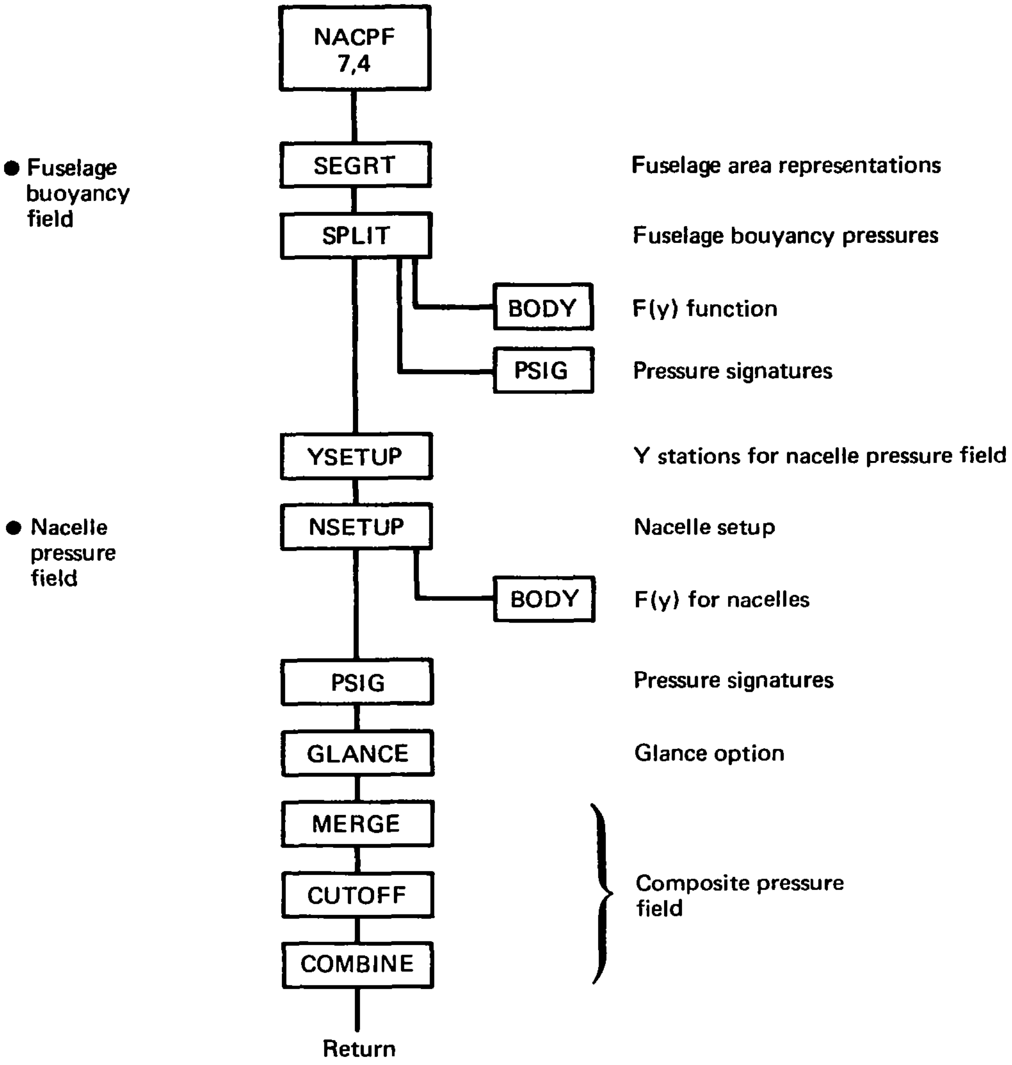


FIGURE 2.6-3.—PROGRAM NACPF SCHEMATIC

different name for near field program to avoid duplicate subroutine names).

USE: CALL ØVERLAY (ANLZ, 7, 4, 0)

INPUT: Configuration geometry, Mach number contained in common blocks.

SUBRCUTINES CALLED: See schematic, figure 2.6-3.

Subroutine BØDY

PURPOSE: To calculate Whitham F(y) function for body of revolution

METHCD: Subroutine BØDY is the same as the previously described NBØDY subroutine in the near-field wave drag module, with two additional provisions:

1) It will compute the F(y) function using the "smooth body" form of the F(y) equation discussed in reference 4, in addition to the Stieltjes integral equation. This provision is controlled by input FYLB in the calling statement. (FYLB less than zero uses smooth body equation).

2) Linear interpolation may be used (instead of quadratic) in fairing the body radius distribution. This provision is selected if FYLB is less than zero or greater than 9.0.

USE: CALL BØDY (TXB, TRB, TNXB, TNCUT, TTAU, TFTAU, JSTO, FYLB, SWET)

INPUT:

TXB, TRB,	Input body X stations and radius values, TNXB of each.
TNCUT	Number of body intervals in F(y) function
TTAU, TFTAU, JSTØ	Y and F(y) function calculated for body, JSTØ values of each
FYLB	Calculation method code (see above)

SUBROUTINES USED: TBLU1

Subroutine SEGRT

PURPOSE: To set up area representations for below-wing and above wing fuselage areas

METHOD: The logic of the below-wing and above-wing fuselage area representations is described in the theory document (Part 1). Subroutine SEGRT computes these area distributions using the wing-body intersection definition found in INTSEC. The fuselage is considered circular in the calculation of the two area distributions, resulting in:

TRABV	above-wing radius distribution
TRBLØW	below-wing radius distribution

Alternatively, SEGRT may use input values of fuselage areas (if SYMM = 2.0)

USE: CALL SEGRT

INPUT: Configuration geometry and wing-fuselage intersection definition contained in common blocks

SUBROUTINES CALLED: None

Subroutine SPLIT

PURPOSE: To calculate asymmetric fuselage volume pressure field

METHOD: Subroutine SPLIT is used to calculate the fuselage pressure field acting on the wing, according to input SYMM. If SYMM=0., the configuration is considered to be mid-wing, and the input fuselage definition is used to calculate a symmetric (non-lifting) fuselage thickness pressure field. If SYMM> 1.0, the above-wing and below-wing fuselage area representations obtained in SEGRT are used to calculate the respective pressure fields acting on the wing.

Pressure signatures due to the fuselage are calculated at the same X and Y stations used for the fuselage upwash field. The resultant fuselage volume pressure field is stored in common block/CPBASM/:

RXUPW	per cent chord array
RYUPW	semi-span percentages

PABØVE	pressure coefficients above wing
PBELØW	pressure coefficients below wing

USE: CALL SPLIT

INPUT: Configuration geometry contained in common blocks.

SYMM	calculation code

SUBROUTINES CALLED: BØDY, PSIG, TBLU1

Subroutine YSETUP

PURPOSE: To set up Y array for nacelle pressure field definition

METHOD: YSETUP sets up a series of Y stations located at each 5 per cent semi-span, plus extra stations located immediately inboard and outboard of each nacelle centerline. Subroutine ØRDER is used to store the array (TYP) in monotonically increasing fashion.

USE: CALL YSETUP

INPUT: Configuration geometry contained in common blocks.

SUBROUTINES CALLED: ØRDER

Program FINISH

PURPOSE: To compute fuselage forces in presence of wing downwash field, add in contribution of horizontal tail, and write out complete configuration force coefficient summaries.

METHOD: The wing/canard lifting pressure distribution and force coefficients are computed in program WING. Summary data from WING are passed to FINISH by common blocks, where the fuselage contribution in the wing/canard downwash field is calculated (subroutine FUSCF), and the direct effects of the canard are added in. All coefficients are based on input reference geometry.

A calculation loop (DØ 140) then calculates the contribution of the horizontal tail at various input incidences (in subroutine HTPART), and adds it to the wing-fuselage-canard data.

A summary of the configuration force coefficients, nacelle-on and nacelle-off, is then computed and printed. This includes lift (XCL), drag (STØT and SCDN) and pitching moment (CMA and CMB) coefficients. Corresponding coefficients for the flat wing configuration are printed for reference.

The streamwise lift distribution is then summed and printed (subroutine STRMWƵ). If wing lifting pressure coefficients at specified lift coefficients were requested, these are then calculated and printed. Finally, the wing-canard spanwise lift distribution is printed.

USE: CALL ØVERLAY (ANLZ, 7, 5, 0)

INPUT: Configuration data in common blocks

SUBROUTINES CALLED: FUSCF, SUMIƵ, HTPART, STRMWƵ

Subroutine HTPART

PURPOSE: To calculate the horizontal tail lifting pressure distribution and force coefficients

METHOD: Subroutine HTPART is used to compute lifting pressure distributions on the tail in the presence of wing-canard downwash. The equations used are the same as those employed for the wing; the tail is broken into exposed and fuselage-carry-over portions, and fuselage upwash and wing downwash added to tail alpha for the purposes of computing lift coefficients.

The lifting pressure distributions are summed over the tail planform to get tail force coefficients, which are then added to the force coefficients of the rest of the configuration. These are passed back to FINISH in common blocks.

USE: CALL HTPART (NH, REFAR)

INPUT:

NH	Tail incidence loop index
REFAR	Reference area in program units

SUBROUTINES CALLED: GGRID, GETR, DUBINT, TBLU1

Subroutine STRMWZ

PURPOSE: To sum and print streamwise lift distribution

METHOD: In STRMWZ, the streamwise lift distributions due to wing/canard, nacelles, fuselage, and horizontal tail are summed together and printed. The presentation is in fraction of total lift coefficient, so that the final number printed for the complete configuration is 1.0.

USE: CALL STRMWZ (REFAR, SCLN9)

INPUT:

REFAR	Reference area in program units
SCLN9	Total lift coefficient

SUBROUTINES CALLED: TBLU1

Subroutine SUMIZ

PURPOSE: To summarize and print configuration force coefficients

METHOD: The configuration force coefficients, including the interference drag terms, are summarized for program FINISH in subroutine SUMIZ.

USE: CALL SUMIZ (N)

INPUT:

N Index variable to identify printout series

1= WING
2= WING + FUSELAGE
3= WING + FUSELAGE + CANARD

SUBROUTINES CALLED: None

Subroutine FUSCF

PURPOSE: To calculate force coefficients of fuselage in presence of wing downwash field

METHOD: FUSCF repeats the slender body fuselage lift calculations of program FUSLGE, adding the wing downwash field computed in HUPWSH to the basic fuselage angle of attack. The fuselage is broken into segments and the equations given in the theory document (Part 1) are used to calculate the fuselage lift. Fuselage drag is computed by applying the fuselage lift distribution to the local mean-line slopes.

Lift for the fuselage at basic incidence and the corresponding incremental (flat) fuselage at one degree angle of attack, plus interference drag terms, are all calculated. The results are stored in common blocks /BØDSØL/ and /BFND/:

TBDLC	basic incidence streamwise lift
TBDLF	flat body streamwise lift (1° alpha)
CLCND, CLFND	lift coefficients of basic and flat solutions
CDCND, CDFND	drag coefficients
CMCND, CMFND	pitching moment coefficients

Data for the isolated fuselage solution (no wing downwash) are also printed for reference.

USE: CALL FUSCF

INPUT: Configuration geometry contained in common blocks. Isolated fuselage force data in /BØDSØL/.

SUBROUTINES CALLED: TBLU1

Program LØAD9

PURPOSE: To read input data for lift analysis module

METHOD: Program LØAD9 reads input data (interface tape written by analysis subprogram of geometry module).

USE: CALL OVERLAY (ANLZ, 7, 8, 0)

INPUT: See user's manual

SUBROUTINES CALLED: None

Program TRNSFM9

PURPOSE: To convert input data to program units and set up grid system

METHOD: The wing, canard, and horizontal tail planforms are represented in the analysis program as a set of rectilinear elements, as described in the theory document (Part 1). Given the number of semi-span element rows (FN0N) used to define the right-hand wing, TRNSFM interpolates the wing planform definition at the mid point of each semi-span row for leading edge and trailing edge X-value. These X values are converted to program scale (by means of RATI0= y wing tip * BETA/FN0N) and stored in arrays TXLE and TXTE, with XLE0 and XTE0 defining the wing centerline grid points.

Storage of wing pressure coefficients and surface slopes uses a space-conserving technique: The leading edge of a spanwise row is stored immediately after the trailing edge of the adjacent inboard row. The index array for the row storage is J0W, which gives the number of elements stored ahead of the leading edge of a selected row. The same storage arrangement is used for canard and horizontal tail, based on indices J0C and J0H.

The factor RATI0 is also used to scale the canard and horizontal tail arrays, as follows:

	Canard	Tail
Leading edge array	TCXLE	THXLE
Trailing edge array	TCXTE	THXTE
Centerline leading edge	CXLE0	HXTE0
Centerline trailing edge	CXTE0	HXTE0

The maximum size of the pressure coefficient arrays for the right hand wing is 2500 for the wing, 200 for the canard, and 500 for the horizontal tail. Also, the maximum X dimension of the configuration, to the most aft point on the wing, is 205 (program units). If any of these dimensions are exceeded, TRNSFM rescales the program units by reducing FN0N.

TRNSFM is also used to identify the grid elements associated with trailing edge flaps. Since the flap edges will usually not coincide with element edges, an approximate element array is used to represent the flaps and the input flap deflection angles are altered such that the product of flap area times deflection is the same for the input and the approximate program definition. The input flap area is computed in subroutine PHLAP.

USE: CALL 0VERLAY (ANLZ, 7, 9, 0)

INPUT: Configuration geometry read in program L0AD9

SUBROUTINES CALLED: PHLAP, GGRID, TBLU1

3.0 REFERENCES

1. Harris, Roy V., Jr.: An Analysis and Correlation of Aircraft Wave Drag. NASA TM X947, 1964.

2. Craidon, Charlotte: Description of a Digital Computer Program for Airplane Configuration Plots. NASA TM X-2074, 1970.

3. Anon: United States Standard Atmosphere, 1962. NASA, USAF, U. S. Weather Bureau. U. S. Printing Office, Washington D. C., 1962.

4. Whitham, G. B.: The Flow Pattern of a Supersonic Projectile. Communications on Pure and Applied Mathematics, Vol. V, No. 3, August 1952, pp. 301-348.

APPENDIX A

INTERACTIVE GRAPHICS SUBROUTINES

The graphics subroutines in the design and analysis program are described in this appendix, except for the LRC standard CRT software routines.

Three general purpose subroutines are described first, followed by the subroutines associated with the individual modules:

Subroutine CSCALE

PURPOSE: Computes a plot origin and scale factor given an array of values.

METHOD: If the values in the input array are not equal, LRC subroutine ASCALE is called to compute an origin and scale factor. If the values in the input array are equal, the origin is set to that value -.5, and the scale factor is set to 2.0/length over which the data is plotted.

USE: CALL CSCALE (ARRAY, S,N,K,DV)

INPUT:

ARRAY = Array of data to be scaled.
S = Length over which data will be plotted.
N = Number of values in ARRAY.
K = Interleave factor. (1=all points).
DV = Number of divisions per inch of paper.

ØUTPUT:

ARRAY (N*K+1) = Plot origin
ARRAY (N*K+1+K) = Plot scale factor

SUBROUTINES CALLED: ASCALE

Subroutine SHOW
Entry SHOWI

PURPOSE: To display an array of floating point values on the CDC250.

METHOD: LRC subroutines NØTATE and NUMBER are called to display a variable name, equal sign and a number of values on the same line. When the display line is complete, the vertical coordinate of the line is decremented by a preset value. Alternate entry point SHOW I is used for integer values.

USE:

CALL SHOW (A,N,BCD,NC)
CALL SHOWI (L,N,BCD,NC)

INPUT:

A	Floating point variable or array
L	Integer variable or array
N	Number of values to display
BCD	Hollerith label preceding the first value
NC	Number of characters in BCD
COMMON/PBLOK/	
YORG	Y coordinate of display line
VORG	X coordinate of first value to display. If values to be displayed are negative, the negative sign will be positioned at VORG-CS, VORG+VDEL-CS and VORG+VDEL+VDEL-CS
YDEL	Vertical distance between lines
VDEL	Horizontal distance between values
CH	Character height
CS	Spacing between characters (6/7*CS)
THETA	Angle of display for label & values
ND	Number of decimal places to display

OUTPUT:

COMMON/PBLOK/
XORG = Coordinate of first character BCD

SUBROUTINES CALLED: NOTATE,NUMBER

EXAMPLE:

```
R( 1 )  =  1.25     -3.79     5.86
R( 4 )  =  6.73      9.50    -3.17
```

Subroutine SHOW3

PURPOSE: To display a label and three floating point variables on the CDC 250.

METHOD: LRC subroutines NOTATE and NUMBER are called to display a hollerith label and three values on the same display line. When the line has been displayed, the vertical coordinate of the line is decremented by a preset value.

USE: CALL SHOW3 (V1, V2, V3, BCD)

INPUT:

V1 = First variable to display
V2 = Second variable to display
V3 = Third variable to display
BCD = Hollerith label (10 character maximum)

COMMØN/PBLOK/

```
        XORG  = X coordinate of label
        YORG  = Y coordinate of display line
        VORG  = X coordinate of V1
        VDEL  = X distance between variables
                If negative, the variables are
                displayed at VORG-CS, VORG+VDEL-CS
                and VORG+VDEL+VDEL-CS
        YDEL  = Y distance between display lines.
          CH  = Character height
          CS  = Spacing between characters (6/7*CH)
       THETA  = Angle of display for label and variables
          ND  = Number of decimal places to display.
```

SUBROUTINES CALLED: NOTATE, NUMBER

EXAMPLE:

```
NAC1   -57.254      9.000           5.790
NAC2    69.874     16.785          -9.103
```

GEOMETRY MODULE

Configuration geometry is displayed and/or edited by program DISGEØM, a secondary overlay in the geometry module.

Program DISGEØM

PURPOSE: To display and/or edit configuration geometry

METHOD: A description of the display capability is presented in Appendix A of the user's manual.

USE: CALL OVERLAY (GEOM, 5, 5, 0)

Subroutine ALTER

PURPOSE: To alter the wing camber surface shape to match a new trailing edge definition.

METHOD: The camber definition at each input airfoil is rotated about the airfoil leading edge point until the trailing edge point coincides with the new trailing edge definition. The new camber surface definition is stored in temporary array BZØRD

USE: CALL ALTER (ZTE)

INPUT: ZTE = Array of new trailing edge values.

COMMON/TEMP/
LECODE = +, ZTE array consists of camber values
LECODE = -, ZTE array consists of camber values + the Z value of the leading edge

COMMON/WING/
TZØRD = Original camber definition

OUTPUT: COMMON/TEMP/
BZØRD = Altered camber definition

Subroutine PLTSIZ

PURPOSE: To compute the configuration minimum and maximum X and Y coordinates, and the fuselage minimum and maximum Z coordinates. A plot scale factor is also output.

METHOD: Each configuration component is analyzed as to its coordinate values. The minimum and maximum values are stored in common. If the range of data in the X direction is greater than that in Y, SCALE is computed as:

$$\frac{XMAX-XMIN}{10.0}$$

If the range of data in the Y direction is greater than that in X, SCALE is computed as:

$$\frac{YMAX-YMIN}{7.0}$$

USE: CALL PLTSIZ (SCALE)

INPUT: All configuration geometry in COMMON.

OUTPUT: SCALE = Plot scale factor
COMMON/ØVL1/
XMIN = Minimum X value of configuration
XMAX = Maximum X value of configuration
YMIN = Minimum Y value of configuration
YMAX = Maximum Y value of configuration
ZMIN = Minimum Z value of fuselage
ZMAX = Maximum Z value of fuselage

FAR-FIELD WAVE DRAG MODULE

The graphics subroutine (DIS080) in the far-field wave drag module is located in program 0UT, overlay (FFWD,3,6).

Subroutine 0UT

PURPOSE: To display area plots and drag summary

METHOD: The CRT is used to display far-field wave drag module results as described in the user's manual, Appendix A.

USE CALL DIS080 (S, B, B0, C, RC, N)

INPUT:

S	Array of X values
B	Array of fuselage areas
B0	Array of optimum fuselage areas
C	Array of overall configuration areas
RC	Array of restrained areas
N	Number of values in input arrays

NEAR-FIELD WAVE DRAG MODULE

The graphics program (DISP916) is called from the primary level of the near-field wave drag overlay.

Program DISP916

PURPOSE: To display near-field wave drag module results

METHOD: DISP916 displays summary results described in the user's manual, Appendix A

USE: CALL 0VERLAY (NFWD, 6, 3, 0)

INPUT: Summary data in common blocks

SKIN FRICTION DRAG MODULE

The graphics subroutine (DISP158) in the skin friction module is called from subroutine DRAG.

Subroutine DISP158

PURPOSE: To display skin friction module results

METHOD: DISP158 displays summary results described in the user's manual, Appendix A.

USE: CALL DISP158

INPUT: Summary data in common blocks

WING DESIGN MODULE

Display and editing in the wing design module is performed by three graphics programs called from the primary overlay.

Program BUCKETP

PURPOSE: To display drag-due-to-lift bucket plot

METHOD: BUCKETP is used to display the K_{ε} versus Cmo plot plus design point solutions described in Appendix A of the user's manual.

USE: CALL ØVERLAY (WDES, 10, 4, 0)

INPUT: Data in common block/BUCKET/

Program EDBUCK

PURPOSE: To permit editing of design point variables

METHOD: EDBUCK allows user to edit wing design program variables Cmo, CLDSIN, RESTART, and CØNSTR(1) through CØNSTR(4). In addition it allows the user to execute the next design case or calculate the edited design point, as described in Appendix A of the user's manual.

USE: CALL ØVERLAY (WDES, 10, 5, 0)

Program STØPØP

PURPOSE: To permit termination of wing design program cases

METHOD: STØPØP allows user to exit from a series of wing design cases, as described in Appendix A of the user's manual.

USE: CALL ØVERLAY (WDEƵ,10,6,0)

LIFT ANALYSIS MODULE

The graphics displays in the analysis module consist of two overlays called from the primary overlay, plus two subroutines called from program FINISH.

Program DISTWST

PURPOSE: To display wing twist and permit editing of twist and several execution codes.

METHOD: DISTWST displays and permits editing of wing twist array, plus canard angles of attack, SYMM, WHUP, and ANYBOD. The display presentation is described in Appendix A of the user's manual.

USE: CALL ØVERLAY (ANLƵ, 7, 6, 0)

INPUT: Input variables in common blocks

Program DISUPWS

PURPOSE: To display fuselage upwash and wing pressure coefficient data

METHOD: DISUPWS provides display options for calculated fuselage upwash or wing pressure coefficient data, as described in Appendix A of the user's manual.

USE: CALL ØVERLAY (ANLƵ, 7, 7, 0)

INPUT: Data in common blocks/UPWSH/and/CPBUPW1/.

Subroutine DISTAB

PURPOSE: To display analysis module force coefficient summary and permit editing of horizontal tail angle of attack.

METHOD: DISTAB provides display of analysis program results as described in Appendix A of the user's manual.

USE: CALL DISTAB (NH, HTALP)

INPUT: NH Horizontal tail angle of attack loop index
HTALP Edited tail alpha

Subroutine EXL00P

PURPOSE: To display and permit editing of variables within DO loops.

METHOD: EXL00P displays current values of Mach number, configuration alpha, and canard alpha. It then permits editing of the next value to change within the cycle, as described in Appendix A of the User's Manual.

USE: CALL EXL00P

INPUT: Configuration data in common blocks

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