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DEPARTMENT OF DEFENCE SUPPORT

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

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MECHANICAL ENGINEERING REPORT 160

COMBAT PERFORMANCE EVALUATION OF FIGHTER AIRCRAFT — A SUITE OF FORTRAN-IV PROGRAMS BASED ON ENERGY MANOEUVRABILITY THEORY.

by

G. W. KIPP.

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COMBAT PERFORMANCE EVALUATION OF FIGHTER AIRCRAFT — A SUITE OF FORTRAN IV PROGRAMS BASED ON ENERGY MANOEUVRABILITY THEORY.

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SUMMARY

A suite of FORTRAN-IV computer programs is described which may be used to assist in evaluating relative combat aircraft performance, using energy manoeuvrability theory. The programs are described in detail using flowcharts, and full operating instructions are given. A selection of outputs illustrates the graphical and printed capabilities of the suite.

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NOTE ON UNIT SYSTEMS

The SI system of units is used as the major unit system in this report. Whenever appropriate, Imperial equivalents are given in parentheses ( ).

The programs described are capable of processing data in both the SI and Imperial systems, since aeronautical practice still makes use of the Imperial system.

CONTENTS

NOTATION

Symbols	*Definition*	*Unit or Value*
a	Sonic speed	m/s (ft/s)
C_D	Drag coefficient	—
$C_{D,i}$	Induced drag coefficient	—
$C_{D,min}$	Minimum drag coefficient	—
$\Delta C_{D,S}$	Store drag coefficient	—
C_L	Lift coefficient	—
$C_{L\alpha}$	Lift curve slope	rad^{-1}
$C_{L,max}$	Maximum lift coefficient	—
D	Aerodynamic drag	N (lb)
E	Total energy	J (ft lb)
E_S	Specific energy, energy height, energy state ..	m (ft)
F_n	Engine net thrust	N (lb)
F_{ND}	Non-dimensionalizing force	N (lb)
g	Acceleration due to gravity	9·80665 m/s^2 (32·17405 ft/s^2)
h	Geopotential altitude	m (ft)
h_p	Pressure altitude	m (ft)
Δh_p	Pressure altitude increment	m (ft)
L	Aerodynamic lift	N (lb)
m	Aircraft mass	kg (slug)
M	Mach number	—
n	Load factor normal to aircraft in plane of symmetry	—
n_T	Number of turns at optimum conditions ..	—
O	Co-ordinate origin	—
P	Ambient pressure	Pa (lb/ft^2)
P_S	Specific excess power, energy rate	m/s (ft/s)
r	Turn radius	m (ft)
R	Range	km (n.m.)
ΔR	Range increment	km (n.m.)
R_{air}	Gas constant for air	287·053 J/kg.K (3089·78 ft^2/Ks^2)
S	Aircraft reference area	m^2 (ft^2)

t	Time	s
Δt	Time increment	s
T	Temperature	K
ν	Flowrate scaling factor	1/3600 lb.hr/lb.s
V	Velocity	m/s (ft/s)
W	Aircraft weight	N (lb)
ΔW	Weight loss due to fuel usage	N (lb)
w_f	Fuel flowrate	kg/s (lb/hr)
x, y, z	Co-ordinate axes	—

Greek symbols	*Definition*	*Unit or value*
α	Body incidence to flight path	rad (deg)
α'	Effective angle of attack ($=\alpha+\sigma$)	rad (deg)
γ	Flight path elevation angle	rad (deg)
γ_{air}	Specific heat ratio for air	1·4
ϵ	Error function to be solved for h_p	m (ft)
λ	Temperature lapse rate	K/m (K/ft)
Λ	Wing sweep angle	rad (deg)
σ	Thrust incidence to body axes	rad (deg)
χ	Energy rate function	—
ϕ	Roll angle	rad (deg)
ψ	Azimuth angle	rad (deg)
ω	Turn rate	deg/s

Subscripts	*Definition*
a	Ambient conditions
av	Average value between two energy states
b	Base or reference level
B	Body-axis co-ordinate
E	Earth-axis co-ordinate
i	Iteration count
SL	Sea level conditions
T	Trimmed aircraft
W	Wind-axis co-ordinates
1,2	Intermediate co-ordinate transformation

Math symbols	*Definition*
$\dot{x}$	Differentiation with respect to time
x'	Differentiation with respect to altitude
$\ln(x)$	Natural logarithm

ABBREVIATIONS AND ACRONYMS

CAS	Calibrated airspeed
c.g.	Centre of gravity
CPU	Central processing unit
deg	Degree
kt	Knot
MAC	Mean aerodynamic chord
MMD	Maximum manoeuvre diagram
n.m.	Nautical mile
SI	Système International d'Unités
TAS	True airspeed

COMPUTER VARIABLES

Program Names

AIRCRAFT	Generic name of main programs for each aircraft
ANY	Member of AIRCRAFT family for data reprocessing
BATCON	ARL system for batch program operations
OPTFIT	B-spline curve-fitting program
P2	Plotting and data reorganisation program
P4	Contour plotting program
PLOTQ	System program for queuing plotter files
SURFM	B-spline data verification program

System Filename Extension

.CTL	BATCON control file
.EXE	Absolute binary core image of program
.FOR	FORTRAN program file
.LOG	BATCON progress file written in user's disk area
.LST	Line printer file deleted when processed
.REL	Relocatable binary file

User Filenames

P2 P2A P2DIFF DUM P4

User Filename Extensions

.OPT .CON .PLT

User Libraries

P1 P1LIB P24LIB GRAFIC EXTRAS

Routines in Program AIRCRAFT

AERO BLOCK DATA THRUST TRIMCL

Routines in Library P1

ALTIT BININ IDENT MAXMAN MONSEP PARAMS P1IN
P1OUT P1OUTA ROMIN SEP TABLE

Routines in Library P1LIB

SURF

Routines in Program P2

GRID INMMD PSCON PSDIFF P2IN RATE1 RATE2 R2DIFF

Routines in Program P4

OUTXT P PLOTD P4MAIN

Routines in Library P24LIB

LINE PLOT

Routines in Library GRAFIC

CONT SMOOTH

Variables Common to P1, P2 and P4

B, C	Reserved storage arrays of equivalenced variables
DELES, DELXM, DELGN	Increments of energy state, Mach number and load factor
ESØ, XMØ, GNØ	Initial grid values of these variables
NES, NXM, NGN	Number of grid values of these variables
IUNITS, IPSTYP	Flags for types of units and energy rate variables
PLA	Power setting

Variables in Library P1

ALB	Mass scale factor (2·2046225 lb/kg)
AM	Length scale factor (0·3048 m/ft)
AWF	Fuel flow rate scale factor (3600 ALB lb.s/kg.h)
HP	Pressure altitude
IERR	Error flag
IGRID	Height variable flag
IOPT	Optimized grid flag
IOUT	File output flag
OMTAB	Turn rate output vector
PSTAB	Energy rate output vector

Variables in Program P2

ICREAT	On-line data generation flag
IONDSK	Differential MMD disk file flag
IOPT	Processing option flag
NAMOUT	Output file name
OMEGA	Turn rate
PS	Energy rate
PSØ, DELPS, NPS	Energy rate grid definition
WORK	Working storage vector

Variables in Program P4

CONLAB, LABFLG	Contour label flag
IC	Running counter of differential MMD boundary points
ICOUNT	Final count of points in each boundary
ICHK	Order flag for x-co-ordinates in boundary vector
IDATA	Data set leap counter
IDEF	Default contour texture flag
IDOT	Current contour texture flag
IDOTØ	Texture flag for zero contour
IGES	Energy state contour flag
IMMD	Turn rate boundary flag
NDATA	Number of data sets
NLEVØ	Level number of zero contour
XPT, YPT	Plotter co-ordinates transmitted by CONT
XTAB, YTAB	Vectors of differential MMD boundary co-ordinates
YLMIN	Minimum y co-ordinate on MMD boundaries
Z, ZG	Working storage vectors

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1. INTRODUCTION

With the increasing complexity of modern combat aircraft and the resulting extension of their capabilities, the need has arisen for techniques to evaluate the relative combat performance of new designs, and to compare these designs against existing aircraft in service.

This report and two companion reports[1,2] dsecribe techniques developed at ARL, which were considered to meet the current needs of the Royal Australian Air Force. This report describes a suite of FORTRAN IV computer programs developed for the computation and presentation of data used in evaluating combat aircraft performance using the energy manoeuvrability theories[3-6] which have been developed in the past two decades.

The suite of programs produces, for a variety of possible aircraft configurations, tabulated and plotted data in either metric or Imperial units, which describe aircraft combat performance in energy manouvrability terms. For each aircraft to be evaluated, the user must supply subroutines which calculate simplified propulsion and aerodynamic characteristics.

The mathematical basis for the calculations is described in Chapter 2. Chapter 3 presents the requirements and capabilities of the suite as a whole.

Chapter 4 describes the main calculation program, given the generic name AIRCRAFT in subsequent pages. Chapter 5 describes the output program P2, which provides plotted output, as well as input for the contour plotting program P4 described in Chapter 6.

Chapters 7, 8 and 9 present a self-contained user's guide with full instructions on how to operate the three programs. Typical outputs are described in Chapter 10.

Chapter 11 concludes with some suggestions of possible extensions to the suite's capabilities.

2. MATHEMATICAL PRELIMINARIES

A complete description of the theoretical background for this suite of programs is given in Reference 1, supplemented by the published literature of References 3–6. The basic equations are given below without derivation.

Where numerical methods are available in the published literature, they are quoted without derivation. An iterative technique developed by the author is the subject of an appendix, and the results are quoted in the body of the text.

2.1 Equations of Motion

The equations of motion in flight path axes as shown in Figures 1 and 2, for an aircraft in general turning flight are:[1]

$$m\dot{V} = F_n \cos\alpha' - D - W \sin\gamma \tag{2.1}$$

$$mV = (-\dot{\gamma}\cos\phi - \dot{\psi}\cos\gamma\sin\phi) = -F_n \sin\alpha' - L + W'\cos\gamma\cos\phi, \tag{2.2}$$

$$mV = (-\dot{\gamma}\sin\phi + \dot{\psi}\cos\gamma\cos\phi) = W\cos\gamma\sin\phi. \tag{2.3}$$

where m = aircraft mass, kg (slug),

W = aircraft weight, N (lb),
V = true airspeed along the flight path, m/s (ft/s),
g = gravity constant, 9·80665 m/s² (32·17405 ft/s²),
F_n = engine net thrust, N (lb),
$\alpha' = \alpha+\sigma$ = effective angle of attack, rad,

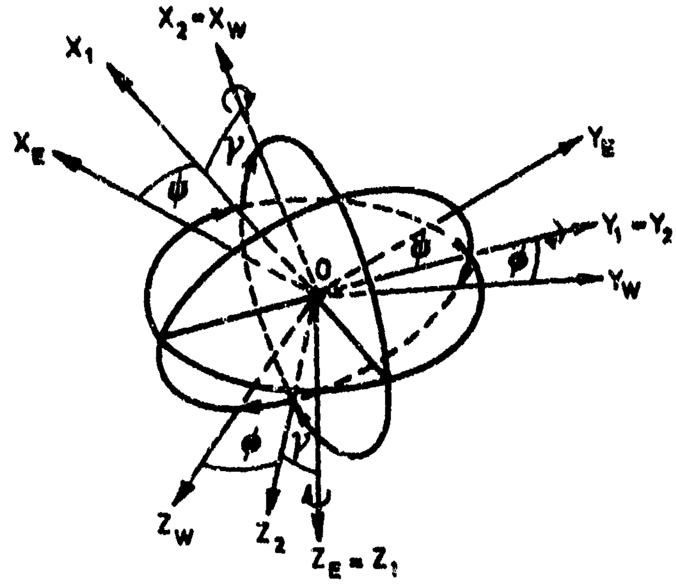

Fig. 1 Earth-and wind-axes systems

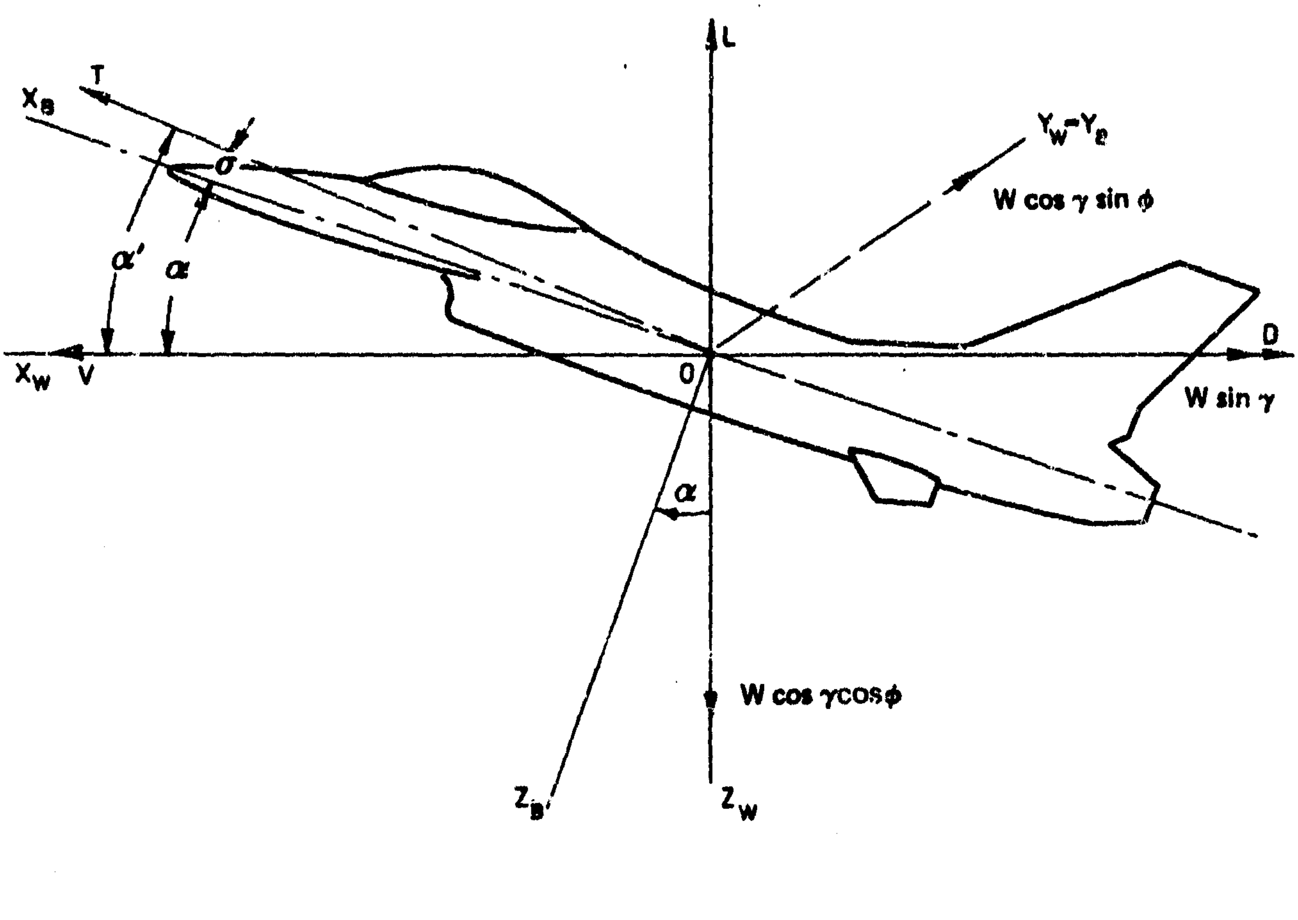

Fig. 2 Force system

D = aerodynamic drag, N (lb),
L = aerodynamic lift, N (lb),
ψ = azimuth angle, rad,
γ = elevation angle, rad,
ϕ = roll angle, rad.

In deriving these equations, it is assumed that

(*a*) the earth is flat;

(*b*) acceleration due to gravity is constant;

(*c*) the aircraft is considered as a point mass;

(*d*) atmospheric parameters follow standard laws;

(*e*) the velocity vector, aerodynamic forces and net thrust are co-planar in the aircraft frame of symmetry.

2.2 Energy Relationships

Using the fundamental relation that energy state (E_S), or specific energy is given by

$$E_S = E/W = h + V^2/2g, \tag{2.4}$$

the equations of motion for flight in a horizontal plane ($\gamma = \dot{\gamma} = \dot{h} = 0$) can be expressed as

$$P_S = \frac{V}{g}\frac{dV}{dt} = V(F_n \cos\alpha' - D)/W, \tag{2.5}$$

and

$$n = 1/\cos\phi = (F_n \sin\alpha' + L)/W, \tag{2.6}$$

where Equation (2.5) is a restatement of Equation (2.1) and Equation (2.6) is a combination of Equations (2.2) and (2.3). In these equations

$P_S = dE_S/dt$ = energy rate, m/s (ft/s)

h = geopotential height, m (ft),

n = load factor normal to the aircraft in the plane of symmetry.

In addition rate of turn ($\dot{\psi}$) is denoted by ω, and it is readily shown that

$$\omega = g(n^2 - 1)^{0.5}/V, \tag{2.7}$$

and

$$r = V/\omega, \tag{2.8}$$

where r is the turn radius, m (ft).

For flight in a vertical plane, Equations (2.1) and (2.2) reduce to

$$P_S = \left(\frac{V}{g}\frac{dV}{dt} + \frac{dh}{dt}\right) = V(F_n \cos\alpha' - D)/W, \tag{2.9}$$

and

$$V\dot{\gamma}/g + \cos\gamma = (F_n \sin\alpha' + L)/W = \text{n}. \tag{2.10}$$

Energy state methods enable climb schedules to be estimated using the calculus of variations[7] based on P_S or some function of P_S:

$$\chi_1 = P_S, \tag{2.11}$$

$$\chi_2 = P_S/w_f, \tag{2.12}$$

$$\chi_3 = P_S V/w_f, \tag{2.13}$$

where w_f = fuel flow rate, kg/s (lb/hr).

Integration of the maxima of these quantities, viz:

$$t = \int_{E_{S_1}}^{E_{S_2}} (1/\chi_{1,\max}) dE_S, \tag{2.14}$$

$$m = \int_{E_{S_1}}^{E_{S_2}} (1/\chi_{2,\max}) dE_S, \tag{2.15}$$

$$m/R = \int_{E_{S_1}}^{E_{S_2}} (1/\chi_{3,\max}) dE_S, \tag{2.15}$$

results in approximate profiles for minimum time, minimum fuel or maximum range respectively.

Apart from P_S, the energy functions χ_i have no unique names. Hence, in the program described in later chapters, an output variable χ_i is referred to either as the "energy parameter", or simply as the energy rate, with the implication that any of the three energy functions may be referred to.

2.3 Atmospheric Relationships

The algorithms used to determine atmospheric pressure, ambient temperature and geopotential height have been presented fully elsewhere,[8] and only the essential details are given here.

Two atmospheres, the ICAO Standard Atmosphere and the ARDU Tropical Atmosphere are provided as atmosphere models. They are approximated to by atmospheric layers with constant temperature lapse rates, and are defined by values of ambient temperature and pressure height at the points where these lapse rates change. The atmospheric pressure is defined by the standard atmosphere relationships

$$\left.\begin{aligned} P &= P_b\{T_b/(T_b+\lambda\Delta h_p)\}^{[g/(R_{air}\lambda)]}, && \lambda \neq 0 \\ &\text{or} \\ P &= P_b \exp\{-g\Delta h_p/(R_{air}T_b)\}, && \lambda = 0 \end{aligned}\right\} \tag{2.17}$$

where P = atmospheric pressure, Pa (lb/ft²)
Δh_p = pressure height in linear segment = $h_p - h_{pb}$, m (ft)
h_p = pressure height, m (ft),
h_{pb} = pressure height of base of linear segment, m (ft),
P_b = atmospheric pressure at base of linear segment, Pa (lb/ft²),
T_b = ambient temperature at base of segment, K,
λ = temperature lapse rate, K/m (K/ft),
R_{air} = gas constant for air, 287·055 J/kg.K (3089·78 ft²/K.s²).

Atmospheric temperature "T" is given by

$$T = T_b + \lambda\Delta h_p, \quad \text{K}. \tag{2.18}$$

In the ARDU tropical atmosphere, geopotential height, required for performance calculation, is obtained by integration over all layers up to the given pressure height

$$h = \sum_{i=1}^{n+1} h_i, \tag{2.19}$$

where

$$\left.\begin{aligned} h_i &= \frac{1}{\lambda}\{\lambda_s h_p + (T_{sb} - T_b\lambda_s/\lambda)\ln(1+\lambda h_p/T_b)\}, && \lambda \neq 0 \\ &\text{or} \\ h_i &= h_p(T_{sb} + \lambda_s h_p/2)/T_b, && \lambda = 0 \end{aligned}\right\} \tag{2.20}$$

and h = geopotential height, m (ft),

h_i = geopotential height increment in ith layer, m (ft),

λ_a = lapse rate in ambient atmosphere, K/m (K/ft),

T_{ab} = temperature at base of layer in ambient atmosphere, K,

n = total no. of layers to the given pressure height in both standard and non-standard atmospheres.

In the ICAO Standard Atmosphere geopotential height and pressure altitude are identical.

Given pressure, altitude and Mach number, and the speed relations

$$V = Ma \tag{2.21}$$

and

$$a = (\gamma_{air} R_{air} T_a)^{0.5}, \tag{2.22}$$

where M = Mach number,

a = sonic speed, m/s (ft/s),

γ_{air} = specific heat ratio for air, $=1 \cdot 4$.

Equation (2.4) may be used to determine energy state.

However, to determine pressure altitude, given energy state and Mach number, the interdependence of geopotential height, pressure height, temperature and Mach number requires the iterative solution of Equation (2.4), which is non-linear in h_p and hence in h. Appendix 1 develops the solution using Newton's method, the result being given below:

$$h_{p,i+1} = h_{p,i} + \delta h_{p,i}, \tag{2.23}$$

where

$$\delta h_{p,i} = -\left[\frac{h + kT_a - E_S}{T_a/T + k\lambda_a}\right]_{h_p = h_{p,i}}, \tag{2.24}$$

$$k = \gamma R_{air} M^2/(2g), \tag{2.25}$$

$$T_a = \text{ambient temperature, K}$$

and i denotes the ith iteration.

Iteration continues until $\delta h_{p,i}$ is less than $0 \cdot 75$ m ($0 \cdot 25$ ft). A suitable initial estimate of h_p is:

$$h_{p0} = E_S - a_{SL}{}^2 M^2/(2g), \tag{2.26}$$

where a_{SL} = sonic speed at sea level, $340 \cdot 30$ m/s ($1116 \cdot 46$ ft/s).

The final atmosphere-related quantity required is the non-dimensionalising force "F_{ND}", which is defined as:

$$F_{ND} = 0 \cdot 5 \gamma_{air} P M^2 S, \text{ N (lb)}, \tag{2.27}$$

where S = aircraft reference area, m² (ft²).

3. REQUIREMENTS AND CAPABILITIES

The object of the suite of programs for air combat performance estimation is to produce tabular and plotted data for accurate assessment of the performance and manoeuvrability of of any aircraft operating in a wide range of weapon/store configurations.

In particular, the programs produce:

(*a*) specific excess power (P_S) plots on a height–Mach number grid for a range of sustained normal loadings;

(*b*) turn rate as a function of P_S at various height and Mach number combinations;

(*c*) optimum turn rate plots on a specific excess power—energy state (P_S—E_S) grid;

(*d*) differential plots of P_S for two aircraft on a height–Mach number grid for a range of sustained normal loadings; and

(*e*) differential plots of optimum turn rate on a P_S—E_S grid.

The tabular and plotted output may also be used to assist in the production of fuel/distance diagrams used in a variety of range calculations. Data which may be obtained from the outputs include:

(*a*) estimated fuel used and range achieved when flying profiles for minimum time, minimum fuel or maximum range;

(*b*) estimated fuel used and combat conditions for optimum sustained manoeuvres;

(*c*) estimated fuel used and range achieved during accelerations using maximum power;

(*d*) estimated maximum speeds at constant altitude;

(*e*) estimated "corner velocity' 'and sustained turn boundaries.

Finally, in order to provide a concise picture of combat performance throughout the aircraft's operating regime, plotted output can be produced on a turn rate/P_S *versus* Mach number grid for a range of load factors for any choice of altitudes or energy states.

The suite consists of three main programs, whose interrelations are shown in Figure 3.

AIRCRAFT is the generic name given to the family of programs which represents particular aircraft. An AIRCRAFT program includes user-defined routines which calculate propulsion and aerodynamic parameters using thrust and drag data files. The program uses input data describing the aircraft configuration, and produces tabular output for line-printer listing, as well as unformatted data files for input to program P2. Program ANY is a particular member of the AIRCRAFT family used to reprocess published performance graphs or unformatted data files, producing listings and further input files for program P2.

P2, the second member of the suite processes the data provided by program AIRCRAFT. For some requirements, disk files are produced which may be immediately plotted off-line. For other requirements program P2 is a pre-processor for the contour plotting program P4, rearranging data arrays and performing elementary operations such as are required for comparing two aircraft.

Program P4 is a contour plotting program producing only files for off-line plotting.

Associated with these three programs are several subroutine libraries used in the loading phase of program operation, containing input–output, curve-fitting, optimisation and plotting routines.

Concise descriptions of the three programs and the required subroutine libraries are given in Table 1. The programs and libraries are described fully in Chapters 4 to 9, together with instructions for using the subroutine libraries in the loading process.

4. PROGRAM "AIRCRAFT" DESCRIPTION

4.1 Program Structure

Program AIRCRAFT is the starting point for all combat performance calculations. It includes aerodynamic and propulsion routines peculiar to each aircraft under assessment, and calculates combat performance parameters, such as energy rate and turn rate, for given values of energy state, Mach number and load factor and for specific aircraft configurations.

Output files may be produced for off-line printing, containing full details of all relevant parameters, or for input to subsequent programs which prepare graphic presentations of the

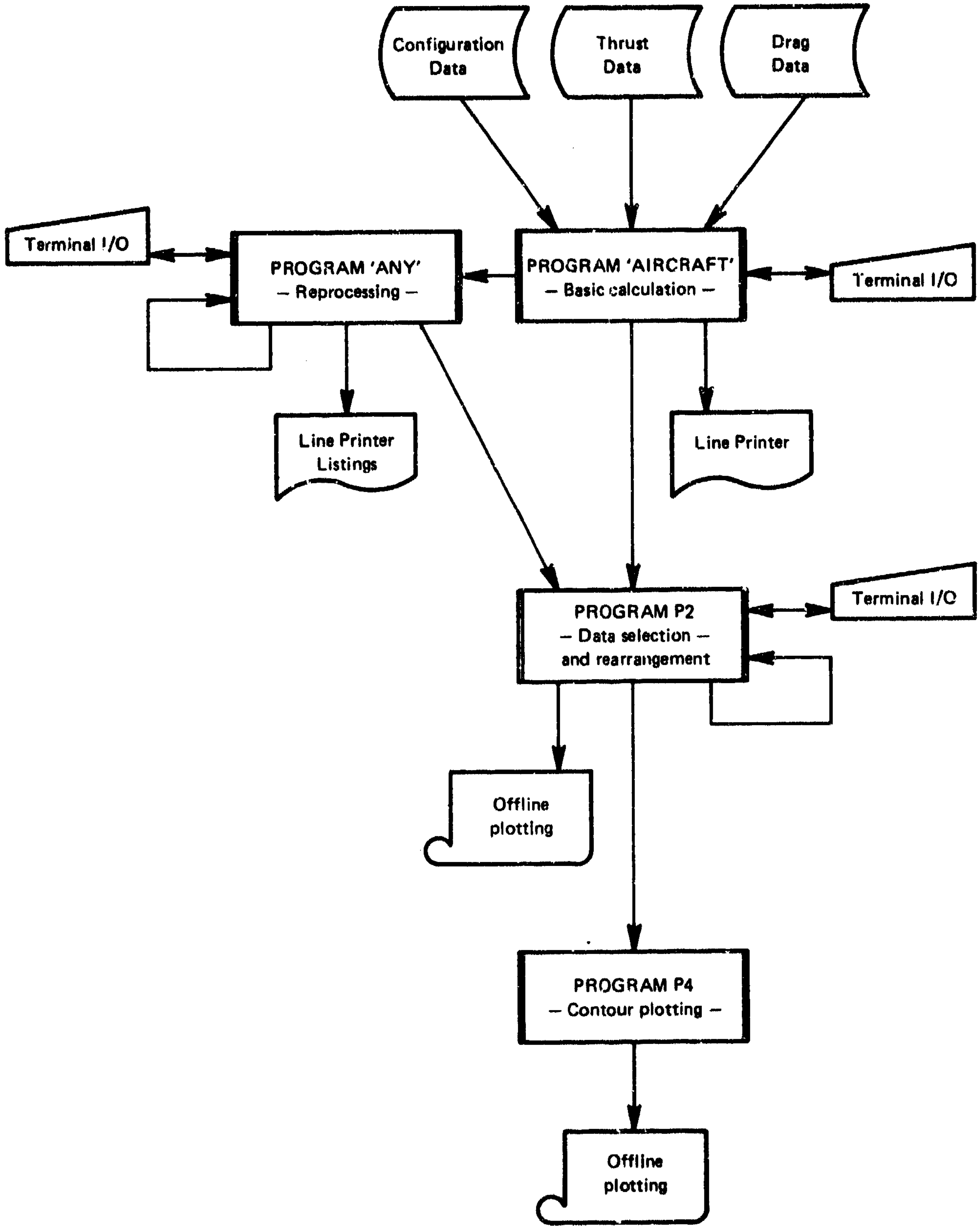

Fig. 3 Suite information flow

TABLE 1

Library Descriptions

Name	Function	Brief description
AIRCRAFT	Program library	Contains calling program, thrust, drag and data subprograms; different for each aircraft.
P2	Program library	Processes output produced by "AIRCRAFT", and produces files for plotting, or data files for input to program P4.
P4	Program library	Processes data produced by program P2 and produces contour plots.
P1	Subprogram library	Processes all input options and produces text output and data output for input to program P2; library for program "AIRCRAFT".
P1LIB	Subprogram library	Contains curve-fitting and optimisation routines; library for program "AIRCRAFT".
P24LIB	Subprogram library	Contains system routines for processing plot instructions; library for programs P2 and P4.
GRAFIC EXTRAS	External subprogram libraries	External libraries containing contour plotting routines.

TABLE 2

Program and Subroutine Libraries

Library name	Routines
AIRCRAFT	MAIN. AERO BLOCK DATA THRUST (and any routines called by AERO and THRUST)
P1	P1IN BADINP TABLE ATMOS INTRP HEIGHT HTRUE IDENT P1OUT BININ ALTIT PARAMS MAXMAN SEP P1OUTA MONSEP
P2	MAIN. GRID INLAB INMMD MMP PLTLAB PSCON PSDIFF P2IN RATE1 RATE2 R2DIFF UNITS WRLAB
P4	MAIN. OUTXT P PLOTD P4MAIN
P1LIB	SURF CUBICS CHECKD SPDER3 ROMIN
P24LIB	INTRP BADINP AXIS NUMBER LINE SYMBOL INLAB PLTLAB UNITS
GRAFIC	Routines required: CONT DIAG SMOOTH REALIN
EXTRAS	Routine required: PROMPT

printed output. Program AIRCRAFT user's guide (Chapter 7) gives an example terminal input. Sample output from co-ordinated running of programs AIRCRAFT, P2 and P4 is given in Chapter 10.

An AIRCRAFT program consists of routines in program library AIRCRAFT, together with routines from subroutine libraries P1 and P1LIB. The routines which make up these libraries are listed in Table 2, and briefly described in Appendices 2 to 4.

The division into program and subroutine libraries is required because the program library is different for each aircraft, but the service routines in the subroutine libraries are unique. The further division of subroutine libraries into two parts, P1 and P1LIB, arises from the routines in P1LIB having their origins in the curve-fitting program OPTFIT.

Appendix 5.1 lists the calling program, designated MAIN. in Table 2, which, together with data subroutine BLOCK DATA, must be included as part of the AIRCRAFT program library for each aircraft.

The two remaining subroutines which make up the AIRCRAFT program library, THRUST and AERO, are aircraft dependent and are fully described in Section 4.5. Sample routines are given in Appendices 5.2 and 5.3. A standardised form for aerodynamic and thrust data files is described in Section 4.6

Data communication between subroutines is principally by means of labelled COMMON areas and EQUIVALENCE statements. Appendix 6 lists the COMMON areas and the storage allocation within each area. As indicated in that appendix, this storage allocation scheme is also used in programs P2 and P4, with slight modifications.

A flowchart for the AIRCRAFT program structure is given in Figure 4, and it can be seen that program operations fall logically into three areas:

(i) input;

(ii) unoptimised grid calculation and output; and

(iii) optimised grid calculation and output.

Each of these areas is discussed below.

4.2 AIRCRAFT Program Input

The details of the conversational input routine P1IN are shown in Figure 5. Subroutine P1IN, called by the main program, performs an on-line dialogue with the user, thereby defining the type of run. The user's guide for program AIRCRAFT given in Chapter 7 gives exact specifications of all FORTRAN input parameters, together with example inputs.

The first task of P1IN is to request the user to specify his output units; P1IN then sets scale factors for length, mass and fuel flowrate accordingly.

The next task is to call subroutine IDENT, which requests the name of the disk file containing the following aircraft configuration information:

(i) descriptive name of the aircraft;

(ii) type of units used for area and weight in the file;

(iii) aircraft wing reference area;

(iv) gross weight for the current role, and centre of gravity position (if required);

(v) description of the current role;

(vi) file names of the thrust and drag data files;

(vii) tabular data defining external store drag; it is assumed that this drag may be defined in terms of drag dount (equal to $\Delta C_{D,S} \times 10^4$) *versus* Mach number, from which linear interpolation yields the external store drag count increment.

These data are then read from the aircraft configuration file, followed by reading of the thrust and drag data files with calls to subroutine BININ. Control then returns to subroutine P1IN to complete the conversational dialogue.

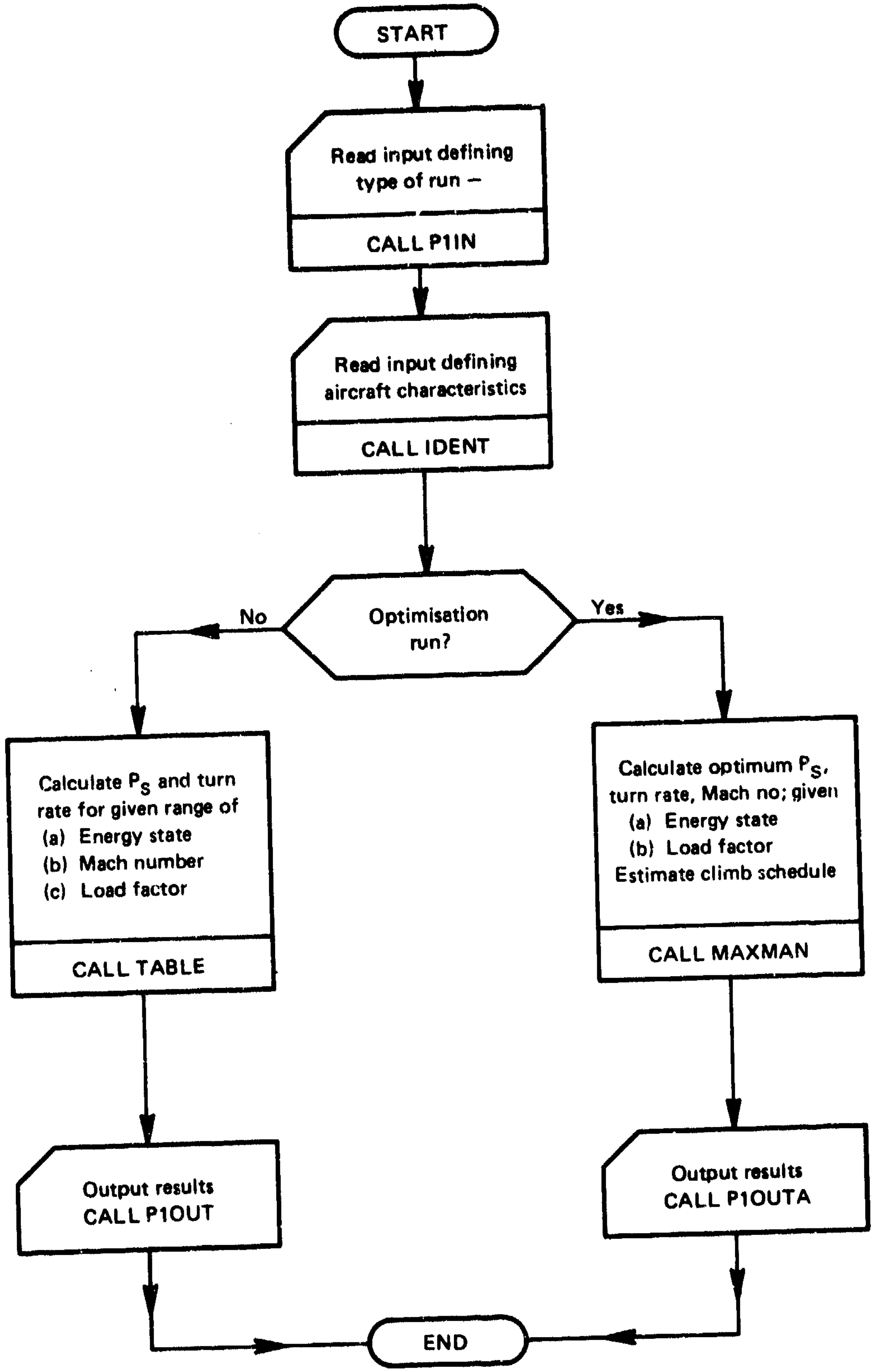

Fig. 4 Program aircraft structure

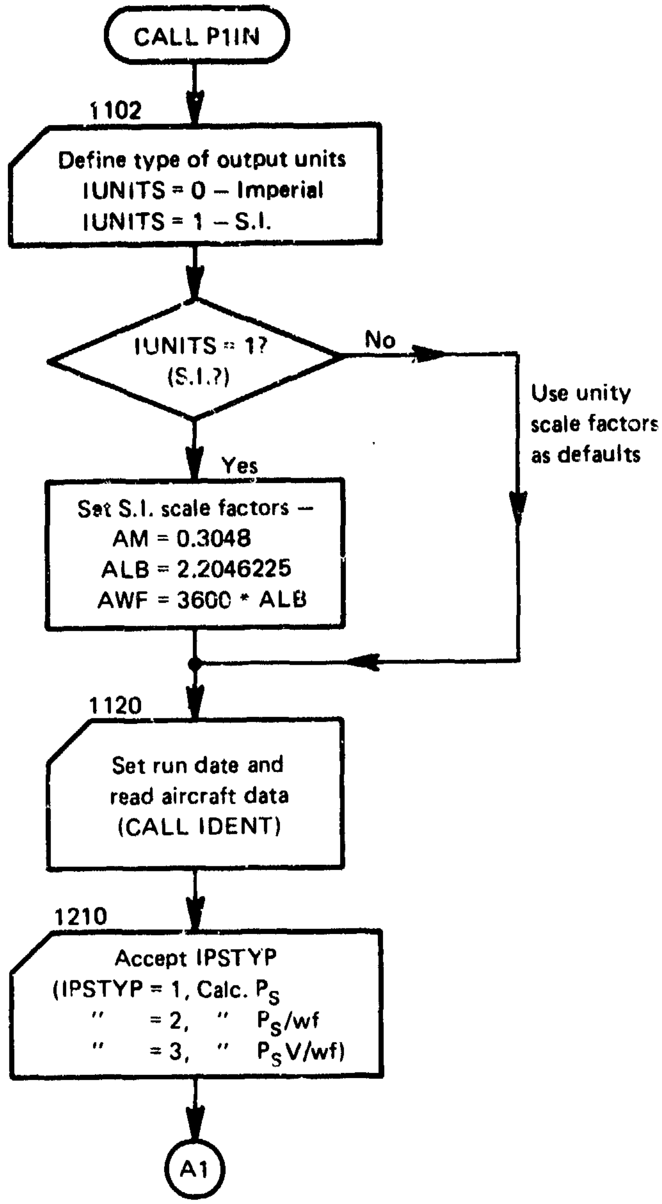

FIG. 5(a) Program AIRCRAFT Conversational Input Flowchart

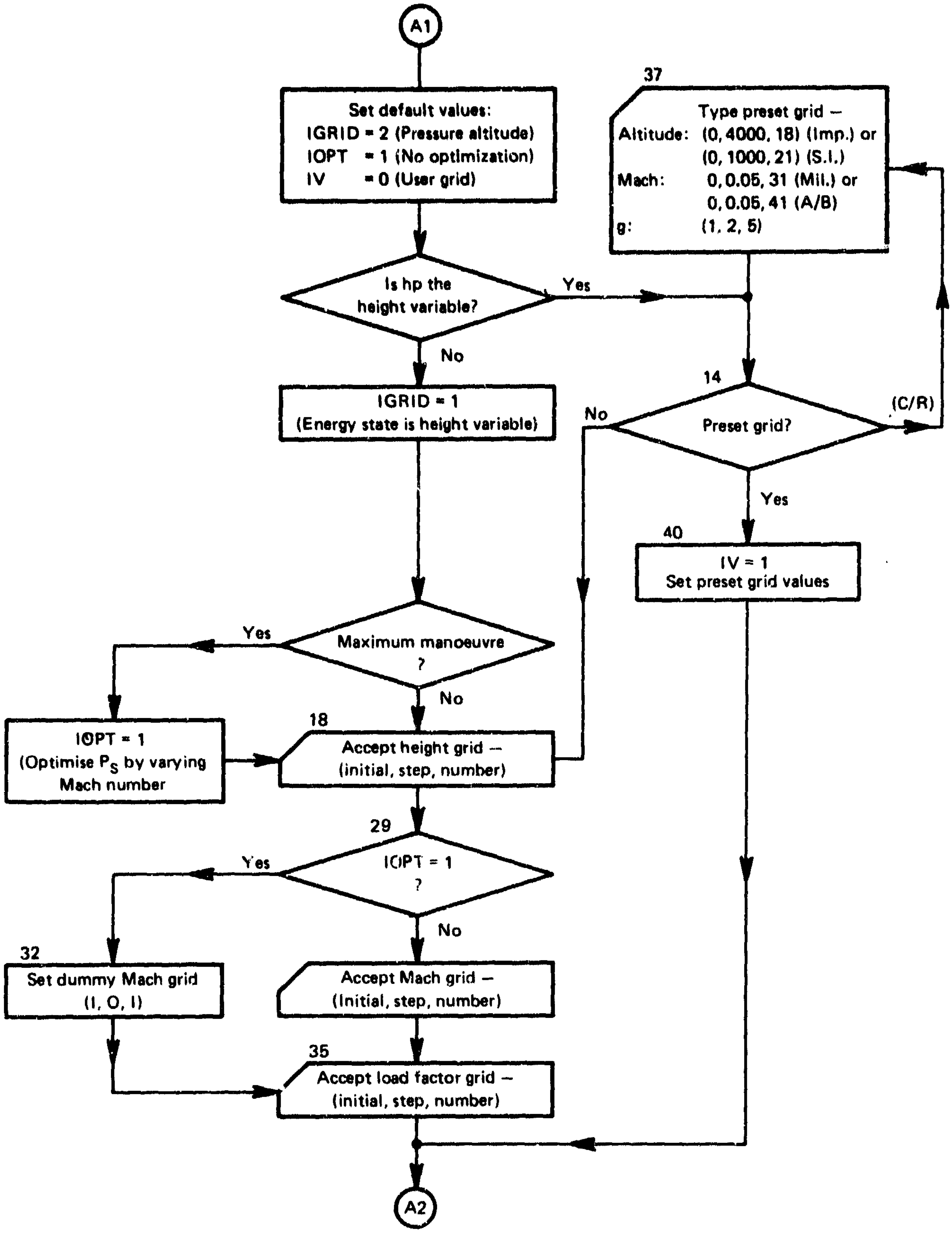

Fig. 5(b) Program AIRCRAFT Conversational Input Flowchart

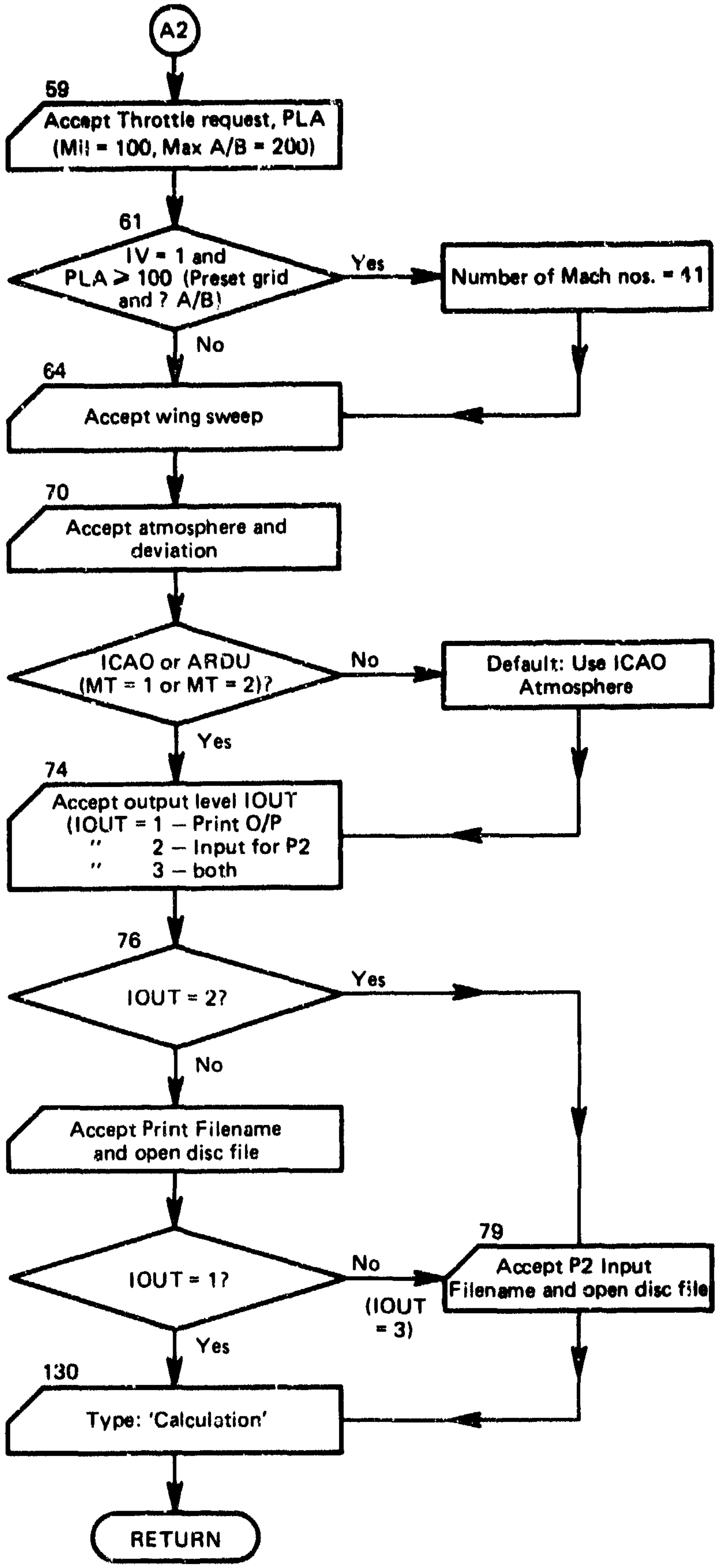

Fig. 5(c) Program AIRCRAFT Conversational Input (Cont.)

The following run data are next supplied in response to program prompts from routine P1IN:

(*a*) The type of calculation required. The energy parameter may be one of:

(i) P_S, IPSTYP = 1,

(ii) P_S/w_t, IPSTYP = 2,

(iii) $P_S V/w_t$, IPSTYP = 3.

(*b*) The height variable to be used as an independent variable.

(*c*) Grid definitions for the independent variable height, Mach number and load factor.

(*d*) Engine power setting.

(*e*) Wing sweep.

(*f*) Atmosphere profile.

(*g*) Output files required.

Grids for height, Mach number and load factor are supplied as the triplet; initial value, increment and number of points. Two height grids are available—energy state (IGRID = 1) and pressure altitude (IGRID = 2). In the latter case, the preset grid indicated in Figure 5 is available as a default (IV = 1), giving a reasonably fine grid for most purposes. The maximum value for the Mach number grid is then either 1·5 or 2·0 depending on military or afterburner throttle setting.

When energy state is requested as the height variable, data may be produced on an optimum P_S–energy state grid by selecting the maximum manoeuvre option. In this case, a Mach number grid is not needed, since Mach number will be chosen by the program to optimise the energy parameter.

Throttle setting is coded in the range 0 to 200 with ranges (0, 100) and (100, 200) denoting partial military or partial afterburner settings. Note that availability of thrust and fuel flow data for these settings depends on data supplied for each aircraft. Wing sweep may be specified if required as an input by the aerodynamic routines.

Where possible, each conversational input line is checked against valid limits, and the input prompt repeated if invalid input is detected. Valid ranges for the various inputs are given in Table 3.

TABLE 3

Program AIRCRAFT Input Data Velocity

Parameter	Valid condition
Calculation type	$1 \leqslant$ IPSTYP $\leqslant 3$
Height and Mach grid	(initial $\geqslant 0$, step > 0, $0 <$ number $\leqslant 50$)
Load factor grid	(initial $\geqslant 1$, step > 0, $0 <$ number $\leqslant 50$)
Throttle	$0 \leqslant$ PLA $\leqslant 200$
Wing sweep	$0 \leqslant$ wing sweep $\leqslant 80$
Output level	$1 \leqslant$ IOUT $\leqslant 3$

4.3 Unoptimised Grid Calculations

Unoptimised grid calculation encompasses all calculation other than that of the maximum manoeuvre diagram, which optimises energy rate (P_S) as a function of Mach number. Hence unoptimised calculations include those for energy rate *vs.* turn rate, energy rate contour plots, and turn rate/energy rate *vs.* Mach number.

Figure 6 presents a flowchart for these unoptimised calculations, controlled by subroutine TABLE.

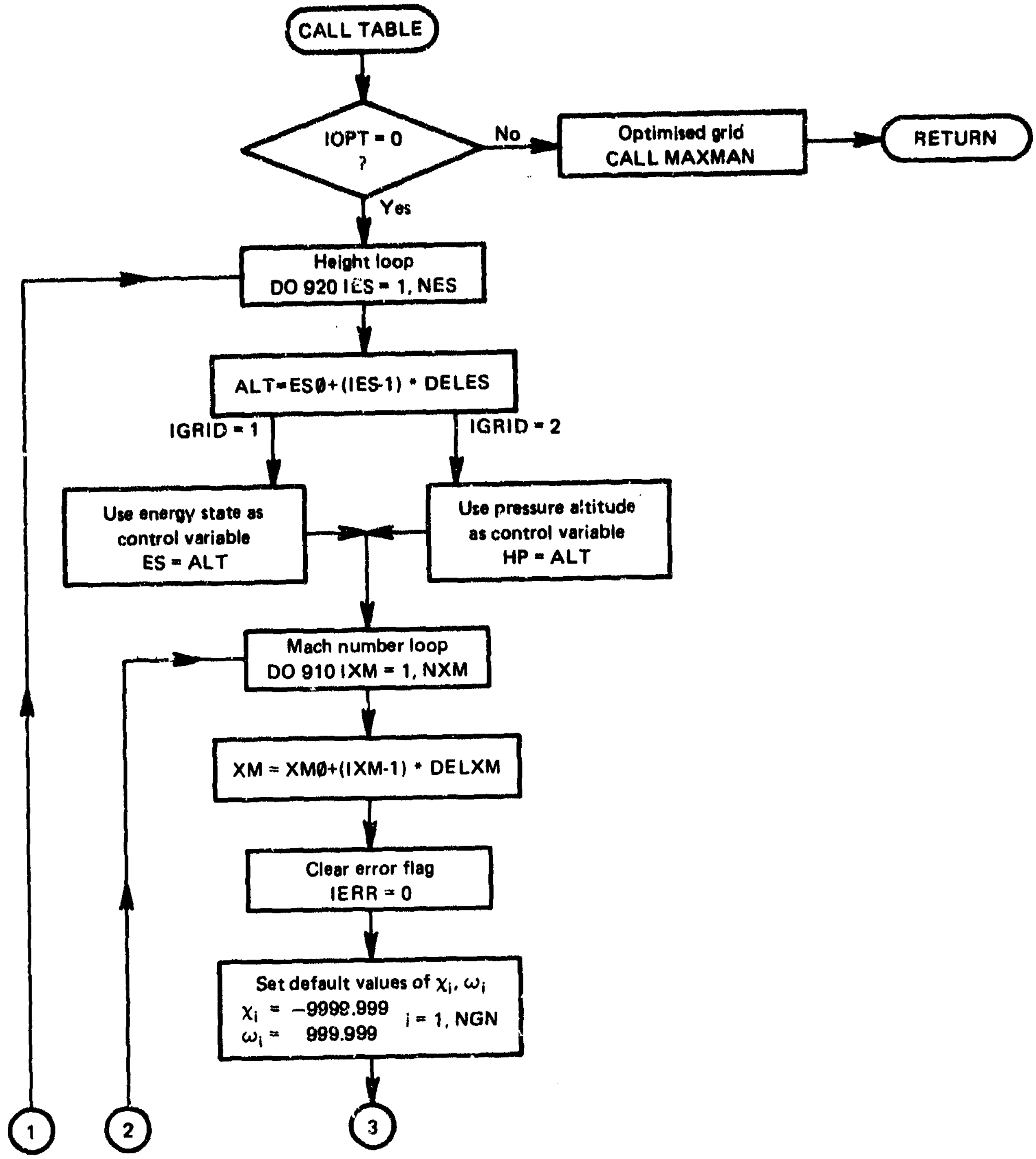

Fig. 6(a) Calculation Flowchart for Unoptimised Grids

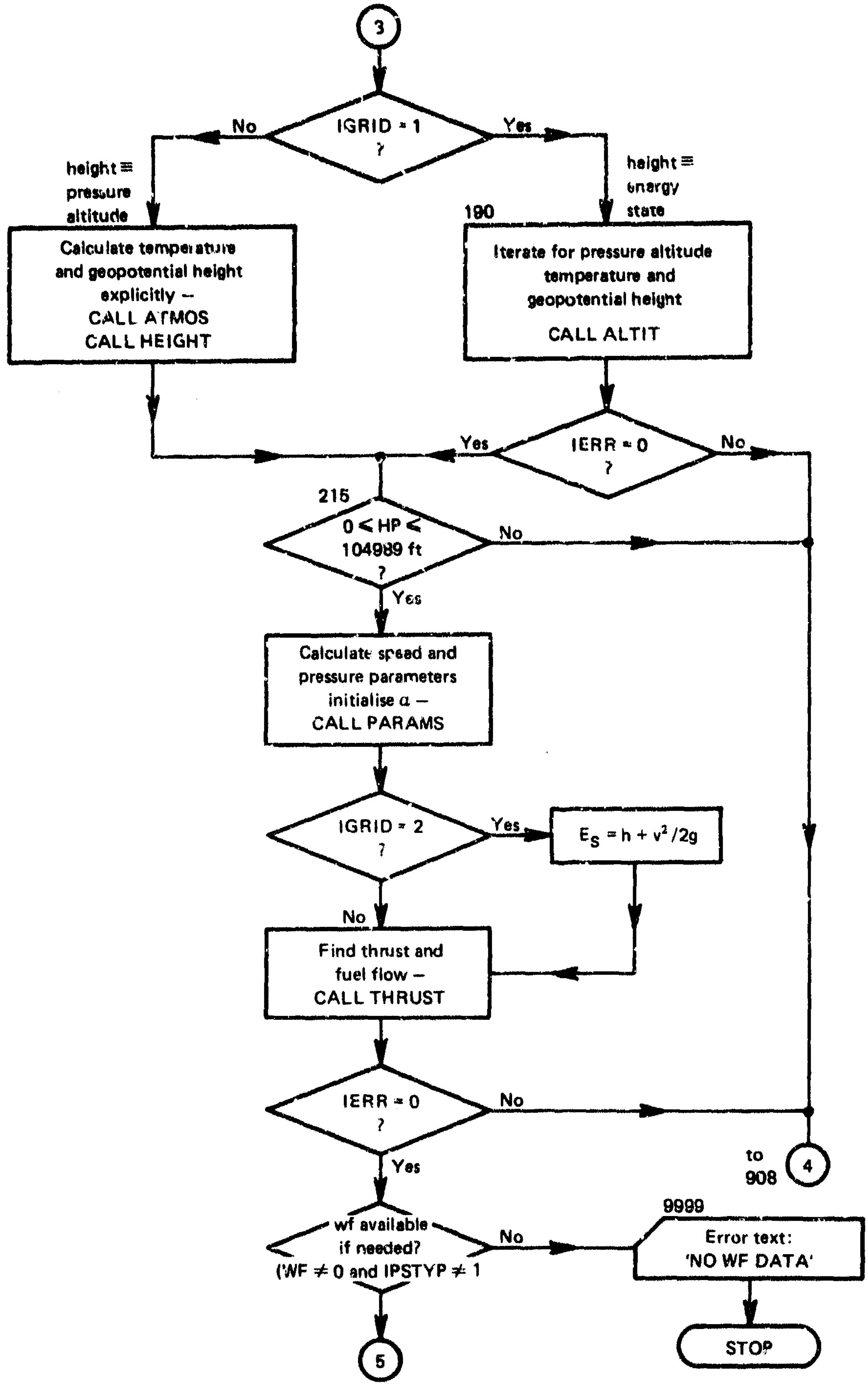

Fig. 6(b) Calculation Flowchart for Unoptimised Grids (Cont.)

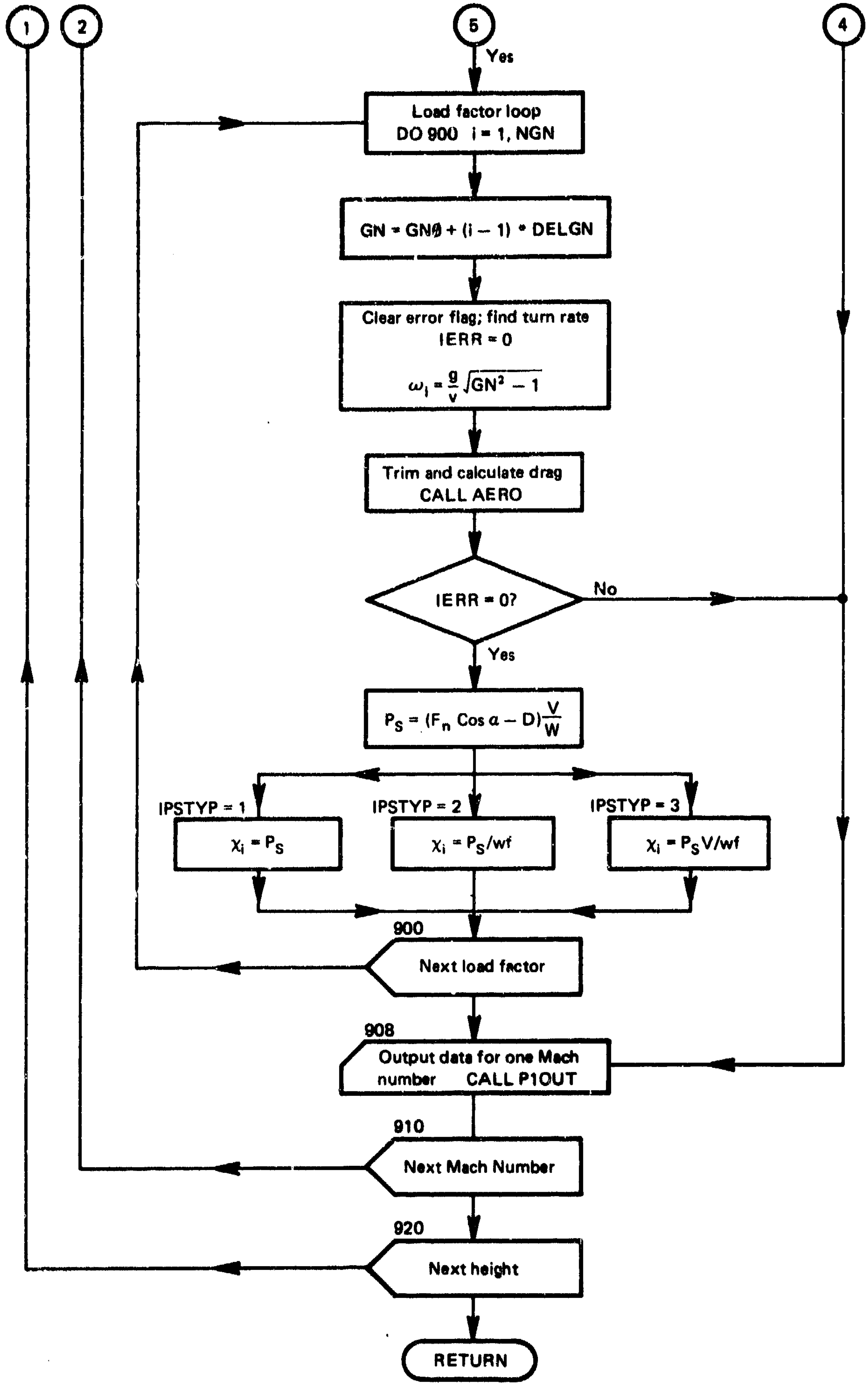

FIG. 6(c) Calculation Flowchart for Unoptimised Grids (Cont.)

Height and Mach number loops are set up according to the grid data supplied by subroutine P1IN. Vectors of energy parameter (χ) and turn rate (ω) are then calculated for the load factor grid specified. At the end of each load factor loop these vectors are transmitted to the output files before passing on to the next Mach number in the grid.

Calculation is straightforward, except that when energy state is the height variable, an iterative calculation is required to determine pressure altitude and hence geopotential height. Subroutine ALTIT performs this iteration using the algorithm developed in Appendix 1.

Output for printing is arranged as a one page summary for each height requested. On this page, each call to P1OUT produced a performance summary for the current Mach number, comprising

Mach number,
True airspeed,
Energy state or pressure altitude,
Geopotential height
Fuel flow rate,
$\left.\begin{array}{l}\text{Energy rate}\\ \text{Turn rate}\end{array}\right\}$ for the requested load factor grid.

These data are also written on the alternative output file as input to program P2. In this output however, a minimum of explanatory text is included.

Provision is made for user subroutines THRUST and AERO to flag error conditions, by returning nonzero values for the parameter IERR. Error conditions encompass thrust or aerodynamic calculations outside the defined data envelopes, inability to trim the aircraft, and altitude iterations which yield pressure altitudes outside the range sea level to 32 km (104,987 ft). When an error condition is detected, an immediate jump is made to call the output routine with default values set for χ_i and ω_i. These default values are used by P1OUT to avoid printing excessive output when error conditions occur; however, default values are included on the P2 input file and subsequently used by program P2. If W_f is required for calculating χ and no data are available, an error text is typed on the terminal and execution ceases.

Routine P1OUT converts output quantities to the required output units; the only exception to this conversion rule is that energy parameter χ is calculated directly in output units in routine TABLE.

4.4 Optimised Grid Calculation

Optimised grid calculation includes calculation of data files to produce maximum manoeuvre diagrams (turn rate contours plotted on a maximum energy rate/energy state grid) and for producing approximate schedules for minimum time, minimum fuel or maximum range climbs. In addition, conditions for optimum sustained turn rate are obtained.

Figure 7 presents a calculation flowchart for the controlling routine, subroutine MAXMAN.

Energy state and load factor loops are set up according to the grid data supplied by subroutine P1IN. The Mach number is then determined, for each combination of energy state and load factor, which optimises the energy parameter χ. The optimisation is performed, using the direct search method proposed by Rosenbrook[9] and implemented by Machura and Mulawa,[10,11] by subroutine ROMIN. The energy parameter to be optimised is calculated by subroutine SEP. Convergence to the optimum is monitored by ROMIN via calls to subroutine MONSEP. Further details concerning the use of ROMIN and its communication with SEP and MONSEP are given in Appendices 3 and 4.

Subroutine SEP calculates energy parameter χ, given energy state and load factor, calling subroutines ALTIT, PARAMS, THRUST and AERO in a similar manner to that shown in Figure 5. Error conditions resulting in nonzero values of IERR assign a default value of χ of $-9999 \cdot 99$, imposing an effective flight envelope constraint on the energy parameter.

Two features of the optimisation process peculiar to the current application deserve special attention. Firstly, the time required to achieve an optimum for any energy state/load factor combination is considerably reduced if the initial Mach number estimate is carefully chosen.

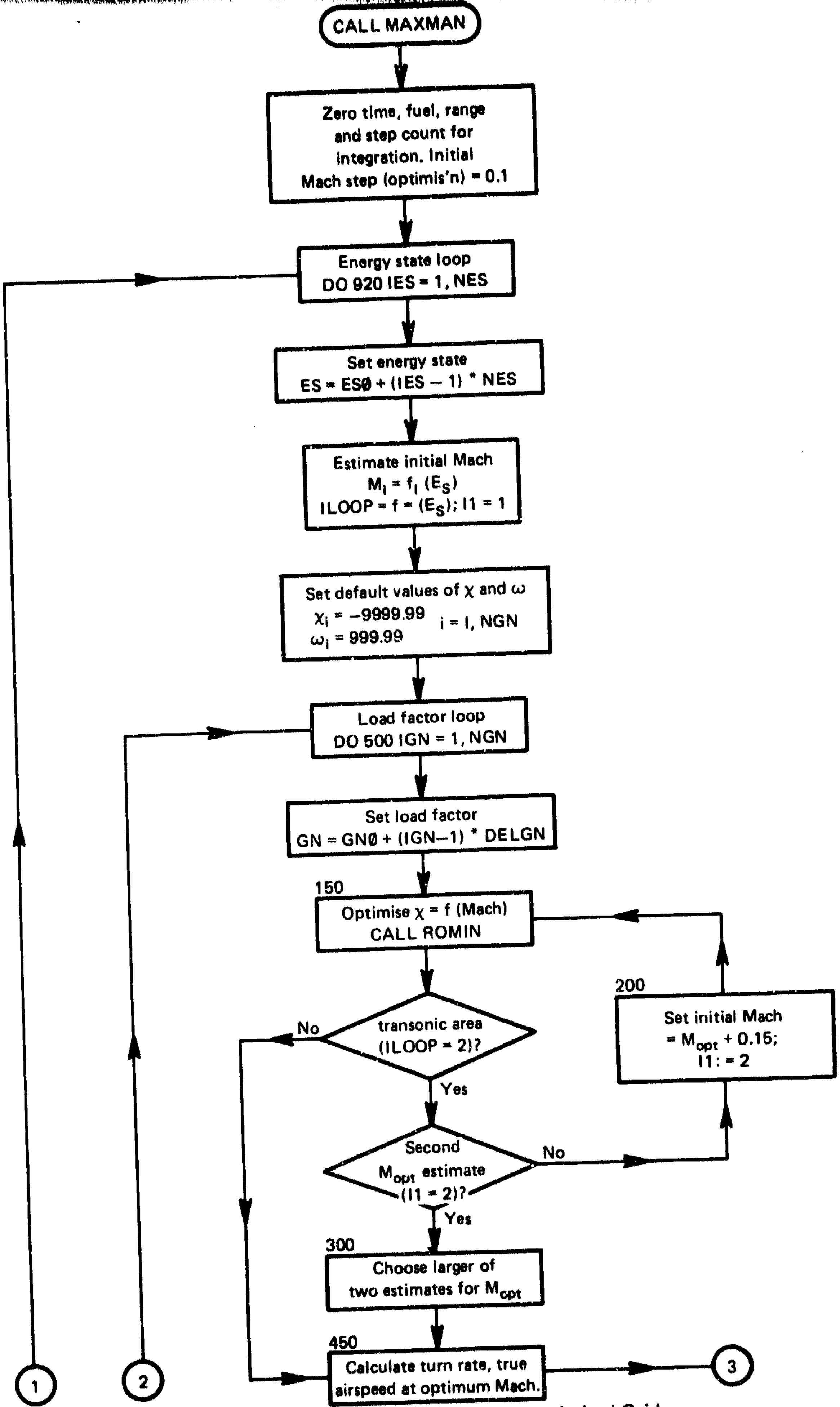

Fig. 7(a) Calculation Flowchart for Optimised Grids

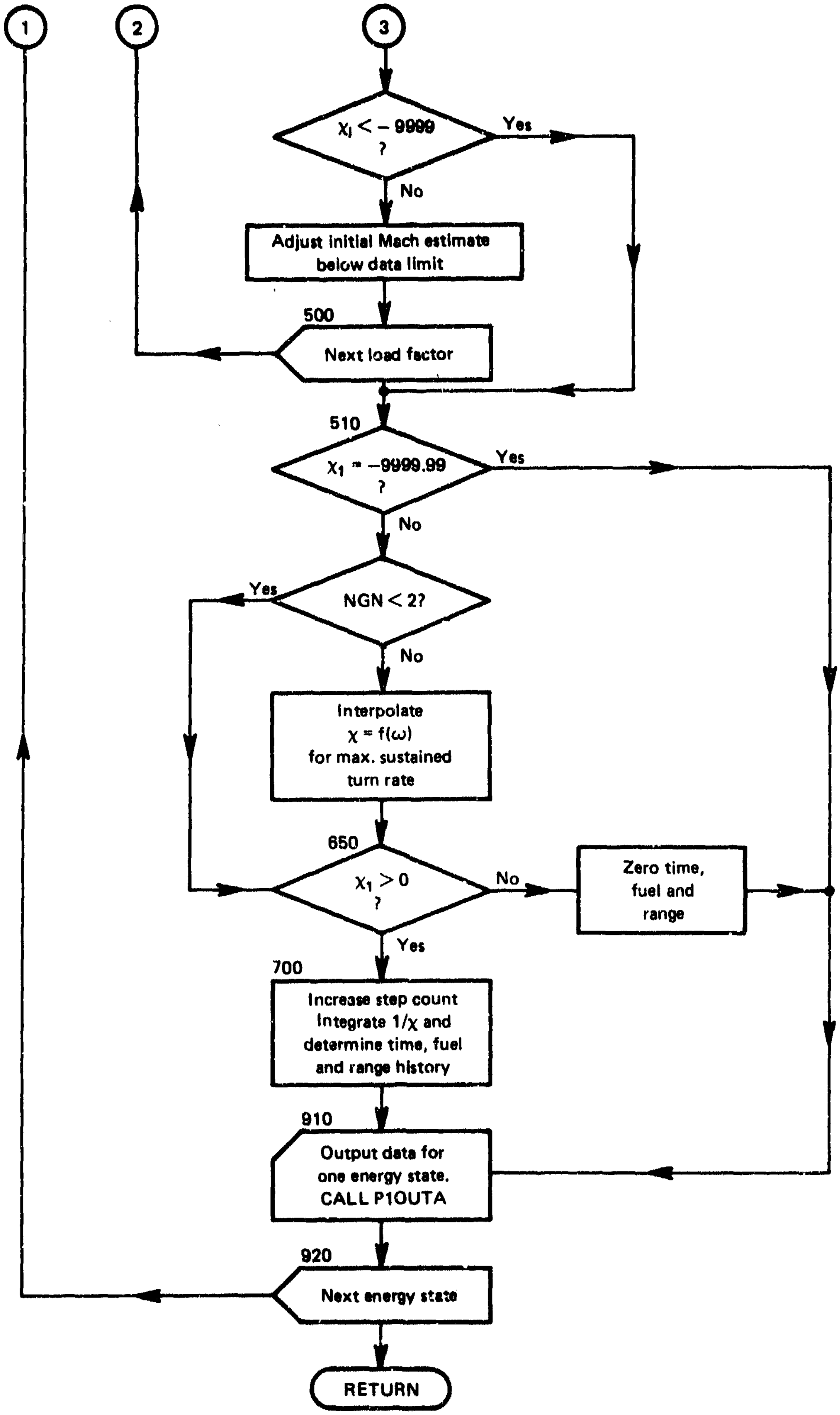

Fig. 7(b) Calculation Flowchart for Optimised Grids (Cont.)

Each time a new energy state is considered, the Mach number estimate is found from an empirically-determined function of energy state as follows:

$$\left.\begin{aligned} M_i &= E_S/10000,\ E_S \leqslant 5000 \\ M_i &= 0\cdot425+3E_S/200000,\ 5000 < E_S \leqslant 35000 \\ M_i &= 0\cdot15+E_S/50000,\ E_S > 35000 \end{aligned}\right\} \tag{3.1}$$

where M_i = initial Mach number estimate,

E_S = energy state in feet.

At each energy state, for load factors other than the first of the grid, the final Mach number from the previous optimisation is used as M_i for the next calculation. A limiting value of (M_{max} $-0\cdot05$) is applied whenever M_i exceeds M_{max}, where M_{max} is the maximum Mach number for which data is available.

Secondly, P_S variation with Mach number is such that the energy parameter χ may have two local maxima, corresponding to subsonic and supersonic regimes. At low values of E_S the subsonic peak dominates, while at higher values of E_S the supersonic peak gives the global maximum. The energy state at which the transition of this global maximum from the subsonic to the supersonic peak occurs is not known *a priori*; hence both local maxima must be investigated. This is done in subroutine MAXMAN when afterburner power is requested, by performing two optimisations for each load factor for energy states between 25000 ft and 50000 ft. M_i for the supersonic optimum is $0\cdot15$ units above the optimum Mach number at the subsonic peak. The P_S values for each optimum are compared and the largest is taken as the global maximum.

Having obtained the maximum values of χ at several values of the load factor grid, the conditions for the best sustained turn are found by interpolating load factor, turn rate, speed and pressure altitude at a value of $\chi = 0$, regarding these variables as a function of χ as load factor increases.

The final calculation performed by MAXMAN is to integrate the values of $(1/\chi)$ at 1g load factor over the available E_S range, giving an approximate climb profile. An estimate of the time taken to change energy state (Δt) is given using Equation (2.14):

$$\Delta t = (1/P_{S,av})\Delta E_S, \tag{3.2}$$

where ΔE_S is the difference in energy states, and the subscript "av" denotes the mean of values at each energy state. P_S is found from Equations (2.11), (2.12) or (2.13) depending on the value of IPSTYP (1, 2 or 3 respectively). Then the fuel increment (ΔW) and the range increment (ΔR) are found from

$$\Delta W = w_{f,av}\Delta t, \tag{3.3}$$

and

$$\Delta R = V_{av}\cos\gamma_{av}\Delta t, \tag{3.4}$$

where

$$\sin\gamma_{av} = h_{p,av}/(V_{av}\Delta t). \tag{3.5}$$

Time, fuel and range increments are summed to give the required estimates in the form of a time-history.

Routine P1OUTA controls the printing of optimised grid data, arranged as a block of data for each energy state. This block includes optimum energy rate, turn rate, Mach number, true airspeed, pressure altutude and fuel flow rate, tabulated at points on the requested load factor grid. It also includes sustained turn rate and climb performance estimates. Turn rate and energy rate data are also transmitted to the alternate output file to be used as input to program P2.

Conversion of all quantities to the required outputs is performed within routine P1OUTA, all other internal calculations being performed in Imperial units.

4.5 User-defined Subroutines

Only subroutines AERO and THRUST need to be defined by the user, although the standard main program and the BLOCK DATA subroutine must be included when creating the AIRCRAFT program library.

Subroutine THRUST returns values of powerplant thrust and fuel flow in Imperial units, using input values of altitude, Mach number, thrust setting and, if required, atmospheric quantities. The latter data is required if thrust data is available either for alternative atmospheres or in non-dimensional form with corrections for atmospheric variations. Usually only thrust for the ICAO Standard Atmosphere will be available.

Thrust and fuel flow values are determined by curve fitting, interpolation, or thermodynamic calculation, depending on which form of data is available. Data required are as follows:

$$\text{Thrust} = fn(M,\ h_p,\ \text{throttle, atmosphere}),$$

$$\text{Fuel flow} = fn(M,\ h_p,\ \text{throttle, atmosphere}).$$

A flowchart for a typical THRUST subroutine is given in Figure 8 and a sample FORTRAN IV thrust routine is given in Appendix 5.2.

Subroutine AERO returns values of angle of attack (degrees) and aerodynamic drag (pounds). Input values required are initial angle of attack estimate, Mach number, thrust, load factor, c.g. position and store drag table. Altitude will be required where aerodynamic data makes provision for any Reynolds number corrections, and wing sweep angle will be required where the aircraft has variable geometry features.

The subroutine would normally be written in two sections. The first section uses Newton's method to solve the implicit equation, (2.6), to determine trim angle of attack (α_T), and hence trimmed lift coefficient (C_{LT}). If this iteration fails to converge, or trims at an α which exceeds the maximum allowed value of C_{LT}, an error flag is set and a return is made. Once C_{LT} is satisfactory, curve fitted or interpolated data is used to determine minimum drag coefficient ($C_{D,min}$), coefficient of drag-due-to-lift ($C_{D,i}$) and store drag coefficient ($\Delta C_{D,S}$). The net aerodynamic drag is then determined by summing the drag components and multiplying by the dimensionalising force, F_{ND}.

Data required for subroutine AERO (or its equivalent) are as follows:

$$C_{LT} = fn(\alpha,\ M,\ \Lambda),$$

$$C_{L,\alpha} = fn(\alpha,\ M,\ \Lambda),$$

$$C_{L,max} = fn(M,\ h_p,\ \Lambda),$$

$$C_{D,min} = fn(M,\ h_p,\ \Lambda),$$

$$C_{D,i} = fn(C_{LT},\ M,\ h_p,\ \Lambda),$$

$$\Delta C_{D,S} = fn(M,\ \Lambda,\ \text{store configuration}).$$

A flowchart for a typical AERO subroutine is given in Figure 9, and a sample FORTRAN aerodynamics routine is given in Appendix 5.3.

Note that any further routines called by THRUST or AERO must be provided in the AIRCRAFT program library. The example in Appendix 5 requires a subroutine TRIMCL to determine aircraft trim. The amount of coding obviously depends on the complexity of the data required to represent a given aircraft.

4.6 Standardised Data Storage Allocation

The method of representation of propulsion and aerodynamic data depends on the format of available data. Where these data are produced by readily available computer programs, these programs can be easily incorporated in program AIRCRAFT as subroutines. The data may be in the form of equations which can be readily coded into FORTRAN statements. Usually, however, the data are in the form of a family of graphs, requiring either curve fitting or interpolation. The former is more economical in storage, and is preferred, providing efficient algorithms are available for evaluating the polynomial expressions using the curve-fitted coefficients.

Two methods of polynomial curve fitting are readily available at ARL. The first[18] uses Chebyshev polynomials, and was developed for use with aerodynamic functions of up to three

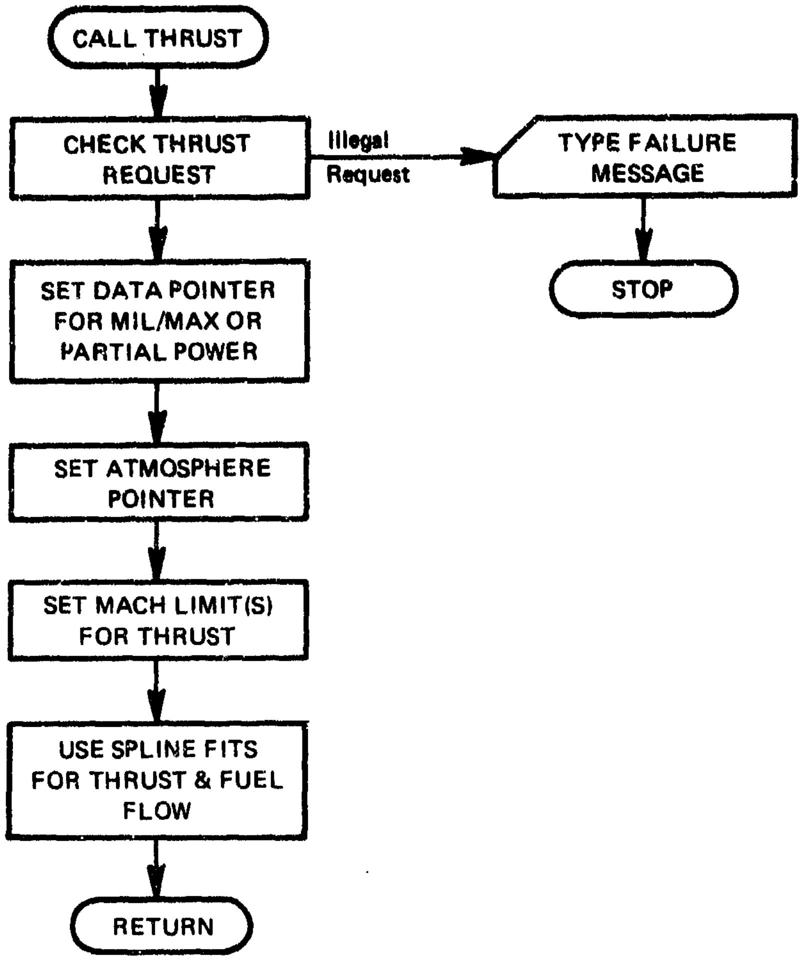

Fig. 8 Typical THRUST Subroutine Flowchart

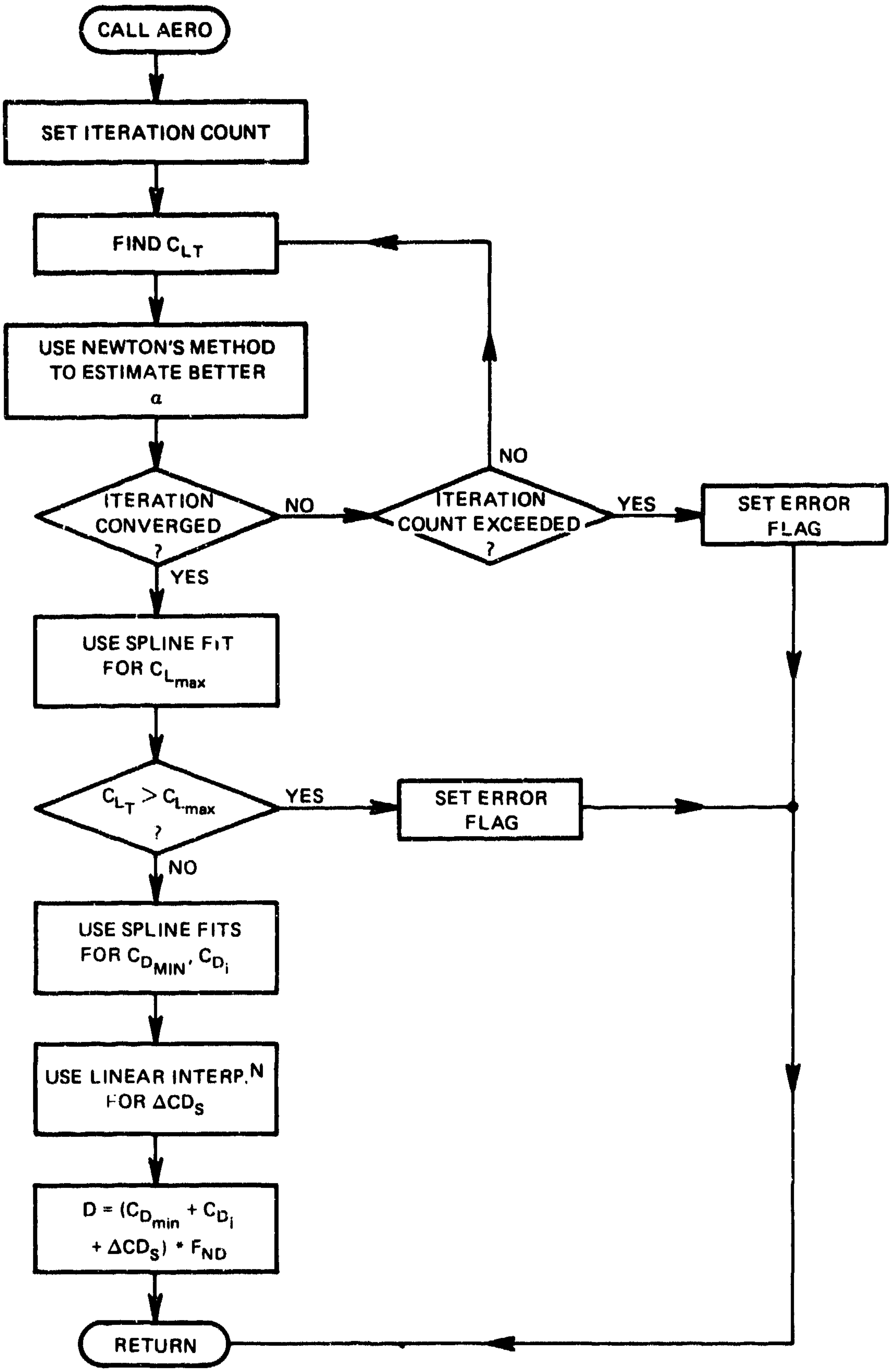

Fig. 9 Typical AERO Subroutine Flowchart

independent variables. The alternative method using B-splines as a basis was developed specifically for use in preparing data for program AIRCRAFT, and experience has shown it to provide fast, accurate evaluation using an economical storage allocation.

The method based on B-splines uses the algorithms developed by Cox[13,14] and de Boor[15] incorporated into a program called OPTFIT, which produces B-spline coefficients with optimum placement of knots. The coefficients are written on disk files which are then read by an auxiliary program, SURFM. This program enables checking of the curve fits over any desired domain of the independent variables, and combines several files of ASCII data into a single binary file of propulsion or aerodynamic data for use with program AIRCRAFT. Program library P1LIB contains the routine SURF and associated routines needed to evaluate the B-spline coefficients and produce the desired propulsion or aerodynamic data.

The sample THRUST and AERO routines presented in Appendix 5 use data stored in this manner. The binary data file structure used to represent aerodynamic and thrust data in arrays E and F is presented in Table 4.

TABLE 4

Binary Data File Structure

The data file consists of a sequence of groups of data, each representing a family of one or more curves of an aerodynamic or propulsion parameter (military power thrust, induced drag coefficient, etc.)

Item	Word	Variable	Description
1	1	AK	Number of words in the current group of data
2	2	TITLE	One word code for group of data
3	3	NCURV	Number of curves in family (floating point format)
4	4→ (NCURV+3)	CURV(1)→ CURV(NCURV)	NCURV values of independent variable y for each curve
5	(NCURV+4)	KØ	Lower bound on independent variable x
6	(NCURV+5)	KM	Upper bound on independent variable x
7	(NCURV+6)	$NCAP_j$	No. of arcs representing jth curve
9	(NCURV+7)→ (NCURV+6+ NCAP)	K(1)→ K($NCAP_j$−1)	(NCAP−1) interior knots representing jth curve
9	(NCURV+7+ $NCAP_j$)→ (NCURV+6+ 2×$NCAP_j$)	C1(1)→ C1($NCAP_j$+3)	(NCAP+3) coefficients representing jth curve

Items 7, 8 and 9 are repeated for each of the curves, giving a total storage requirement for each group of data of $(4\times \mathrm{NCURV}+2\sum_{J=1}^{\mathrm{NCURV}} \mathrm{NCAP}(J)+5)$.

4.7 Program ANY

If basic aeropropulsion data for an aircraft is not available, but comparative combat performance is still required, it is possible to use published performance curves of energy rate against turn rate or energy rate contours on a height/Mach number grid.

For this purpose a special member of the class of AIRCRAFT programs called ANY has been compiled. This makes use of the unoptimised grid calculations (Section 4.3), replacing the calculation of energy parameter using thrust and drag data by a conversational input. No input files are required, all data being supplied via the user's terminal. Output files are produced as before, with one file intended for printing and the other as input for program P2. An additional feature included in program ANY is that it will re-read the alternate output file (possibly with corrections required by on-line typing errors) to reproduce the printed output file.

Such a program has been found to be useful for a variety of purposes:

(*a*) Published turn rate curves or energy rate contours may be replotted on a more suitable scale.

(*b*) Data files can be produced for differential contour plots. Data from aeropropulsion sources can be readily compared with that from published graphs, as well as comparing one set of published graphs with another.

(*c*) The re-reading feature can be used to reproduce formatted printer files (provided P2 input is retained) without the need to recalculate the complete grid.

(*d*) Airspeed-altitude data can be produced in printed or plotted form, to complement energy rate data over the required energy state/Mach number/load factor grid.

A similar feature for replotting and comparing optimised grids (maximum manoeuvre diagrams) is incorporated as an option in program P2.

5. PROGRAM P2 DESCRIPTION

5.1 Program Structure

Program P2 is essentially a dual purpose program. On the one hand, it prepares plotter output for turn rate diagrams and overview plots of the data grid. On the other hand, it prepares data files for the contour plotting program P4. In addition assistance is given in calculating turning endurance for given fuel quantities.

The input to the program consists of data files prepared for particular aircraft by program AIRCRAFT, and additionally in the case of maximum manoeuvre diagrams, comparative aircraft data based on existing diagrams may be supplied in a conversational mode.

The modular structure of program P2 may be seen with reference to Figure 10. Subroutine P2IN opens data files and reads identification headers and then converses with the user to determine what operations to perform on the data. This is indicated by parameter IOPT, whose range of seven values determines the subroutine call for subsequent processing. The modular structure allows for easy future addition of other data processing operations.

The actions taken by the input routine P2IN and the various subroutine options are considered in the remainder of this chapter.

Brief descriptions of all user subroutines required by program P2 are given in Appendices 7 and 8. Examples of terminal input are given in the user's guide for program P2 in Chapter 8, and examples of output produced by co-ordinated running of programs AIRCRAFT, P2 and P4 are given in Chapter 10.

5.2 Input Operations with Subroutine P2IN

Subroutine P2IN determines the option parameter IOPT and performs various preliminary data input operations, depending on the value of IOPT. Figure 11 provides a flowchart for this subroutine.

After initial settings of the default output filename and recording the current CPU time, an option code is requested to determine the type of run. The seven codes, their meanings, and output files produced, are indicated by the following terminal prompt:

```
OPTIONS ARE (OUTPUT FILENAME IN BRACKETS) :                  IOPT
4A   PS CONTOUR PLOT.                               (P2.CON)    1
4B   PS VS TURN RATE FOR GIVEN HEIGHT.              (P2.PLT)    2
4C   MAXIMUM MANEUVER DIAGRAM - MMD.                (P2.OPT)    3
4D   PS DIFFERENTIAL PLOT.  (P2.CON,P2A.CON,P2DIFF.CON)         4
4E   MMD DIFFERENTIAL PLOT. (P2.OPT,P2A.OPT,P2DIFF.OPT)         5
4F   MMP CALCULATION ASSISTANCE.                                6
4Z   TURN RATE, PS VS MACH FOR GIVEN HEIGHT.        (P2.PLT)    7
**   ANY OTHER REPLY PRODUCES THIS HELP TEXT
```

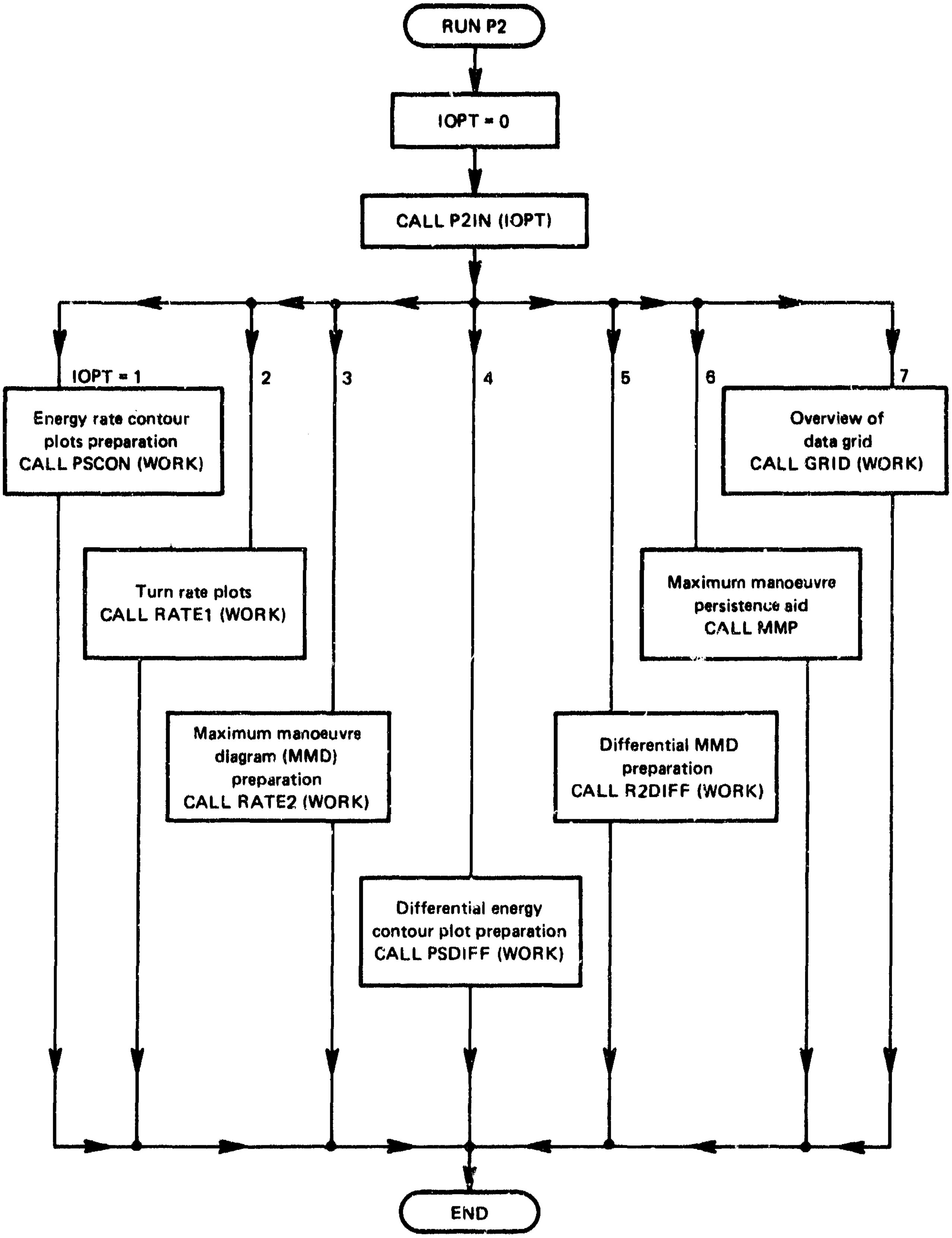

Fig. 10 Program P2 Structure

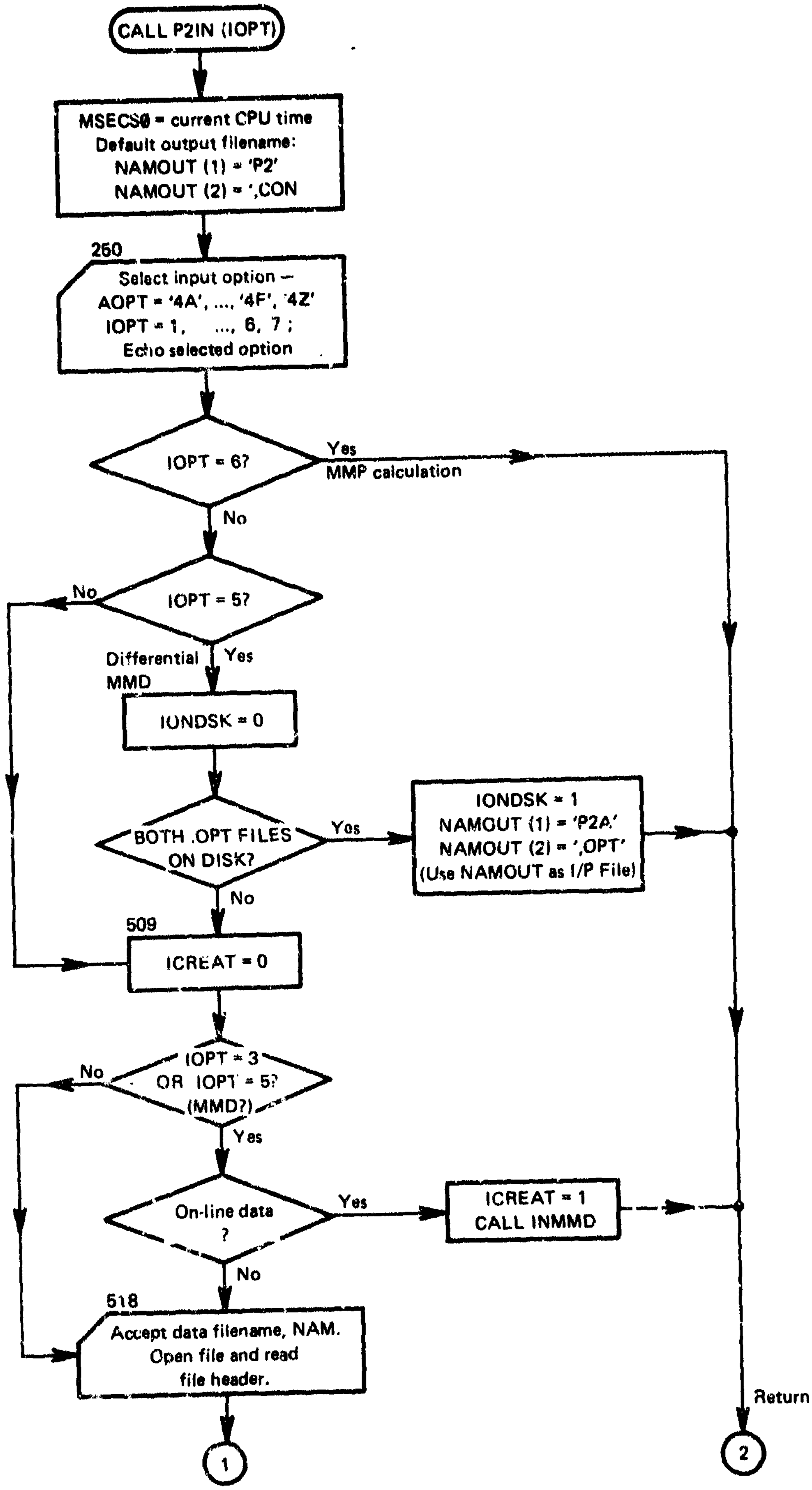

Fig. 11(a) Subroutine P2IN Flowchart

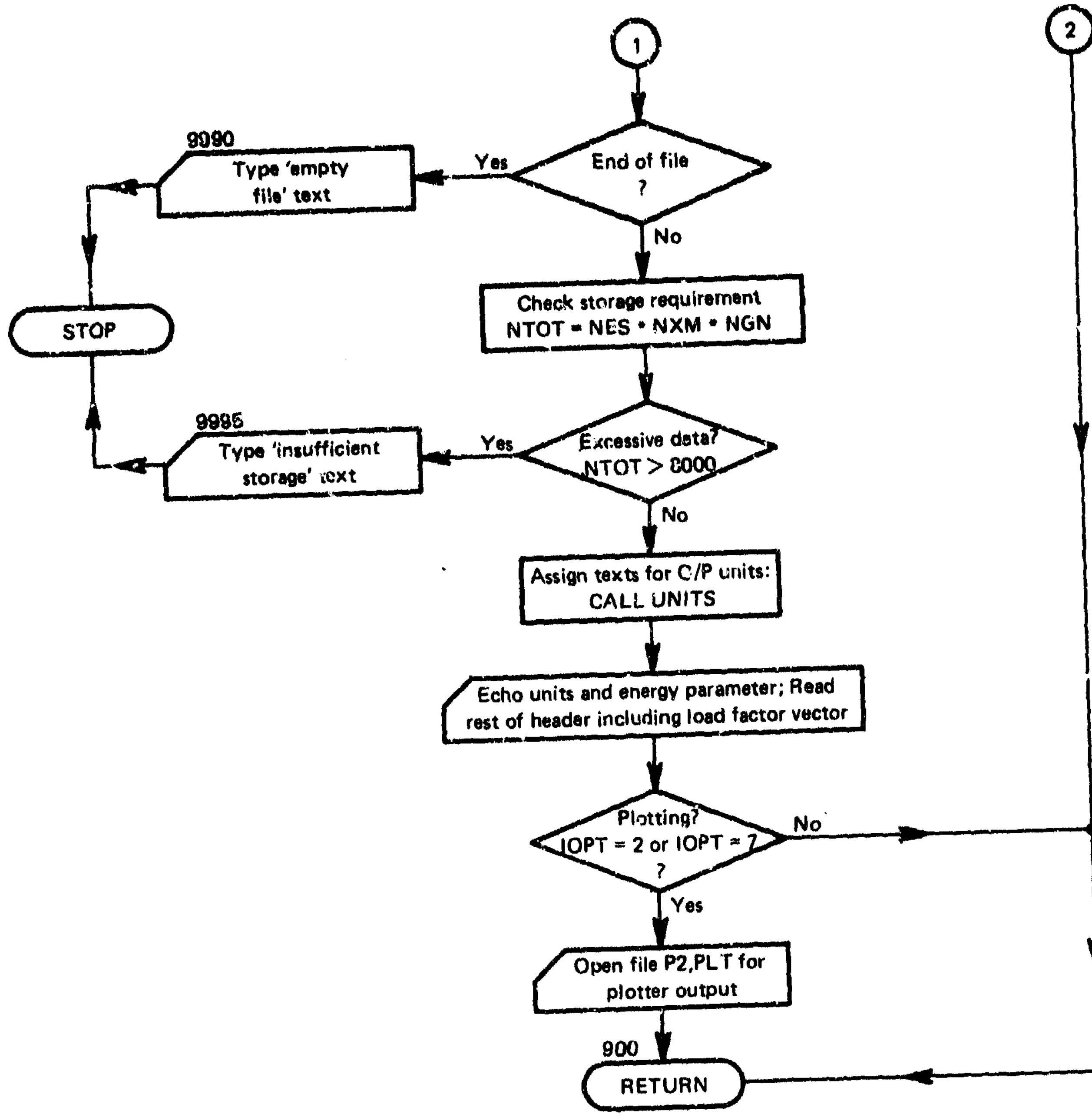

Fig. 11(b) Subroutine P21N Flowchart (Cont.)

If MMP calculation assistance is requested, an immediate return to the main program is made, since all input/output operations for that option are conversational, on the user's terminal.

If a differential MMD is requested (IOPT = 5), a further test is made if the two files of required comparative data (filenames P2.OPT and P2A.OPT) already exist on disk. If not, subroutine P2IN continues in order to produce these files. If ".OPT" files do already exist, the flag IONDSK is set, and comparison filename P2A.OPT stored in NAMOUT before returning to the calling program.

If any type of MMD is requested (IOPT = 3 or 5) and on-line data is to be supplied, flag ICREAT is set, and routine INMMD is called to accept identifying text before returning to the calling program.

For remaining options, a filename of output from program AIRCRAFT is supplied and header data identifying the aircraft and the data grids is read. The storage requirement is checked against the 8000 words available in array WORK, and, if it is excessive, an error text is typed on the user's terminal and execution ceases. If sufficient storage is available, execution continues by assigning text headings and echoing data units and the type of energy parameter on the terminal.

If plotter output is to be produced (IOPT = 2 or 7), plot file P2.PLT is opened before returning to the main program.

5.3 Subroutine PSCON to Produce Energy Rate Contour Data

The purpose of subroutine PSCON is to rearrange the grid data produced by program AIRCRAFT and produce energy rate contour output compatible with the requirements of the contour plotting program P4.

The operation of the subroutine is quite straightforward, and can be described without reference to flowcharts. The file indicated by NAMOUT is opened and the header text written. An outer loop for the height variable and an inner loop for Mach number are set up and Mach number and energy state are read from the input file, followed by energy rate data over the full load factor grid. The matrix of energy stated on the Mach number/altitude grid is written on the output file, in case energy state contours will be required.

The energy rate matrix on the Mach number/altitude grid is then written on the output file for each of the requested load factors. A conversational input allows the user to select the load factors for which contour plots are desired, from the available data.

Load factor requests are stored, so that if PSCON is called by subroutine PSDIFF to produce data for differential contour plots, the load factor grid will be identical.

At the end of the load factor loop, control returns to the calling routine, either the main program or subroutine PSDIFF.

5.4 Subroutine RATE1 to Produce Turn Rate Data

Subroutine RATE1 is called when IOPT has the value 2 (option 4B). Its purpose is to read the data file produced by program AIRCRAFT and produce plots of energy rate against turn rate. The plots are produced by joining the (turn rate, energy rate) co-ordinates of points calculated at small increments of load factor.

A flowchart for the subroutine is given in Figure 12. The first action of the subroutine is to plot a header text on the plot file on logical unit 1, followed by setting of storage pointers. Axis scales and energy rate axis definition are provided on the user's terminal. An "invalid input" text is given if either scale is zero or if the y-axis length is not in the range 0 to 26·7 cm (10·5 in.).

One page of plots is produced for each requested height variable on an A4 size area. From the sets of height and Mach number data on the data input file (logical unit 5), particular combinations of height and Mach number may be selected by replying to the prompts as follows:

Reply		*Meaning*
YES	.. ..	Plot data for this value
NO	.. ..	Skip to the next value
ALL	.. ..	Plot data for all remaining curves at this height
END	.. ..	Terminal execution now.

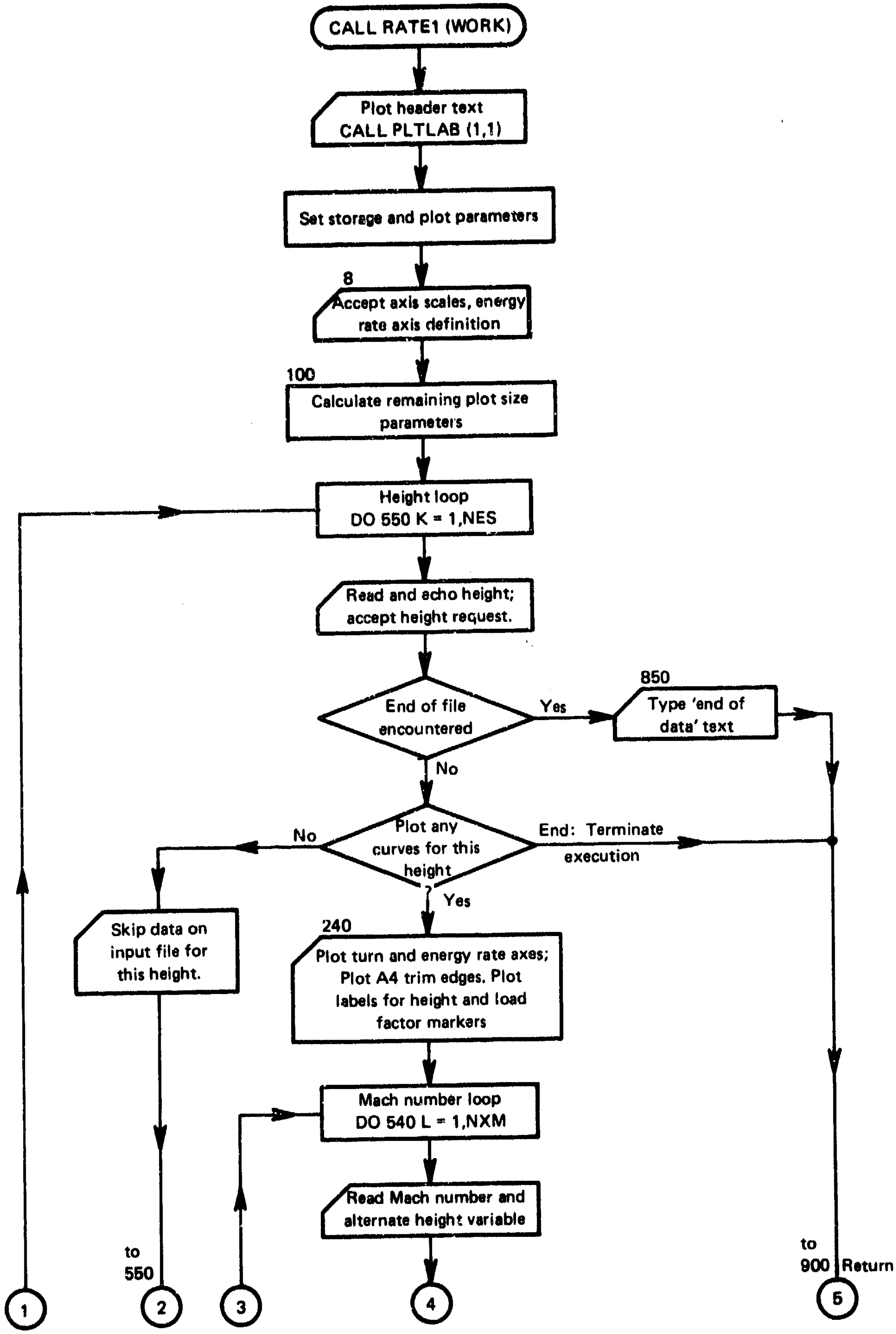

Fig. 12(a) Subroutine RATE1 Flowchart

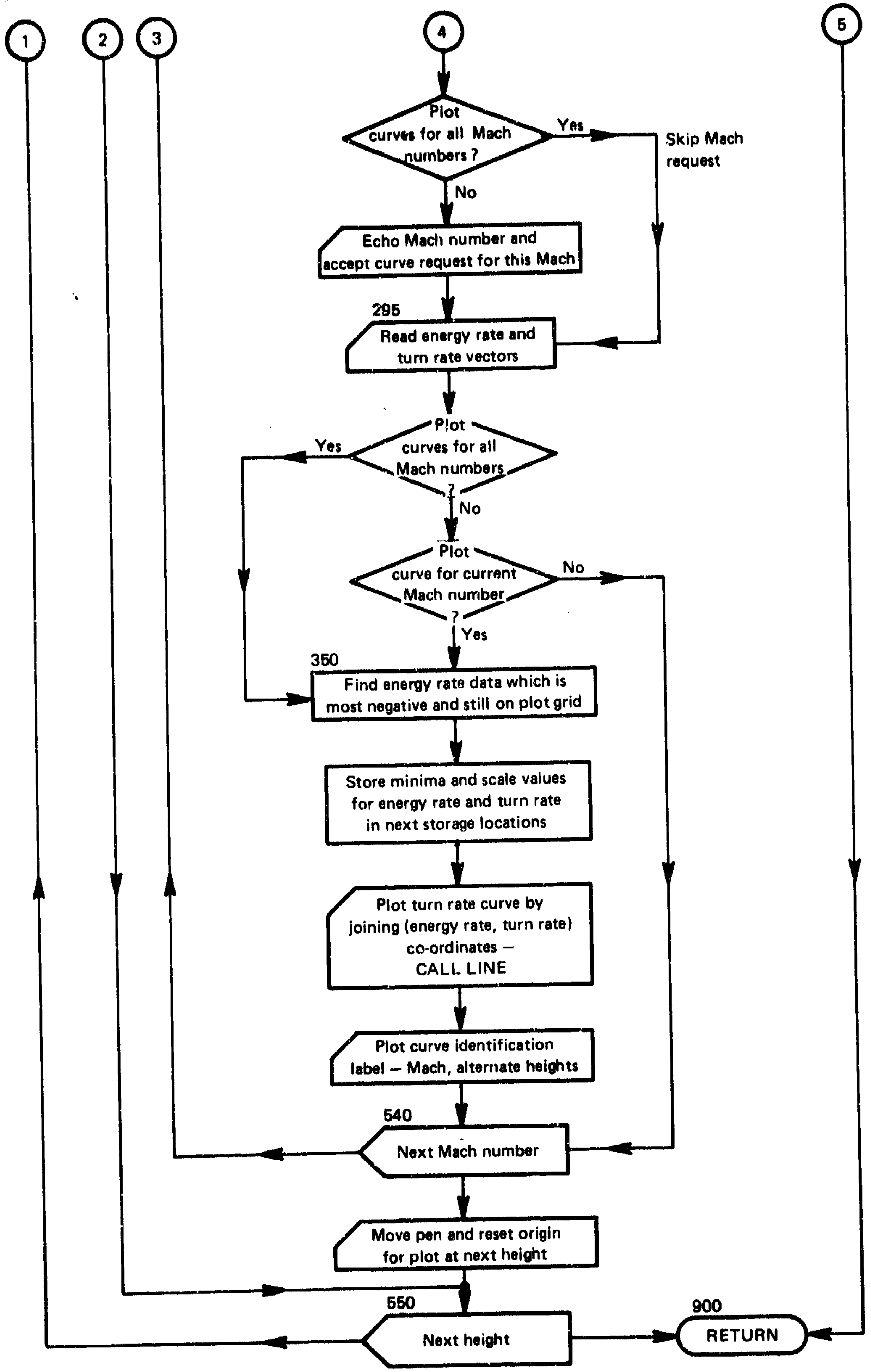

Fig. 12(b) Subroutine RATE1 Flowchart (Cont.)

If data are not required for any height, the input file is advanced to consider the next height. Otherwise axes, A4 trim edges and height and load factor labels are plotted before reading turn rate data for the first Mach number. If all Mach numbers are requested, plotting is continued without further Mach number prompts.

If data is not requested at any Mach number, the program reads in data for the next Mach number before giving the request prompt. For each Mach number requested, scales and minimum values of the x- and y-axes are stored in locations required by subroutine LINE before calling that subroutine to join the (turn rate, energy rate) co-ordinates with straight lines. These co-ordinates are at fixed increments of load factor, and it is evident that reasonably small increments are required when running program AIRCRAFT (approximately $0 \cdot 25g$) to produce a smooth curve. $1g$ increments of load factor are indicated on the curve, together with a label identifying the Mach number and alternate height for the curve. ("Alternate height" refers to whichever of the two height variables, energy state or pressure altitude, is *not* being used as the controlling grid.)

After all Mach numbers for the given height have been considered, the pen is moved to a new origin for the next value of height. After all heights have been considered, control returns to the main program to terminate execution.

5.5 Subroutine RATE2 to Produce MMD Data

The purpose of subroutine RATE2 is to produce turn rate contour data output on an energy state/optimum energy rate grid prior to processing by the contour plotting program P4. Usually the input will be a data file produced by program AIRCRAFT as optimum energy rate data on an energy state/load factor grid; the data is rearranged to the desired output format. Alternatively, input may be supplied in conversational mode, reproducing published MMD plots on the required MMD grid.

Figure 13 presents a flowchart for this subroutine. The energy rate grid for the MMD contour plot is supplied via the user's terminal as the first operation. Definition of this grid is not required if on-line data is being supplied or if a file of comparative data is being produced, since the grid has already been defined, either in a call to subroutine INMMD, or in a previous call to the subroutine RATE2.

Within the loop for each energy state two main operations occur. These are, firstly, to construct two vectors of optimum energy rate and corresponding turn rate data as load factor increases (if on-line data is being supplied). Secondly, using either this on-line data or data read from a disk file, to interpolate or extrapolate turn rate values at fixed increments of optimum energy rate.

In supplying on-line MMD data, pairs of (turn rate, optimum energy rate) are requested, with turn rate increasing. If a non-increasing turn rate value is detected, all data for the current energy state is rejected and the data input restarted. Up to 50 data points may be supplied, the end of the curve being indicated by a negative value of turn rate.

In using the PSTAB and OMTAB vectors to find turn rate values at fixed increments of optimum energy rate (P_S), three regions are detected. If data limits are exceeded (e.g. lift limit) at large negative values of P_S, default values for turn rate ($-10 \cdot 0$) and P_S ($-9999 \cdot 99$) are stored in the grid matrix WORK. If the grid value of P_S is above the zero turn rate boundary, nominal values of turn rate are calculated by extrapolation. These (negative) values of turn rate are physically unrealisable, but are useful in providing a smooth zero turn rate contour on MMD plots. The third region is that where valid turn rate data is calculated by linear interpolation in the vectors OMTAB and PSTAB at the grid value of P_S.

After all input energy states have been considered, the turn rate matrix is written on the output file on an energy state/optimum energy rate grid, for use as input to the contour plotting program P4.

5.6 Subroutine PSDIFF to Produce Differential Energy Rate Contour Data

Subroutine PSDIFF is called by the main program when IOPT has the value 4 (option 4D). Data files produced by program AIRCRAFT are read in order to produce differential energy rate contour data for input to program P4.

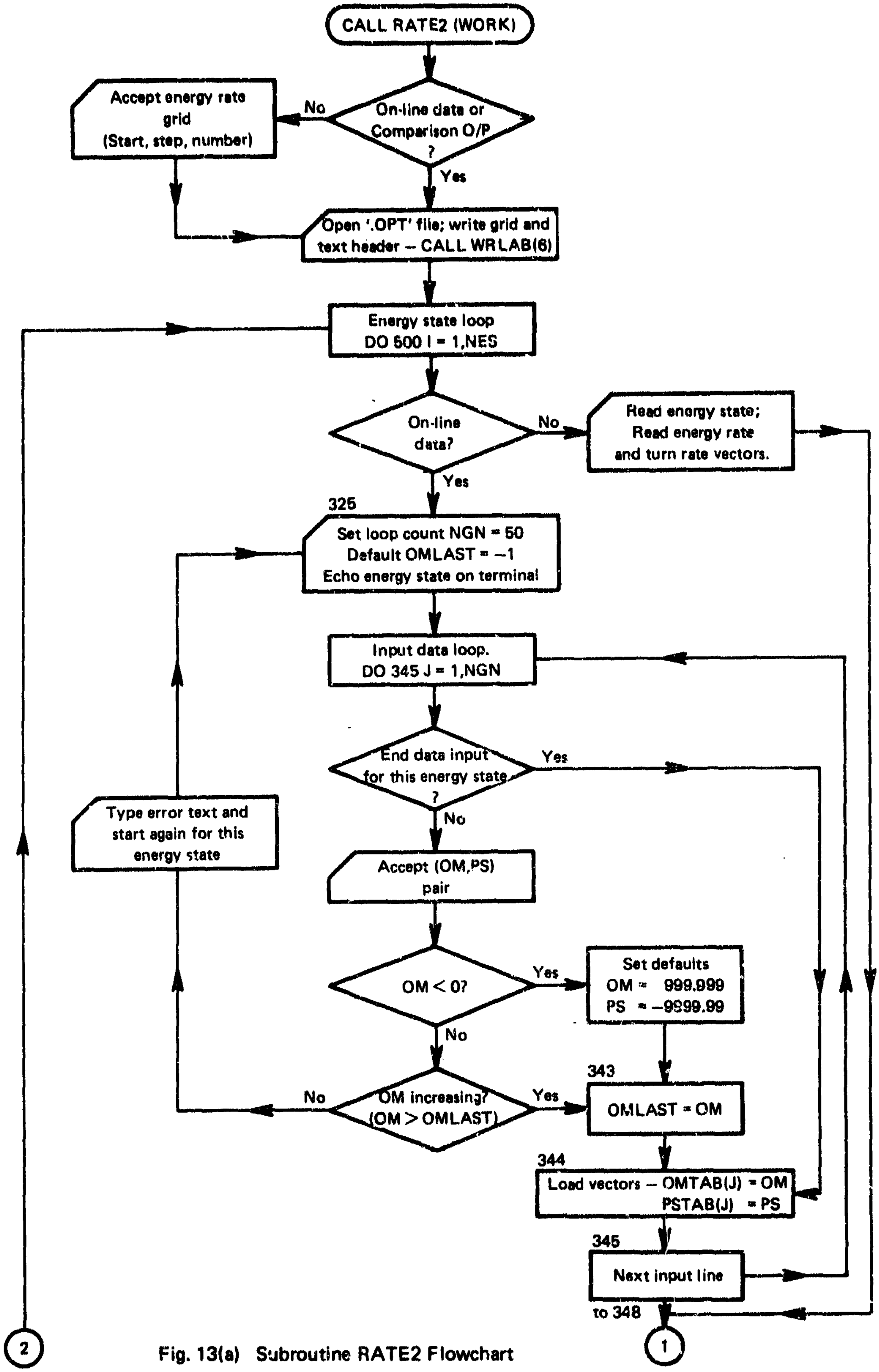

Fig. 13(a) Subroutine RATE2 Flowchart

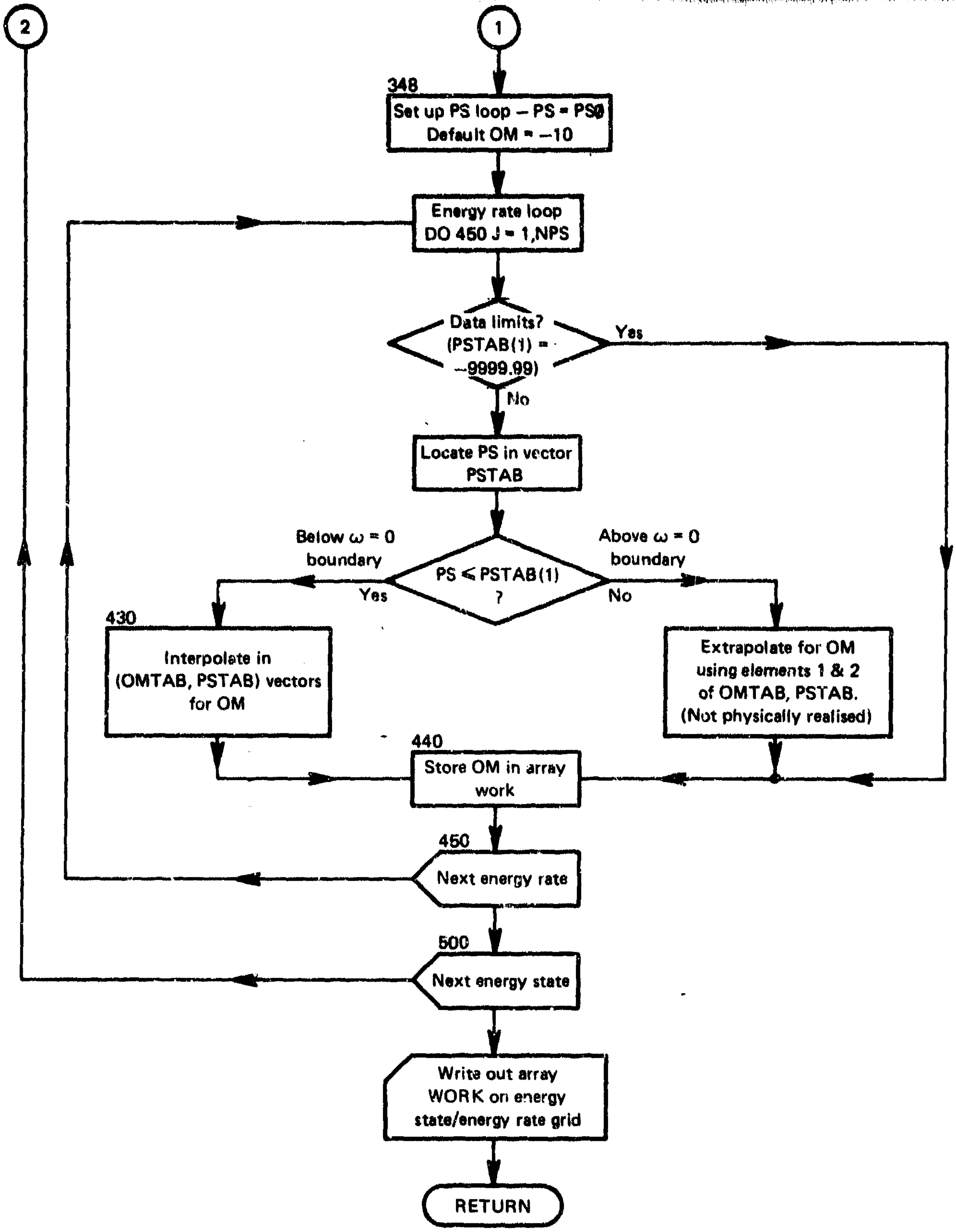

Fig. 13(b) Subroutine RATE2 Flowchart (Cont.)

A flowchart for the subroutine is given in Figure 14. The logic is straightforward, but input and output file operations need some comment. Using the file indicated as primary input, subroutine PSCON is called to produce base data on file "P2.CON". These input and output files are closed and the comparison file is opened and grid data read. If the base and comparison grids for height, Mach number or load factor, or flags for unit systems or types of energy parameter differ in any way, an error text is typed and execution terminated.

If the grids are identical, comparison contour plot data is written on file P2A.CON with a second call to subroutine PSCON. Input and output files are again closed; base and comparison data files opened as input files, and file "P2DIFF.CON" opened to receive the differential contour data. Grid data is transferred to the output file, together with identifying texts for both aircraft. Energy state contour data is written for the required Mach number/height grid and input files positioned to read energy rate data.

Load factor and height loops are set up, to read vectors of energy rate data at each height. These vectors are subtracted, and the difference vector written on the output file. The load factor loop continues until all requested load factors have been processed. If any load factors were not requested for plotting during calls to PSCON, unit 4 will run out of data before the loop terminates, and an information text to that effect is typed on the terminal.

It is seen that using the option for differential plots results in three data files—one for each aircraft and the differential data, any of which may then be processed with program P4.

5.7 Subroutine R2DIFF to Produce Differential MMD Data

Subroutine R2DIFF is called by the main program when IOPT has the value 5 (option 4E). Data files produced previously may be read, or data may be supplied in a conversational mode, in order to produce differential maximum manoeuvre diagram data as input to program P4.

A flowchart for the subroutine is given in Figure 15. The structure is similar to that for subroutine PSDIFF, but is made more complex by the provision of options for generating data on-line and for using existing ".OPT" files to generate a differential data file. The subroutine is roughly in two phases: generation of base and comparison files (Fig. 15*a*) and generation of the differential file (Fig. 15*b*).

If the files for comparison are on disk when R2DIFF is called (IONDSK = 1), the first phase is skipped. Otherwise the base and comparison files are generated with calls to subroutine RATE2, using either on-line data or data files generated by program AIRCRAFT. Units 5 and 6 are used as input and output units respectively, in this phase. Energy state grids of base and comparison data and flags for unit systems and types of energy parameter are compared, and, if different, an error text is typed before terminating execution. In the first phase there is no need to compare energy rate grids because the same input reply has been used for both sets of data. Base and comparison data are written on files "P2.OPT" and "P2A.OPT" respectively.

In the second phase, a preliminary file of differential turn rate is written on file "DUM", using files "P2.OPT" and "P2A.OPT" as logical units 4 and 5 respectively. Identifying text headers are not needed on this preliminary output, and input files are positioned accordingly by the loop "Skip file headers". If independently generated ".OPT" files are used, it is necessary to compare data grid definitions. If any difference appears, an error text is typed and execution terminated.

Turn rate vectors for each energy rate level are then read from the input files, subtracted, and the result written on the output file. The system program PIP is run to combine the input files and the preliminary output file into the final output file "P2DIFF.OPT". This file now contains contour data for both aircraft and their comparison; the three sets of data are required for program P4 to generate zero turn rate (1*g*) boundaries as well as differential turn rate contours.

CPU time used is calculated by subroutine R2DIFF because the running of program PIP bypasses CPU time output generated by the FORTRAN operating system.

5.8 Subroutine MMP to Aid in Maximum Manoeuvre Persistence Calculation

Subroutine MMP is called by the main program when IOPT has the value 6 (option 4F). No input or output files are involved as all communication is via the user's terminal. When

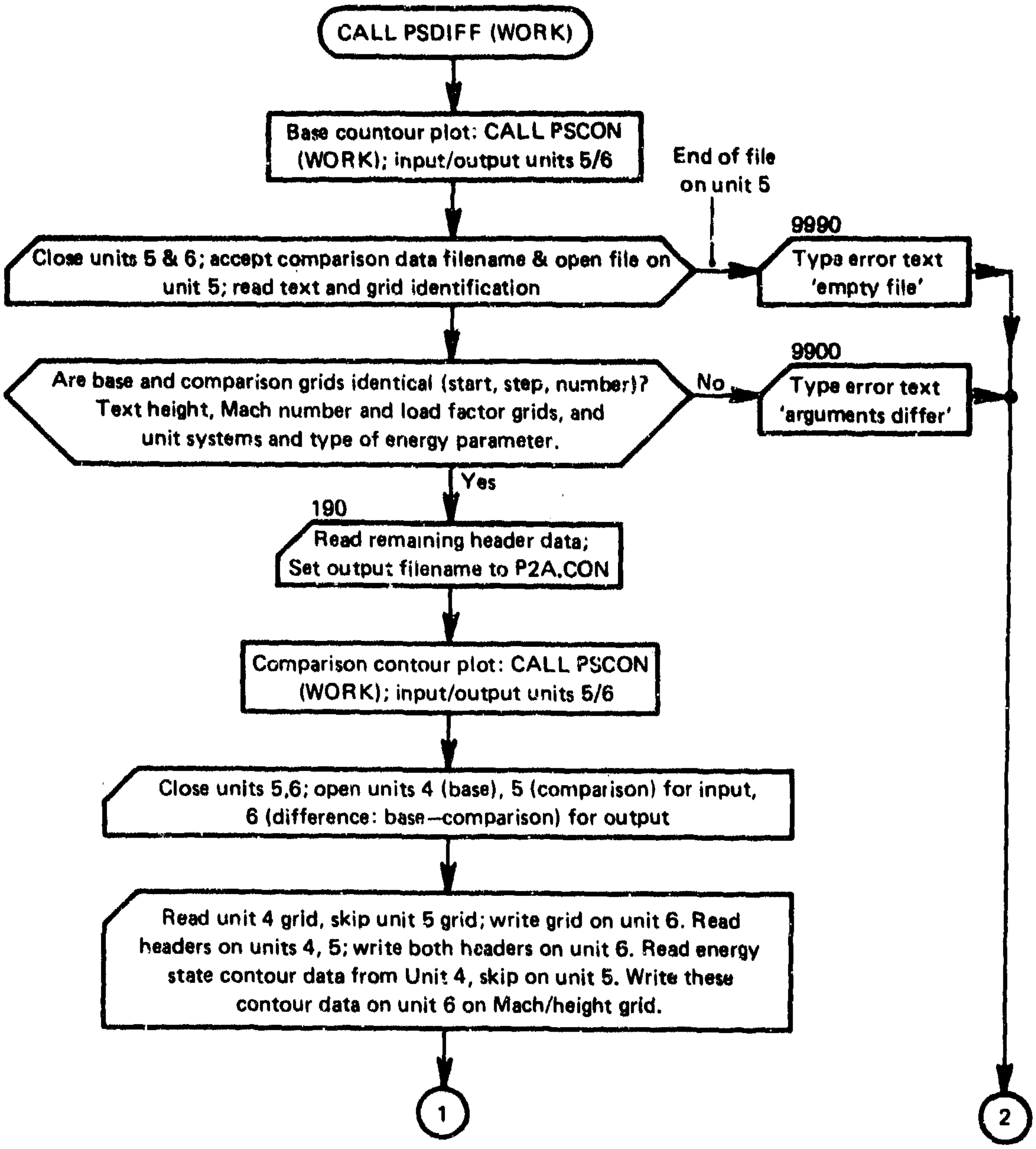

Fig. 14 (a) Subroutine PSDIFF Flowchart

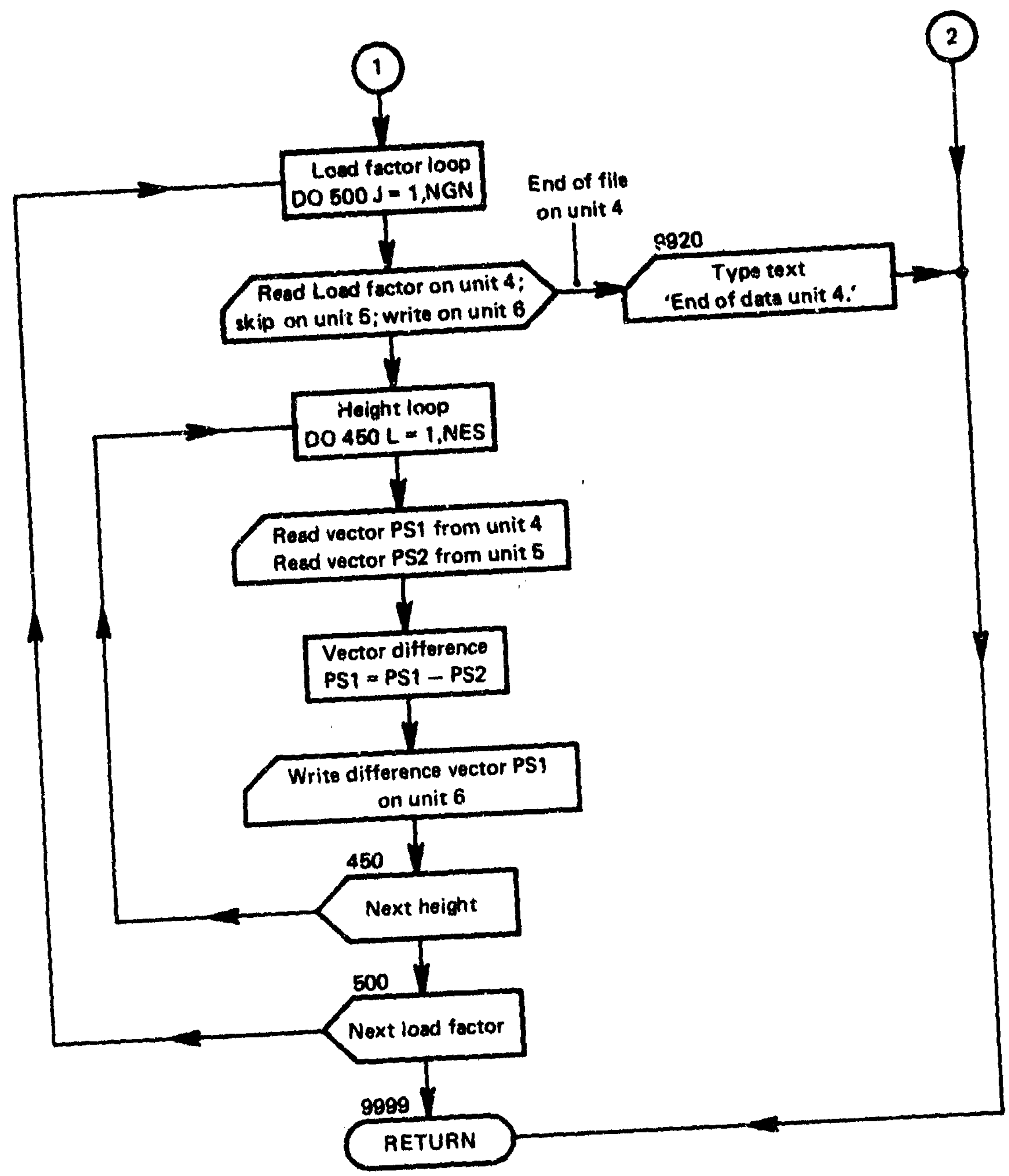

Fig. 14 (b) Subroutine PSDIFF Flowchart (Cont.)

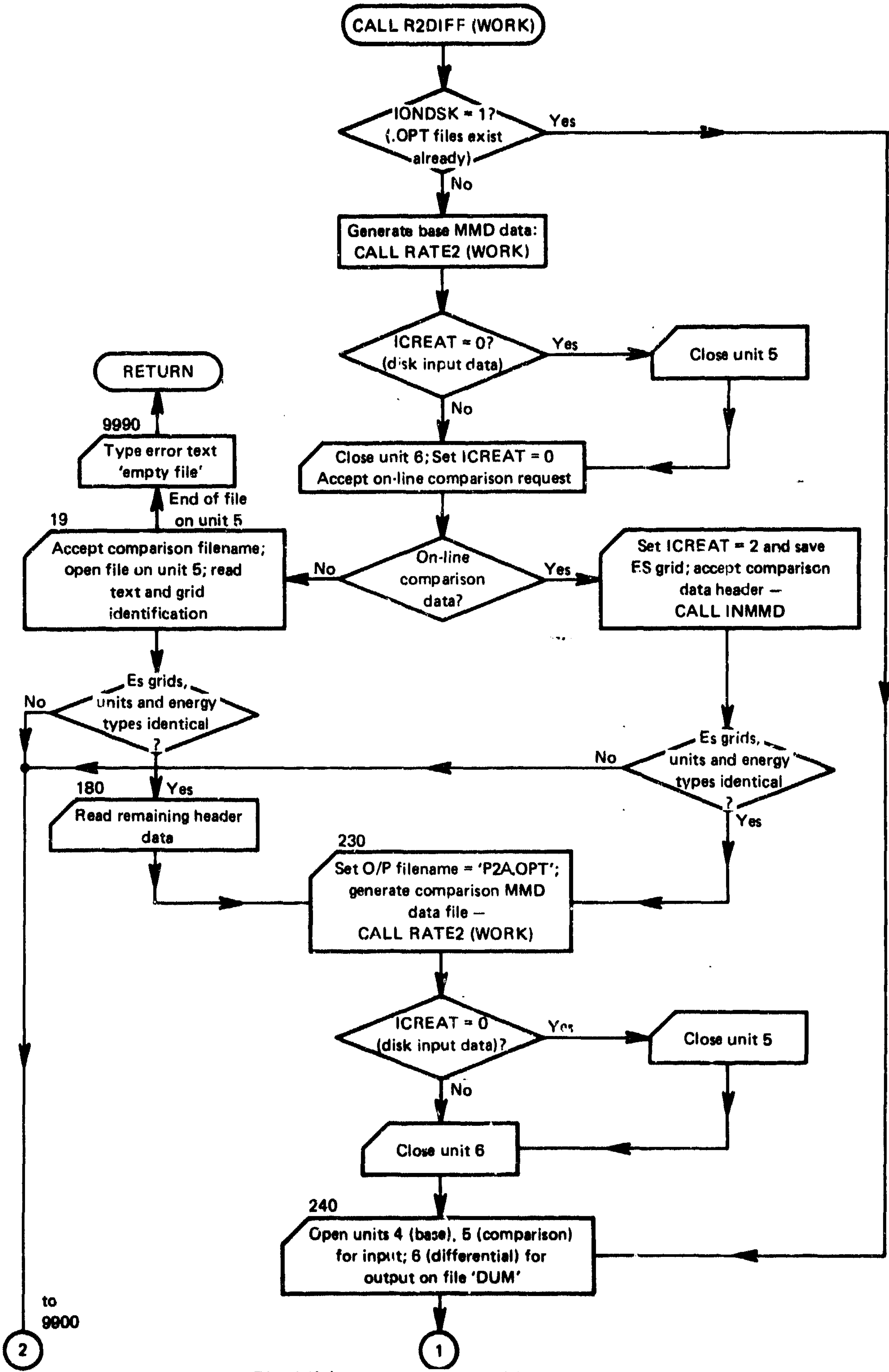

Fig. 15(a) Subroutine R2DIFF Flowchart

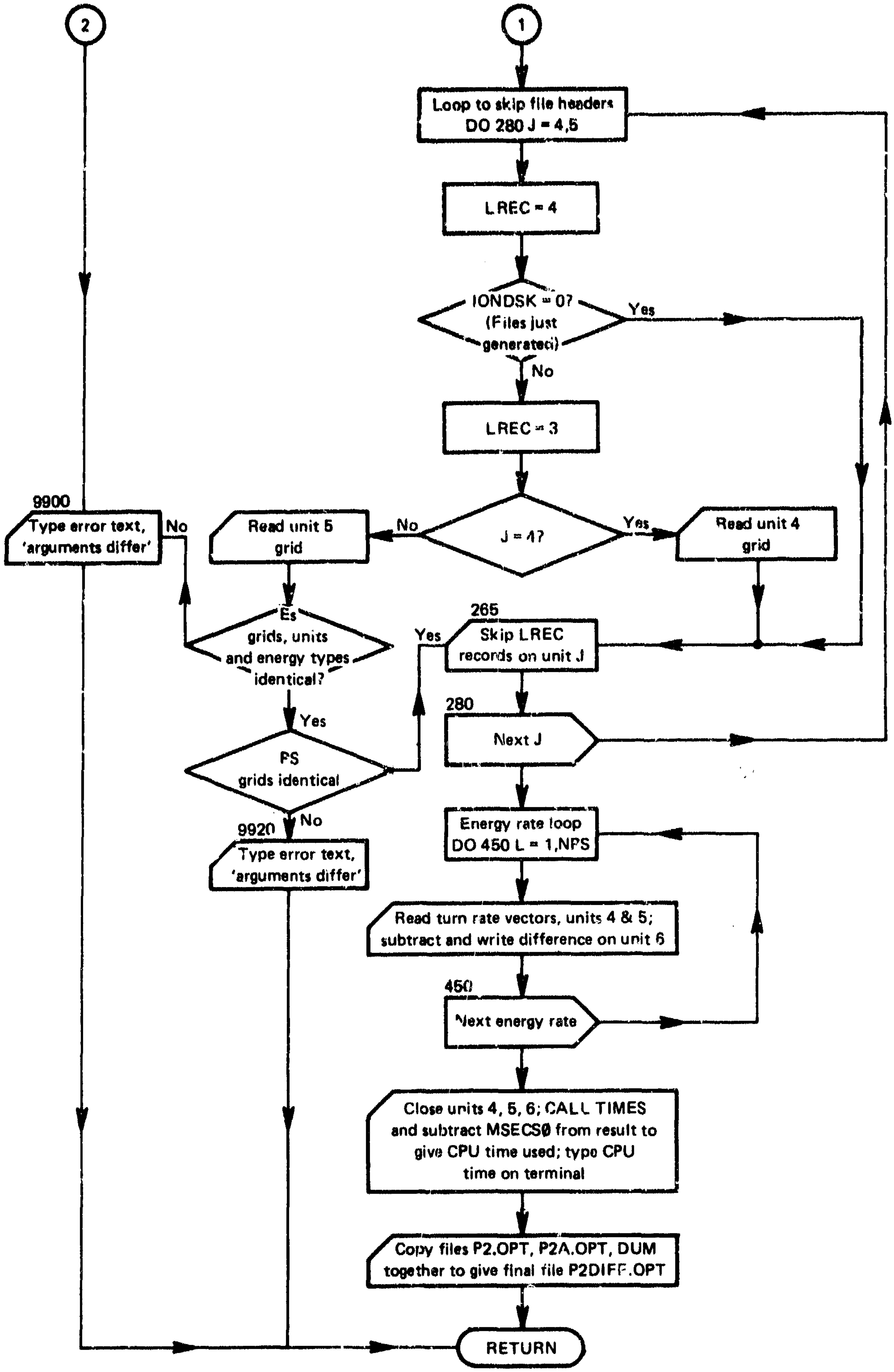

Fig. 15(b) Subroutine R2DIFF Flowchart (Cont.)

fuel/distance diagrams are constructed for outward and return legs of a mission,[2] the resulting wedge represents the diminishing fuel available for manoeuvres as range from base increases. For any given energy state, using maximum manoeuvre output from program AIRCRAFT the user can determine optimum sustained turn rate and the fuel flow rate at the resulting Mach number and altitude. Subroutine MMP aids in calculating the number of turns (n_T) possible at optimum turn rate and fuel flow rate, given the available fuel quantity, according to

$$n_T = \frac{10\omega \, . \, W}{\nu w_f}, \tag{5.1}$$

where ω = optimum sustained turn rate (deg/s),
w_f = fuel flow rate, kg/s (lb/hr),
W = available fuel, kg (lb),
ν = unit scale factor = 1/3600 (1 for Imperial units).

The routine first accepts the number of ranges and the available fuel at each of these ranges. Then for a given energy state, optimum turn rate and fuel flow rate are provided, and Equation (5.1) is calculated for each range. New energy state data are requested and calculation repeated until a zero value of energy state is supplied, when execution terminates.

n is termed the maximum manoeuvre persistence, and may be plotted either against energy state at fixed ranges, or against range at fixed energy states. The former is more informative. Example plots are given in Reference 2.

5.9 Subroutine GRID to Produce Raw Data Overview Plots

Subroutine GRID is called when IOPT has the value 7 (option 4Z). Its purpose is to read the data file produced by program AIRCRAFT, and produce plots of turn rate and energy rate against Mach number for given values of the height variable. The plots are produced by joining the required points, calculated at small increments of Mach number. These plots are intended as an overview of the data grid, and consequently are produced with predetermined scales. The variable ranges obtained using these scales are shown in Table 5.

A flowchart for the subroutine is given in Figure 16. The first action is to plot a header text on logical unit 1, followed by allocation of storage constants. From the grid data supplied on the data input file (logical unit 5), particular combinations of height and load factor may be selected by replying "YES", "NO", "ALL" or "END", as indicated in Section 6.4. If data is not to be

TABLE 5

Ranges of Variables Plotted by Routine GRID

Axis	Variable	IPSTYP	IUNITS	Units	Range		Scale units/in.
					Min.	Max.	
x	Mach number			—	0	2·5	0·4
y1	Turn rate			deg/s	0	25	5
y2	P_S	1	0	m/s	−600	400	200
			1	ft/s	−1500	1000	500
	P_S/w_f	2	0	m/kg	−75	50	25
			1	ft/lb	−150	100	50
	$P_S V/1000 w_f$	3	0	m²/kg.s	−75	50	25
			1	ft²/lb.s	−150	100	50

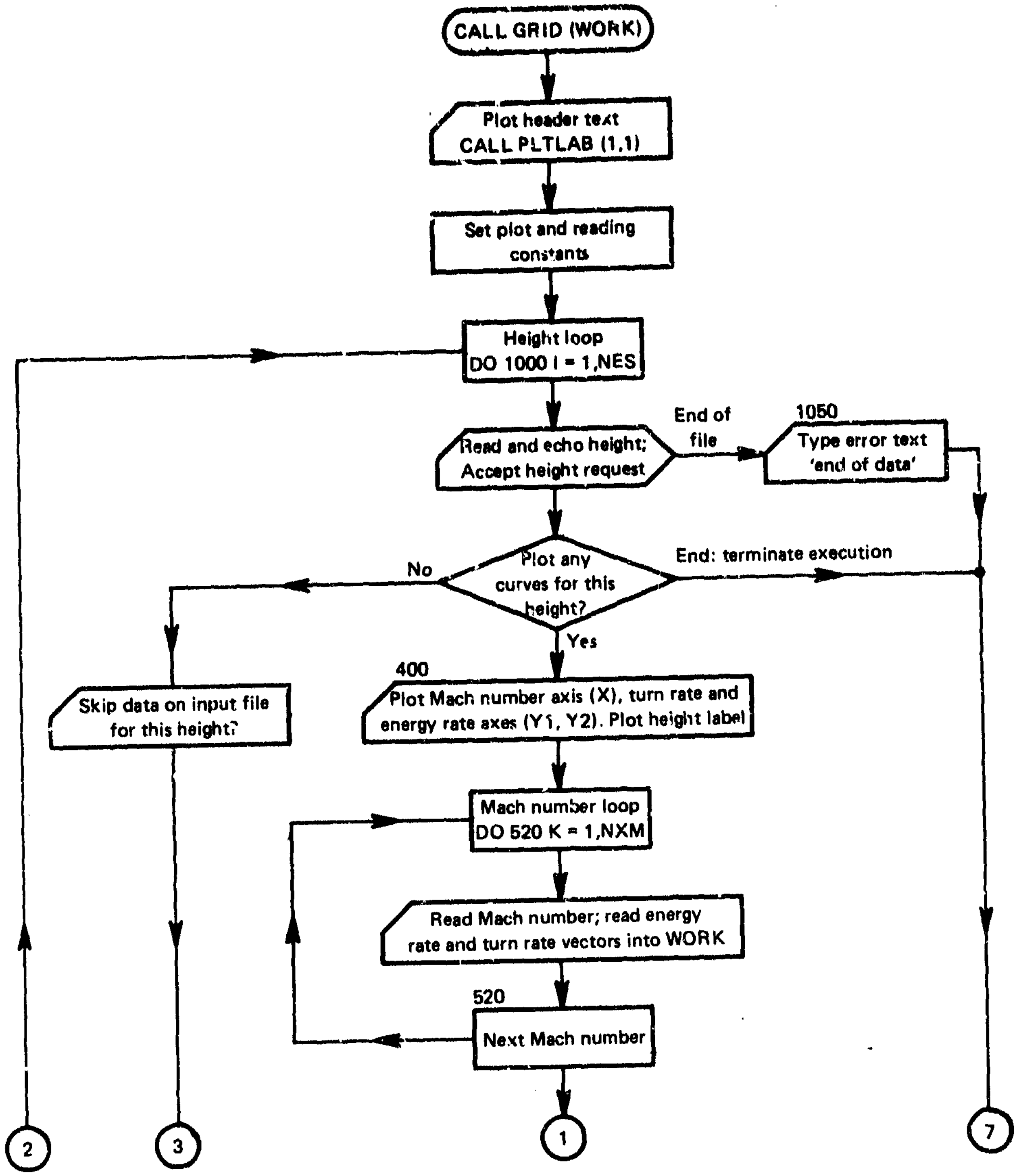

Fig. 16(a) Subroutine GRID Flowchart

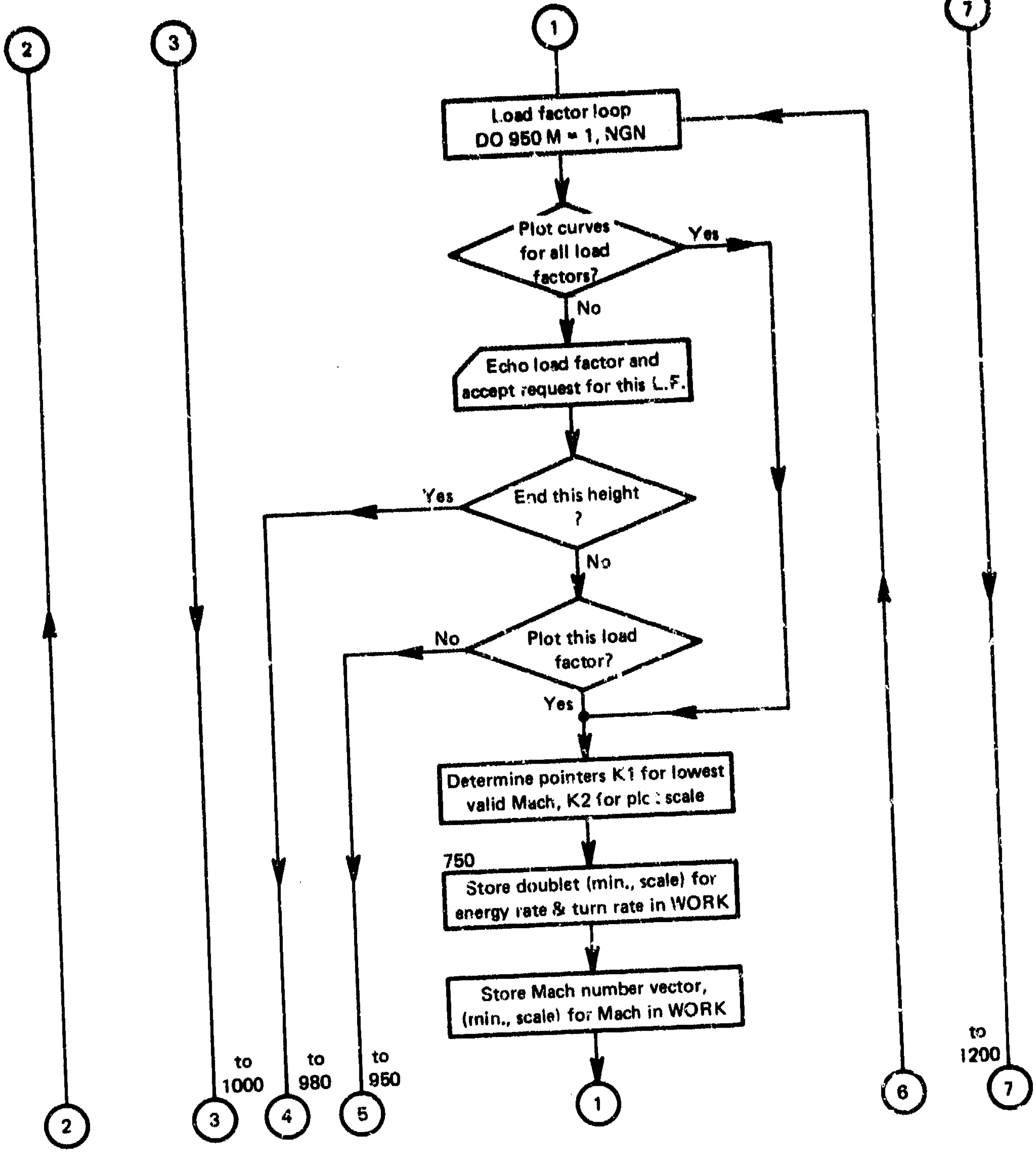

Fig. 16(b) Subroutine GRID Flowchart (Cont.)

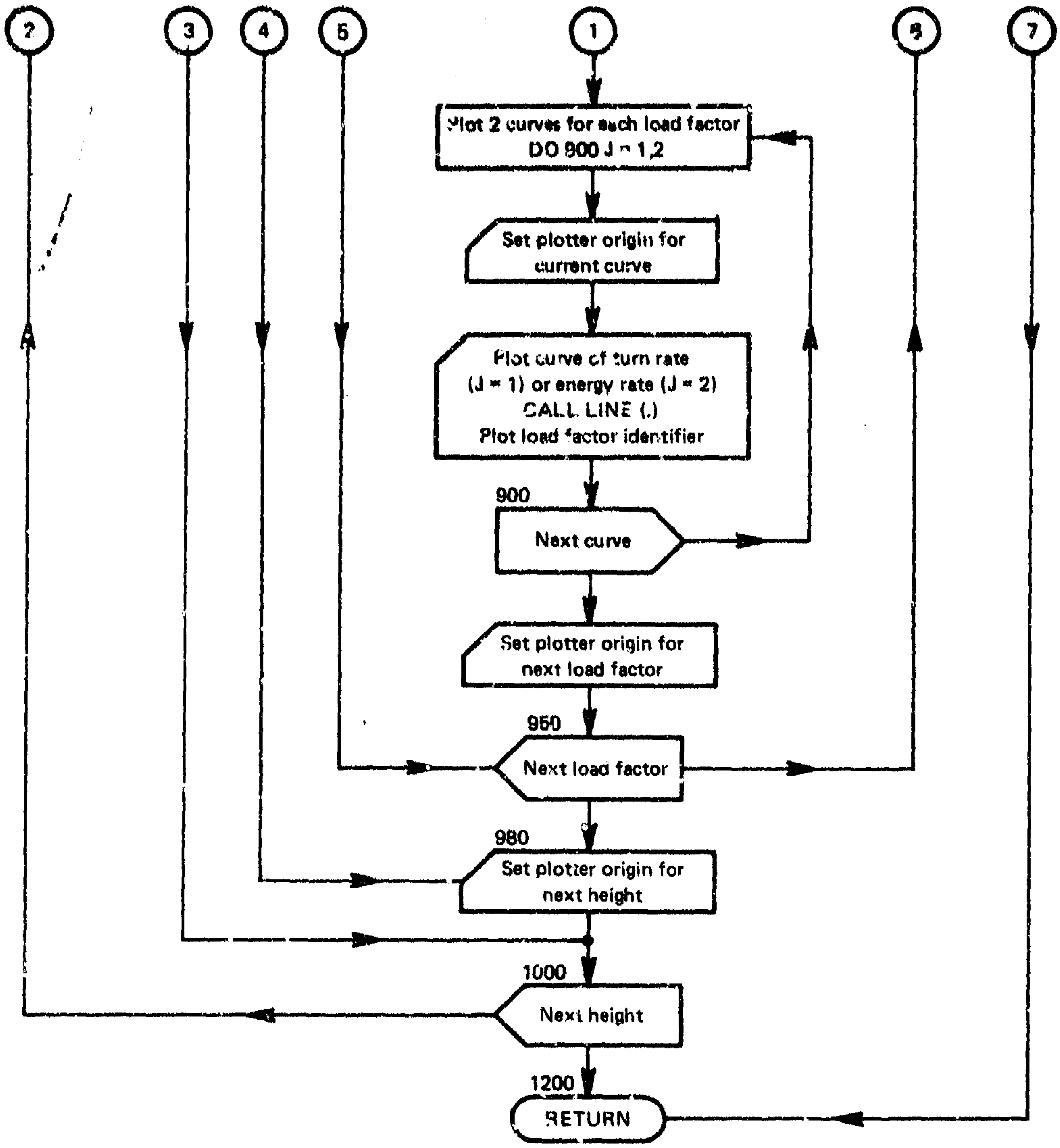

Fig. 16 (c) Subroutine GRID Flowchart (Cont.)

plotted for any height, the input file is advanced to the next height. Otherwise, axes for turn rate and energy rate are plotted in the y direction, and Mach number axes are plotted in the x direction, together with a height label for each pair of graphs. For each Mach number, energy rate and turn rate vectors are read into the array WORK.

At this point all the data for the plot at the current height has been read in. The remainder of the subroutine is concerned with plotting the data in a different grid order from that on the input file. A load factor loop is set up and requests for plots of curves at selected load factors are supplied via the user's terminal. For each load factor selected pointers K1 and K2 are calculated to indicate storage locations corresponding to the lowest valid Mach number and plot scale parameters. These parameters (minimum value and axis scale) and then stored for each of energy rate, turn rate and Mach number, together with a copy of the Mach number data vector. This storage in array WORK is carefully allocated to make use of the "repeat" cycle concept[16] used in subroutine LINE to plot multidimensional data.

Subroutine LINE is then called twice to plot turn rate and energy rate curves for the selected load factor. The plotter origin is adjusted after each curve, and again between each set of graphs for the selected height. Control returns to the main program to terminate execution after all heights have been considered.

6. PROGRAM P4 DESCRIPTION

6.1 Program Summary

Program P4 is a multi-purpose contour plotting program: input consists of data files produced by program P2. The output is a single file, P4.PLT, to be submitted to the system program PLOTQ for off-line plotting.

The main program is very short, and simply accepts an input data filename, reads the grid definitions and header text and calls the major control subroutine P4MAIN. This routine controls all logic functions for the various type of data, processes scale and contour level requests, draws axes and controls pen positioning for each page of plotter output.

Subroutine CONT, called from subroutine P4MAIN, processes the data grid and searches along the requested contours, plotting points where the linear approximation changes direction, with calls to the auxiliary subroutine P.

The following sections discuss the types of plots which may be produced and describe the routines involved with the control logic, subroutines P4MAIN and P. Subroutine CONT and several utility routines are portions of a larger contouring package used at ARL.

Brief descriptions of all routines used by program P4 are given in Appendices 8, 9 and 10. Examples of terminal input are given in the user's guide for program P4 in Chapter 9, and examples of contour plots produced by co-ordinated running of programs AIRCRAFT, P2 and P4 are given in Chapter 10.

6.2 Classification of Contour Plots

The control logic of subroutine P4MAIN is capable of differentiating four types of contour plot, based on input data filenames, as shown in Table 6.

Each data file contains grid definitions and text descriptions of the aircraft configurations. The energy rate data files contain, in addition, data for plotting energy state contours if desired. One page of plots is produced for each load factor, which may be selected from the available load factor grid.

The differential MMD data files contain, in addition to the differential data, turn rate data for both aircraft from which zero turn rate ($1g$ load factor) boundaries are obtained. Contours of differential turn rate are then plotted only when they are bounded by both of these boundaries.

For all types of contours, a terminal dialogue is used to define the range of contours required and the scales to be used on the x and y axes.

TABLE 6

Contour Plot Classification

Plot type	Input data filenames	Brief description
1	P2.CON, P2A.CON	Energy rate contour plots. Input data contains energy state contour data, followed by energy rate contour data for selected load factors.
2	P2DIFF.CON	Differential energy rate contour plots. Input data contains descriptive texts for both aircraft, followed by energy state and differential energy rate contour data as above.
3	P2.OPT, P2A.OPT	Maximum manoeuvre diagrams (MMD). Input data contains only turn rate contour data.
4	P2DIFF.OPT	Differential MMD. Input data contains copies of files P2.OPT and P2A.OPT for base and comparison aircraft, respectively, followed by differential turn rate contour data.

6.3 Subroutine P4MAIN

Subroutine P4MAIN controls all of the logic functions for the four types of contour plot, and performs a dialogue with the user to supply scale and contour level data. It also controls reading of the input file, plots axes on the output file, positions the plotter pen for each page of plots, and calls subroutine CONT to trace the requested contours through the grid data. A flowchart for the subroutine is given in Figure 17.

Several important switches are used to control the logic operations. The first, IMMD is set to 1 (otherwise 0) for MMD plots, based on input data filename. If the MMD plot is also a differential plot, the data set loop counter NDATA is set to 3 (otherwise 1). For the first two passes through the data set loop (IDATA = 1 or 2), switch IGRID is set to 1 (otherwise 0) to indicate that only the zero turn rate boundary is to be plotted. For each of these boundaries counter IC records the number of points used to define the boundary (limit of 400 allowed), and switch LABFLG is set to .F. (otherwise .T.) to indicate that contours are not be labelled.

For contour plots, switch IGES is set to 1 (otherse 0) if energy state contours are to be plotted; these are plotted with a dotted line, and do not require contour labels, being readily identified by their intersection with the height axis.

The subroutine proceeds by plotting identifying labels, accepting axis scales and positioning the plotter pen for each set of contour data on the input file.

Two loops are set up in P4MAIN. The first of these is for the number of data sets on the data file, NDATA. After checking for a differential MMD label, the first set of contour data is read into array Z. Pointers IGRID and IES are given default values of zero, and if a differential MMD zero turn rate boundary is being plotted, the first word of the contour request vector is set to zero.

MMD plots then proceed immediately to the load factor loop (executed only once); otherwise the energy state contour request is processed. If these contours are requested, matrix Z is copied into matrix ZG, switch IGES is set and the energy state contour vector constructed, using the user's terminal input.

The load factor loop is then entered and, if energy rate contours are being plotted, data is read into matrix Z and the load factor request processed. If the data is to be skipped, control jumps to the end of the load factor loop. Energy rate/MMD contours are then specified and the plotter origin reset, *x* and *y* axes are drawn (these are skipped if the MMD zero turn rate boundary

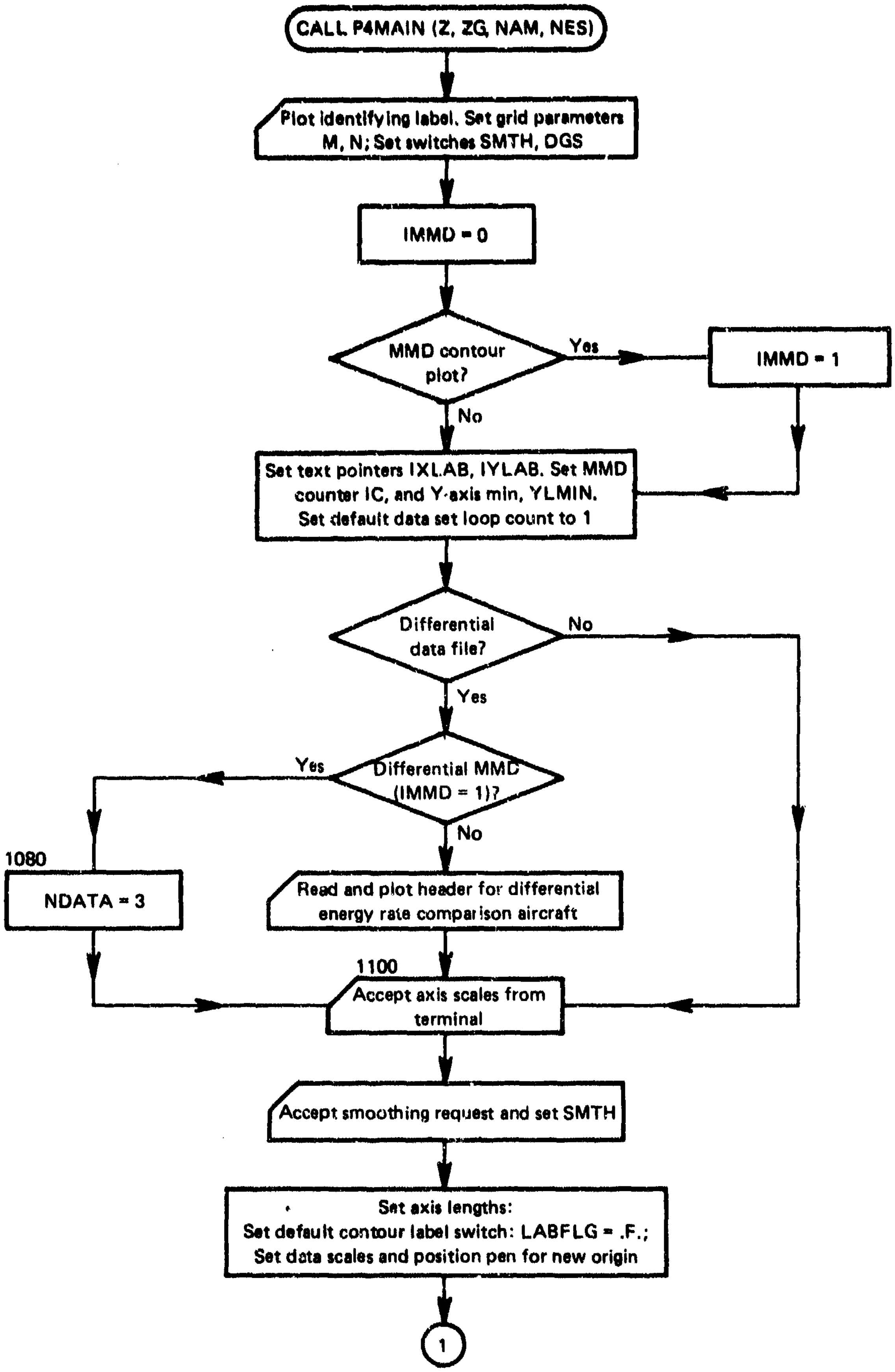

Fig. 17(a) Subroutine P4MAIN Flowchart

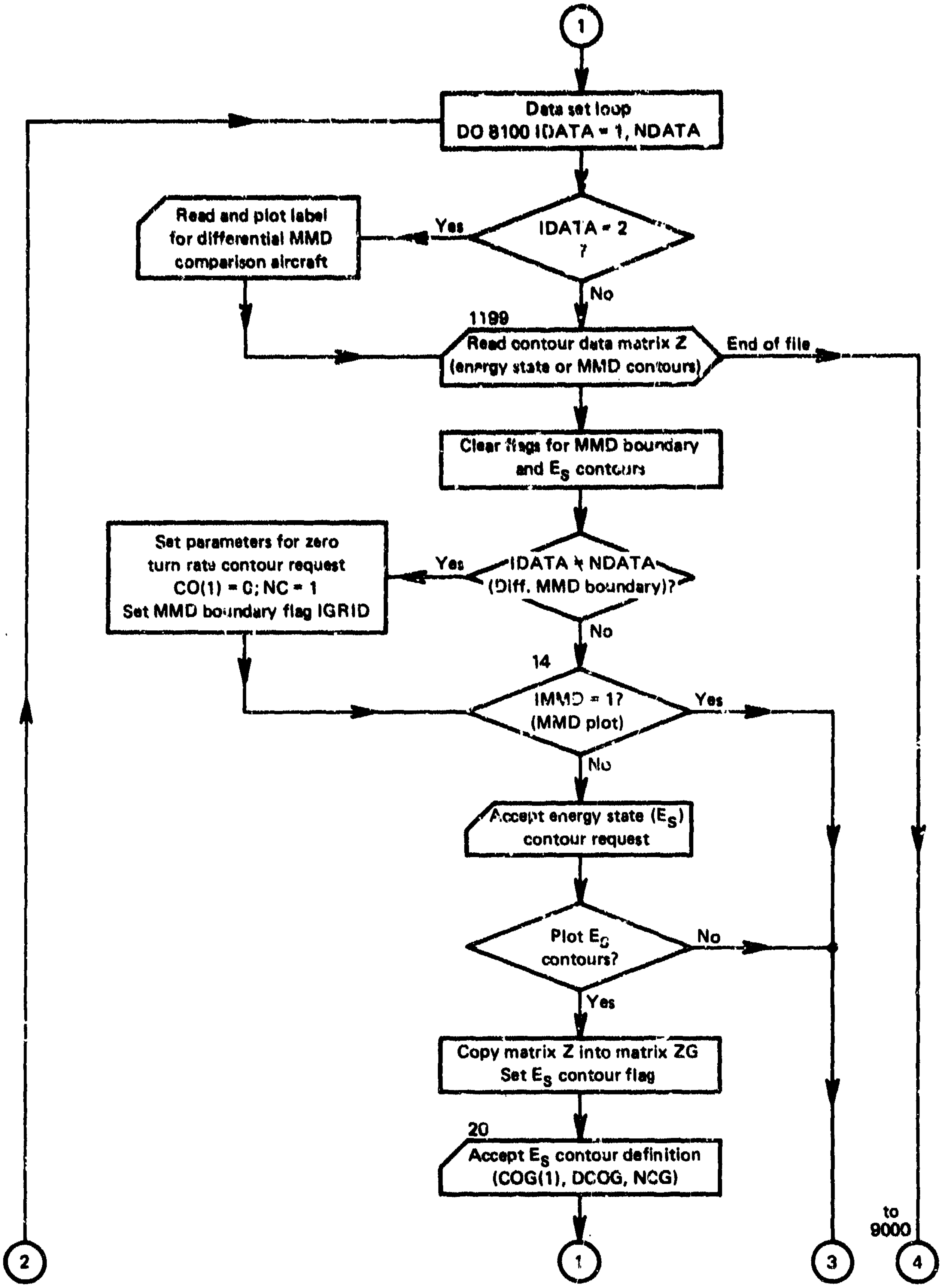

Fig. 17(b) Subroutine P4MAIN Flowchart (Cont.)

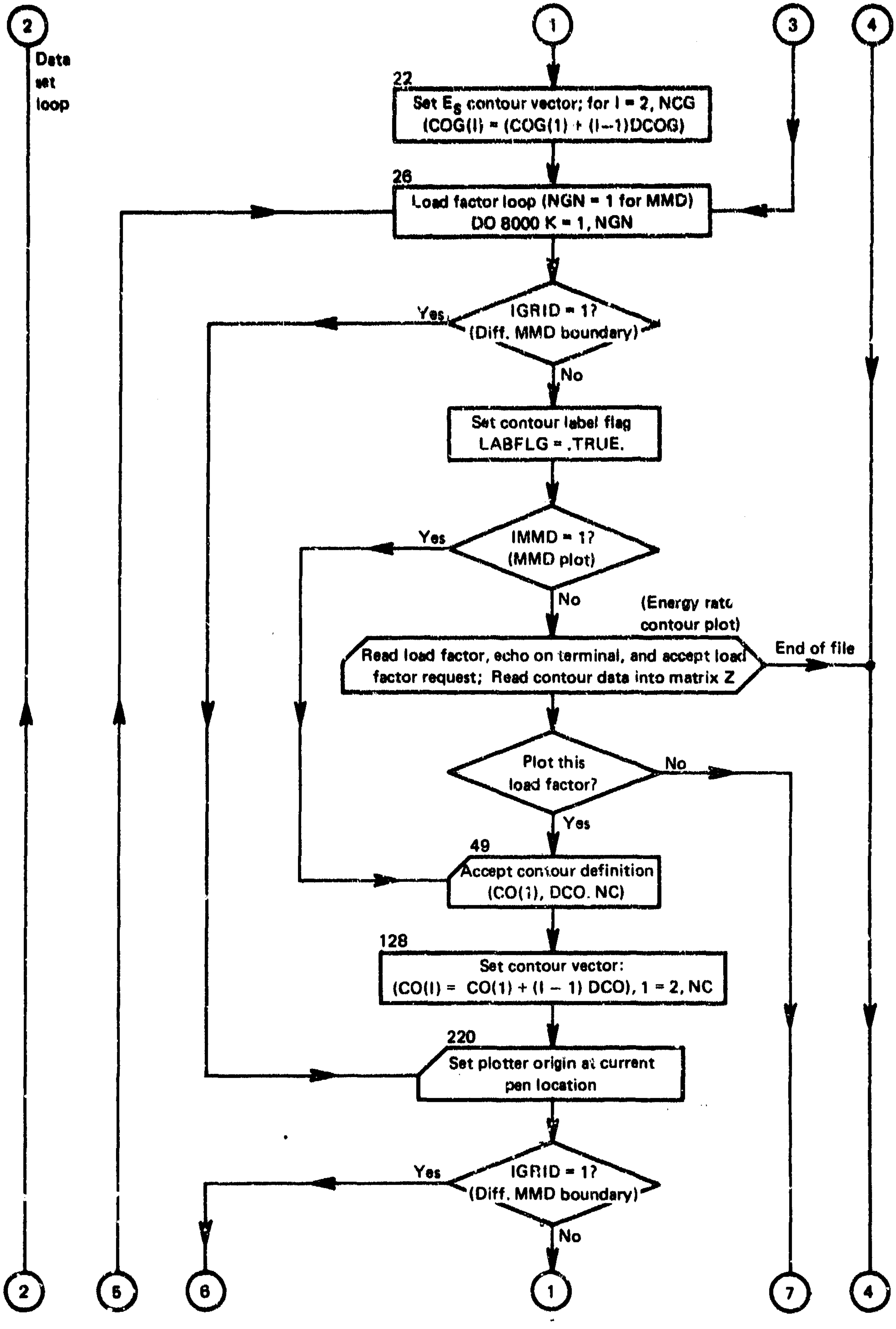

Fig. 17(c) Subroutine P4MAIN Flowchart (Cont.)

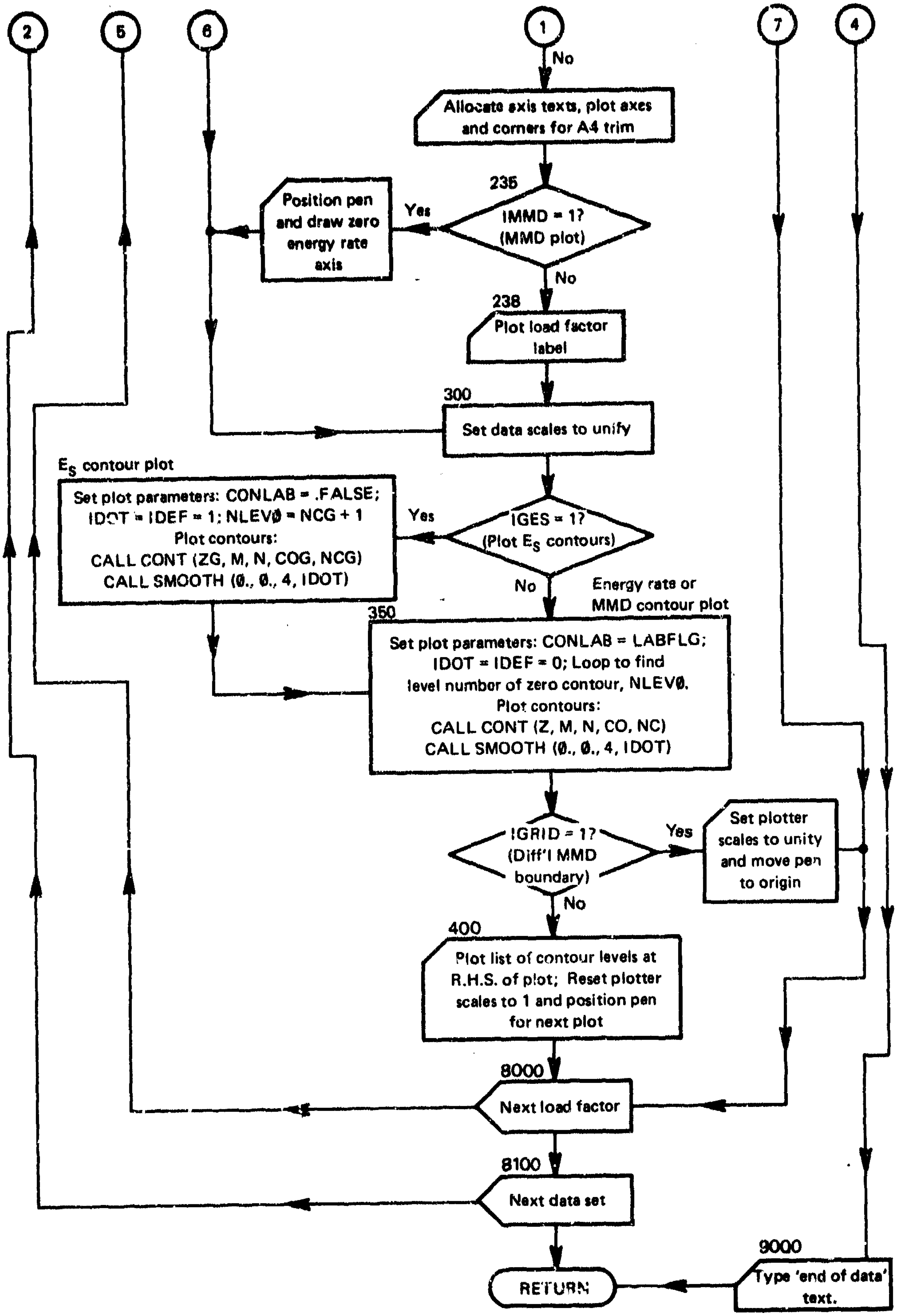

Fig. 17(d) Subroutine P4MAIN Flowchart (Cont.)

is being plotted), and either a load factor label or a zero energy rate axis is drawn, depending on the type of plot.

Data scales are set to unity for plotting the contours themselves, as the contouring routines plot data in real inches of plot. Scaling to these units is performed in subroutine P.

If energy state contours have been requested on energy rate plots, these contours are plotted first as a broken line with a call to CONT, after setting parameters as follows:

Parameter	*Value*
CONLAB ..	.. .T. to label contours, .F. to omit,
IDOT, IDEF..	.. 1 to draw contours with a broken line (dashes), 0 for a solid line, and −3 for an interrupted line (dot–dash).
NLEVØ ..	.. Level number of zero contour

A second call to CONT plots energy rate/MMD contours with a solid line, except for the zero contour which is plotted using a dot–dash format to distinguish it from other contours. Sharp corners of the contours are smoothed using a smoothing interval of 0·05 in.; calls to subroutine SMOOTH with a pen command of 4 are required whenever the type of contour line changes, to finish the current line.

For the remainder of the load factor loop, if MMD boundaries are being plotted, scales are reset to unity and the pen moved to the origin before jumping to the end of the loop. Otherwise, the list of contour levels is plotted before resetting plotting scales to unity and positioning the pen for the next plot.

When all load factors and data sets on the data file have been considered, control returns to the main program to terminate execution.

Errors when replying to terminal prompts result in the prompts being repeated. Encountering an end-of-file on the input file before the end of the data set or load factor loops results in an "end of file" text being typed on the terminal before ceasing execution.

6.4 Subroutine P

Subroutine P is an interface routine between subroutine CONT and the plotter software, which renders CONT independent of plotter conventions. It modifies pen-up and pen-down movements commanded by CONT, taking into account the zero turn rate boundary when producing differential MMD plots. It also controls the parameter IDOT specifying the type of line used in plotting a contour. A flowchart for the subroutine is given in Figure 18.

P is called with co-ordinate and pen command arguments supplied by CONT. (XPT, YPT) are the co-ordinates of the point to be plotted in mesh co-ordinates, which have ranges (1, NXM) and (1, NES) for XPT and YPT respectively. The co-ordinates (x, y) are adjusted to a zero origin, and a local copy of the pen command is made in NSAV.

A test is next made of IDATA, the counter for the loop in P4MAIN which has called CONT. If a differential MMD boundary is being plotted, P also stores copies of the co-ordinates in vectors XTAB and YTAB for future reference. Counter IC is incremented each time a point is stored, and the two-word vector ICOUNT records the value of IC at which data for the two boundaries finishes. If the maximum values of IC of 400 is exceeded, execution ceases after typing a failure text on the terminal. The minimum value of y on either boundary is recorded in YLMIN, and flag ICHK set to zero. This records that the order of x values in XTAB is undefined (ascending or descending). A jump is then made to statement 1000 to plot the boundary point.

For all other types of contour plot, y is first tested against YLMIN. Unless a differential MMD is being plotted, this has a default value equal to the maximum y mesh co-ordinate; hence the test is always satisfied and a jump always made to statement 1000 to plot the point. If the test is not satisfied, the point (x, y) must be further tested against both of the stored MMD boundaries.

The first time this area of code is entered, ICHK is zero, and the data in vectors XTAB and YTAB are rearranged if necessary to guarantee each boundary is stored in ascending order of x values. This is done in the loop ending at statement 580. ICHK is set to 1 so that future calls to P skip this rearrangement.

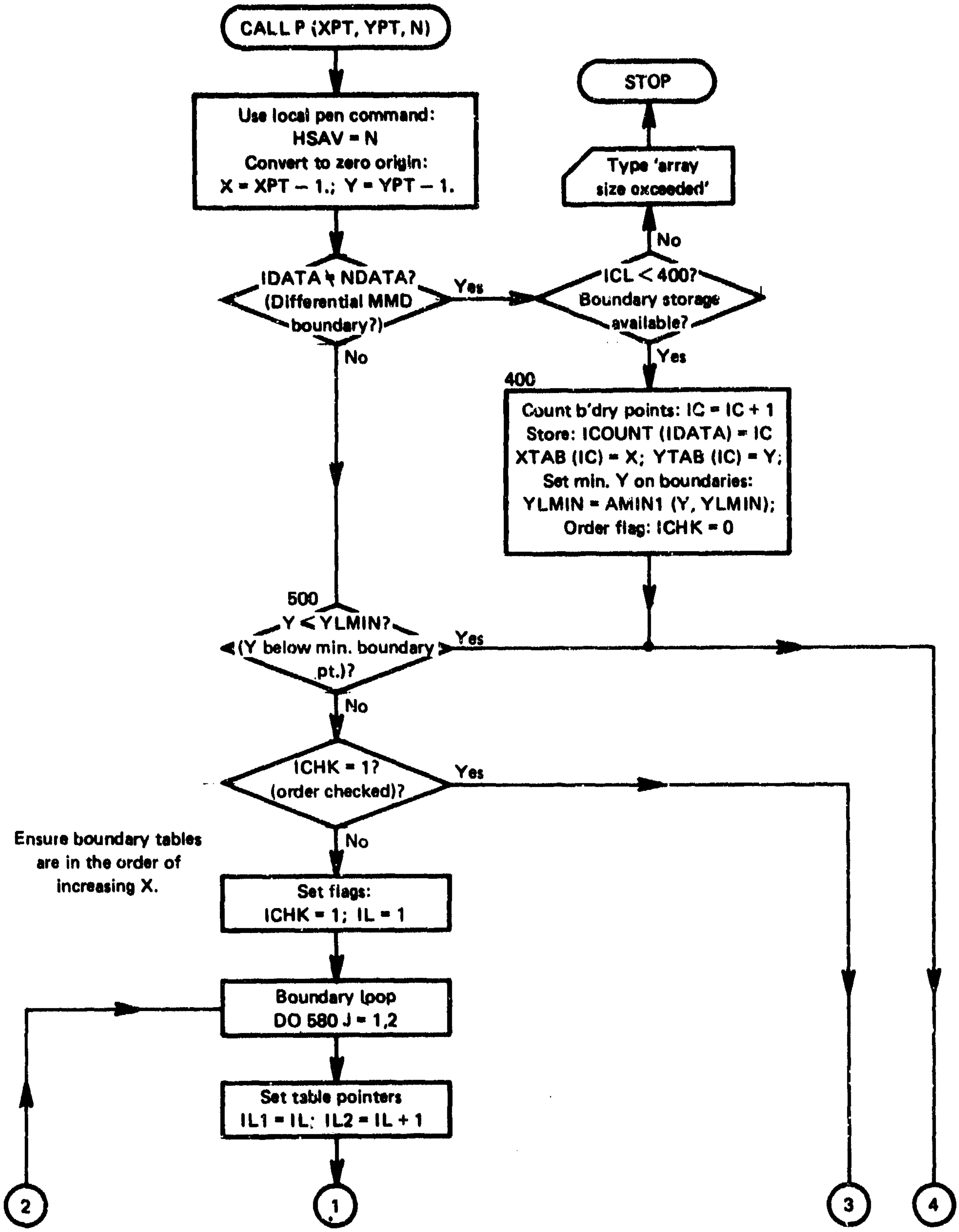

Fig. 18(a) Subroutine P Flowchart

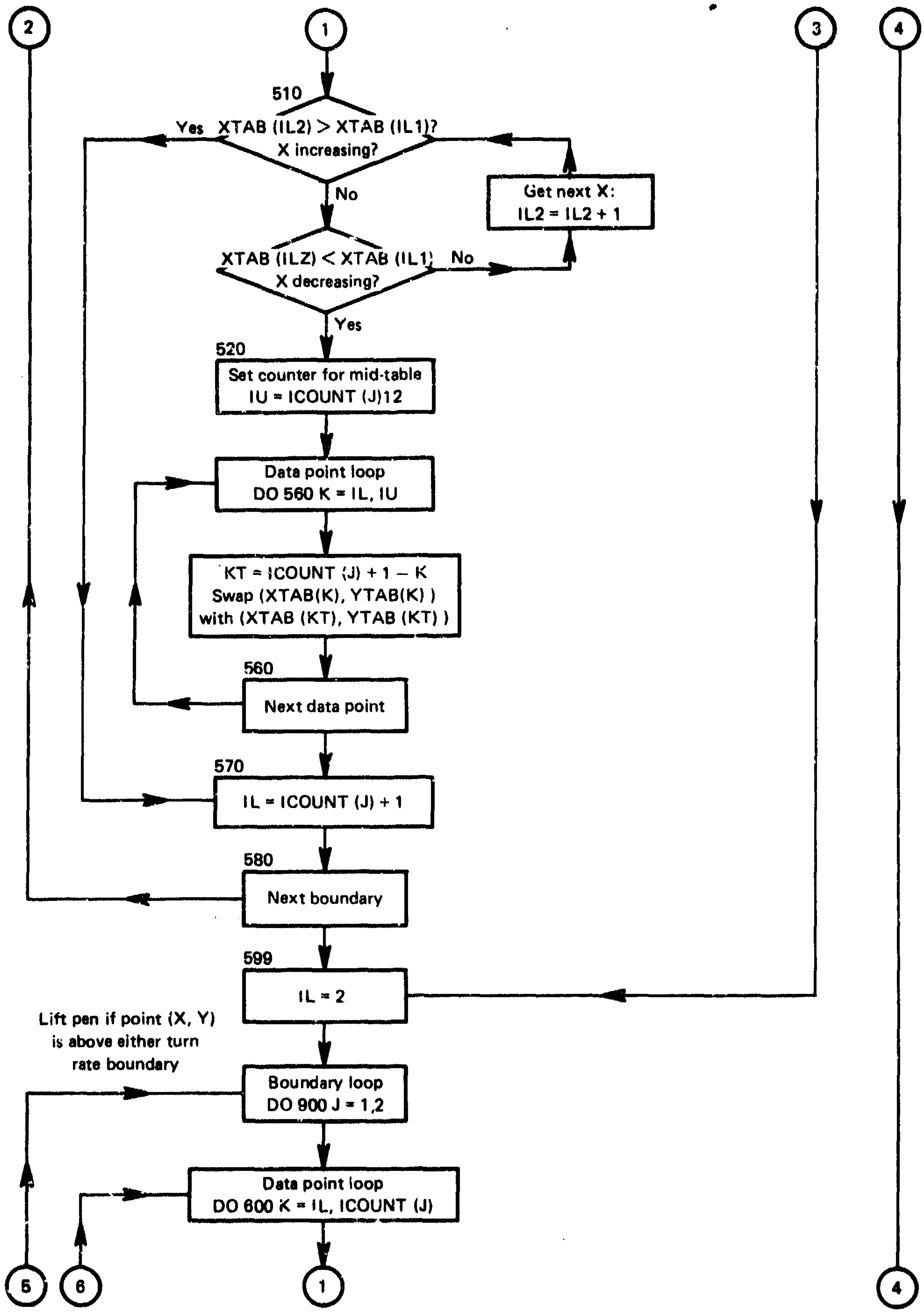

Fig. 18(b) Subroutine P Flowchart (Cont.)

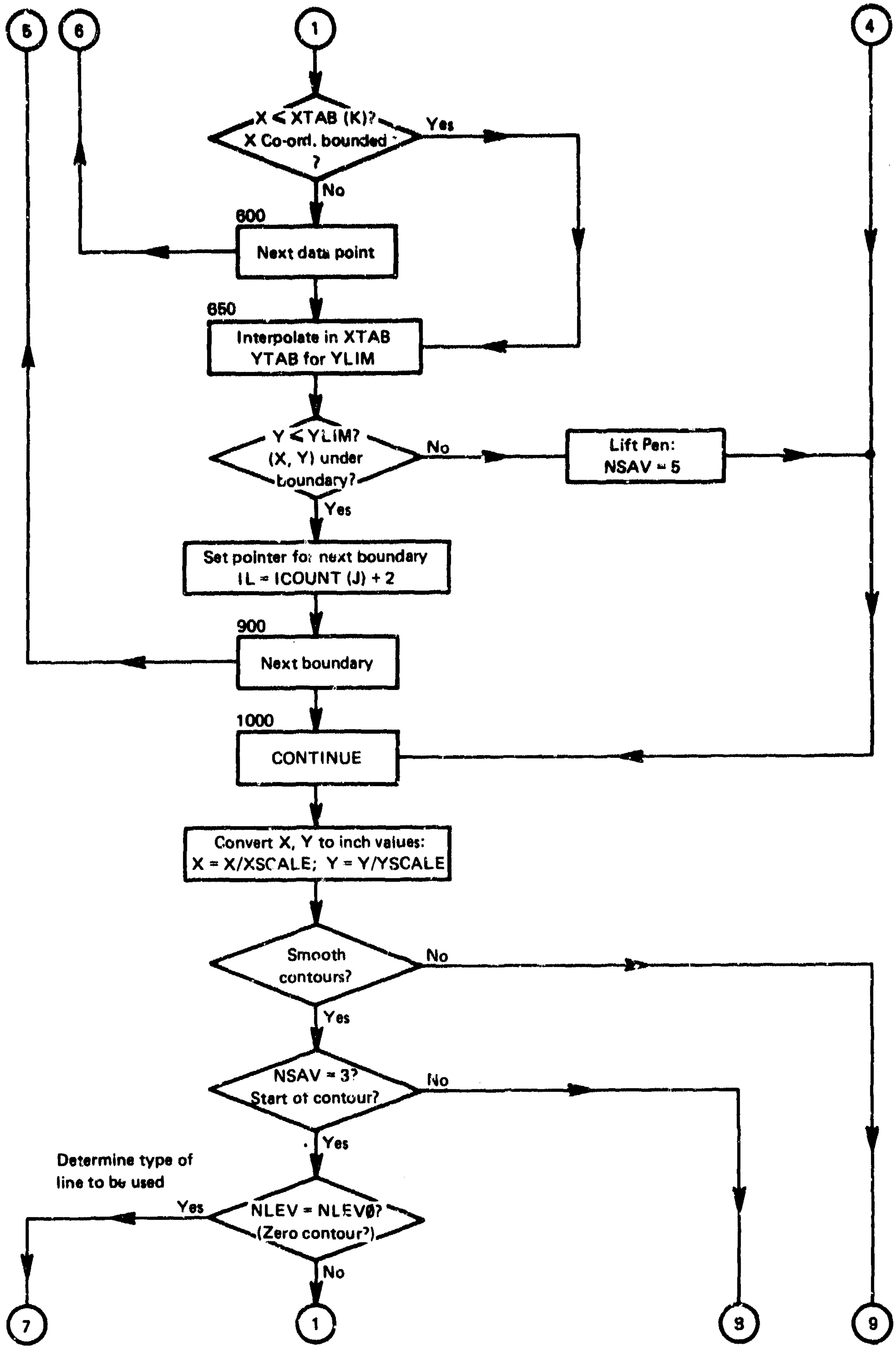

Fig. 18(c) Subroutine P Flowchart (Cont.)

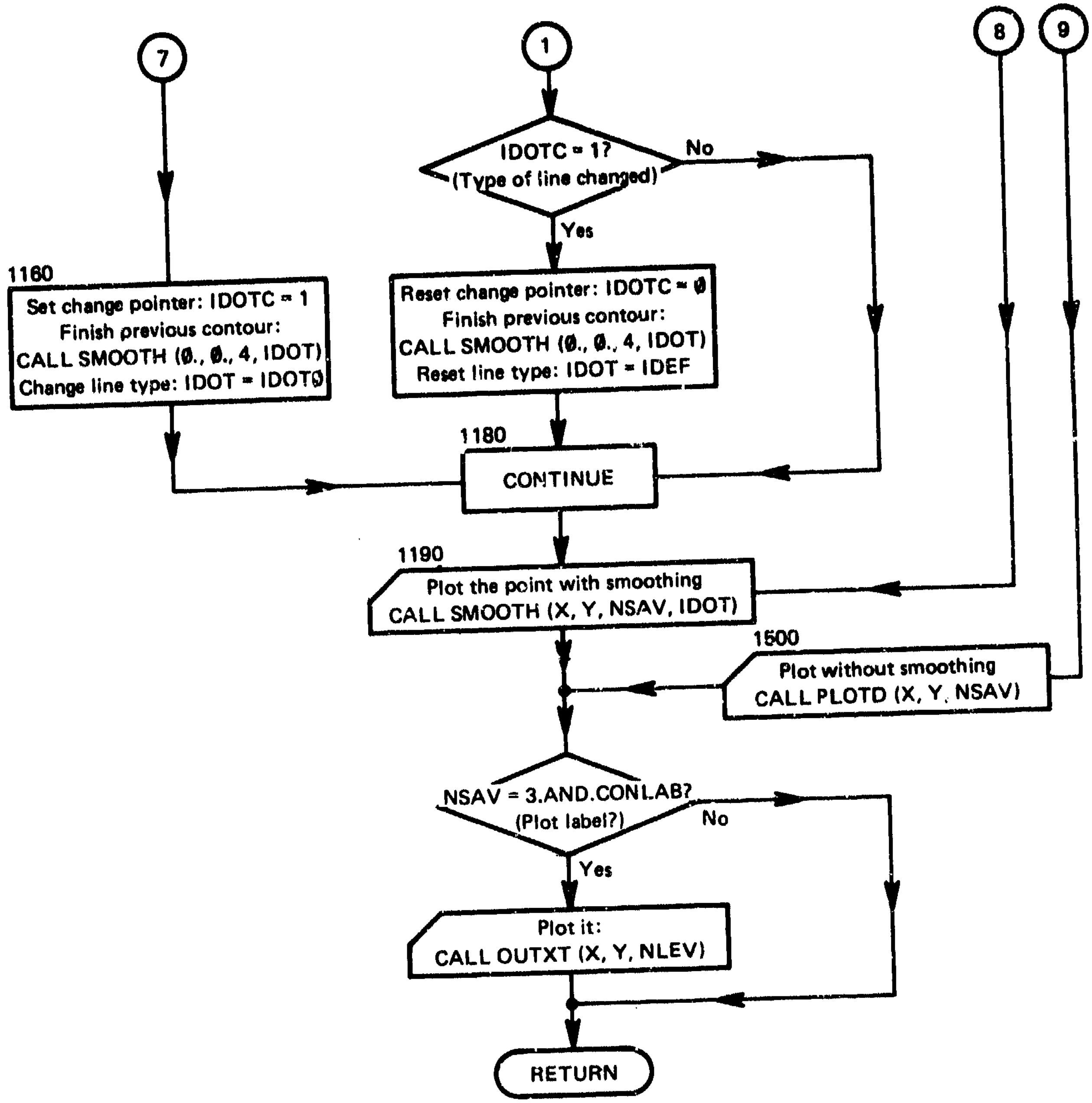

Fig. 18(d) Subroutine P Flowchart (Cont.)

Subsequent differential MMD calls jump to statement 599 to compare the y co-ordinate with the YTAB co-ordinates at the current value of x. The XTAB values for each boundary are bounded, and interpolation yields two values against which y must be compared. If y is greater than either of these two values, the pen is lifted (NSAV = 5) before proceeding.

At statement 1000, P is now ready to plot the point and the co-ordinates are converted to inches of plot. If contour smoothing is not requested, the point is plotted by a call to PLOTD. Otherwise it is plotted with a call to SMOOTH. In the latter case, the texture of zero contours is varied by changing the parameter IDOT. However, each time the texture is changed, an additional call to SMOOTH is required to terminate the previous contour. Flag IDOTC is used to indicate a change in contour texture.

The beginning of contours are flagged with their contour level number via a call to routine OUTXT, unless the pen has been lifted by P or energy state contours are being plotted (CONLAB is then .FALSE.). Having plotted the point control returns to the calling routine, CONT.

6.5 Communication with System Routine PLOT

The basic unit for plotting a point using the CALCOMP plotting software[16] is a call to PLOT of the form

CALL PLOT (LU, X, Y, N),

where LU is the logical unit number of the output channel;

(X, Y) are the co-ordinates of the point;

N is an integer specifying the pen command—

1 use (X, Y) as axis scaling factors,
2 establish new origin with current pen position at (X, Y),
3 lift pen, move to (X, Y), drop pen,
4 drop pen, draw straight line to (X, Y),
5 lift pen, move to (X, Y).

The pen commands used by the contouring routines are the same as these, except that the meaning for N = 4 has been transformed to N = 2. Hence the sole task of routine PLOTD, whose call statement is identical to that above, is to replace a value of N = 4 by N = 2, before calling PLOT.

Routine SMOOTH also plots by calls to routine PLOTD, but the call includes the additional calling parameter IDOT, used to indicate the mark : space ratio for broken lines. A smoothing interval of 0·05 is transmitted via the COMMON area GDMDOT.

In operation, SMOOTH has a plotting lag of one point, required by the splining technique used. Successive points are joined by cubic arcs with tangential coincidence at the end points. The plotting lag results in an additional call to SMOOTH being required, to finish the previous contour, whenever a change in contour texture is made. The pen command N = 4 is used to request this updating procedure.

7. PROGRAM "AIRCRAFT" USER'S GUIDE

7.1 Loading and Saving of Absolute Files

Given a file AIRCRA.FT containing a main program, the BLOCK DATA subroutine and thrust and drag routines, the commands for loading the file and producing an absolute copy of the program on disk, together with a symbol map, are:

```
.LOAD/MAP AIRCRA.FT,/SEARCH P1,P1LIB
FORTRAN: AIRCRA
MAIN.
.BLOCK
TRIMCL
AERO
THRUST
LINK:   Loading

EXIT

.SAVE
AIRCRA saved
```

In this example, and in subsequent examples of terminal operations, user responses are underlined.

The above operations produce a file AIRCRA.EXE on disk which is then executed with the RUN command.

7.2 Program Execution

The conversational input to the program is best described with reference to a typical run to produce data for plots of energy rate against turn rate at several altitude /Mach number combinations. Numbers in the left-hand margin indicate subsections in which the various responses are discussed.

7.2.1 Imperial (Ø) or SI (1) Units

Replies of Ø or 1 indicate that output quantities are to be in Imperial or SI units respectively. Any other reply results in the text

INVALID INPUT! TRY AGAIN

being typed on the user's terminal, and the prompt is repeated.

```
.RUN AIRCRA


MANEUVERABILITY GRID CALCULATION

1    IMPERIAL (0) OR S.I. (1) UNITS   ? 1

2    AIRCRAFT DATA FILENAME           ? ASTORE

     AIRCRAFT EXAMPLE     DATE  1-Apr-82   TIME 12:17 37.1
     AIR SUPERIORITY - 2 AAM + GUN + 50% FUEL

3    PS, PS/WF OR PS*V/WF (1, 2 OR 3) ? 1

4    IS HP THE HEIGHT VARIABLE        ? Y

5    PRESET GRID (Y, N OR C/R)        ? _

     PRESET GRID :
     HP = 0(4000)68000 (IMP.) OR 0(1000)20000 (S.I.)
(6)  MN = 0(0.05)1.5 (MIL) OR 0(0.05)2.0 (MAX)
     G  = 1(2)9
     PRESET GRID (Y, N OR C/R)        ? N

7    HPO , HP STEP (M ), NO. OF STEPS ? 0,5000,4

8    MACHO, MACH STEP  , NO. OF STEPS ? .8,.9

     INVALID INPUT! TRY AGAIN -
     MACHO, MACH STEP  , NO. OF STEPS ? .8,.1,2

9    GO    , G STEP     , NO. OF STEPS ? 1,.25,24

10   POWER (MIL=100,MAX=200)          ? 200

11   WING SWEEP (IF VARIABLE)         ? ___

12   ATMOSPHERE , DEVIATION           ? ___

     ATMOSPHERE       IS INVALID; ICAO ASSUMED
13   OUTPUT (1=TEXT,2=NOS.,3=BOTH)    ? 3

14   O/P FILENAME FOR UNIT 6          ? TEST.LST

     O/P FILENAME FOR UNIT 8          ? TEST.NUM

     CALCULATION :

              ALTITUDE HP =       0.0 M
              ALTITUDE HP =    5000.0 M
              ALTITUDE HP =   10000.0 M
              ALTITUDE HP =   15000.0 M
     STOP

     END OF EXECUTION
     CPU TIME: 6.96  ELAPSED TIME: 3:13.76
     EXIT
```

7.2.2 Aircraft Data File Name

Supply up to 10 characters giving the name of a file on disk containing data for the given aircraft for the current run. In the example, file ASTORE is as follows:

```
EXAMPLE
350.,0
20442.,30.
AIR SUPERIORITY - 2 AAM + GUN + 50% FUEL
CF.BIN
CA.BIN
8
.2,.92,.96,.98,1.01,1.1,1.2,2.0
8,8,10,15,17,15,14,14

.
```

Items in this file are as follows

Line	Format	Description
1	2A5	Aircraft name—up to 10 characters
2	G	Wing reference area (ft² or m²), file units flag (0 or 1 respectively)
3	2G	Gross weight (lb or kg), c.g. position (%MAC)
4	14A5	Role description—up to 70 characters
5	2A5	Thrust data filename—up to 10 characters
6	2A5	Aerodynamic data filename—up to 10 characters
7	G	No. of points in store drag table
8	10G	Mach no. list in store drag table *
9	10G	Drag count list in store drag table *

* 10 items per line; carry on to next line if more than 10 entries on any line. Not needed if Ø points indicated by item 7.

As shown, reference area and weight are in units indicated by the file units flag; 0 indicates Imperial units and 1 indicate SI units.

Action in the case of input error:

(*a*) If the specified file does not exist, an erro message is typed and a new filename is requested. Either type the correct filename or return to the monitor (↑C) and generate the required file.

(*b*) If items in the file are incorrect or out of order, no checking is possible and execution errors will result.

7.2.3 PS, PS/WF or PS*V/WF (1, 2 or 3)

Replies of 1, 2 or 3 indicate as follows:

Reply	*Meaning*
1	Calculate P_S as dependent variable. This is the most common case. Use for minimum time climb schedule (1*g* load factor).
2	Calculate P_S/w_f as dependent variable. Use for minimum fuel climb schedule (1*g* load factor).
3	Calculate $P_S V/1000 w_f$ as dependent variable. Use for maximum range climb schedule (1*g* load factor).

Values 1, 2 and 3 are valid as input. Any other value produces the text

INVALID INPUT! TRY AGAIN

to be typed, and the prompt is repeated.

The type of energy parameter indicated by IPSTYP and units indicated by IUNITS are evident from the printed listing; this information is also transmitted to input files to programs P2 and P4 as well, so that all outputs from all programs carry correct identification of output variables and units.

7.2.4 Is HP the Height Variable?

A reply "Y" (for "YES") indicates that pressure altitude is to be used as the height grid variable. Any other reply will result in energy state being used as the height variable.

7.2.5 Preset Grid (Y, N or C/R)

For some contour plots, such as differential energy rate plots, a preset or standardised grid may be useful. A carriage return reply results in the preset grid values being typed on the user's terminal, as shown. The values indicated for each grid are in the form "initial value (increment) final value". A reply "Y" results in this grid being used for the pressure altitude (no preset grid is available for energy state); grid requests 7, 8 and 9 are then omitted.

Any other reply will result in requests for grid data for pressure altitude, Mach number and load factor.

7.2.6 Maximum Manoeuvre

This prompt (not shown in the example given) is made if energy state is selected as the height variable. Any reply other than "Y" will result in an unoptimised grid, and a Mach number grid will be requested.

Reply "Y" will cause an optimisation of energy rate as a function of Mach number, preparing data for a maximum manoeuvre diagram (MMD), climb schedules or optimum sustained turn rates.

7.2.7 HPØ, HP Step, Number of Steps

This prompt requests parameters defining the height grid ("HP" is replaced by "ES" in the prompt if energy state is the height variable). Three items are requested, separated by commas. These are

- initial value,
- a positive increment,
- number of points, including first and last.

Units for initial value and increment (FT or M) are indicated in the prompt.

A valid combination of the three parameters is:

(i) initial value $\geqslant 0$,

(ii) increment value > 0,

(iii) $0 <$ number of values < 50.

Any other combination causes the text

INVALID INPUT! TRY AGAIN

to be typed, and the prompt is repeated.

7.2.8 MACHØ, MACH Step, Number of Steps

The Mach number grid request is similar to the height grid request together with its error test. This prompt is not given if an optimal grid has been requested.

7.2.9 GØ, G Step, Number of Steps

The load factor grid request is also similar to the height grid request.

7.2.10 Power (MIL = 100, MAX = 200)

Military power is indicated by a value in the range 0 to 100, and maximum power in the range 100 to 200. Tens and units digits indicate a percentage of the maximum of that range.

A valid reply is $0 \leqslant$ Power $\leqslant 200$. Any other reply causes

INVALID INPUT! TRY AGAIN

to be typed, and the prompt is repeated.

7.2.11 Wing Sweep (if Variable)

Supply wing sweep in degrees if aerodynamic data requires it. Otherwise reply with a carriage return.

A nominal valid reply is $0 \leqslant$ Wing sweep $\leqslant 80$. Any other reply causes

INVALID INPUT! TRY AGAIN

to be typed, and the prompt repeated.

If any other wing sweep limit is desired, it should be included in the aerodynamic routines for the aircraft.

7.2.12 Atmosphere, Deviation

This is an input provided if a THRUST subroutine is loaded for a given aircraft which can handle alternative atmospheres. Valid replies are

$$\left.\begin{array}{l}\text{ICAO},X\\ \text{ARDU},X\end{array}\right\}\text{FORMAT (A4,G)}$$

where X is a deviation from the nominated atmosphere in degrees Celsius. It may be omitted if X is zero.

Action in Case of Input Errors

If the first four characters are neither ICAO nor ARDU, the text

ATMOSPHERE (name) IS INVALID; ICAO ASSUMED

is typed, and calculation proceeds assuming an ICAO atmosphere.

7.2.13 Output (1 = Text, 2 = Nos., 3 = Both)

Replies 1, 2 or 3 indicate as follows:

(1) formatted output with full ASCII text is requested;

(2) numerical (data) output is required, for input to program P2;

(3) both types of output are required.

A reply K is valid if $1 \leqslant K \leqslant 3$. Any other reply causes

INVALID INPUT! TRY AGAIN

to be typed, and the prompt is repeated.

7.2.14 O/P Name for Unit m

Supply a 10-character filename for output as requested. $m = 6$ is the logical unit number for full format output. $m = 8$ is the logical unit number for numerical output.

Formatted output should be printed with /P/B switches to produce listings suitable for permanent retention.

Numerical output may be printed if required.

7.3 Core Storage Requirements and Execution Speed

Storage requirements and execution speed are both very much dependent on user-defined routines for the propulsion and aerodynamic calculations.

A typical example requires a total coresize of 53 pages (about $27K_8$ words) of core and processes an energy state contour plot request using the default grid in 3 min. 18 sec. of CPU time. This example uses a thermodynamic model of the propulsion system giving thrust and fuel flow data at all power settings, and B-spline representations of maximum C_L, C_L versus α and full drag polars for one representative c.g. location.

Progress of the calculation is indicated on the user's terminal by typing out each value of the height grid as it is processed.

8. PROGRAM P2 USER'S GUIDE

8.1 Loading and Saving of Absolute Files

The commands for loading program P2 and saving an absolute copy on disk, together with a symbol map are:

```
.LOA/MAP P2,P24LIB/SEARCH
FORTRAN: P2
MAIN.
GRID
INLAB
INMMD
MMP
PLTLAB
PSCON
PSDIFF
P2IN
RATE1
RATE2
R2DIFF
UNITS
URLAB
LINK:   Loading

EXIT

.SAV
P2 saved
```

The absolute copy of the program is saved on the disk file P2.EXE, which is then executed with the RUN command. Core storage requirement is 34 pages ($17K_8$ words). If the storage allocation for array WORK (8000 words) is found to be insufficient for large grids, there is thus ample core storage in reserve, should a program change be necessary.

8.2 Program Execution

The basic inputs to program P2 consist of data files created in a standard format by program AIRCRAFT. The data are then manipulated according to commands supplied at the user's terminal during the execution of the program. Some options allow the user to supply on-line data, in which case the data format is specified during the terminal dialogue. In either case, run-time input file preparation is not required for program P2, all data files being generated by program AIRCRAFT.

Output files are of two types. Options 4B and 4Z produce files for off-line plotting using the system program PLOTQ. Other options produce data files for input to the contour plotting program P4.

The remaining sections of this chapter describe the terminal operations required for each option, with reference to example dialogue. User input to terminal prompt is underlined.

8.3 Option 4A—Energy Rate Contour Data

```
.RUN P2


COMBAT PERFORMANCE PROCESSING


OPTION OR (CR) FOR HELP : 4A

4A  PS CONTOUR PLOT.                          (P2.CON)
DATA BASE  FILENAME     : A.NUM

*** DATA ARE IN METRIC   UNITS, ENERGY PARAMETER IS PS/WF      ***

REPLY "YES", "NO", "ALL" OR "END" :
OUTPUT DATA FOR N =    1.00 ? Y

OUTPUT DATA FOR N =    3.00 ? Y

OUTPUT DATA FOR N =    5.00 ? Y

OUTPUT DATA FOR N =    7.00 ? N

OUTPUT DATA FOR N =    9.00 ? N

END OF EXECUTION
CPU TIME: 0.88  ELAPSED TIME: 1:11.50
EXIT
```

This option produces energy rate contour data on a Mach number (x axis) versus altitude (y axis) grid, at selected values of load factor.

8.3.1 Option, or (CR) for Help

Reply with the appropriate option code. A carriage return (CR) is interpreted as a request for help, and a one line description of each option, together with the output files produced, is typed on the terminal. An example of this help text is given in Section 5.2.

8.3.2 Data Base Filename

Reply with the name of the appropriate data file produced by program AIRCRAFT as logical unit 8. After reading the header on the files, P2 echoes the unit system and type of energy parameter on the user's terminal.

8.3.3 Output Data for N = n.nn

Reply with "Y" or "N", depending on whether a contour plot is required for the load factor specified or not. Output is written on file P2.CON, for input to program P4. This file is in ASCII and may be printed, but it is not formatted for output listing.

8.3.4 Input Errors

(*a*) If the specified input file does not exist, an error message is typed and a new filename is requested. Supply the correct name to continue or (↑C) to abort the job.

(*b*) Replies other than Y to load factor requests are interpreted as N.

8.4 Option 4B—Turn Rate Plots

```
OPTION OR (CR) FOR HELP : 4B

4B  PS VS TURN RATE FOR GIVEN HEIGHT.          (P2.PLT)
DATA BASE  FILENAME     : B.NUM

*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS        ***

SCALES IN UNITS/INCH OF PLOT
OMEGA / ENERGY VARIABLE : 4,400

MAXIMUM FOR ENERGY AXIS : 1200

ENERGY AXIS LENGTH (IN) : 7

REPLY "YES", "NO", "ALL" OR "END" :
HEIGHT =      0.0 FT    ? Y

  MACH =  .800 ? Y

  MACH =  .900 ? N

HEIGHT =  10000.0 FT    ? Y

  MACH =  .800 ? N

  MACH =  .900 ? Y

HEIGHT =  20000.0 FT    ? A

HEIGHT =  30000.0 FT    ? E

END OF EXECUTION
CPU TIME: 6.80  ELAPSED TIME: 2:6.50
EXIT
```

This option produces plots of energy rate against turn rate for selected values of Mach number. One page of plots is produced for each requested altitude.

8.4.1 Data Base Filename

Reply with the appropriate filename, as in Section 8.3.2.

8.4.2 Scales in Units/Inch of Plot

Reply with the amount of the physical quantity which one inch of plot would represent on each axis. The scales presented in Table 5 may be used as a guide in selecting suitable values.

OMEGA, the turn rate variable, will vary from 0 to 20 deg/s or more, and 4 deg/s per inch is a representative value. OMEGA is plotted as the x axis.

PS will usually represent specific excess power and will have significance between values of (approximately) −600 and +400 m/s (−1800 and +1200 ft./s). A value of 150 m/s (400 ft/s) per inch is representative. When PS represents other energy parameters, the scales of Table 5 should be used as a guide. PS is plotted as the y axis.

8.4.3 Maximum for PS Axis

Reply with the approximate maximum PS value of interest. This value, together with the PS scale, determines the range of values on the y axis.

8.4.4 PS Axis Length (in.)

Reply with the length in inches of the vertical axis. A value of 7 in. is representative for easy trimming to A4 size.

8.4.5 Height = nnnnnn.n M (ft)

One page of curves is plotted for each height selected. The replies and their significance are indicated below.

Reply	*Meaning*
Y(ES) ..	.. Plotting is required for that height value. Mach numbers will be listed from which a choice is to be made.
N(O) ..	.. Plotting is not required for that height value. Go to the next set of data, for which a further height prompt will be given.
A(LL) ..	.. Plot all the data given for that height value. Use this reply when the Mach number set is known, to avoid repetition of Mach number requests.
E(ND) ..	.. Finish considering height values. This in effect terminates program execution before all the data has been processed.

8.4.6 Mach = n.nnn

The replies and their meanings are indicated as follows.

Reply	*Meaning*
Y(ES) ..	.. Plot a curve for this Mach number.
N(O) ..	.. Skip this Mach number.
A(LL) ..	.. Plot curves for all remaining Mach numbers in the data, for the current height.
E(ND) ..	.. Skip the remaining Mach numbers in the data, and go on to the next height value.

The output file P2.PLT contains the requested plots, and is submitted to the off-line plot queue by running the system program PLOTQ. As a rough guide, each height value requires about 30 cm (12 in.) of plot, depending on the x axis scale used.

8.4.7 Input Errors

(*a*) Incorrect filename—as in Section 8.3.4.

(*b*) If either of the axis scales is zero, the message

INVALID INPUT! TRY AGAIN

is typed, and new scales are requested.

(*c*) Any reply to the HEIGHT or MACH prompts, other than the four listed, is interpreted as "NO".

8.5 Option 4C—Maximum Manoeuvre Diagram (MMD)

```
OPTION OR (CR) FOR HELP : 4C

4C  MAXIMUM MANEUVER DIAGRAM - MMD.          (P2.OPT)
ON-LINE DATA           ? N

DATA BASE  FILENAME     : C.MMD

*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS          ***

DEFINE ENERGY GRID - (POSITIVE INCREMENT)
START, STEP, NO OF STEPS: -1200,100,25

END OF EXECUTION
CPU TIME: 0.64  ELAPSED TIME: 49.46
EXIT
```

This option produces turn rate contour data on an energy state (x axis) versus optimum energy rate (y axis) grid.

8.5.1 On-line Data?

Reply "Y" or "N" depending on whether data from a prior MMD is to be supplied on-line or not. If the reply is "N", data will be expected on a file produced by program AIRCRAFT. (An example of on-line data is given below.)

8.5.2 Data Base Filename

Reply as in Section 8.3.2.

8.5.3 Energy Grid—Start, Step, Number of Steps

The reply to this prompt defines an energy parameter grid which, together with the energy state grid defines the independent variable for the MMD.

Three systems are requested, separated by commas:

- minimum value;
- increment value—must be positive;
- number of values, including first and last.

Typical ranges, together with appropriate units depending on the values of parameters IPSTYP and IUNITS, are given in Table 5.

8.5.4 Input Errors

(*a*) Incorrect filename—as in Section 8.3.4.

(*b*) Energy rate grid—a valid combination will ensure:

(i) increment value > Ø; and

(ii) 0 < number of values ⩽ 50.

An invalid combination causes

INVALID INPUT! TRY AGAIN

to be typed on the terminal, and the prompt repeated.

Output is written in ASCII mode on file P2.OPT for input to program P4. Again, this file may be printed if desired, but it is not formatted for output listing.

8.5.5 On-line Data Example

A reply "Y" to "ON-LINE DATA?" results in a dialogue as shown over. Data defining system of inputs, type of energy parameter, aircraft name, role, weight, wing sweep (optional), power setting and atmosphere are supplied in response to the appropriate prompts. The energy state and energy rate grids, over which turn rate data are to be plotted, are also given.

8.5.6 nnnnnn.M (ft)

For each energy state, pairs of points on an energy rate vs. turn rate curve are supplied. The turn rate values must be in increasing order; a negative value of turn rate indicates the end of data for that energy state. Linear interpolation at fixed levels of energy rate are performed using these points, so the accuracy of the final diagram depends largely on using increments of turn rate over which a linear approximation is valid. (In the example given, a coarse grid is used to abbreviate the text.) In practice, a grid interval of 1500 m (5000 ft) in energy state, together with about ten pairs of points, will produce a reasonably smooth contour plot.

8.5.7 On-line Input Errors

(*a*) Energy state and energy rate grids—valid combinations of parameters are such that

(i) increment value > 0; and

(ii) 0 < number of values ⩽ 50.

An invalid combination causes

INVALID INPUT! TRY AGAIN

to be typed on the terminal, and the prompt repeated.

(*b*) Non-increasing values of turn rate cause

?OMEGA NOT INCREASING—START AGAIN:

to be typed on the terminal, and the loop for accepting data points to be restarted.

(*c*) Typing mistakes in values of turn rate or energy rate may be corrected after running program P2 by using the text editing program TECO.

```
RUN P2

COMBAT PERFORMANCE PROCESSING

OPTION OR (CR) FOR HELP : 4C

4C  MAXIMUM MANEUVER DIAGRAM - MMD.          (P2.OPT)
ON-LINE DATA            ? Y

IMPERIAL (0) OR S.I. (1) UNITS   ? 1

DATA REPRESENTS PS,
PS/WF OR PS*V/1000WF (1,2, OR 3) ? 1

AIRCRAFT NAME                    : EXAMP

ROLE : AIR SUPERIORITY

WEIGHT( KG), WING SWEEP(DEG)     : 9000

ESO, ES STEP ( M ), NO. OF STEPS : 3000,3000,5

PSO, PS STEP, NO. OF STEPS       : -300,25,25

POWER (MIL=100,MAX=200)          : 200

ATMOSPHERE, DEVIATION            : ICAO

SUPPLY (OMEGA,PS) PAIRS, OMEGA INCREASING.
FINISH EACH ES SET WITH NEGATIVE OMEGA.

   3000. M
 1 : 0,138

 2 : 4,133

 3 : 7.5,110

 4 : 14.4,0

 5 : 19.7,-270

 6 : -1

   6000. M
 1 : 0,145

 2 :
   15000. M
 1 : 0,50

 2 : 1,47

 3 : 3.5,0

 4 : 8.4,-270

 5 : -1

END OF EXECUTION
CPU TIME: 1.30  ELAPSED TIME: 4:24.78
EXIT
```

8.6 Option 4D—Differential Energy Rate Contour Data

This option functions by processing two files, based on identical altitude, mach number and load factor grids, as in option 4A, and then subtracting the data at the grid points. An example follows:

```
OPTION OR (CR) FOR HELP : 4D

4D  PS DIFFERENTIAL PLOT.  (P2.CON,P2A.CON,P2DIFF.CON)
DATA BASE  FILENAME     : D.NUM

*** DATA ARE IN METRIC  UNITS, ENERGY PARAMETER IS PS/WF      ***

REPLY "YES", "NO", "ALL" OR "END" :
OUTPUT DATA FOR N =   1.00 ? Y

OUTPUT DATA FOR N =   3.00 ? N

OUTPUT DATA FOR N =   5.00 ? A

COMPARISON FILENAME     : A.NUM

END OF DATA ON LOG4

END OF EXECUTION
CPU TIME: 1.78  ELAPSED TIME: 47.54
EXIT
```

8.6.1 Data Base File Name

8.6.2 Output Data Base for N = n.nn

Replies to these prompts are the same as for those of option 4A. Load factor selection then applies both to the base file and to the comparison file considered.

8.6.3 Comparison Filename

Reply with the filename of the data file to be compared with the base file. Data files are considered to be valid for comparison if the following parameters, specified when running program AIRCRAFT to create the data, are identical for both files:

HØ, H STEP, NO. OF STEPS (of HP or ES)
MACHØ, MACH STEP, NO. OF STEPS (of M)
GØ, G STEP, NO. OF STEPS (of G)
IPSTYP, IUNITS

Altitude, Mach number and load factor grid identity is assured if the PRESET I.V. INCREMENTS option is used when running AIRCRAFT to create both data files.

8.6.4 Input Errors

(a) If, for any reason, the grid parameters are not identical, the message

? FILE ARGUMENTS ARE DIFFERENT

is typed together with a listing of the grid parameters, and execution finishes immediately.

(*b*) **If either of the specified input files does not exist, an error message is typed and a new filename is requested. Supply the correct name to continue or (↑C) to return to the monitor.**

(*c*) **Replies to "?" other than "Y" are interpreted as "N".**

Notes:

(1) When considering whether a comparison file is valid, only the grid parameters mentioned above are checked. Other parameters, such as power setting, wing sweep and atmosphere type are not checked.

(2) If not all of the available load factors are selected for output, the informative

END OF DATA ON LOG4

is typed on the terminal. This is not an error condition, but simply echoes that only selected load factors will appear on the output file.

Output for this option is in ASCII mode on three files, viz. P2.CON, P2A.CON and P2DIFF.CON.

P2.CON is the same as would be produced by running option 4A with the same replies, using DATA BASE FILENAME as input.

P2A.CON is the same as would be produced with option 4A using COMPARISON FILENAME as input.

P2DIFF.CON is the file for the differential contour plot.

All three files are intended as input to program P4, but may be printed if desired.

8.7 Option 4E—Differential MMD

This option functions by processing two sets of data and subtracting the data at the grid points to produce values of differential turn rate. An example follows:

```
OPTION OR (CR) FOR HELP : 4E

4E  MMD DIFFERENTIAL PLOT. (P2.OPT,P2A.OPT,P2DIFF.OPT)

ARE BOTH ".OPT" FILES ALREADY ON DISK ? N

ON-LINE DATA             ? N

DATA BASE  FILENAME      : E.MMD

*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS          ***

DEFINE ENERGY GRID - (POSITIVE INCREMENT)
START, STEP, NO OF STEPS: -1200,100,25

ON-LINE COMPARISON DATA ? N

COMPARISON FILENAME      : C.MMD

CPU TIME USED =    0 MINS    1.56 SECS
```

8.7.1 Are Both ".OPT" Files Already on Disk?

Answers "Y" if comparison files P2.OPT and P2A.OPT, produced by prior runs of program P2, are to be used as input data. This facility is included to enable comparison of files generated using on-line data, without the need to repeat the on-line dialogue to recreate the comparison files. An answer "Y" results in completion of execution without any further user interaction. Execution proceeds normally, with interruption only if energy state or energy rate data grids differ.

Answer "N" if on-line data or program AIRCRAFT output files are to be used as input data.

8.7.2 On-line Data

8.7.3 Data Base Filename

8.7.4 PSØ, PS Step, Number of Steps

Reply to these three prompts as for option 4C. The energy rate grid chosen applies for both the base file and the comparison file.

8.7.5 On-line Comparison Data

Comparison data may also be in a disk file or supplied on-line from the terminal. Reply "Y" or "N" as required.

8.7.6 Comparison Filename

This prompt is given if data is not being supplied on-line. Reply with the name of the file of comparison data. Data files are considered valid for comparison if the energy state grid parameters are valid for both sets of data.

8.7.7. Input Errors

(*a*) If the grid definitions are not identical, the text

? FILE ARGUMENTS ARE DIFFERENT

is typed, followed by the arguments for the two grids; execution then terminates.

(*b*) If either of the specified input files cannot be found on disk, an error message is typed, and a new filename is requested. Supply the correct name to continue or ↑C to abort the job and return to the monitor.

(*c*) Energy rate grid—a valid combination ensures:

(i) increment value > 0; and

(ii) $0 <$ number of values $\leqslant 50$.

An invalid combination causes the text

INVALID INPUT! TRY AGAIN

to be typed on the terminal, and the prompt is repeated.

(*d*) On-line input errors—remarks made in Section 8.5.7 also apply for on-line differential data.

Output for option 4E is in ASCII mode on three files, viz., P2.OPT, P2A.OPT and P2DIFF.OPT, containing data for base, comparison and differential MMD contour plots, respectively. Each is intended as input to program P4, but may be printed if required.

8.8 Option 4F—Maximum Manoeuvre Persistence Aid

This option supplies an on-line calculation aid in determining manoeuvre capability at a number of ranges from base. An example follows:

```
OPTION OR (CR) FOR HELP : 4F

4F  MMP CALCULATION ASSISTANCE.
IMPERIAL (0) OR S.I. (1) UNITS ? 0

NO OF RANGES
* 4

FUEL VECTOR - LB
* 4153

* 3216

* 2220

* 1180

ES - FT, OM - DEG/S, WF - LB/HR
* 5000,24.014,58710

TURNS:  16.99 13.15  9.08  4.83
* 10000,22.376,56073

TURNS:  16.57 12.83  8.86  4.71
* 15000,20.492,52205

TURNS:  16.28 12.60  8.70  4.62
* 20000,18.776,49240

TURNS:  15.84 12.26  8.47  4.50
* 25000,17.253,46519

TURNS:  15.40 11.93  8.23  4.38
* 30000,15.523,46133

TURNS:  13.97 10.82  7.47  3.97
* 35000,12.457,48465

TURNS:  10.67  8.27  5.71  3.03
* 40000,9.106,37840

TURNS:   6.54  5.06  3.50  1.86
* 45000,8.071,49598

TURNS:   6.76  5.23  3.61  1.92
* 50000,6.990,46831

TURNS:   6.20  4.80  3.31  1.76
* )

STOP

END OF EXECUTION
CPU TIME: 0.99  ELAPSED TIM : 5:17.44
EXIT
```

8.8.1 Imperial (∅) or SI (1) Units

Reply ∅ or 1 to indicate Imperial or SI unit systems, respectively.

8.8.2 Number of Ranges

Reply with the number of ranges for which available fuel quantities are known.

8.8.3 Fuel Vector—kg (lb)

Reply with the values of fuel availability each at range from base, one value per line. The values should be at distances either increasing or decreasing from base.

8.8.4 ES—m (ft), OM—deg/s, WF—kg/s (lb/hr)

Reply with values of optimum turn rate and fuel flow rate, in the units indicated, at each energy state for which turning data is required, three values per line, in response to the asterisk prompt.

The program responds by typing the numbers of turns possible using the given fuel vector. Execution terminates by replying to the prompt with a carriage return.

8.8.5 Input Errors

(*a*) If the number of range/fuel availability pairs is greater than 50, or

(*b*) If the value of fuel flow rate is not positive,

the error text

INVALID INPUT! TRY AGAIN

is typed on the terminal and the prompt is repeated.

8.9 Option 4Z—Overview of Data Grid

This option presents, in a concise form, the fundamental data representation for the energy-manoeuvrability method. Turn rate and energy parameter are plotted against Mach number for several values of load factor. One page of graphs is produced for each value of the height varaiable, which may be energy state or pressure altitude. An example follows:

```
OPTION OR (CR) FOR HELP : 4Z

4Z  TURN RATE, PS VS MACH FOR GIVEN HEIGHT.   (P2.PLT)
DATA BASE  FILENAME     : A.NUM

*** DATA ARE IN METRIC  UNITS, ENERGY PARAMETER IS PS/WF      ***


REPLY "YES", "NO", "ALL" OR "END" :

HEIGHT =         0.0 M   ? Y

 G =  1.00 ? Y

 G =  3.00 ? Y

 G =  5.00 ? Y

 G =  7.00 ? E

HEIGHT =     10000.0 M   ? A

HEIGHT =     20000.0 M   ? N

END OF EXECUTION
CPU TIME: 4.45  ELAPSED TIME: 42.92
EXIT
```

8.9.1 Data Base Filename

Reply with the name of the data file created for this option. In operation, any data file created by program AIRCRAFT will be able to be plotted except those created for optimised grids (maximum manoeuvre diagrams).

8.9.2 Height = nnnnnn.n m (ft)

8.9.3 G = nn.nn

For these two prompts, replies "YES", "NO", "ALL" or "END" have the same meanings as comparable replies when using option 4B (Sections 8.4.5 and 8.4.6). This range of replies allows a selection to be made from the data available on the input file.

The output file P2.PLT contains the requested plots, and is submitted to the plotter queue in the usual way. Each height value requested produces approximately 20 cm of plotted output.

Since this is an additional plot provided for an overall view of the grid for an aircraft, no options for variation of plotting scales are provided. Each group of curves is plotted on a double graph of size 25 cm by 14 cm (10 in. by 6 in.) with a common Mach number axis (x axis). The scales and ranges for the axes are shown in Table 5.

8.9.4 Input Errors

(*a*) In correct filename—the correct filename is requested, as in other options.

(*b*) Any reply to a height or load factor prompt other than the four above is interpreted as "NO".

9. PROGRAM P4 USER'S GUIDE

9.1 Loading and Saving of Absolute Files

The commands for loading and saving an absolute copy of program P4 on disk, and producing a symbol map are:

```
.LOA/MAP @P4LOAD
FORTRAN: P4
MAIN.
OUTXT
P
PLOTD
P4MAIN
LINK:   Loading

EXIT

.SAV
P4 saved
```

The indirect loading command "@" is employed to instruct the linking loader to use the loading sequence contained in the disk file P4LOAD. The content of this file is the string

```
P4,/SEARCH P24LIB,[1033,1022]GRAFIC,EXTRAS,GRAFIC
```

File P24LIB.REL and files GRAFIC.REL and EXTRAS.REL (both on disk area [1033, 1022]) are searched as user libraries.

The absolute copy of the program is saved on the disk file P4.EXE, which is then executed using the RUN command. Core storage requirement is 37 pages (approximately $19K_8$ words). The storage allocation of array WORK is again set at 8000 words, as for program P2. This storage limit will need changing only if the allocation in program P2 is changed.

9.2 Program Execution

The inputs to program P4 consist of data files created in standard formats by program P2. A selection is then made using, terminal inputs, of data to be plotted. The sole output of the program is the plotter file P4.PLT.

A classification of input data files into four types is given in Section 6.2. The four types are energy rate contour plots, differential energy rate contour plots, maximum manoeuvre diagrams, and differential maximum manoeuvre diagrams.

The following sections of this chapter describe the terminal operations required for each type of data, using sample dialogue. User input to terminal prompts is again underlined.

9.3 Energy Rate Contour Plots

Example:

```
RUN P4


INPUT FILENAME : P2.CON

*** DATA ARE IN METRIC   UNITS, ENERGY PARAMETER IS PS/WF      ***

CONTOUR PLOTTING

SCALES IN UNITS/IN OF PLOT - X, Y : 0.4,4000

SMOOTHED AND TEXTURED CONTOURS    ? Y

PLOT ES CONTOURS ? Y

CONTOUR LEVELS - START, STEP, NO. : 0,2000,25

PLOT N =   1.00  ? Y

CONTOUR LEVELS - START, STEP, NO. : 0,5,15

PLOT N =   3.00  ? Y

CONTOUR LEVELS - START, STEP, NO. : -10,5,15

PLOT N =   5.00  ? N

PLOT N =   7.00  ? Y

CONTOUR LEVELS - START, STEP, NO. : -30,5,150

INVALID INPUT! TRY AGAIN -
CONTOUR LEVELS - START, STEP, NO. : -30,5,15

PLOT N =   9.00  ? E

STOP

END OF EXECUTION
CPU TIME: 14.81 ELAPSED TIME: 2:57.08
EXIT
```

9.3.1 Input Filename

Program P2 produces files with filenames

P2.CON   or   P2A.CON

for single aircraft contour plots (the latter during a comparison run). One of these two names is required as a reply. P4 responds with the unit system for the data and the type of energy parameter.

9.3.2 Scale in Units/in. of Plot—x, y

Reply with the amount of the physical quantity which one inch of plot would represent on each axis. For energy rate contour plots, the x- and y-axes represent Mach number and altitude respectively.

x-axis
The Mach number covers the range

$$(\text{Min}, \text{Min}+(\text{No. of Machs}-1)\times \text{Inc.})$$

where the values of Min, No. and Inc. are the defining grid values specified when running program AIRCRAFT. A scale between 0·2 and 0·4 unit/in. is usual, such that the axis length is less than 20 cm (8 in.) for adequate A4 trim.

y-axis
Altitude range is determined by a similar formula to that above. Usual range is approximately 0 to 20,000 m (0 to 60,000 ft), so that a scale of 4000 m/in. (10,000 ft/in.) provides adequate A4 trim. The altitude variable will normally be pressure altitude, but it is also possible to plot energy state as the altitude variable, in which case the scales suggested should be halved.

9.3.3 Smoothed and Textured Contours

Reply "Y" or "N" as required.

The smoothing interval of 0·05 in. chosen for P4 results in rounding off the sharp corners where the otherwise essentially linear contour approximations meet. It also provides a visually pleasing mark : space ratio for contour texturing, which cannot be chosen unless smoothing is requested.

For most plots except those with very fine grid spacings, smoothing results in a more attractive plot without loss of accuracy, at the expense of a slight increase in computing time.

9.3.4 Plot ES Contours

Information is carried in the data file to enable contours of constant energy state to be superimposed on the requested plots. Reply "Y" if these are required.

9.3.5 Contour Levels-Start, Step, Number

This prompt is given to define energy state contours (if specified) and to define energy rate contours for each load factor specified. *For energy state contours* the following are typical values:

START: 2000 m (5000 ft),
STEP : 2000 m (5000 ft),
NO. : up to 30, depending on ranges for x- and y-axes.

For energy rate contours, values of START, STEP and NO. should cover the complete range of energy parameters expected for the given aircraft configuration and load factor. Table 5 gives a guide to the ranges for the energy parameters in the two unit systems. Obviously as load factor increases, more negative contours should be plotted.

9.3.6 Plot N = x.xx

The prompt will supply each load factor in turn for which data exists on the data file. Reply "Y" or "N" as desired. Contour level definition will then be requested for each load factor to be plotted.

Depending on the x-axis scales used, 20 to 35 cm (8 to 14 in.) of plot is required for each load factor requested. Submit the output file P4.PLT to the plot queue in the usual way for plotting.

9.3.7 Input Errors

(*a*) *Incorrect filename.*—An error message is typed on the user's terminal if the specified input file cannot be found on disk, and a new filename is requested. Supply the correct name to continue or (↑C) to abort the job.

(*b*) *Axis scales.*—If either scale is zero, the message

INVALID INPUT! TRY AGAIN

is typed, and new scales are requested.

(*c*) *PLOT prompts.*—Any reply other than "Y" is interpreted as "N".

(*d*) *Contour level specification.*—A valid combination ensures:

(i) increment value $\neq 0$, and

(ii) $0 <$ number of steps $\leqslant 50$.

An invalid combination causes the text

INVALID INPUT! TRY AGAIN

to be typed on the terminal, and the prompt is repeated.

Notes:

(1) If any of the load factors specified in the grid definition have been bypassed by program P2, the informative text

END OF DATA ON LOG5

will be typed on the terminal. It does not indicate an error condition, but is informative only.

(2) File P4.PLT must be submitted to the plotter queue after each run of P4, otherwise the plot may be accidentally overwritten the next time P4 is run.

9.4 Differential Energy Rate Contour Plots

```
.RUN P4


INPUT FILENAME : P2DIFF.CON

*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS          ***

CONTOUR PLOTTING

SCALES IN UNITS/IN OF PLOT - X, Y : 0.4,10000

SMOOTHED AND TEXTURED CONTOURS    ? Y

PLOT ES CONTOURS ? N

PLOT N =    1.00   ? Y

CONTOUR LEVELS - START, STEP, NO. : -500,50,16

PLOT N =    3.00   ? Y

CONTOUR LEVELS - START, STEP, NO. : -1000,100,16

PLOT N =    5.00   ? Y

CONTOUR LEVELS - START, STEP, NO. : -1000,100,16

PLOT N =    7.00   ? N

STOP

END OF EXECUTION
CPU TIME: 11.44 ELAPSED TIME: 2:25.24
EXIT

.
```

Filename P2DIFF.CON indicates differential energy rate data.

Replies for this type of run are very similar to those for an energy rate contour plot for a single aircraft. The only difference is that requests for contour levels now refer to the *difference* between the two aircraft at each grid point. The aircraft referred to by program P2 as the DATA BASE will be indicated by positive contours, and that referred to as the COMPARISON will be indicated by negative contours. Full identification-headers are included on the plotted output on file P4.PLT.

9.5 Maximum Manoeuvre Diagrams

This type of run produces a single graph of turn rate contours on an optimum energy rate (y-axis) vs. energy state (x-axis) grid.

```
.RUN P4


INPUT FILENAME : P2.OPT

*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS          ***

CONTOUR PLOTTING

SCALES IN UNITS/IN OF PLOT - X, Y : 10000,400

SMOOTHED AND TEXTURED CONTOURS    ? N

CONTOUR LEVELS - START, STEP, NO. : 0,2,16

STOP

END OF EXECUTION
CPU TIME: 6.75  ELAPSED TIME: 1:17.86
EXIT

.
```

9.5.1 Input Filename

Program P2 produces files with filenames

P2.OPT   or   P2A.OPT

for a single aircraft MMD (the latter during a comparison run). One of these two names should be typed as a reply. P4 responds with the unit system for the data and the type of energy parameter.

9.5.2 Scales in Units/in. of Plot—X, Y

Reply, as before, with the amount of the physical quantity which one inch of plot would represent on each axis. For MMD plots, the x- and y-axes represent energy state and energy rate, respectively.

x-*axis*
Energy state covers the range defined when running program AIRCRAFT (see Section 9.3.2). The usual range will be approximately 2000 to 24,000 m (5000 to 75,000 ft), so that a scale of 4000 m/in. (10,000 ft/in.) provides adequate A4 trim.

y-*axis*
Energy rate covers the range defined in the usual way when running program P2. The scales given in Table 5 may be used as a guide for all combinations of type of energy parameter and unit system.

9.5.3 Smoothed and Textured Contours

Reply "Y" or "N" as required.

9.5.4 Contour Levels—Start, Step, Number

Reply with parameters defining the turn rate contours. Typical values are:
START: 0 deg/s;
STEP : 2 deg/s;
NO. : up to 16.

9.5.5 Input Errors

Input errors in filename, axis scales and contour levels are the same as those for the energy rate contour plots (Section 9.3.7)

After execution, output file P4.PLT is submitted to the plotter queue in the usual way. About 40 cm (16 in.) of plot will be produced for each run.

9.6 Differential Maximum Manoeuvre Diagrams

```
.RUN P4


INPUT FILENAME : P2DIFF.OPT

*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS        ***

CONTOUR PLOTTING

SCALES IN UNITS/IN OF PLOT - X, Y : 10000,400

SMOOTHED AND TEXTURED CONTOURS    ? Y

CONTOUR LEVELS - START, STEP, NO. : -10,2,11

STOP

END OF EXECUTION
CPU TIME: 6.34  ELAPSED TIME: 1:13.52
EXIT

.
```

Filename P2DIFF.OPT indicates a differential optimum turn rate (MMD) plot. Replies for this type of run are similar to those above for a MMD plot for a single aircraft. Again, the only difference is that contour levels now represent differences between two aircraft, and the levels will cover a range from negative to positive, rather than being strictly positive as for a single aircraft.

Base aircraft superiority will be indicated by positive contours, and the comparison aircraft superiority will be indicated by negative contours. Full identification headers are included on the plotted output on file P4.PLT.

10. INPUT/OUTPUT EXAMPLES

10.1 Introduction

Previous chapters have discussed fully the various programs in the suite. This chapter presents examples of inputs and outputs when using the programs in a co-ordinated fashion to produce tabular summaries and contour, turn rate and maximum manoeuvre plots.

10.2 File Handling

For any given aircraft, a variety of input and output files will be used, requiring some form of standardised housekeeping for efficient storage and retrieval of files.

Each aircraft is represented by files of propulsion, aerodynamic and configuration data, together with source and absolute versions of the FORTRAN programs. These files are conveniently stored on DECtape, since changes to one or more files will be needed as data banks and programs are developed.

Output files for line-printer listing or plotting may be preserved or deleted as required, but it is useful to maintain copies of files needed for comparative energy rate contour plots or maximum manoeuvre diagrams. Once produced, these files are not changed, so it is convenient to store them on magnetic tape. A suitable naming convention is required, indicating:

- type of aircraft
- power setting
- configuration or role
- wing sweep (if applicable)
- atmosphere
- type of run (MMD, contour plot, etc.).

Other data identifying the files, such as unit system, type of energy parameter and grid parameters, are carried within the files and used by program P2 to ensure valid comparative data. Thus there is no necessity to identify these data in the file name.

As an example, the filename "AMXSUP.MMD" might be used to identify maximum manoeuvre diagram (MMD) data for aircraft A operating in the air superiority role (SUP) with maximum power (MX). ICAO Standard Atmosphere is implied, and no wing sweep variation is needed. A standardised data grid is used (discussed below) and separate magnetic tapes may be used for data in the two unit systems.

10.3 Energy Rate Contour Plots

Figure 19 shows a sample run of a typical AIRCRAFT program and the processing of data using programs P2 and P4 to produce a set of energy rate contour plots.

The example shown uses the preset data grid (see Fig. 5(*b*) or Section 7.2). Program AIRCRA produces a file line-printer listing (AMXSUP.LST) and a file for input to program P2 (AMXSUP.CON).

Figure 20 shows portion of file AMXSUP.LST and illustrates the main features of the listed output. The header page identifies the run and echoes configuration data supplied in the configuration file. Subsequent pages group energy rate data and turn rate data for each specified altitude. The lowest Mach number shown for each altitude is the lowest Mach number specified by the data grid within the 1*g* lift-limited envelope. No structural limits are indicated at higher Mach numbers; these placard limits must be applied off-line.

The file AMXSUP.CON contains all the information of the line-printer listing in a condensed format. In addition, energy rate values outside the lift-limited envelope are flagged with the values of −9999·99.

Figure 19 shows that the running of program P2 using option 4A is straightforward. In this case, all load factors are specified, and data are written on file P2.CON.

The scales used when running program P4, and the ranges of contour level are discussed in the User's Guide for program P4 (Section 9.3). It is likely that the first attempt to plot contours may omit some contours of interest, and this trial run may be accelerated by omitting the time-consuming smoothing process.

```
.RUN AIRCRA


MANEUVERABILITY GRID CALCULATION

IMPERIAL (0) OR S.I. (1) UNITS   ? 0
AIRCRAFT DATA FILENAME           ? ASTORE

AIRCRAFT EXAMPLE      DATE 30-Apr-79   TIME 14:10 24.9
AIR SUPERIORITY - 2 AAM + GUN + 50% FUEL

PS, PS/WF OR PS*V/WF (1, 2 OR 3) ? 1
IS HP THE HEIGHT VARIABLE        ? Y
PRESET GRID (Y, N OR C/R)        ? Y
POWER (MIL=100,MAX=200)          ? 200
WING SWEEP (IF VARIABLE)         ?
ATMOSPHERE , DEVIATION           ? ICAO
OUTPUT (1=TEXT,2=NOS.,3=BOTH)    ? 3
O/P FILENAME FOR UNIT 6          ? AMXSUP.LST
O/P FILENAME FOR UNIT 8          ? AMXSUP.CON

CALCULATION :

         ALTITUDE HP =       0.0 FT
         ALTITUDE HP =    4000.0 FT
         ALTITUDE HP =    8000.0 FT
         ALTITUDE HP =   12000.0 FT
         ALTITUDE HP =   16000.0 FT
         ALTITUDE HP =   20000.0 FT
         ALTITUDE HP =   24000.0 FT
         ALTITUDE HP =   28000.0 FT
         ALTITUDE HP =   32000.0 FT
         ALTITUDE HP =   36000.0 FT
         ALTITUDE HP =   40000.0 FT
         ALTITUDE HP =   44000.0 FT
         ALTITUDE HP =   48000.0 FT
         ALTITUDE HP =   52000.0 FT
         ALTITUDE HP =   56000.0 FT
         ALTITUDE HP =   60000.0 FT
         ALTITUDE HP =   64000.0 FT
         ALTITUDE HP =   68000.0 FT
STOP

END OF EXECUTION
CPU TIME: 1:19.02        ELAPSED TIME: 5:59.42
EXIT
```

Fig. 19(a) Sample dialogue for energy rate contour plot

```
.RUN P2

COMBAT PERFORMANCE PROCESSING

OPTION OR (CR) FOR HELP : 4A
4A  PS CONTOUR PLOT.                              (P2.CON)
DATA BASE  FILENAME      : AMXSUP.CON
*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS         ***

REPLY "YES", "NO", "ALL" OR "END" :
OUTPUT DATA FOR N =   1.00 ? A

END OF EXECUTION
CPU TIME: 14.39 ELAPSED TIME: 1:8.02
EXIT

.RUN P4

INPUT FILENAME : P2.CON
*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS         ***

CONTOUR PLOTTING

SCALES IN UNITS/IN OF PLOT - X, Y : 0.25,10000
SMOOTHED AND TEXTURED CONTOURS    ? Y

PLOT ES CONTOURS ? Y
CONTOUR LEVELS - START, STEP, NO. : 5000,5000,25
PLOT N =   1.00  ? Y
CONTOUR LEVELS - START, STEP, NO. : 0,100,12
PLOT N =   3.00  ? Y
CONTOUR LEVELS - START, STEP, NO. : -500,100,17
PLOT N =   5.00  ? Y
CONTOUR LEVELS - START, STEP, NO. : -1000,100,21
PLOT N =   7.00  ? Y
CONTOUR LEVELS - START, STEP, NO. : -1900,100,21
PLOT N =   9.00  ? Y
CONTOUR LEVELS - START, STEP, NO. : -1500,100,21
STOP

END OF EXECUTION
CPU TIME: 57.05 ELAPSED TIME: 7:13.66
EXIT
```

Fig. 19(b) Sample dialogue for energy rate contour plot (cont.)

```
AIRCRAFT MANEUVERABILITY TABLE FOR  AIRCRAFT EXAMPLE

ROLE : AIR SUPERIORITY - 2 AAM + GUN + 50% FUEL

NOMINAL ARGUMENTS :   18    ALTITUDES FROM      0. TO  60000. IN INCREMENTS OF  4000. FT
                      41 MACH NUMBERS FROM   0.000 TO   2.000 IN INCREMENTS OF  0.050 MACH
                       5 LOAD FACTORS FROM    1.00 TO    9.00 IN INCREMENTS OF   2.00 G

       WING REFERENCE AREA  350.00 FT**2        EXTERNAL DRAG TABLE HAS  8 DATA POINTS

MACH NOS.     0.200 0.920 0.960 0.985 1.010 1.100 1.200 2.000
DRAG COUNTS      8.    8.   10.   15.   17.   15.   14.   14.

ICAO ATMOSPHERE + (  0.0)C  CG 30.00%MAC  WT 20442.LB  100.0% A/B POWER   WING SWEEP  0.00 DEG   DATE 30-Apr-79   TIME 14:10 24.9
```

Fig. 20(a) Sample listing of energy rate contour data — header page

ALTITUDE HP = 0.0 FT

TABULATED VALUES : PS - FT/S
TURN RATE - DEG/S

I	MACH NO	TAS KT	ES FT	H FT	WF LB/HR	LOAD FACTOR G UNITS 1.00	3.00	5.00	7.00	9.00
3	0.100	66.15	194.	0.	50418.	102.78	-9999.99	-9999.99	-9999.99	-9999.99
						0.000	999.999	999.999	999.999	999.999
4	0.150	99.22	436.	0.	51031.	180.11	-9999.99	-9999.99	-9999.99	-9999.99
						0.000	999.999	999.999	999.999	999.999
5	0.200	132.30	775.	0.	51754.	255.36	-9999.99	-9999.99	-9999.99	-9999.99
						0.000	999.999	999.999	999.999	999.999
6	0.250	165.37	1211.	0.	52588.	325.81	94.04	-9999.99	-9999.99	-9999.99
						0.000	18.681	999.999	999.999	999.999
7	0.300	198.44	1743.	0.	53534.	394.03	268.08	-9999.99	-9999.99	-9999.99
						0.000	15.567	999.999	999.999	999.999
8	0.350	231.52	2373.	0.	54593.	461.15	371.66	-6.92	-9999.99	-9999.99
						0.000	13.343	23.112	999.999	999.999
9	0.400	264.59	3099.	0.	55769.	527.71	454.15	241.64	-459.47	-9999.99
						0.000	11.676	20.223	28.599	999.999
10	0.450	297.66	3923.	0.	57061.	593.77	531.85	374.01	-22.01	-1000.35
						0.000	10.378	17.976	25.421	32.819
11	0.500	330.74	4843.	0.	58471.	659.71	606.14	474.80	216.65	-381.01
						0.000	9.340	16.178	22.879	29.537
12	0.550	363.81	5860.	0.	60002.	727.84	673.75	567.49	357.40	-31.01
						0.000	8.491	14.707	20.799	26.852
13	0.600	396.89	6973.	0.	61654.	797.05	739.62	647.17	481.36	171.78
						0.000	7.784	13.482	19.066	24.614
14	0.650	429.96	8184.	0.	63430.	863.24	809.65	718.86	584.46	339.09
						0.000	7.185	12.445	17.599	22.721
15	0.700	463.03	9491.	0.	65330.	927.41	880.58	789.89	670.81	476.48
						0.000	6.672	11.556	16.342	21.090

Fig. 20(b) Sample listing of energy rate contour data — extract

The $1g$ load factor energy rate contour plot produced using the dialogue in Figure 19 is shown in Figure 21. The size of the plot is a function of the Mach number and altitude grids and the scale specified. The different contour textures available for energy state contours and the zero-energy rate contour are clearly seen. Contours are labelled at their start with a level number. Contour values for each level are plotted at the right hand side of the plot; units are given on the printed output (file AMXSUP.LST). Configuration identification is given at the start of each plotting run (not shown in Fig. 21).

Lift limits and placard limits may be added by hand (as shown on Fig. 21). Manual retouching may be used to delete contours falling outside the operating envelope or to smooth contours in the vicinity of the lift limit boundary.

10.4 Differential Energy Rate Contour Plots

The same sequence of running programs AIRCRAFT, P2 and P4 is used to generate differential energy rate contour plots, as used in the previous example.

Data files of comparative data for input to program P2 are generated by running programs for each aircraft; alternatively published energy rate data can be used in conjunction with program ANY, as shown in Figure 22. Energy rate values at the specified increments of load factor are entered on each line. In the example shown, only one value is entered per line since the load factor grid has specified only the $1g$ load factor level. Data outside the $1g$ lift or structural limits is indicated by replying to the prompt with a carriage return. (This requires that data values of zero be entered as small non-zero numbers, e.g. 0·001).

Option 4D is used when running program P2, generating input files to program P4 for each aircraft, and a third file of differential data. An example of a differential energy rate plot produced by running program P4 is shown in Figure 23.

Obviously, differential contours only have meaning within the operating envelope common to both aircraft. Outside this envelope (shown by hatching in the figure), contours would be deleted by hand in preparing a final plot; smoothing is also required in the vicinity of the inner lift limit boundary.

10.5 Turn Rate Plots

Figure 24 shows a typical set of terminal dialogue for producing turn rate plots using programs AIRCRAFT and P2.

The data grid shown in the example provides, in the file AMXSUP.TRN, data for high subsonic manoeuvres up to 9000 m (approximately 30,000 ft). A load factor increment of 0·25 provides sufficiently smooth curves when the data is plotted. Figure 25 shows part of the listing file AMXSUP.LST, and illustrates the tabular layout for the 33 load factors specified. In this example, SI units are nominated, and all output headings and numerical values vary accordingly.

Four combinations of Mach number and altitude are selected for plotting when running program P2 using option 4B. The User's Guide for program P2 (Section 8.4) should be consulted if uncertain of the scale and range for the energy rate axis. Each turn rate curve plotted is identified with Mach number and energy state annotation. The turn rate plot for 3000 m altitude from the above example is shown in Figure 26.

10.6 Maximum Manoeuvre Diagrams

The usual sequence of running programs AIRCRAFT, P2 and P4 may be used to obtain maximum manoeuvre diagrams. However, the optimization process involved in program AIRCRAFT is time-consuming, and on-line running of this program can be replaced by batch running using the ARL Computer Centre's BATCON system.[17] This simply involves grouping the commands required to run AIRCRAFT into a single file with the extension ".CTL".

Such a file, named MMD.CTL, is shown in Figure 27. The commands in the file run AIRCRAFT, supplying all the conversational replies required, prints the listing file AMXMMD.LST, and leaves the input data for program P2 in file AMXSUP.MMD on the

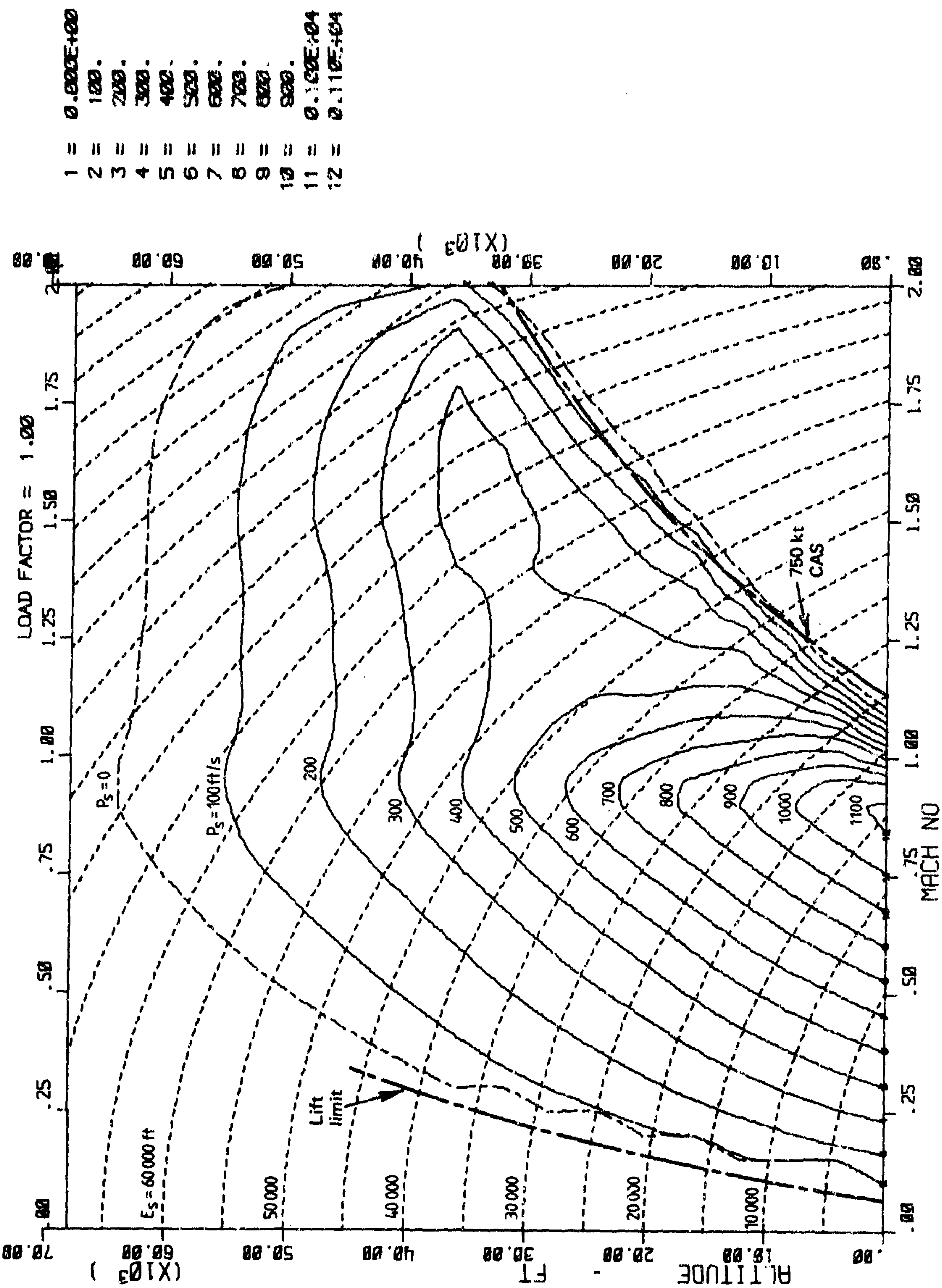

Fig. 21 Sample 1g energy rate contour plot

```
.RUN ANY


RERUN ? N
IMPERIAL (0) OR S.I. (1) UNITS   ? 0

MANEUVERABILITY GRID CALCULATION

AIRCRAFT NAME                     ? COMPARISON
WEIGHT(LB)                        ? 20500

ROLE : AIR SUPERIORITY
AIRCRAFT COMPARISON  DATE  2-May-79   TIME 10:27 38.1

WHICH FUNCTION - PS,
PS/WF OR PS*V/1000WF (1,2 OR 3) ? 1
IS HP THE ALTITUDE VARIABLE     ? Y
HP0, HP STEP (FT), NO. OF STEPS ? 0,5000,13
MACH0, MACH STEP , NO. OF STEPS ? 0,.1,21
G0    , G STEP    , NO. OF STEPS ? 1,1,1
POWER (MIL=100,MAX=200)         ? 200
WING SWEEP (IF VARIABLE)        ?
ATMOSPHERE , DEVIATION          ? ICAO
OUTPUT (1=TEXT,2=NOS.,3=BOTH)   ? 3
O/P FILENAME FOR UNIT 6         ? ZMXSUP.LAT
O/P FILENAME FOR UNIT 8         ? ZMXSUP.CON

CALCULATION :

HEIGHT =         0.
M .000 :
M .100 : -60
M .200 : 70
M .300 : 162
M .400 : 237
M .500 : 291
M .600 : 337
M .700 : 378
M .800 : 420
M .900 : 410
M1.000 : 50
M1.100 : -220
M1.200 :
M1.300 :
M1.400 :
M1.500 :
M1.600 :
M1.700 :
M1.800 :
M1.900 :
M2.000 :
HEIGHT =      5000.
M .000 :
```

Fig. 22 Use of program ANY to generate energy rate contour date

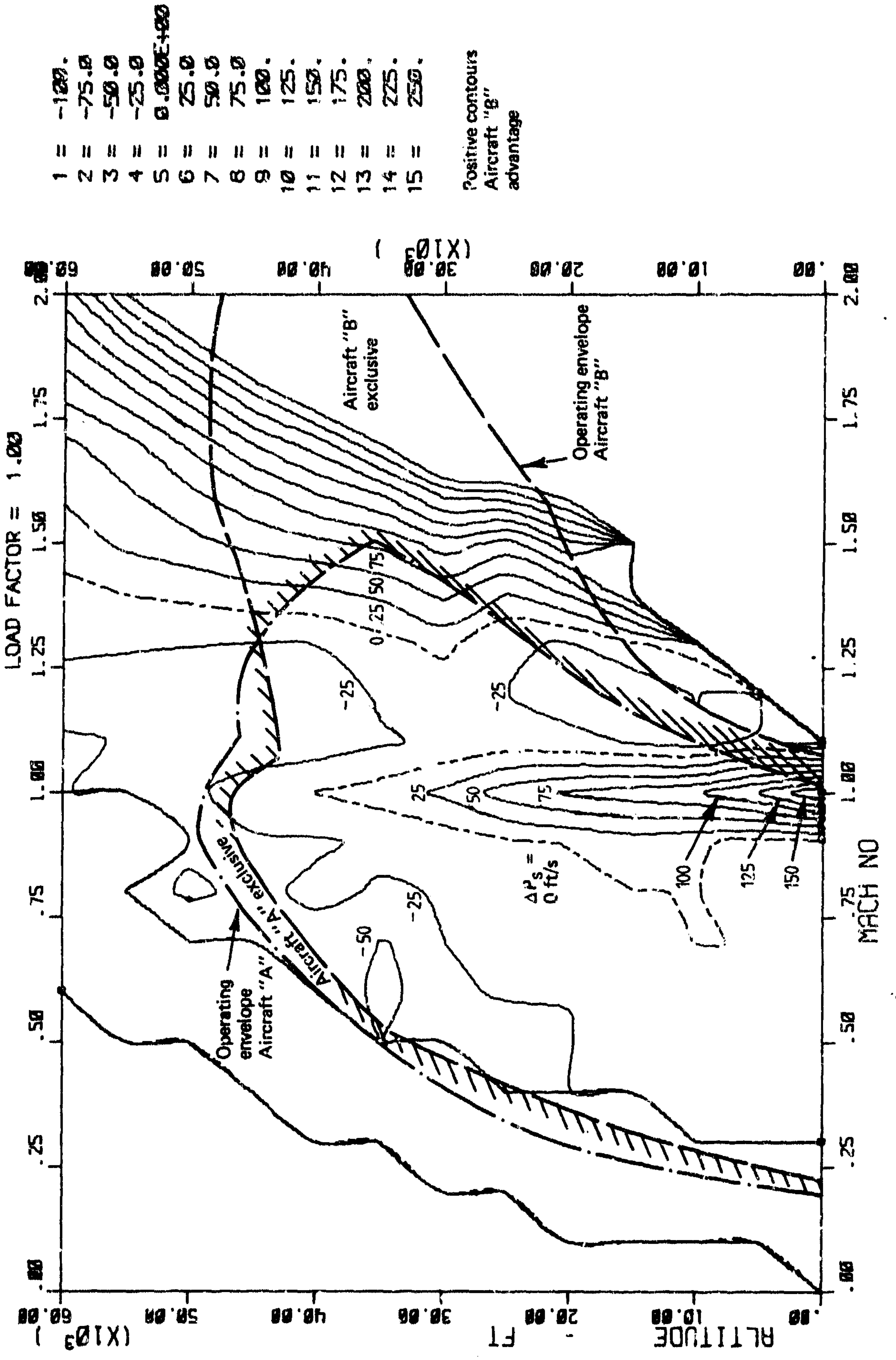

Fig. 23 Sample 1g differential energy rate contour plot

```
.RUN AIRCRA


MANEUVERABILITY GRID CALCULATION

IMPERIAL (0) OR S.I. (1) UNITS   ? 1
AIRCRAFT DATA FILENAME           ? ASTORE

AIRCRAFT EXAMPLE     DATE 30-Apr-79   TIME 14:45 02.3
AIR SUPERIORITY - 2 AAM + GUN + 50% FUEL

PS, PS/WF OR PS*V/WF (1, 2 OR 3) ? 1
IS HP THE HEIGHT VARIABLE        ? Y
PRESET GRID (Y, N OR C/R)        ? N
HP0 , HP STEP (M ), NO. OF STEPS ? 0,3000,4
MACH0, MACH STEP  , NO. OF STEPS ? 0.8,.1,2
G0   , G STEP     , NO. OF STEPS ? 1,.25,33
POWER (MIL=100,MAX=200)          ? 200
WING SWEEP (IF VARIABLE)         ?
ATMOSPHERE , DEVIATION           ? ICAO
OUTPUT (1=TEXT,2=NOS.,3=BOTH)    ? 3
O/P FILENAME FOR UNIT 6          ? AMXSUP.LST
O/P FILENAME FOR UNIT 8          ? AMXSUP.TRN

CALCULATION :

         ALTITUDE HP =       0.0 M
         ALTITUDE HP =    3000.0 M
         ALTITUDE HP =    6000.0 M
         ALTITUDE HP =    9000.0 M
STOP

END OF EXECUTION
CPU TIME: 9.86  ELAPSED TIME: 1:50.58
EXIT
```

```
.RUN P2


COMBAT PERFORMANCE PROCESSING


OPTION OR (CR) FOR HELP : 4B
4B  PS VS TURN RATE FOR GIVEN HEIGHT.        (P2.PLT)
DATA BASE  FILENAME     : AMXSUP.TRN
*** DATA ARE IN METRIC   UNITS, ENERGY PARAMETER IS PS        ***

SCALES IN UNITS/INCH OF PLOT
OMEGA / ENERGY VARIABLE : 4,100
MAXIMUM FOR ENERGY AXIS : 400
ENERGY AXIS LENGTH (IN) : 7

REPLY "YES", "NO", "ALL" OR "END" :
HEIGHT =      0.0 M     ? Y
  MACH =  .800 ? Y
  MACH =  .900 ? N
HEIGHT =   3000.0 M     ? Y
  MACH =  .800 ? N
  MACH =  .900 ? Y
HEIGHT =   6000.0 M     ? Y
  MACH =  .800 ? N
  MACH =  .900 ? Y
HEIGHT =   9000.0 M     ? Y
  MACH =  .800 ? N
  MACH =  .900 ? Y

END OF EXECUTION
CPU TIME: 10.78 ELAPSED TIME: 2:15.80
EXIT
```

Fig. 24 Sample dialogue for turn rate plot

ALTITUDE HP = 0.0 M

TABULATED VALUES : PS - M/S
TURN RATE - DEG/S

I	MACH NO	TAS KT	ES M	H M	WF KG/S	LOAD FACTOR G UNITS									
						1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25
						3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	5.50	5.75
						6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25
						8.50	8.75	9.00							
1	0.800	529.18	3779.	0.	8.758	320.72	320.35	319.73	318.88	317.78	316.46	314.90	313.12	311.11	308.87
						0.000	1.548	2.308	2.964	3.575	4.160	4.729	5.287	5.838	6.382
						306.42	303.76	300.87	297.78	294.48	290.98	287.28	283.37	279.27	274.98
						6.923	7.460	7.994	8.526	9.056	9.584	10.111	10.637	11.163	11.687
						270.50	265.83	260.98	255.94	250.73	245.34	239.78	234.05	228.15	222.09
						12.211	12.734	13.256	13.778	14.300	14.821	15.341	15.862	16.382	16.902
						215.87	209.49	202.96							
						17.422	17.941	18.461							
2	0.900	595.33	4782.	0.	8.976	341.22	341.04	340.61	339.92	338.98	337.79	336.34	334.63	332.67	330.45
						0.000	1.376	2.051	2.635	3.178	3.698	4.204	4.700	5.189	5.673
						327.97	325.23	322.23	318.97	315.44	311.66	307.61	303.29	298.71	293.86
						6.154	6.631	7.105	7.578	8.049	8.519	8.988	9.455	9.922	10.388
						288.74	283.36	277.71	271.79	265.60	259.13	252.40	245.39	238.10	230.55
						10.854	11.319	11.783	12.247	12.711	13.174	13.637	14.100	14.562	15.024
						222.71	214.60	206.21							
						15.486	15.948	16.409							

Fig. 25 Sample listing of turn rate data (extract)

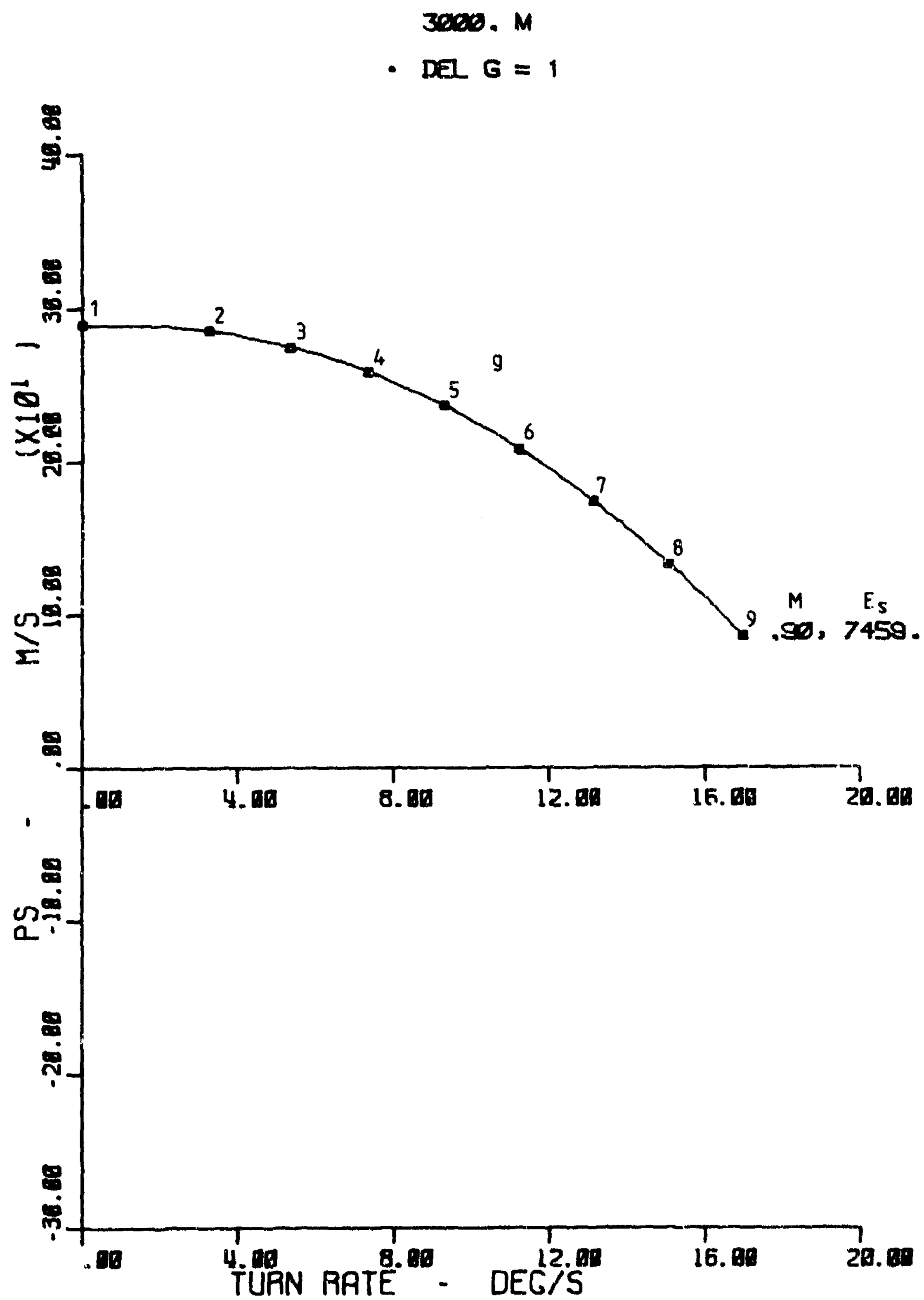

Fig. 26 Sample turn rate plot

```
*458920
.COPY/X=[1021,1203]AIRCRA.EXE,ASTORE,CF.BIN,CA.BIN
.IF(ERROR) .GOTO STOP
.RUN AIRCRA
*0
*ASTORE
*1
*N
*Y
*5000,5000,15
*1,.5,17
*200
*
*ICAO
*3
*AMXMMD.LST
*AMXSUP.MMD
.IF(ERROR).CLOSE
%FIN:: .COPY/X[1021,1203]=AMXSUP.MMD
.R PRINT
*ASTORE,AMXMMD.LST(P100L)
STOP:: .DEL *.*
```

Fig. 27 Batcon commands in file MMD.CTL

user's disk area. The energy state/load factor grid used in that example (15 states from 5000 ft to 75,000 ft and 17 load factors from $1g$ to $9g$) has been used as a suitable compromise between computing time (approximately 6 minutes CPU time for the example shown) and interpolation accuracy. Finer grids could be used if required.

An extract of file AMXMMD.LST for the above example is shown in Figure 28. This extract indicates the data calculated at each energy state, as well as the approximate time histories of fuel used and range obtained by integration from the initial energy state, using Equations (3.2) to (3.5).

The $1g$ load factor points provide the Mach number/altitude schedule for the optimum energy climb. The right-hand load factor column provides optimum sustained turn conditions for use in maximum manoeuvre persistence calculations. In the example shown, extrapolation beyond the $9g$ data limit indicates that at the energy states shown, the sustained turn would be load-factor limited, rather than thrust-limited. The listing is of considerable use in identifying limits applied to the final plot for lift, load factor and airspeed limitations.

Running programs P2 (option 4C) and P4 is straightforward, as outlined in the User's Guides (Sections 8.5 and 9.5). An example output plot from program P4 for a typical modern generation air-superiority fighter is shown in Figure 29. Lift limits, structural limits and airspeed limits are applied off-line as shown. Contours below these limits represent excursions outside the flight envelope, and are deleted by hand. Contour levels are labelled, and aircraft configuration identified in the usual way with text at the right- and left-hand sides of the plot (the latter not shown).

In the example shown, a small region in the left-hand corner of the plot shows where the grid is too coarse for linear interpolation to give satisfactory results. This situation could be remedied by using a finer grid for the whole plot, or by calculating data for the suspect region on a very fine grid and adjusting the plot by hand.

10.7 Differential Maximum Manoeuvre Diagrams

Generation of MMD data files for aircraft comparisons is performed using program AIRCRAFT as in the previous section, or using program P2 to supply data on-line (see Section 8.5.5).

Option 4E is used when running program P2. In the example shown in Figure 30, data files AMXSUP.MMD and BMXSUP.MMD were generated using the BATCON system in separate runs. MMD data files for both aircraft, as well as for their comparison, are created by running program P2 and the example shows that program P4 can be used with any of the three data files in successive runs, so long as copies of the output file P4.PLT are made using a different filename.

Running P4 is a simple operation; guidance with scales and contour levels is given in the User's Guide (Sections 9.5 and 9.6). The plot produced in the above example is shown in Figure 31. The zero turn rate boundaries for the two aircraft are plotted by program P4; lift, load factor and airspeed limits for the two aircraft must be added by hand. Again, contours exterior to the common flight envelope (shown hatched) have no significance, and would be deleted. Some touching up would also be necessary in the immediate vicinity of the lower turn rate boundary, if the plot were to be required for publication. That the area of comparison is so small indicates the vast superiority of aircraft "A" (1980 generation fighter) over aircraft "B" (1960 generation fighter).

10.8 Overview Plots of Data Grid

Programs AIRCRAFT and P2 are used to produce overview plots of the data covering any selected portions of the altitude (or energy state)/Mach number/load factor grid.

Input files to program P2 may be generated for particular altitudes of interest, or program P2 may be used to select altitudes from the energy rate contour plot data. Figure 32 is an example of these grid plots at a typical combat altitude. Each plotted curve is identified by a load factor annotation.

*** ENERGY STATE ES = 15000.0 FT ***

G		1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	15.54
PS	FT/S	1122.55	1120.51	1115.16	1106.51	1094.51	1079.18	1060.51	1038.48	1013.10	984.28	0.06
OMEGA	DEG/S	0.000	2.098	3.250	4.299	5.307	6.293	7.267	8.232	9.192	10.149	29.139
MACH		0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.880
TAS	KT	582.036	582.054	582.072	582.090	582.090	582.090	582.090	582.090	582.090	582.036	582.090
HP	FT	3.	2.	1.	0.	0.	0.	0.	0.	0.	3.	-0.
WF	LB/HR	71248.	71250.	71251.	71252.	71252.	71252.	71252.	71252.	71252.	71248.	71252.

G		6.00	6.50	7.00	7.50	8.00	8.50	9.00	15.54
PS	FT/S	952.17	916.68	877.78	835.46	789.73	740.57	687.99	0.00
OMEGA	DEG/S	11.101	12.051	13.000	13.947	14.893	15.838	16.783	29.139
MACH		0.880	0.880	0.880	0.880	0.880	0.880	0.880	0.880
TAS	KT	582.054	582.072	582.090	582.090	582.090	582.090	582.090	582.090
HP	FT	2.	1.	0.	0.	0.	0.	0.	-0.
WF	LB/HR	71250.	71251.	71252.	71252.	71252.	71252.	71252.	71252.

TIME	S	10.99
FUEL	LB	199.
RANGE	N.M.	1.402

Fig. 28 Sample maximum manoeuvre diagram data (extract)

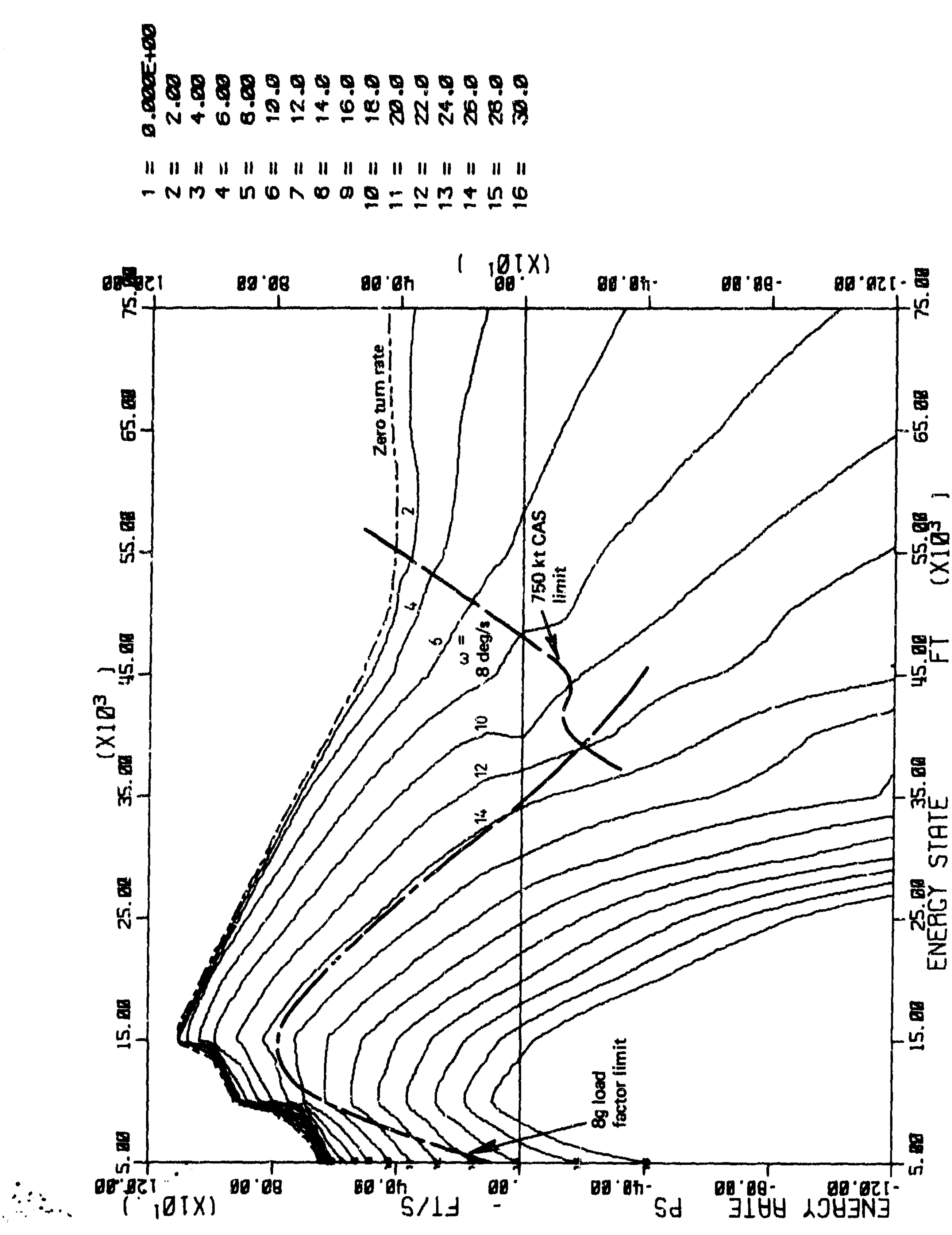

Fig. 29 Sample maximum manoeuvre diagram (MMD)

```
.RUN P2

COMBAT PERFORMANCE PROCESSING


OPTION OR (CR) FOR HELP : 4E
4E  MMD DIFFERENTIAL PLOT. (P2.OPT,P2A.OPT,P2DIFF.OPT)

ARE BOTH ".OPT" FILES ALREADY ON DISK ? N
ON-LINE DATA              ? N
DATA BASE  FILENAME       : AMXSUP.MMD
*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS          ***

DEFINE ENERGY GRID - (POSITIVE INCREMENT)
START, STEP, NO OF STEPS: -1200,100,25
ON-LINE COMPARISON DATA ? N

COMPARISON FILENAME       : BMXSUP.MMD

CPU TIME USED =    0 MINS   5.94 SECS

.RUN P4


INPUT FILENAME : P2.OPT
*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS          ***

CONTOUR PLOTTING

SCALES IN UNITS/IN OF PLOT - X, Y : 10000,400
SMOOTHED AND TEXTURED CONTOURS    ? Y
CONTOUR LEVELS - START, STEP, NO. : 0,2,16
STOP

END OF EXECUTION
CPU TIME: 9.21  ELAPSED TIME: 1:23.32
EXIT

.COPY MMD.PLT=P4.PLT

.RUN P4


INPUT FILENAME : P2DIFF.OPT
*** DATA ARE IN IMPERIAL UNITS, ENERGY PARAMETER IS PS          ***

CONTOUR PLOTTING

SCALES IN UNITS/IN OF PLOT - X, Y : 10000,400
SMOOTHED AND TEXTURED CONTOURS    ? Y
CONTOUR LEVELS - START, STEP, NO. : -20,2,21
STOP

END OF EXECUTION
CPU TIME: 10.46 ELAPSED TIME: 1:20.54
EXIT

.COPY DIFMMD.PLT=P4.PLT
```

Fig. 30 Sample dialogue for differential MMD plots

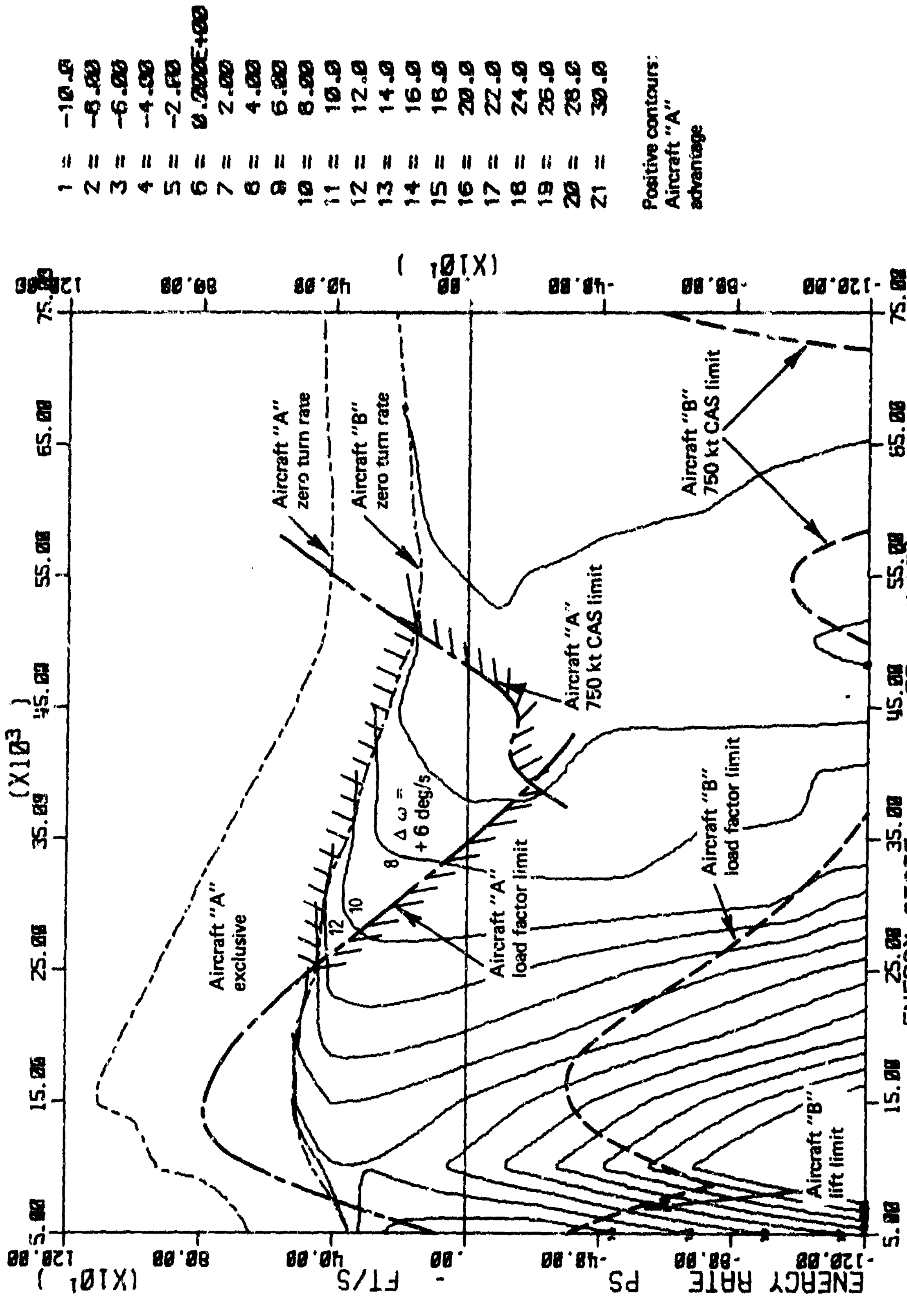

Fig. 31 Sample differential MMD

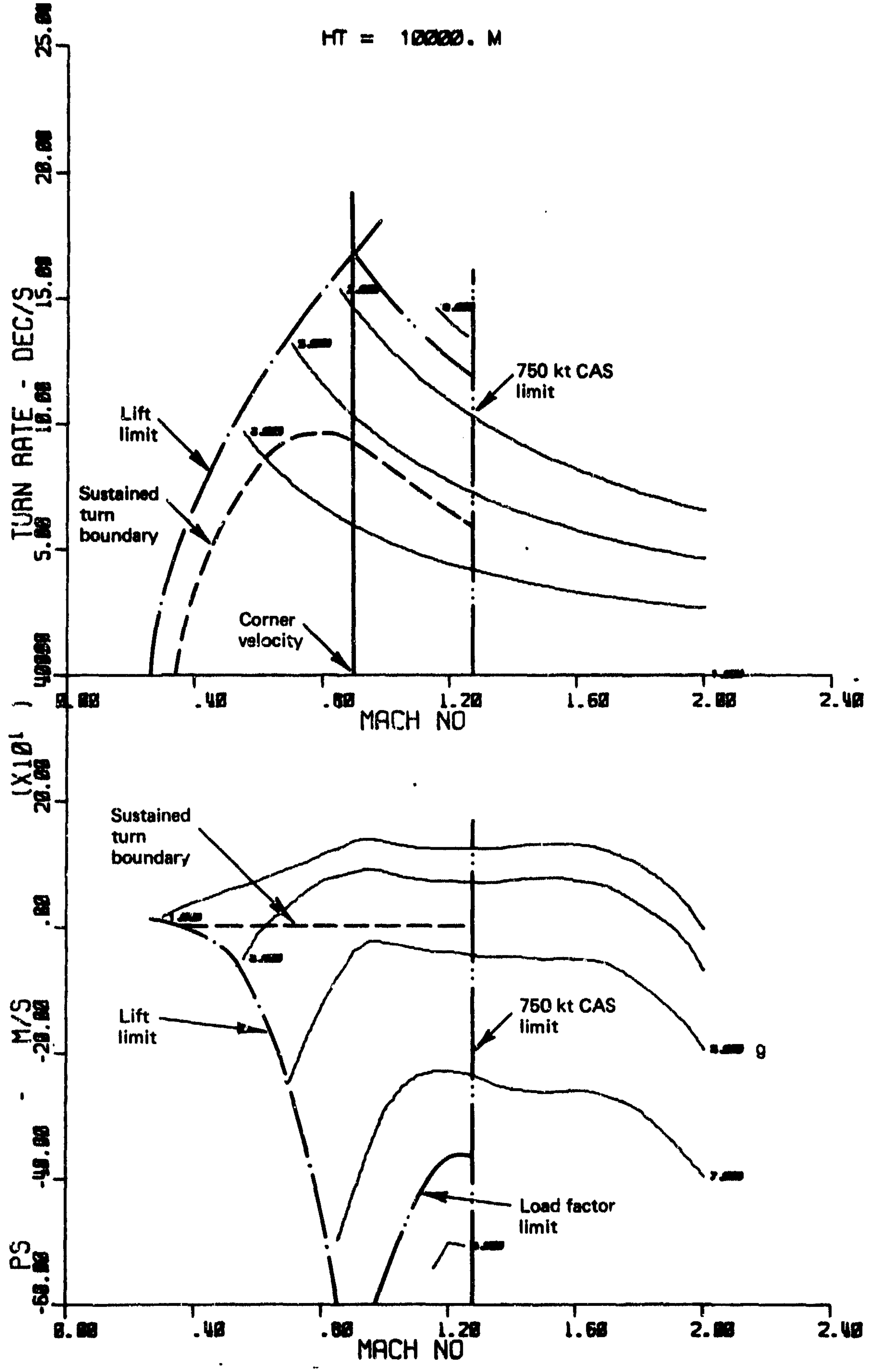

Fig. 32 Sample grid plot for specified attitude

As with other plots, lift, load factor and airspeed limits may be added by hand to give the aircraft's flight envelope at that altitude. The $P_S = 0$ axis may be used to plot the sustained turn boundary on the upper graph, and the lift limit/load factor limit intersection provides an estimate of the "corner velocity".

Although intended as an overview plot when the suite of programs was designed, plots on this format have proven to be of use to operational pilots, and the format could be further developed.

11. FUTURE PROGRAM DEVELOPMENT

11.1 Introduction

The development of the suite of programs described has been completed, and the range and type of outputs produced satisfy the requirements of the combat performance evaluation task. The quality of output is superior, for example, to that produced by the specific excess power programs developed for use with the Langley differential manoeuvring simulator.[18]

Nevertheless, it is always possible, given the need and the time, to improve a working product, and the suite described is no exception. This chapter discusses several areas in which accuracy, presentation and ease of operation could be improved if the need arises. Any improved accuracy resulting from the use of improved computational techniques should always be weighed against the errors inherent in the data presentation and representation.

11.2 Accuracy Improvements

There are two areas where variations in numerical methods could give improved accuracy, albeit at the expense of greater complexity and reduced operating speeds.

The first area is in the use of higher order interpolation schemes, particularly in the maximum manoeuvre options of program P2. At present, linear interpolation is used and a finer grid may be used to overcome irregularities in the plotted output. Routines such as SURF are already included in the subroutine library P1LIB and little extra programming effort would be needed.

The second area where improved numerical methods may be useful is in the integration of the energy function to provide time histories of optimum climb profiles.

The present simple Euler method could be replaced by an algorithm incorporating Simpson's rule, but in this case the improvements in calculation accuracy are limited by modelling considerations. The energy state approximations assume that potential and kinetic energy interchanges (i.e. "zoom" dives or climbs) at constant energy state occur in zero time, and do not take into account short period pull-ups/push-overs required in the transition from accelerated flight to constant energy flight. These factors are considered in more detail by Spillman.[7]

11.3 Presentation Improvements

Two aspects of presentation could be improved by further development.

At present, operating envelopes for particular aircraft are added to plotted output off-line. Lift limits are obtainable from plotted or printed output by extrapolation. Structural and airspeed limitations are obtainable only from data sources. All limits are configuration-dependent and thus conveniently determined and applied by hand after each run. It is possible to include these limits with the configuration data file, but this will involve programming changes to plotting routines to control pen operation, as well as careful monitoring of input files as configurations are changed.

A second presentation change which could be needed as service personnel become familiar with the plotted outputs, is to extend the grid option of program P2 (option 4Z) by plotting energy rate contours on the Mach number/turn rate axes (i.e., combine the two plots shown in Fig. 32). The changes required to do this are not trivial, but the benefits in presentation may justify the programming effort involved. The modular structure of program P2 minimizes the problems associated with such a change, and facilitates the addition of any future options which might be thought necessary.

11.4 Operation Improvements

A recent addition to the PDP-10 system facilities at ARL is the MIC system for on-line execution of commands in a user-defined control file.

Changes could be made to all the programs in the ARL suite to take advantage of this system program, particularly for production running, where terminal responses vary little from run to run. The changes would involve writing the user responses to the programs in a series of control files, which the MIC system is then commanded to process. User interaction is then minimal, ensuring error-free production running. The amount of program changes required depends only on the extent to which the MIC system is involved.

12. CONCLUSION

A suite of FORTRAN IV computer programs has been developed for the computation and presentation of data used in evaluating combat aircraft performance using energy manoeuvrability theory.

The arrangement of programs and subroutine libraries allows for flexibility of data representation of comparison aircraft, producing a variety of printed and plotted outputs. The programs have been fully described, presenting self-contained user's guides and reference documentation.

13. ACKNOWLEDGMENTS

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APPENDIX 1

Newton's Method Iteration for Calculating Geopotential Height

Energy state (E_S) is expressed in terms of geopotential height (h) and true airspeed (V) as:

$$E_S = E/W = h + V^2/2g \tag{A.1}$$

or, since both h and V are functions of pressure height (h_p):

$$E_S = h(h_p) + \{V(h_p)\}^2/2g. \tag{A.2}$$

By definition, Mach number (M) is related to true airspeed by:

$$M = V/a = V/(\gamma_{air} R_{air} T_a)^{0.5} \tag{A.3}$$

where a = sonic speed, m/s (ft/s),

γ_{air} = specific heat ratio for air, 1·4,

R_{air} = gas constant for air, 287·055 J/kg.K (3089·78 ft²/K.s²),

T_a = ambient temperature, K.

Solving Equation (A.3) for V and substituting in Equation (A.2) yields E_S in terms of h_p:

$$E_S = h(h_p) + \{\gamma_{air} R_{air} M^2/(2g)\} \,.\, T_a(h_p). \tag{A.4}$$

When E_S and M are specified, Equation (A.4) represents a non-linear equation in h_p, which may be solved using Newton's method (see example ref. 19, pp. 92, 157–160).

Let

$$k = \gamma_{air} R_{air} M^2/(2g) \tag{A.5}$$

which is a constant for a given M, and rewrite Equation (A.4) as an equation in h_p, viz.

$$\epsilon(h_p) = h(h_p) + kT_a(h_p) - E_S = 0. \tag{A.6}$$

Let $h_{p,i}$ denote the ith approximation to h_p. Then, using Newton's method,

$$h_{p,i+1} = h_{p,i} - \frac{\epsilon(h_{p,i})}{\epsilon'(h_{p,i})} \tag{A.7}$$

where

$$\epsilon'(h_{p,i}) = [\partial\epsilon/\partial h_p]_{h_p = h_{p,i}} \tag{A.8}$$

and ′ denotes differentiation w.r.t. h_p.

Differentiating (A.6) w.r.t. h_p gives

$$\epsilon'(h_p) = h'(h_p) + kT_a'(h_p). \tag{A.9}$$

For the atmospheric models used, it can be shown[8] that, in a given linear segment in a non-standard atmosphere,

$$h'(h_p) = (\Delta h_p)' = (T_{ab} \times \lambda_a \Delta h_p)/T_b + \lambda\Delta h_p), \tag{A.10}$$

i.e.

$$h'(h_p) = T_a(h_p)/T(h_p), \tag{A.11}$$

where atmospheric temperature (T) is given by

$$T = T_b + \lambda \Delta h_p. \tag{A.12}$$

Differentiation of Equation (A.12) w.r.t. h_p gives

$$T_a'(h_p) = \lambda_a (\Delta h_p)' = \lambda_a, \tag{A.13}$$

since

$$(\Delta h_p)' = (h_p - h_{pb})' = h_p' = 1. \tag{A.14}$$

Thus, substituting Equations (A.11) and (A.13) into Equation (A.9) gives

$$\epsilon'(h_p) = T_a(h_p)/T(h_p) + k\lambda_a, \tag{A.15}$$

and substituting Equations (A.15) and (A.6) into Equation (A.7) gives

$$h_{p,i+1} = h_{p,i} + \delta h_{p,i}$$

where

$$\delta h_{p,i} = -\frac{h(h_{p,i}) + kT_a(h_{p,i}) - E_S}{T_a(h_{p,i})/T(h_{p,i}) + k\lambda_a}. \tag{A.16}$$

A suitable iterative algorithm can now be written as follows:

(1) estimate $h_{p0} = E_S - a_{SL}{}^2 M^2/(2g).(=h_0)$;

(2) set $i = 1$;

(3) use subroutines ATMOS and INTRP given in Reference 8 to determine h, T_a, T and L;

(4) solve (A.16) for $\delta h_{p,i}$;

(5) if $\delta h_{p,i} <$ tolerance [say, 0·075 m (0·25 ft)], exit;

(6) increment i by 1 and return to step 3.

On exit, the required values of h_p, h and T_a are the exit values of these parameters as determined by subroutine ATMOS.

APPENDIX 2

"AIRCRAFT" Program Library

A2.1 AIRCRAFT Program

Purpose

This is a small routine to call for program input and to start calculation of aircraft performance parameters.

Use

.RUN AIRCRAFT (monitor command)

User routines called

PIIN TABLE

A2.2 AERO Subroutine (example)

Purpose

AERO is an aircraft-dependent routine which determines trimmed aircraft aerodynamic parameters, using curve-fitted data in COMMON EDATA. An initial estimate of angle of attack is required as input, and trimmed angle of attack is returned as output. Input and output are via COMMON B.

Use

CALL AERO

Input

GN XM W FN ALPHA DIM CGPERC NDCDS
XMDCDS DELCDS

(and any other parameters needed)

Output

ALPHA D IERR

Routines Called

SURF (and any other aircraft-dependent routines)

Calling Routines

TABLE SEP

A2.3 BLOCK DATA

Purpose

To define data in COMMON C, representing atmospheric profiles, text constants and other numeric constants.

Use

Loaded during loading phase.

A2.4 THRUST Subroutine (example)

Purpose

THRUST is an aircraft-dependent routine which determines engine thrust and fuel flow, using curve-fitted data in COMMON FDATA. An auxiliary output is the lower limit of Mach number validity.

Input and output are via COMMON B.

Use

CALL THRUST

Input

XM HP PLA DTEMP MT

(and any other parameters needed)

Output

FN WF XMLIM IERR

User Routines Called

SURF (and any other aircraft-dependent thrust routines)

Calling Routines

TABLE SEP

APPENDIX 3

P1 Subroutine Library

A3.1 ALTIT Subroutine

Purpose

ALTIT performs a Newton's method iteration to determine pressure height and other atmospheric quantities, when the independent variables are energy height and Mach number.

Input and output are via COMMON B. Atmosphere profiles defined in COMMON C are used.

Use

CALL.ALTIT

Input

COMMON B: ES XM
COMMON C: TICAO GAMMA R G

Output

COMMON B: T TS HP H ALAPSE CI IERR

User Routines Called

ATMOS HEIGHT

System Routines Called

ABS

Calling Routines

TABLE SEP

Comment

This subroutine embodies the algorithm of Appendix 1. A failure exit is made with error indicator IERR set to 201 if more than 20 iterations are required for ES convergence to within 0·25 ft.

A3.2 ATMOS Subroutine

Purpose

ATMOS calculates atmospheric parameters, giving temperature as a function of pressure height in either ICAO or ARDU Atmospheres.

Input and output are via COMMON B. Atmosphere profiles defined in COMMON C are also used.

Use

CALL ATMOS

Input

COMMON B: HP MT DTEMP
COMMON C: HICAO TICAO HARDU TARDU

Output

COMMON B: ALAPSE TS T ALPSTD LEV

User Routine Call
INTRP

Calling Routines
TABLE ALTIT

A3.3 BADINP Subroutine

Purpose

BADINP types out an error message on the user's terminal. It is used while checking input validity during conversational input operations. If invalid input is detected, recovery is achieved by repeating the input prompt after return from BADINP.

Use
CALL BADINP

Calling Routine
PIIN

A3.4 BININ Subroutine

Purpose

BININ opens and reads data into a nominated storage area from a specified disk file. This file must consist of a sequence of binary records, with the first word in each record being the number of data items in that record.

Use
CALL BININ (A, NA, LIMA, FILNAM)

Input

A	The array into which data is to be read
NA	The index of the first location in A
LIMA	The dimension of A
FILNAM	A double precision text variable or literal giving the name of the disk file.

Output

A	Array containing the data.

Calling Routine
IDENT

A3.5 HEIGHT Subroutine

Purpose

HEIGHT calculates the geopotential height corresponding to a given pressure height in the nominated atmosphere.

Input and output are via COMMON B. Atmosphere profiles defined in COMMON C are used.

Use
CALL HEIGHT

Input

COMMON B:	HP	MT	DTEMP	
COMMON C:	HICAO	HARDU	TICAO	TARDU

Output
COMMON B: H

User Routines Called
INTRP HTRUE

System Routine Called
AMINI

Calling Routines
TABLE ALTIT

A3.6 HTRUE Function

Purpose
HTRUE is called by HEIGHT to integrate over constant temperature lapse rates to obtain a geopotential height increment, using the method of Reference 8.

Use
HG = HTRUE (A, B, C, D, H2, H1)

Input

A	Ambient lapse rate
B	ICAO lapse rate
C	Sea level extrapolated ambient temperature
D	Sea level extrapolated ICAO temperature
H2	Upper pressure height
H1	Lower pressure height

Output
HG Geopotential height increment

System Routine Called
ALOG

Calling Routine
HEIGHT

A3.7 IDENT Subroutine

Purpose
IDENT is an input subroutine which reads the aircraft identification data file and calls BININ to read thrust and drag data files.

Aircraft identification data is transmitted via COMMON B, while aerodynamic and thrust data are transmitted via COMMON EDATA and COMMON FDATA.

Use
CALL IDENT

Output
COMMON B: SREF W FRAME SWPMIN SWPMAX NDCDS XMDCDS DELCPS ROLE CGPERC
COMMON EDATA: E
COMMON FDATA: F

User Routine Called
BININ

Calling Routine
PIIN

A3.8 INTRP Subroutine

Purpose
INTRP is a linear interpolation routine, returning ordinate and gradient information.

Use
CALL INTRP (TABT, TABH, DTDH, HP, TEMP, N)

Input

TABT	Table of ordinate values (x_i)
TABH	Table of abscissa values (y_i)
HP	Independent variable (x)
N	Index of next $x_i > x$

Output

DTDH	Slope (dy/dx)
TEMP	Dependent variable (y)

Calling Routine

ATMOS HEIGHT MAXMAN

A3.9 MAXMAN Subroutine

Purpose

MAXMAN controls the calculation and output of the optimised manoeuvrability grid, using energy height and load factor as grid variables. Energy parameter is optimised by varying Mach number, and a simple Euler integration is performed at each energy state to estimate a climb time history.

Input and output are via COMMON areas B, TABLES, TABLET, ZEROPS and CLIMBS. Data constants are input via COMMON C.

Use

CALL MAXMAN

Input

COMMON B: PLA DELES NES DELGN NGN ES0 GN0 IPSTYP

COMMON C: G RADIAN HOUR

Output

COMMON B:	ES	GN	XM	HP	IES	
COMMON TABLES:	PSTAB	OMTAB	GNTAB			
COMMON TABLET:	XMTAB	VTAB	HPTAB	WFTAB		
COMMON ZEROPS:	GNPS0	OMPS0	XMPS0	VPS0	HPPS0	WFPS0
COMMON CLIMBS:	TI	FU	RA			

User Routines Called

SEP INTRP ROMIN PIOUTA MONSEP

System Routines Called

SQRT ASIN ABS COS

Calling Routine

TABLE

A3.10 MONSEP Subroutine

Purpose

MONSEP is a routine called by ROMIN to monitor the convergence of the energy parameter optimisation. The convergence criterion to be satisfied at the *i*th optimisation step is

$$|f_i(X_M)-f_{i-1}(X_M)| < |10^{-4}f_i(X_M)|.$$

If more than 50 evaluations of $f(X_M)$ are required the optimisation is terminated by setting the convergence flag and returning to ROMIN.

All input and output are via the arguments of the subroutine call, except for input parameter IFAIL, which is transmitted via COMMON B.

Use

CALL MONSEP (N, AX, F, R, BETA, CON, NR)

Input

N	The number of independent variables (= 1, in this program)
AX	The vector of independent variables (Mach number)
F	The current value of the (negative) energy parameter
R	The actual number of energy parameter evaluations
BETA	The value of the Euclidian norm of the vector representing the total progress since the last axis rotation
NR	A monitor index— 0 indicates initial function evaluation; 1 indicates a single function evaluation; 2 indicates completion of an iteration stage

Output

CON — A logical variable set to .TRUE. if the convergence criterion has been satisfied, otherwise .FALSE.

System Routine Called

ABS

Calling Routine

ROMIN

A3.11 PARAMS Subroutine

Purpose

PARAMS calculates airspeed and pressure parameters, and sets the initial angle of attack estimate for each aircraft trim calculation.

Input and output are via COMMON B, and atmospheric constants stored in COMMON C are used.

Use

CALL PARAMS

Input

COMMON B: XM T TS HP SREF LEV ALPSTD C2
COMMON C: HICAO TICAO PTAB GAMMA R G

Output

COMMON B: P A V ALPHA DIM

System Routine Called

SQRT EXP ABS

Calling Routines

TABLE SEP

A3.12 P1IN Subroutine

Purpose

P1IN controls all input data. All aircraft-independent parameters defining the type of calculations required are accepted in conversational mode, with validity checks where possible. Aircraft-dependent data is read from disk via a call to IDENT. Output files are opened before returning to the calling program.

Output variables are transmitted via COMMON B, and constants stored in COMMON C are used.

Use

CALL P1IN

Input

COMMON C: NIO AMET R G HOUR GRID1

Output

COMMON B:	SWP	PLA	DTEMP	MT	C2	DELES	NES		
	DELXM	NXM	DELGN	NGN	ESØ	XMØ			
	GNØ	IOPT	FRAME	DAY	CLOCK	IOUT			
	IGRID	ROLE	IUNITS	AM	ALB	AWF			

User Routines Called

IDENT BADINP

System Routines Called

DATE TIME

Calling Routine

AIRCRAFT program

A3.13 P1OUT Subroutine

Purpose

P1OUT provides output control for unoptimized performance calculations. A text-formatted output file is produced for printing, an alphanumeric output file is produced as input to program P2, and altitude variable is output to the user's terminal to indicate progress of the calculation. Output units may be Imperial or SI, as selected by the user during the input dialogue.

Input of data to be printed is via COMMON B and COMMON TABLES. Data constants used are transmitted via COMMON C.

Use

CALL P1OUT

Input

COMMON B:	ES	XM	HP	V	H	SWP	PLA	SREF	W
	DTEMP	MT	WF	DELES	NES	DELXM	NXM		
	DELGN	NGN	ESØ	XMØ	GNØ	FRAME	IES		
	IXM	DAY	CLOCK	IOUT	IGRID	NDCDS			
	XMDCDS	DELCDS	ROLE	IPSTYP	CGPERC				
	IUNITS	IPSTYP	AM	ALB	AWF				
COMMON C:	NIO	AMET	GRID1	GRID2					
COMMON TABLES:	PSTAB	OMTAB	GNTAB						

System Routines Called

FLOAT MINØ

Calling Routine

TABLE

A3.14 P1OUTA Subroutine

Purpose

P1OUTA provides output control for optimized performance calculations, in a like manner to subroutine P1OUT.

Input of data to be printed is via COMMON areas B, TABLES, TABLET, ZEROPS and CLIMBS. Data constants used are transmitted via COMMON C.

Use

CALL P1OUTA

Input

COMMON B:	As for subroutine P1OUT				
COMMON C:	NIO	AMET			
COMMON TABLES:	As for subroutine P1OUT				
COMMON ZEROPS:	GNPSØ	OMPSØ	SMPSØ	VPSØ	HPPSØ
	WFPSØ				
COMMON CLIMBS:	TI	FU	RA		
COMMON TABLET:	XMTAB	VTAB	HPTAB	WFTAB	

System Routine Called

FLOAT   MINØ

Calling Routine

MAXMAN

A3.15 SEP Subroutine

Purpose

SEP calculates the energy parameter at a given grid point, for use with the optimisation routine ROMIN.

Input and output are via the subroutine arguments listed below. During calculation variable data is transmitted between subroutines via COMMON B. Data constants in COMMON C are also used.

Use

CALL SEP (N, X, F)

Input

N   The number of independent variables (=1, in this program)

X   The vector of independent variables (Mach number)

Output

F   The current value of the (negative) energy parameter

COMMON Input

COMMON B: W   IERR   IPSTYP

COMMON C: HICAO   HOUR

COMMON Area Output

COMMON B: XM   HP   V   FN   WF   ALPHA   D   IERR

User Routines Called

ALTIT   PARAMS   THRUST   AERO

System Routine Called

COSD

Calling Routines

MAXMAN   ROMIN

A3.16 TABLE Subroutine

Purpose

TABLE controls the calculation and output of the unoptimised manoeuvrability grid, using altitude, Mach number and load factor as grid variables. (The altitude may be energy height and pressure height, depending on the input request.) The principle outputs are energy parameter and turn rate.

Input and output are via COMMON areas B and TABLES. Data constants stored in COMMON C are also used.

Use

CALL TABLE

Input

COMMON B: DELES   NES   DELXM   NXM   DELGN   NGN
ESØ   XMØ   GNØ   IOPT   IGRID   IPSTYP   AM
ALB

COMMON C: HICAO

Output

COMMON B: ES GN XM HP V H W FN WF ALPHA D IES IXM IERR

COMMON TABLES: PSTAB OMTAB GNTAB

User Routines Called

MAXMAN ATMOS HEIGHT ALTIT PARAMS THRUST AERO P1OUT

System Routines Called

SQRT COSD

Calling Routine

AIRCRAFT program

APPENDIX 4

P1LIB Subroutine Library

The curve-fitting techniques used in preparing thrust and drag data are fully described in Reference 9; a brief description of the polynomial evaluation routines is given below.

A4.1 CHECKD Subroutine

Purpose

CHECKD checks the validity of data supplied to subroutine CUBICS for curve-fitting. In the present application, CUBICS is called to fit a simple cubic to four points by subroutine SURF, and so the parameter IFAIL should always return a zero value.

Use

CALL CHECKD (M, NCAP, X, W, K, IFAIL, NCAP3, B)

Input

M	The number of data points (here, 4)
NCAP	The number of intervals, n (here, 1)
X	The data abscissae $(x(j), j = 1, M)$
W	The weight vector $(w(j), j = 1, M)$ (here $w(j) = 1$, all j)
AK	The vector of knots $(ak(j), j = -3, A+3)$. (Here there are no external knots, so only the storage space for internal knots is required)
NCAP3	An integer $= n+3$
B	A working vector $(b(j), j = 1, n)$

Output

IFAIL The error indicator—

$= 0$ for valid data

$= 1$ to 6 for invalid data (see subroutine CUBICS)

Calling Routine

CUBICS

A4.2 CUBICS Subroutine

Purpose

CUBICS applies a least-squares cubic spline fit of B-splines to weighted data points with selected knots. In the present task, CUBICS is only required to fit a simple cubic to four points; hence the fit is exact, all weights are unity, and no external knots are required.

Use

CALL CUBICS (M, NCAP, X, Y, W, AK, C, SS, IFAIL, NCAP3, A, DIAG, B)

Input

M	The number of data points (here, 4)
NCAP	The number of intervals (here, 1)
X	The data abscissae ($x(j), j = 1, M$)
Y	The data ordinates ($y(j), j = 1, M$)
W	The weight vector ($w(j), j = 1, M$) (here $w(j) = 1$, all j)
AK	The vector of knots ($ak(j), j = -3, n+3$)
NCAP3	An integer $= n+3$
A	A working array (($a(i,j), i = 1, n+3(, j = 2, 4$)
DIAG	A working vector (diag (j), $j = 1, n+3$)
B	A working vector ($b(j), j = 1, n$)

Output

C	The vector of B-spline coefficients ($c(j), j = 1, n+3$)
SS	The residual sum of squares (here, ≈ 0)
IFAIL	The error indicator—

= 0 for a successful call

= 1 for un-ordered knots

= 2 for non-positive weights

= 3 for un-ordered abscissae

= 4 if the no. of distinct data abscissae does not exceed n by at least three

= 5 if there are too many knots for the number of data points

= 6 if NCAP3 $\neq$ NCAP+3

(The application here is such that IFAIL = 0 should be the only output)

User Subroutine Called
CHECKD

Calling Routine
SURF

A4.3 ROMIN Subroutine

Purpose
ROMIN finds the local minimum of an unconstrained function of n variables using the method of Rosenbrock.[10-12] In this application ROMIN is called by MAXMAN with $n = 1$ (Mach number is the only independent variable).

Use
CALL ROMIN (N, X, FUNCT, STEP, MONITR)
with input

N	The number of independent variables, n
X	A vector giving an initial estimate of the solution ($x(i), i = 1, n$)
FUNCT (N, X, F)	An EXTERNAL subroutine to calculate the function $f(x)$ to be minimised

STEP An initial step length for all co-ordinate directions

MONITR (N, X, F, R, B, CON, NR) EXTERNAL subroutine to monitor convergence and provide diagnostics

and subroutine arguments

F	The value of the function $f(x)$ to be minimised
R	The total number of function evaluations
B	The Euclidian norm of the vector representing progress since the last axis rotation
CON	A logical variable set to .FALSE. by ROMIN initially, and set to .TRUE. by by MONITR to stop the process
NR	A monitor index supplied by ROMIN—

= 0 for initial calculation
= 1 for function evaluation
= 2 for new axis rotation

Output is via subroutine MONITR and the vector X.

Note: In the current application ROMIN is called by MAXMAN as

CALL ROMIN (1, X, SEP, STEP, MONSEP)

with STEP = 0·1.

User Subroutines Called

SEP MONSEP

System Routine Called

SQRT

Calling Routine

MAXMAN

A4.4 SPDER3 Subroutine

Purpose

SPDER3 evaluates the cubic spline $f(x)$ and its first derivative $df(x)/dx$, based on normalised B-spline coefficients and associated knot positions.

Use

CALL SPDER3 (NCAP, AK, C, X, IFAIL, F, DFDX, NCAP3)

with input

NCAP	The number of intervals, n
AK	The vector of knots $(ak(j), j = -3, n+3)$
C	The B-spline coefficients $(c(j), j = 1, n+3)$
X	The value x at which $f(x)$ is required
NCAP3	An integer $= n+3$

and output

F	The value of $f(x)$
DFDX	The derivative $df(x)/dx$
IFAIL	An error indicator—

= 0 if $f(x)$, $df(x)dx$ are successfully calculated
= 1 if x is outside the valid range $ak(0) \leqslant x \leqslant ak(n)$
= 2 if NCAP3 $\neq$ NCAP+3

Calling Routine

SURF

A4.5 SURF Subroutine

Purpose

SURF takes spline-fit information representing a surface stored in vector form and provides, at the grid point (x, y), the function value $z = f(x, y)$, and, if requested, the derivatives $\partial f/\partial x$, $\partial f/\partial y$ and $\partial^2 f/\partial x \partial y$.

The spline data represent knots and B-spline coefficients for least-square curve-fits of z against x for discrete values of y. $f(x, y)$ is evaluated by bounding the requested y with four appropriate values $(y(i), i = 1, 4)$, evaluating the four values $(z(i) = f(x, y(i)))$, and performing a final cubic fit to these four points to obtain $z = f(x, y)$. The calculation includes checking x and y against valid ranges allowed by the data.

SURF also allows for the degenerate case where the "surface" is a single curve.

Use

CALL SURF (TAB, X, Y, Z, DZDX, DZDY, D2ZDXY, IERR)

Input

TAB	The array of spline coefficients and knots in "standard" form (see Section 4.6)
X	The first independent variable
Y	The second independent variable
IERR	An integer set to -1 if derivatives are required

Output

Z	The function value $z = f(x, y)$
DZDX	The first derivative $\partial f/\partial x$.
DZDY	The first derivative $\partial f/\partial y$
D2ZDXY	The second derivative $\partial^2 f/\partial x \partial y$
IERR	An error indicator = 10M+IFAIL, where

M = 1 if number of curves in TAB is 2,3 or more than 30
= 2 if y is outside the valid range
= 3 if number of intervals for any curve excees 19
= 4 if an error occurs evaluating $(z(i), i = 1, 4)$
= 5 if an error occurs fitting a cubic to $z(i)$
= 6 if an error occurs evaluating z or $\partial z/\partial y$
= 7 if an error occurs fitting a cubic to $\partial z/\partial x$
= 8 if an error occurs evaluating $\partial z/\partial x$ or $\partial^2 z/\partial x \partial y$

and IFAIL is defined as for CUBICS (M = 5, 7) or for SPDER3 (M = 4, 6, 8)

IERR = 0 indicates a successful calculation

(In use with the present program IERR values of 20 or 41, indicating y or x values out of range respectively, will normally occur when invalid Mach number or altitude requests are made.)

User Routines Called

SPDER3 CUBICS

Calling Routines

THRUST AERO (if needed)

APPENDIX 5

Sample AIRCRAFT Program Library Listing

A5.1 Main Program

```
C       PROGRAM AIRCRAFT EXAMPLE
C  G. KIPP  ARL  FEB 1976
C
        CALL P1IN
        CALL TABLE
        STOP
        END
        BLOCK DATA
C
C COMMON DATA FOR PROGRAMS P1, P2 AND P3
C
        COMMON /C/C(200)
        DIMENSION HICAO(4), TICAO(4), HARDU(6), TARDU(6), AMET(3),
     + NIO(10), PTAB(3), GRID1(2), GRID2(6)
        EQUIVALENCE   ( HICAO,C(  1)),( TICAO,C(  5)),( HARDU,C(  9)),
     +( TARDU,C( 15)),(   NIO,C( 21)),(  PTAB,C( 31)),(  AMET,C( 34)),
     +( GAMMA,C( 37)),(     R,C( 38)),(     G,C( 39)),(RADIAN,C( 40)),
     +(  HOUR,C( 41)),( GRID1,C(121)),
     +( GRID2,C(123))
        DATA HICAO /0.0, 36089.24, 65616.8, 104986.88/
        DATA TICAO /288.15, 216.65, 216.65, 228.65/
        DATA HARDU /0.0, 25000., 45000., 54000., 70000., 104986.88/
        DATA TARDU /301., 253., 205., 193., 213., 238.912/
        DATA AMET /'ICAO ARDU      '/
        DATA GAMMA, R, G, RADIAN, HOUR
     +    /1.4, 3089.78, 32.17405, 57.2957795, 3600./
        DATA NIO /1, 2, 3, 4, 5, 6, 7, 8, 9, 10/
        DATA PTAB /2116.22, 472.680, 114.345/
        DATA GRID1 /'ES','HP'/
        DATA GRID2 /'ENERGY STATE','    ALTITUDE'/
        END
```

A5.2 Sample THRUST Subroutine

```
      SUBROUTINE THRUST
C
C THRUST ROUTINE FINDS NET THRUST AND FUEL FLOW FOR COBRA AIRCRAFT,
C BASED ON STANDARDISED DATA FORMAT FOR ARRAY F
C    REV GWK FEB 77.
C
      COMMON /B/ B(200)
      COMMON /FDATA/ F(2000)
      EQUIVALENCE   (    XM,B(  3)),(    HP,B(  6)),(   PLA,B( 15)),
     +( DTEMP,B( 18)),(    MT,B( 19)),(    FN,B( 41)),(    WF,B( 42)),
     +( XMLIM,B( 61)),(  IERR,B( 75))
C
C IDENTIFY POWER LEVEL (MIL: I=1, MAX: I=2)
C
      DO 50 I=1,2
              AI = FLOAT(I)
              IF (ABS(PLA-100.*AI) .LE. 0.001) GOTO 100
   50 CONTINUE
   70 TYPE 75, PLA
   75 FORMAT (/,' CANNOT PROCESS ',F6.2,'% THRUST REQUEST YET')
      STOP
  100 NJ = 1
      IF (I.EQ.2) GOTO 200
C
C IF MAX THRUST, SKIP TO CALCULATE; OTHERWISE JUMP TO MIL DATA
C
      DO 150 I=1,2
              L = F(NJ) + 0.001
  150 NJ = L + NJ
  200 NJ = NJ + 1
C
C SET NOMINAL MACH NO LIMIT
C ***** N.B. SUPPLY NEXT TWO LINES FOR ALL AIRCRAFT
C
      LX = F(NJ+1) + 0.001
      XMLIM = F(NJ+LX+3)
C
C PROCESS SPLINE DATA FOR FN (I=1) AND WF (I=2)
C
      DO 250 I=1,2
              CALL SURF (F(NJ), XM, HP, D1, DFDM, DFDH, D2FDMH, IERR)
              IF (IERR.NE.0) GOTO 300
              L = F(NJ-1) + 0.001
              NJ = L + NJ
              GOTO (215,230), I
  215         FN = D1
              GOTO 250
  230         WF = D1
  250 CONTINUE
  300 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AERO
C
C   AERO ROUTINE FINDS DRAG, D, AND ANGLE OF ATTACK, ALPHA (DEGREES)
C   GWK ARL MAR 76
C
      COMMON /B/ B(200)
      COMMON /C/ C(200)
      COMMON /EDATA/ E(2000)
      DIMENSION XMDCDS(20), DELCDS(20)
      EQUIVALENCE   (RADIAN,C( 40))
      EQUIVALENCE   (    GN,B(  2)),(    XM,B(  3)),(     W,B( 17)),
     +(    FN,B( 41)),
     +( ALPHA,B( 43)),(   DIM,B( 44)),(     D,B( 45)),(   CLT,B( 46)),
     +( CLALF,B( 47)),(  IERR,B( 75)),
     +( NDCDS,B( 80)),(XMDCDS,B( 81)),(DELCDS,B(101))
      FINTRP(X,X1,Y1,X2,Y2) = Y1 + (X-X1) * (Y2-Y1) / (X2-X1)
C
C ITERATE FOR ALPHA AND CLT. ASSUME INITIAL ALPHA IS GIVEN.
C
      DALF = 0.5
      NIT = 0
  100 CONTINUE
      CALL TRIMCL
      IF (IERR.NE.0) GOTO 900
      IF (ABS(DALF).LT.0.01) GOTO 110
      DALF = (FN*SIND(ALPHA) + CLT*DIM - GN*W) /
     +          (FN*COSD(ALPHA)/RADIAN + CLALF*DIM)
      ALPHA = ALPHA - DALF
      NIT = NIT + 1
      IF (NIT.LE.20) GOTO 100
      IERR = 102
      GOTO 900
  110 CONTINUE
C
C NOW FIND DRAG
C
C I=1 FINDS CLMAX AND CHECKS CLT
C I=2 FINDS CDMIN
C I=3 FINDS CDL
C
      NJ = 2
      DO 400 I=1,3
              GOTO (120,120,140) I
  120         X = XM
              Y = 0.
              GOTO 160
C
C IF M<MMIN, USE MMIN CURVE
C
  140         X = CLT
              Y = AMAX1 (E(NJ+2),XM)
  160         CALL SURF (E(NJ), X, Y, Z, D1, D2, D3, IERR)
              IF (IERR.NE.0) GOTO 900
              L = E(NJ-1) + 0.001
              NJ = NJ + L
              GOTO (200,220,240) I
  200         CLMAX = Z
              IF (CLT.LE.CLMAX) GOTO 400
              IERR = 103
              GOTO 900
  220         CDMIN = Z
              GOTO 400
  240         CDL = Z
  400 CONTINUE
C
C FIND STORE DRAG
      CDS = 0.
      IF (NDCDS.EQ.0) GOTO 550
C
      IF (XM.LE.XMDCDS(1)) CDS = DELCDS(1)
      IF (XM.GE.XMDCDS(NDCDS)) CDS = DELCDS(NDCDS)
      IF (XM.LE.XMDCDS(1) .OR. XM.GE.XMDCDS(NDCDS)) GOTO 540
      DO 450 I=2,NDCDS
  450 IF (XM.LE.XMDCDS(I)) GOTO 500
      IERR = 104
      GOTO 900
  500 IM = I-1
      CDS = FINTRP (XM, XMDCDS(IM), DELCDS(IM), XMDCDS(I), DELCDS(I))
  540 CDS = CDS * 1.0E-04
  550 D = (CDMIN + CDL + CDS) * DIM
  900 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRIMCL
C
C     ROUTINE FOR CLTRIM AND DCL/DALPHA, GIVEN ALPHA IN DEGREES, USING
C LINEAR APPROXIMATIONS TO CLTRIM VS ALPHA. (C ONLY)
C     GUK MAR 76
C
      COMMON /B/ B(200)
      DIMENSION CLTAB(4,4), AAT(4,4), NT(4), XMT(4), CLDUM(4), CLADUM(
4)
      EQUIVALENCE   (    XM,B(  3)),( ALPHA,B( 43)),(   CLT,B( 46)),
     +( CLALF,B( 47)),(  IERR,B( 75))
      FINTRP (X,X1,Y1,X2,Y2) = Y1 + (X-X1) * (Y2-Y1) / (X2-X1)
      DATA CLTAB /.05,1.47,1.80,0.,.02,.67,1.42,1.52,0.,.97,3*0.,
     +   .39,2*0./
      DATA AAT /0.,15.2,30.0,2*0.,6.6,23.0,27.0,0.2,12.6,2*0.,1.0,
     +   9.2,2*0./
      DATA NT /3,4,2,2/
      DATA XMT /.2,.8,1.2,2.0/
      DATA NCURV /4/
C
C CHECK ALPHA LIMITS
C
      XMTR = XM
      IF (XM.LT.XMT(1)) XMTR = XMT(1)
      DO 50 II=2,NCURV
      I = II
   50 IF (XM.LT.XMT(I)) GOTO 100
  100 IM = I-1
      ALFLIM = FINTRP (XMTR, XMT(IM), AAT(NT(IM),IM), XMT(I),
     +   AAT(NT(I),I))
      IF (ALPHA.GT.ALFLIM) GOTO 900
C
C USE LINEAR INTERPOLATION IN 2-DIMENSIONS TO GET CL, CLA
C
      DO 300 K=IM,I
              DO 200 J=2,NT(K)
  200         IF (ALPHA.LE.AAT(J,K)) GOTO 300
  300 CALL INTRP (CLTAB(1,K), AAT(1,K), CLADUM(K), ALPHA, CLDUM(K), J)
      CLT = FINTRP (XMTR, XMT(IM), CLDUM(IM), XMT(I), CLDUM(I))
      CLALF = FINTRP (XMTR, XMT(IM), CLADUM(IM), XMT(I), CLADUM(I))
      GOTO 950
C
C EITHER MACH NO OR ALPHA EXCEEDS DATA LIMITS
C
  900 IERR = 101
  950 RETURN
      END
```

APPENDIX 6

Storage Allocation of Labelled Common Areas

The following paragraphs define storage allocation in the various labelled common areas in programs AIRCRAFT, P2 and P4.

In general, an attempt has been made to restrict data communication to a COMMON area B of dimension 200, and to use this area for all three programs; however, this was not always possible, and other COMMON areas are used.

In particular, COMMON C has been used for data constants set by the BLOCK DATA subroutine, and areas TABLES and TABLET (AIRCRAFT), and ESLIST, RPTLST and TABLES (P2) have been used to store grid data prior to calling output routines.

COMMON areas CLIMBS and ZEROPS are used with the optimised grids when producing climb profiles and optimum sustained turn rate data. Areas EDATA and FDATA, both of dimension 2000, are reserved for aerodynamic and propulsion data, and may be enlarged or reduced as required. COMMON area E is used by programs P2 and P4 in transferring aircraft identification data from input to output files.

The units of variables in program AIRCRAFT are those associated with internal storage; in general Imperial units are used with slight variations to allow for standard aeronautical practice. Output units of this program are chosen by the user. The units of variables in programs P2 and P4 are Imperial or SI, depending on the output of program AIRCRAFT.

A6.1 Program AIRCRAFT

A6.1.1 Labelled Common B

Word	*Variable*	*Description*
1	ES	Energy height (ft)
2	GN	Normal load factor (g)
3	XM	Mach number
4	T	Ambient temperature (K)
5	TS	ICAO standard temperature (K)
6	HP	Pressure altitude
7	P	Ambient pressure (lb/ft^2)
8	A	Speed of sound (ft/s)
9	V	True airspeed (ft/s)
10	H	Geopotential height (ft)
11	IUNITS	Unit flag
12–13	—	Unallocated
14	SWP	Wing sweep angle (deg)
15	PLA	Throttle setting code
16	SREF	Wing reference area (ft^2)
17	W	Combat weight (lb)
18	DTEMP	Deviation from reference atmosphere (K)
19	MT	Atmosphere type
20–35	—	Local working storage
36	ALAPSE	Ambient temperature lapse rate (K/ft)
37	LEV	ICAO atmosphere layer number
38	ALPSTD	ICAO atmosphere temperature lapse rate (K/ft)
39	C1	Constant = $\gamma RM^2/2g$ (ft/K)
40	C2	Constant = R/g (ft/K)
41	FN	Net thrust (lbf)
42	WF	Fuel flowrate (lb/hr)
43	ALPHA	Trimmed angle of attack (deg)
44	DIM	Dimensionalising force = $0 \cdot 5\gamma PM^2S$ (lbf)
45	D	Drag (lb)
46	CLT	Trimmed lift coefficient
47	CLALF	Lift curve slope = $dC_L/d\alpha$ (deg^{-1})
48	—	Unallocated
49	IGN	Load factor loop index
50	CDT	Trimmed drag coefficient
51	DELES	Height variable increment (ft)
52	NES	Number of points on height grid
53	DELXM	Mach number increment
54	NXM	Number of points on Mach number grid
55	DELGN	Load factor increment (g)
56	NGN	Number of points on load factor grid
57	ESØ	Initial height
58	XMØ	Initial Mach number
59	GNØ	Initial load factor
60	IOPT	Optimised grid switch
61	XMLIM	Upper Mach number limit on data
62–63	FRAME	Aircraft name (double precision text)
64	IES	Height loop index
65	IXM	Mach number loop index
66–67	DAY(2)	Date
68–69	CLOCK(2)	Time of day
70–71	—	Unallocated
72	SWPMIN	Minimum wing sweep angle (deg)

Word	Variable	Description
73	SWPMAX	Maximum wing sweep angle (deg)
74	—	Unallocated
75	IERR	Error Flag
76	IOUT	Output file switch
77	IGRID	Height grid switch
78–79	—	Unallocated
80	NDCDS	Number of points in drag count table
81–100	XMDCDS(20)	Mach number list for drag count table
101–120	DELCDS(20)	Drag count table
121–134	ROLE(14)	Description of current role
135	IPSTYP	Energy parameter switch
136	CGPERC	c.g. position (%MAC)
137	AM	Conversion factor (metres per foot)
138	ALB	Conversion factor (pounds per kilogram)
139	AWF	Conversion factor (kg/sec per lb/hr)
140–200	—	Unallocated

A6.1.2 Labelled Common C

Word	Variable	Description
1–4	HICAO(4)	ICAO atmosphere pressure altitude table (ft)
5–8	TICAO(4)	ICAO atmosphere temperature table (K)
9–14	HARDU(6)	ARDU atmosphere pressure altitude table (ft)
15–20	TARDU(6)	ARDU atmosphere temperature table (K)
21–30	NIO(10)	Integer constants, 1–10
31–33	PTAB(3)	Base pressures of ICAO temperature profile (lbf/ft^2)
34–36	AMET(3)	Atmosphere text
37	GAMMA	Specific heat ratio (1·4)
38	R	Gas constant for air (3089·78 ft^2/Ks^2)
39	G	Acceleration due to gravity (32·17405 ft/s^2)
40	RADIAN	Degrees/radian (57·2957795 deg/rad)
41	HOUR	Seconds/hour (3600 s/hr)
42–120	—	Unallocated
121–122	GRID1(2)	Height variable input text
123–128	GRIS2(6)	Height variable output text
129–200	—	Unallocated

A6.1.3 Labelled Common CLIMBS

Word	Variable	Description
1	TI	Time to climb (s)
2	FU	Fuel used (lb)
3	RA	Range (n.m.)

A6.1.4 Labelled Common EDATA

Word	Variable	Description
1–2000	E(2000)	Storage reserved for aerodynamic data

A6.1.5 Labelled Common FDATA

Word	Variable	Description
1–2000	F(2000)	Storage reserved for propulsion data

A6.1.6 Labelled Common TABLES

Word	*Variable*	*Description*
1–50	PSTAB(50)	Energy parameter output table
51–100	OMTAB(50)	Turn rate output table (deg/s)
101–150	GNTAB(50)	Load factor grid (*g*)

A6.1.7 Labelled Common TABLET

Word	*Variable*	*Description*
1–50	XMTAB(50)	Mach number output table
51–100	VTAB(50)	True airspeed output table (kn)
101–150	HPTAB(50)	Pressure height output table (ft)
151–200	WFTAB(50)	Fuel flowrate output table (lb/hr)

A6.1.8 Labelled Common ZEROPS

Word	*Variable*	*Description*
1	GNPSØ	Optimum sustained load factor (*g*)
2	OMPSØ	Optimum sustained turn rate (deg/s)
3	XMPXØ	Mach number at optimum condition
4	VPSØ	True airspeed at optimum condition (kn)
5	HPPSØ	Pressure altitude at optimum condition (ft)
6	WFPSØ	Fuel flowrate at optimum condition (slug/s)

A6.2 Program P2

A6.2.1 Labelled Common B

Word	*Variable*	*Description*
1	ES	Energy height (ft or m)
2	GN	Load factor (*g*)
3	XM	Mach number
4–10	—	Not used
11	IUNITS	Unit flag
12–13	—	Not used
14	SWP	Wing sweep (deg)
15	PLA	Throttle setting (% max)
16	—	Not used
17	W	Combat weight (lb or kg)
18	DTEMP	Deviation from reference atmosphere (K)
19–24	—	Not used
25	AOPT	Terminal reply (local to P2IN)
26	ICREAT	Flag to indicate on-line data generation
27	IONDSK	Flag to indicate both differential MMD files on disk
28–47	—	Not used
48	MSECSØ	CPU time used (ms)
49–50	—	Not used
51	DELES	Height variable increment (ft or m)
52	NES	Number of points on height grid
53	DELXM	Mach number increment
	DELPS	Energy rate increment (MMD)
54	NXM	Number of points on Mach number grid
	NPS	Number of points on energy rate grid (MMD)

Word	Variable	Description
55	DELGN	Load factor increment (*g*)
56	NGN	Number of points on load factor grid
57	ESØ	Initial height (ft or m)
58	XMØ	Initial Mach number
	PSØ	Initial energy rate (MMD)
59	GNØ	Initial load factor
60–61	—	Not used
62–63	FRAME	Aircraft name (double precision)
64–65	—	Not used
66–67	DAY(2)	Date
68–69	CLOCK(2)	Time of day
70–120	—	Not used
121–134	ROLE(14)	Description of current role
135	IPSTYP	Energy parameter flag
136–200	—	Not used

A6.2.2 Labelled Common C

Word	Variable	Description
1–41	—	Not used
42–43	TYPE	Units text (double precision)
44–45	ENERGY	Energy variable text (double precision)
46–37	PSUNIT	Energy unit text (double precision)
48	FACT	Energy variable scaling factor text
49	ALUNIT	Length unit text
50	AMUNIT	Weight unit text
51–200	—	Not Used

A6.2.3 Labelled Common E

Word	Variable	Description
1–6	—	Not used
7	ESFIN	Maximum value on height grid (ft or m)
8	XMFIN	Maximum value on Mach number grid
9	GNFIN	Maximum value on load factor grid
10	RATING	Power regime
11–14	—	Not used
15	AMET	Atmosphere description
16–17	NAMOUT(2)	Output filename
	FILNAM	Output filename (double precision)
18–200	—	Not used

A6.2.4 Labelled Common ESLIST

Word	Variable	Description
1–50	ESTAB(50)	Energy state grid
	OMTAB(50)	Turn rate grid (MMD)

A6.2.5 Labelled Common RPTLST

Word	Variable	Description
1–50	GNLST(50)	Table of load factor request replies

A6.2.6 Labelled Common TABLES

Word	Variable	Description
1–50	XMTAB(50)	Mach number grid
	PSTAB(50)	Energy rate grid (MMD)
51–100	GNTAB(50)	Load factor grid

A6.3 Program P4

A6.3.1 Labelled Common B

Word	Variable	Description
1–10	—	Not used
11	IUNITS	Unit flag
12, 13	—	Not used
14	SWP	Wing sweep (deg)
15	PLA	Throttle setting (% max)
16	—	Not used
17	W	Combat weight (lb or kg)
18	DTEMP	Deviation from reference atmosphere (K)
19–24	—	Not used
25	YLMIN	Lowest energy rate for zero turn rate boundary
26–27	NAM(2)	Input filename
28–29	—	Not used
30	IDATA	Data set counter
31	NDATA	Number of data sets
32	IC	Running count of points on zero turn rate contour
33–34	ICOUNT(2)	Number of points on two zero turn rate contours
35	NSAV	Default pen command if above zero turn rate boundaries
36–50	—	Not used
51	DELES	y-axis increment (ft or m)
52	NES	Number of points on y-axis grid
53	DELXM	x-axis increment
54	NXM	Number of points on x-axis grid
55	DELGN	Load factor increment
56	NGN	Number of points on load factor grid
57	ESØ	Initial y-axis value
58	XMØ	Initial x-axis value
59	GNØ	Initial load factor
60–61	—	Not used
62–63	FRAME	Aircraft name (double precision)
64–65	—	Not used
66–67	DAY(2)	Date
68–69	CLOCK(2)	Time of day
70–120	—	Not used
121–134	ROLE(14)	Description of current role
135	IPSTYP	Energy parameter flag
136–200	—	Not used

A6.3.2 Labelled Common C

Word	Variable	Description
1–43	—	Not used
44–45	ENERGY	Energy variable text (double precision)
46–47	PSUNIT	Energy unit text (double precision)
48	FACT	Energy variable scaling factor text
49	ALUNIT	Length unit text
50–200	—	Not used

A6.3.3 Labelled Common E

Word	*Variable*	*Description*
1–9	—	Not used
10	RATING	Power regime
11–14	—	Not used
15	AMET	Atmosphere description
16–200	—	Not used

A6.3.4 Labelled Common CONPLT

Word	*Variable*	*Description*
1	CONLAB	Flag to request contour identification
2	XSCALE	x-axis scale in units per inch of plot
3	YSCALE	y-axis scale in units per inch of plot
4	SMTH	Flag to request smoothing of contours
5	IDOT	Integer indicating contour texture

A6.3.5 Labelled Common GDMDOT

Word	*Variable*	*Description*
1	DINT	Contour smoothing interval (in.)

A6.3.6 Labelled Common GDMSWT

Word	*Variable*	*Description*
1	DGS	Flag to bypass biquadratic diagonal interpolation
2	NLEV	Level of contour being plotted

A6.3.7 Labelled Common LIMS

Word	*Variable*	*Description*
1–400	XTAB(400)	x-co-ordinates of differential MMD boundaries
401–800	YTAB(400)	y-co-ordinates of differential MMD boundaries

A6.3.8 Labelled Common NLEVØ

Word	*Variable*	*Description*
1	NLEVØ	Level number of zero contour
2	IDOTØ	Integer giving texture of zero contour
3	IDEF	Integer giving texture of non-zero contours

APPENDIX 7

P2 Program Library

A7.1 P2 Program

Purpose

The program P2 processes data files produced by program AIRCRAFT and produces plotter files and output files for input to program P4.

Plotter files (named P2.PLT) produced are of two types: (*a*) energy parameter versus turn rate for a specified altitude, and (*b*) turn rate and energy parameter versus Mach number for various load factors, for a specified height (energy height or pressure height).

P4 input files produced are P2.CON, P2A.CON and P2DIFF.CON (energy parameter contours on a Mach number versus pressure altitude grid) and P2.OPT, P2A.OPT and P2DIFF.OPT (optimum turn rate contours on an energy state versus energy parameter grid).

In addition a conversational routine is included which assists in calculating Maximum Manoeuvre Persistance.

The main program calls routine P2IN to determine parameters defining the type of run, and then calls a control subroutine for that run, after which execution ceases.

Use

RUN P2 (Monitor command)

User Routines Called

P2IN PSCON RATE1 RATE2 PSDIFF R2DIFF MMP GRID

A7.2 GRID Subroutine

Purpose

GRID reads from disk storage data files produced by program AIRCRAFT, expressed on a (Mach number, load factor) grid for each height requested, and prepares a disk file P2.PLT for plotting. Turn rate and energy parameter are plotted against Mach number for each load factor requested. A separate page of plots is produced for each value of the height variable (energy height or pressure height).

COMMON areas B, C and TABLES provide variable communication.

Use

CALL GRID (WORK)

where WORK is an 8000-word vector of working storage.

Input

COMMON B: NES NXM NGN IUNITS IPSTYP
COMMON C: ENERGY PSUNIT FACT ALUNIT
COMMON TABLES: GNLIST

Output

COMMON B: ES GN

User Routines Called

PLTLAB AXIS LINE

System Routines Called

PLOT TEXT

Calling Routine

P2 program

A7.3 INLAB Subroutine

Purpose

INLAB reads an alphanumeric identifying header from an input disk file produced as output by program AIRCRAFT.

COMMON B and COMMON E provide data communications.

Use

CALL INLAB (LU)

Output

LU The logical unit number for the disk file

COMMON Output

COMMON B:	SWP	PLA	W	DTEMP	FRAME	DAY	CLOCK	
	ROLE							
COMMON E:	RATING	AMET						

Calling Routine

PSDIFF

A7.4 INMMD Subroutine

Purpose

INMMD performs a conversational dialogue with the user to accept text, grid data and configuration parameters for on-line provision of maximum manoeuvre diagram (MMD) data.

COMMON B and COMMON E provide data communication.

Use

CALL INMMD

COMMON Output

COMMON B:	SWP	PLA	W	DTEMP	FRAME	DAY	CLOCK
	ROLE	DELES	NES	ESØ	DELPS	NPS	PSØ
	ROLE						
COMMON E:	RATING	AMET					

User Routines Called

BADINP UNITS

System Routines Called

DATE TIME

Calling Routine

INMMD R2DIFF

A7.5 MMP Subroutine

Purpose

MMP is a conversational routine to assist in calculating data for the Maximum Manoeuvre Persistance (MMP) Diagram. Fuel available for optimum manoeuvres at discrete range intervals, together with energy state, maximum sustained turn rate and fuel flow, are requested as terminal input, and the number of sustained turns at each range is provided as terminal output.

Use

CALL MMP

User Routine Called

BADINP

Calling Routine

P2 program

A7.6 PLTLAB Subroutine

Purpose

PLTLAB outputs the identifying header read by INLAB to a plotter file. A header for a comparison aircraft is output with a second call to PLTLAB with input argument N = 2.

Data communication is via COMMON areas B, C and E.

Use

CALL PLTLAB(LU,N)

Input

LU The logical unit number of the plotter file

N The aircraft number

N = 1 base aircraft

N = 2 comparison aircraft

COMMON Input

COMMON B:	SWP	PLA	W	DTEMP	FRAME	DAY	CLOCK
	ROLE						
COMMON C:	AMUNIT						
COMMON E:	RATING	AMET					

Systems Routine Called

WHERE PLOT TEXT

Calling Routines

RATE1 GRID

A7.7 PSCON Subroutine

Purpose

PSCON reads from disk storage data files produced by program AIRCRAFT, expressed on a (load factor, Mach number) grid for each pressure height requested, and prepares a disk file P2.CON for input to program P4. Data is output on a (Mach number, altitude) grid for each load factor.

Variable communication is via COMMON areas B, E, TABLES, ESLIST and RPTLST.

Use

CALL PSCON(WORK)

where WORK is an 8000-work vector of working storage.

Input

COMMON B:	DELES	NES	DELXM	NXM	DELGN	NGN
	ESØ	XMØ	GNØ			
COMMON E:	NAMOUT					
COMMON TABLES:	GNTAB					
COMMON RPTLST:	GNLST					

Output

COMMON TABLES:	GNTAB
COMMON ESLIST:	ESTAB
COMMON RPTLST:	GNLST

User Routine Called

WRLAB

Calling Routines

PSDIFF P2 program

A7.8 PSDIFF Subroutine

Purpose

PSDIFF performs the functions of PSCON with two separate disk files representing comparison aircraft and prepares output files P2.CON and P2A.CON for input to program P4.

While doing this the grid specifications are checked for equality, and a third, differential file, P2DIFF.CON is produced for input to program P4. An error halt occurs if the data grids differ in any way.

Data communication is via COMMON areas B, E and ESLIST.

Use

CALL PSDIFF(WORK)

where WORK is an 8000-word vector of working storage.

Input

COMMON B: DELES NES DELXM NXM DELGN NGN ESØ XMØ GNØ IPSTYP IUNITS

COMMON ESLIST: ESTAB

Output

COMMON B: SWP PLA W DTEMP FRAME DAY CLOCK ROLE IPSTYP IUNITS

COMMON E: RATING AMET NAMOUT

COMMON ESLIST: ESTAB

User Routine Called

PSCON INLAB WRLAB

Calling Routine

P2 program

A7.9 P2IN Subroutine

Purpose

P2IN is called by the main program to process the aircraft identification header on the input disk file and requests an option code for the type of run. An error halt is forced if the 8000 words allocated for vector WORK is too small to accommodate the data required by the input grid. It is the user's responsibility to ensure that the option requested is consistent with the purpose for which program AIRCRAFT produced the data.

Data communication is via COMMON areas B, E and TABLES.

Use

CALL P2IN(IOPT)

Output

IOPT The option control as follows:

- = 1 Energy parameter contour plot
- = 2 Plot of energy parameters versus turn rates
- = 3 Maximum Manoeuvre Diagram (MMD) contour plot
- = 4 Differential energy parameter contour plot
- = 5 Differential MMD contour plot
- = 6 Maximum manoeuvre persistence (MMP) calculation
- = 7 Plot of turn rate and energy parameter versus Mach number

COMMON Output

COMMON B: SWP PLA W DTEMP MSECSØ DELES NES DELXM NXM DELGN NGN ESØ XMØ GNØ FRAME DAY CLOCK ROLE

COMMON TABLES: GNTAB

COMMON E: ESFIN XMFIN GNFIN RATING AMET NAMOUT

User Routine Called

UNITS INMMD

System Routines Called
TIMES

Calling Routine
P2 program

A7.10 RATE1 Subroutine

Purpose

RATE1 reads data produced by program AIRCRAFT from disk expressed as energy parameter versus turn rate, for a range of altitudes (pressure height or energy height) and Mach numbers, and prepares a plotter file of this data. A separate plotter page is produced for each value of the altitude variable.

COMMON B and COMMON C provide data communication

Use

CALL RATE1(WORK)

where WORK is an 8000-word vector of working storage

Input

COMMON B:	NES	DELXM	NXM	DELGN	NGN	XMØ
COMMON C:	ENERGY	PSUNIT	FACT	ALUNIT		

User Routines Called
PLTLAB AXIS LINE SYMBOL

System Routines Called
TEXT PLOT

Calling Routine
P2 program

A7.11 RATE2 Subroutine

Purpose

RATE2 reads data produced by program AIRCRAFT from disk representing the maximum Manoeuvre Diagram (MMD). This provides optimum energy parameter and turn rate versus load factor for a range of energy states. A linear interpolation is performed and a disk file P2.OPT for input to program P4 is prepared. This data provides turn rate in an (energy state, energy parameter) grid.

Data communication is via COMMON areas B, E, TABLES and ESLIST.

Use

CALL RATE2(WORK)

where WORK is an 8000-word vector of working storage.

Input

COMMON B:	DELES	NES	DELGN	NGN	ESØ	GNØ
COMMON E:	NAMOUT					

User Routines Called
WRLAB INTRP

System Routine Called
ABS

Calling Routine
R2DIFF P2 program

A7.12 R2DIFF Subroutine

Purpose

R2DIFF performs the functions of RATE2 with two separate disk files representing comparison aircraft and prepares output files P2.OPT and P2A.OPT for input to program P4. While doing this the grid specifications are checked for equality, and a third differential file, P2DIFF.OPT is produced for input to program P4. An error halt occurs if the data grids differ in any way.

Data communication is via COMMON areas B, E and ESLIST.

Use

CALL R2DIFF(WORK)

where WORK is an 8000-word vector of working storage.

Input

COMMON B: MSECS0 DELES NES DELGN NGN ES0 GN0 IPSTYP IUNITS

Output

COMMON B: SWP PLA W DTEMP FRAME DAY CLOCK ROLE IPSTYP IUNITS

COMMON E: RATING AMET NAMOUT

COMMON ESLIST: OMTAB

User Routines Called

RATE2 INMMD

System Routines Called

CSTRING TIMES RUNPRG

Calling Routine

P2 program

A7.13 UNITS Subroutine

Purpose

UNITS allocates text strings to variables for use in terminal dialogue and plotter axis labelling, dependent on the values of variables IUNITS and IPSTYP read from input data files.

Data communication is via COMMON areas B and C.

Use

CALL UNITS

Input

COMMON B: IPSTYP IUNITS

Output

COMMON C: TYPE ENERGY PSUNIT FACT ALUNIT AMUNIT

Calling Routine

P1IN

A7.14 WRLAB Subroutine

Purpose

WRLAB writes the descriptive header read by INLAB onto an output disk file to be used as input to program F4.

COMMON B and COMMON E provide data communication.

Use

CALL WRLAB(LU)

with input

LU The logical unit number for the output disk file.

Input

COMMON B:	SWP	PLA	W	DTEMP	FRAME	DAY	CLOCK
	ROLE						
COMMON E:	RATING	AMET					

Calling Routines

PSCON RATE2 PSDIFF

APPENDIX 8

P24LIB Subroutine Library

A8.1 Nature of Library

This relocatable binary library, used when loading programs P2 and P4, is derived from several sources. It consists of routines for numerical interpolation, common input/output routines, plotting routines and a routine to allocate texts for the two unit systems. The routines are described briefly below; fuller details may be found in the sources indicated.

A8.2 Routines from Library P1

Routine INTRP (numerical interpolation) and routine BADINP (input error text) are obtained from subroutine library P1 which is fully described in Appendix 3.

A8.3 Routines from Library P2

Input/output routines INLAB andPLTLAB, and text allocation routine UNITS are obtained from program library P2 which is fully described in Appendix 6.

A8.4 Plotting Subroutines

Routines AXIS, LINE, NUMBER and SYMBOL are obtained from the CALCOMP plotter software library in use at ARL's Computer Centre. Full machine-readable documentation may be obtained by running program ALLPL3.FOR available on DECtape 17 at the Computer Centre. A brief statement of the purpose of each routine is given below.

A8.4.1 AXIS Subroutine

This routine draws labelled axes suitable for plotting graphs. The axes may be drawn at any specified angle from an arbitrary origin. It calls P24LIB routines SYMBOL and NUMBER and system routine PLOT.

A8.4.2 LINE Subroutine

This routine plots a line on the plotter using a set of co-ordinates stored in input vectors. It calls P24LIB routine SYMBOL and system routines PLOT and WHERE.

A8.4.3 NUMBER Subroutine

This routine plots the value of a real number on the plotter, calling P24LIB routine SYMBOL and system routine PLOT

A8.4.4 SYMBOL Subroutine

This routine plots ASCII characters and special symbols on the plotter, calling system routines PLOT, SIN and COS.

APPENDIX 9

P4 Program Library

A9.1 P4 Program

Purpose

The program P4 processes data files produced by program P2 and produces contour plots for off-line plotting.

The contour plots on file P4.PLT are of four types (input filenames shown in parentheses):

(*a*) energy rate contour plots (P2.CON, P2A.CON);
(*b*) differential energy rate contour plots (P2DIFF.CON);
(*c*) maximum manoeuvre diagrams (P2.OPT, P2A.OPT);
(*d*) differential maximum manoeuvre diagrams (P2DIFF.OPT).

The type of plot is determined by the input filename.

A conversational dialogue allows the user to vary several features of the plots:

(i) smoothness of the plotted output;
(ii) texture of critical contours;
(iii) number and level of contours;
(iv) selection of load factors
(v) inclusion of energy state contours } energy rate plots only.

Energy rate contours are plotted on a Mach number versus altitude grid and maximum manoeuvre diagrams present turn rate contours on an energy state versus energy parameter grid.

The brief main program performs preliminary input operations and calls routine P4MAIN to perform the major control operations.

Plotted output is written on logical unit 1. COMMON areas B and C are used for variable communication.

Use

RUN P4 (monitor command)

User Routines Called

P4MAIN UNITS INLAB

A9.2 OUTXT Subroutine

Purpose

OUTXT is called by routine P at the start of a contour line to output the contour level on the plotter.

Use

CALL OUTXT(N)

with input

N The contour level to be plotted

System Routines Called

PLOT TEXT

Calling Routine

CONT

A9.3 P Subroutine

Purpose

Subroutine P controls pen-up and pen-down increments, taking into account zero turn rate contour boundaries when plotting differential maximum manoeuvre diagrams.

Plotting is achieved by calls to PLOTD or SMOOTH, for straight line or smoothed plots, respectively. The pen is lifted (N reset to 5) if the requested point is outside either turn rate boundary (differential MMD only).

Data communication is via COMMON areas B, LIMS, CONPLT, NLEVØ, and GDMSWT.

Use

CALL P(X, Y, N)

Input

X,Y Co-ordinates of the contour point in units of X and Y grid intervals.

N Integer supplying pen position requested by the contouring routine:

3 lift pen, move to (X,Y), drop pen;
2 drop pen, move to (X,Y);
5 lift pen, move to (X,Y).

COMMON Input

COMMON B: IC YLMIN IDATA NDATA ICOUNT
COMMON LIMS: XTAB YTAB
COMMON CONPLT: CNOLAB XSCALE YSCALE SMTH IDOT
COMMON NLEVØ: NLEVØ IDOTØ IDEF
COMMON GDMSWT: NLEV

COMMON Output

COMMON B: IC ICOUNT NSAV
COMMON CONPLT: IDOT

User Routines Called

PLOTD SMOOTH INTRP OUTXT

System Routine Called

AMIN1

Calling Routine

CONT DIAG

A9.4 PLOTD Subroutine

Purpose

PLOTD is a dummy interface between the plot calls in routines P and SMOOTH and the CALCOMP software routine PLOT. Use of this interface renders the contouring routines independent of conventions for plotter pen commands. In this application it is needed to change the pen-down command from N = 2 (CONT) to N = 4 (PLOT).

Use

CALL PLOTD (X, Y, N)

with inputs X, Y and N defined as for routine P.

System Routine Called

PLOT

Calling Routines

P SMOOTH

A9.5 P4MAIN Subroutine

Purpose

P4MAIN is the control routine for the contour plotting program P4. It uses the input data filename to differentiate between requests for single aircraft or comparison plots, and the filename extension to differentiate between requests for maximum manoeuvre diagrams (turn rate contour plots) and energy rate contour plots. In the latter case, a preliminary plot of energy state contours may also be requested. P4MAIN controls the setting up and plotting of identifying text and axes, the reading of grid data, and the calling of routine CONT to plot the contours.

COMMON areas B, C, CONPLT, NLEV0, GDMDOT, and GDMSWT are used for data communication.

Use

CALL P4MAIN (Z, ZG, NXM, NES)

Input

Z	The (empty) data buffers for turn rate or energy rate data.
ZG	The (empty) data buffer for energy state data
NXM	The number of points of the x-axes grid (energy state or Mach numbers).
NES	The number of points on the y-axes grid (energy rate or pressure altitude).

COMMON Input

COMMON B:	NAM	DELES	DELXM	NGN	ES0	XM0
COMMON C:	ENERGY	PSUNIT	FACT	ALUNIT		

User Routines Called

SMOOTH BADINP SYMBOL AXIS CONT INLAB PLTLAB

System Routines Called

TEXT AMAX1 FLOAT ABS WHERE PLOT

Calling Routine

P4 program

APPENDIX 10

Routines from Libraries GRAFIC and EXTRAS

A10.1 Nature of Libraries

GRAFIC[18] is a system for graphical presentation of three-dimensional fluid flows, and EXTRAS is a library used by GRAFIC. Both of these libraries are available on disk area [1033, 1022] for use by ARL staff.

The contouring routine CONT and associated routines DIAG, SMOOTH, REALIN and PROMPT form but a small subset of the GRAFIC system required by program P4. These routines are outlined briefly below.

A10.2 CONT Subroutine

Purpose

CONT is a routine in GRAFIC for drawing a contour map based on data supplied for a regular rectangular grid.

A feature of CONT is that it is independent of plotter conventions, calling a user-written interface routine P, which then processes the plot request.

COMMON area GDMSWT is used for additional data communication.

Use

CALL CONT (T, M, N, CONLEV, NC, LABFLG)

Input

T	The array containing the grid values.
M	The first dimension of T.
N	The second dimension of T.
CONLEV	The vector containing the requested contour levels.
NC	The number of contour levels.
LABFLG	A logical switch set to .TRUE. if the contour level is to be output at the start of each contour, .FALSE. otherwise.

Output

Data is plotted via calls to P(X, Y, NN) with

X	The x-co-ordinate in the range (1, FLOAT(M)).
Y	The y-co-ordinate in the range (1, FLOAT (N)).
NN	The pen code: NN = 3 plot with pen up, NN = 2 plot with pen down.

COMMON Input

COMMON GDMSWT: DGS, a logical variable set to .TRUE. in P4MAIN to bypass calls to DIAG.

COMMON Output

COMMON GDMSWT: NLEV, the level number of the contours currently being plotted.

User Routines Called

DIAG P

Calling Routine

P4MAIN

A10.3 DIAG Subroutine

Purpose

DIAG is a routine in GRAFIC called by CONT to interpolate along a mesh diagonal using a simple biquadratic representation of the mesh. As used in program P4, diagonal interpolation is bypassed by setting switch DGS to 'TRUE'.

COMMON area GDMSWT is used for additional data communication.

Use

CALL DIAG (T, M, M1, N1, I, J, C1)

Input

T	The array of grid values.
M	The first dimension of T.
M1, N1	Direction along M and N direction, respectively: +1 denotes positive, −1 denotes negative.
(I, J)	Index of current grid reference.
C	Current contour level.

COMMON Input

COMMON/GDMSWT/DGS

User Routine Called

P

System Routine Called

SQRT

Calling Routine

CONT

A10.4 SMOOTH Subroutine

Purpose

SMOOTH is a routine in GRAFIC which smooths the contour plots by joining successive points on the contour with cubic arcs having tangential coincidence at their common points (knots). The tangential slope is set equal to the mean of the slopes of the straight lines that would otherwise join points on either side of the knot. When smoothing is selected, an additional call to SMOOTH is required to complete the current contour before proceeding to the next contour request.

Common area GDMDOT is used for additional data transmission.

Use

CALL SMOOTH (X, Y, N, IDOT)

Input

X, Y	The co-ordinates of the point to be plotted.
N	The pen-up command: N = 2 put pen down and draw to (X, Y), N = 3 move to (X, Y) with pen up and drop pen, N = 4 finish smoothing the current contour.

IDOT An integer specifying the mark:space ratio for broken lines:

IDOT = 0 continuous line,
IDOT > 1 space is larger than mark,
IDOT < 1 mark is greater than space,
IDOT = 1 mark = space.

COMMON Input

COMMON GDMDOT: DINT, the smoothing interval, set to 0·05 in. in routine P4MAIN.

User Routines Called

PROMPT REALIN

System Routines Called

SQRT

Calling Routines

P4MAIN P

A10.5 REALIN Subroutine

Purpose

REALIN is a routine in GRAFIC, which accepts real numerical data from the user's terminal. It is not called during the execution of P4, but is required to complete the loading process.

User Routines Called

PROMPT

Calling Routine

SMOOTH

A10.6 PROMPT Routine

Purpose

PROMPT is a routine in library EXTRAS, which writes a text on the user's terminal. It is not called during the execution of P4, but is required to complete the loading process.

Calling Routines

SMOOTH REALIN

APPENDIX 11

System Routine Requirements

Routine	Required by: P1	P2	P4	P1LIB	P24LIB	GRAFIC	Brief description
ABS	×	×	×				Absolute value of real argument
FLOAT	×		×				Integer to floating point conversion
AMIN1	×		×				Minimum of real arguments
AMAX1			×				Maximum of real arguments
MINØ	×						Integer minimum of integer arguments
ALOG	×						Natural logarithm
EXP	×						Exponential
SQRT	×			×		×	Square root
SIN					×		Sine
ASIN	×						Inverse sine
COS	×				×		Cos
COSD	×						Cos, argument in degrees
DATE	×	×					Current date
TIME	×	×					Current daytime
TIMES		×					Current CPU time used
RUNPROG		×					Transfer control to another program
CSTRING		×					Generate CUSP command string
PLOT		×	×		×		Plot a point on the plotter
TEXT		×	×				Write a text on the plotter
WHERE		×			×		Provide current plotter co-ordinates

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16. Abstract

A suite of FORTRAN-IV computer programs is described which may be used to assist in evaluating relative combat aircraft performance, using energy maneuverability theory. The programs are described in detail using flowcharts, and full operating instructions are given. A selection of outputs illustrates the graphical and printed capabilities of the suite.

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