STUDY FOR THE INDICIAL LOAD EFFECTS ON MULTISTAGE SPACE VEHICLE SYSTEMS

[A Description of the Computer Programs Employed]

ANNUAL SUMMARY REPORT - Volume III
21 June 1963 - 20 August 1964

Contract No. NAS8-11012
Control No. TP3-81150 & S-1 (1F)
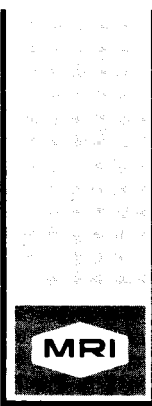   CPB 16-609-63 & S-1

MRI Project No. 2715-P

N65 21719
(ACCESSION NUMBER)

FACILITY FORM 602

(PAGES)

(NASA CR OR TMX OR AD NUMBER)

(THRU)

(CODE)

08
(CATEGORY)

?or

National Aeronautics and Space Administration
Procurement and Contracts Office
George C. Marshall Space Flight Center
Huntsville, Alabama 35812
Attn: Procurement and Contracts Office, M-P&C-MEA

MIDWEST RESEARCH INSTITUTE

425 VOLKER BOULEVARD/KANSAS CITY, MISSOURI 64110/AC 816 LO 1-0202

STUDY FOR THE INDICIAL LOAD EFFECTS ON MULTISTAGE
SPACE VEHICLE SYSTEMS

A Description of the Computer Programs Employed

by

Duncan Sommerville
Robert R. Blackburn

For

National Aeronautics and Space Administration
Procurement and Contracts Office
George C. Marshall Space Flight Center
Huntsville, Alabama 35812
Attn: Procurement and Contracts Office, M-P&C-MEA

MIDWEST RESEARCH INSTITUTE

425 VOLKER BOULEVARD/KANSAS CITY, MISSOURI 64110/AC 816 LO 1-0202

PREFACE

This report was prepared by Midwest Research Institute under Contract No. NAS8-11012. The work was performed under the technical supervision of Mr. M. H. Rheinfurth, staff member of the Dynamics and Flight Mechanics Division, Marshall Space Flight Center.

This report describes the computer program written in support of the work on Part II (Volume II) of the contract during the contract period 21 June 1963 to 20 August 1964.

The authors wish to thank Miss Mary Fontille and the staff of General Electric's Computing Laboratory for their assistance in debugging the computer programs described here and in adapting them to the NASA processing system.

The project leader on this program was Mr. A. D. St. John, Acting Head, Mathematical Analysis Section. Those who contributed in writing and documenting the computer program were Dr. William Glauz and Messrs. Donald Kobett, John E. Scheu and Duncan Sommerville. This report was compiled by Robert R. Blackburn and Duncan Sommerville.

Approved for:

MIDWEST RESEARCH INSTITUTE

Sheldon L. Levy, Director
Mathematics and Physics Division

9 October 1964

TABLE OF CONTENTS

ABSTRACT

21719

This volume describes the computer programs written for the IBM 7094 to perform the computations and analyses discussed in Volume II. There are four programs which have the following purposes:

Program A: Find indicial and impulsive missile responses.

Program B: Perform a Duhamel integration to find responses to actual wind profiles.

Program C: Plot and analyze results of Program A.

Program D: Plot and analyze results of Program B.

I. INTRODUCTION

This volume contains documentation of the computer programs written for the IBM 7094 in support of the work on Part II of the contract (see Volume II).

Four distinct programs are described.

Program A finds indicial* and impulsive** responses for a specified missile configuration (in this case, Saturn C-5) using three types of wind-induced forcing functions. The forcing functions considered are assembled from combinations of the geometric and aerodynamic representations. The simplest type is called "instantaneous immersion" and uses the instantaneous immersion geometric representation with quasi-steady aerodynamics. A more accurate type, called "pure penetration," uses penetration geometrics and quasi-steady aerodynamics. The most accurate type of forcing functions is called "penetration with lift growth." These later functions use the penetration geometrics with transient aerodynamics. These forcing function representations are discussed in Volume II.

Program B uses the responses found in Program A and actual wind measurements to calculate the wind-induced responses of the vehicle for the three forcing function representations.

Program C plots the indicial responses and analyzes the data for extrema and occurrences of some prespecified value.

Program D plots the wind-induced responses and also analyzes them for extrema and axis crossings.

II. GENERAL COMMENTS ON THE PROGRAMS AND THEIR INTERRELATION

Program A is written in FORTRAN II, version 3, for operation under IBSYS. The other programs are written in FORTRAN IV except for one or two extremely short subroutines which are in MAP.

---

* Response to a unit step.
** Response to a unit impulse.

The flow of data between the various programs is illustrated in Fig. 1. Further information is given in the sections on input and output for each of the programs.

When Program A, which was the original program, was being written, an effort was made to keep it as flexible as possible, since results of the preliminary runs would have a bearing on the way in which the program would later be used. However, after a pilot run was made and analyzed, a decision was made to choose the most efficient sequence for running the desired cases and standardize upon this sequence in order to facilitate input into Programs B and C. Consequently, Programs B and C are written to expect that the binary indicial and impulsive response tape will contain responses for only one flight time. Also unit impulse responses should precede unit step responses, and under each of these categories the aerodynamics options are ordered: (1) instantaneous immersion; (2) pure penetration; and (3) penetration with lift growth. Permutations of the indicated order will result in tapes which cannot be read by Programs B and C unless subroutine FINDEN is rewritten.

Program A contains a plot routine which uses a version of QUIK3V from the library of NASA's Computer Division at George C. Marshall Space Flight Center. In order to use the library version of this routine with FORTRAN II, version 3, a binary patch was made. This program must not be confused with the subroutine of the same name used by Programs C and D, which is from the NASA IBSYS Processor library tape.

Storage limitations prevented Program A from plotting more than about 800 points for each response. From the pilot run it was seen that more points would be needed to provide necessary resolution. Hence, Program C was provided with the capability of plotting up to 1189 points for each response. Control data in either Program A or C can suppress undesired plots.

There are several features about the four programs which should probably be changed if any extensive use of them is planned. The undesirable features result in inconvenience of operation but do not prevent the obtaining of correct answers. Since there was no opportunity to test any changes designed to improve these features, it was decided to leave the program as it was when last compiled and to add comment cards in the source deck to indicate the nature of recommended changes and the locations where they should be made. The deck as delivered, however, should produce a program giving results identical with those reported if the same data are used.

No listing of the program is included in this report. However, a complete source deck, from which a listing can be made, as well as sample data
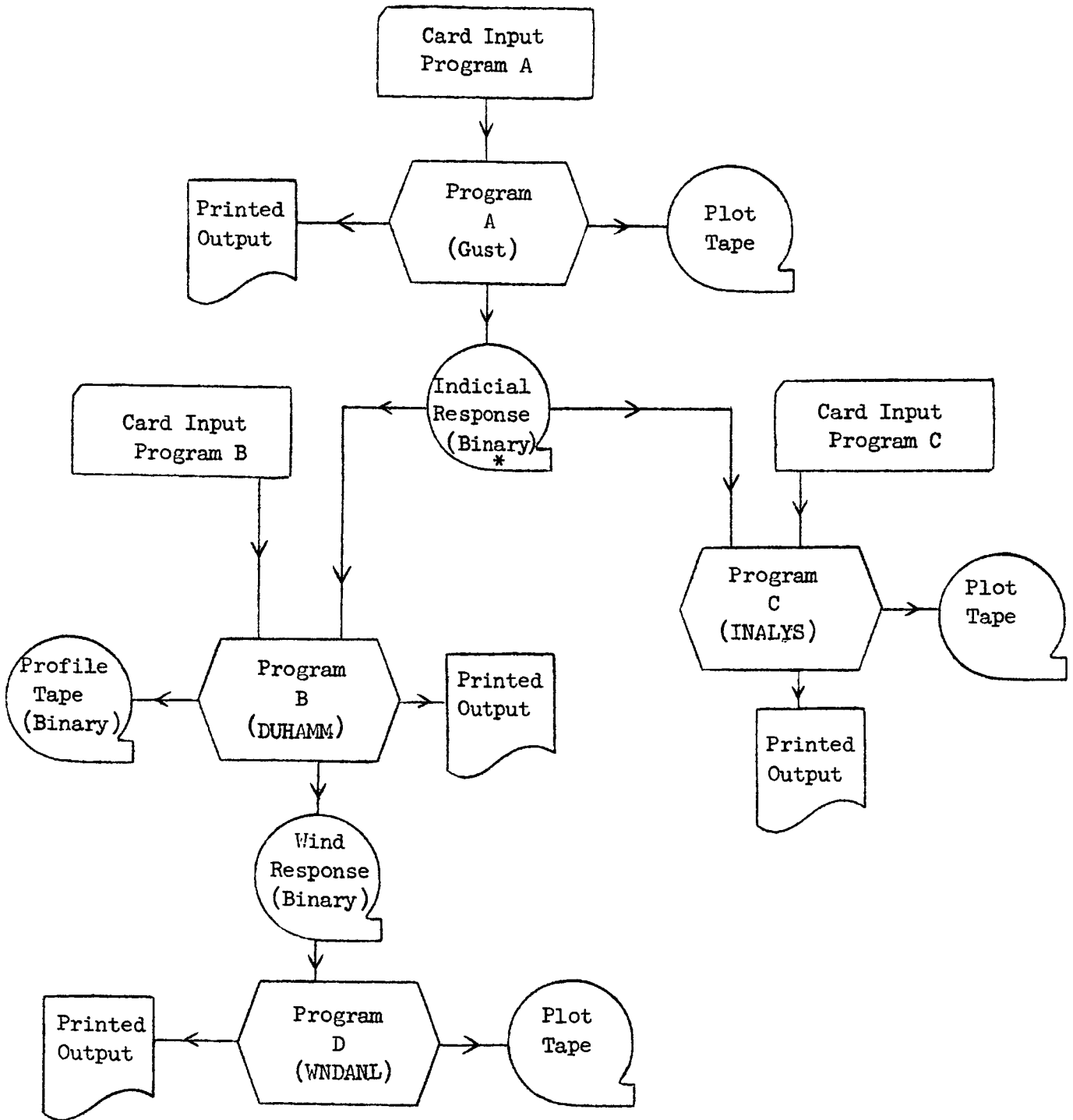
```
                    ┌─────────────────┐
                    │  Card Input     │
                    │  Program A      │
                    └────────┬────────┘
                             │
                             ▼
┌──────────┐      ╱───────────────╲      ╭──────────╮
│ Printed  │◄─────│   Program A     │────►│   Plot   │
│ Output   │      │   (Gust)        │     │   Tape   │
└──────────┘      ╲───────────────╱      ╰──────────╯
                             │
                             ▼
                       ╭───────────╮
                       │ Indicial  │
                       │ Response  │
                       │ (Binary)  │
                       │    *      │
                       ╰───────────╯
```

- 4 -

decks for each of the programs will be supplied to the Dynamic Analysis Branch, Dynamics and Flight Mechanics Division of the Aero-Astrodynamics Laboratory, NASA, in Huntsville.

In addition to the decks mentioned above, a deck named TESTPR will be provided which is a version of subroutine PROFIL used for debugging. This program defines an artificial wind profile furnished by NASA which was used for test purposes. If this deck is used instead of deck PROFIL, no profile tape is needed in running Program B.

An object deck for the plot routine QUIK3V to be used with Program A will be provided. This deck will contain the binary patch mentioned above. This deck should not be loaded with Programs C and D.

Meanings of symbols used in this report without definition may be found in Volume II.

III. DISCUSSION OF PROGRAM A (DECK NAME GUST)

Program A computes indicial and impulsive responses for a specified missile configuration. The missile configuration and trajectory parameters are read into the array $R(1-165)$.

For a specified missile and trajectory there are several options provided by the program. Either unit impulses or unit step responses or both may be computed. In addition, for either or both of these responses the user may specify aerodynamic forcing functions based on one or more of the following:*

1. Instantaneous immersion;

2. Pure penetration; and

3. Penetration with lift growth.

The responses which the program always finds are translation, rotation, two sloshing modes, and control. In addition to these, the user may specify how many bending modes are to be found. The number of bending modes must be 0, 1, 2, 3, or 4. The swivel engine deflection may also be used if desired.

---

* See associated restrictions on sequence (of K values) for subsequent input to Programs B and C.

The basic function of Program A is the determination of indicial and impulsive responses at time $T + \Delta$ given the responses at time T. This is attained through the use of a fourth order Runge-Kutta method. Other functions of Program A include:

1. The determination of the initial response values based on the impulsive and/or indicial aerodynamic forces resulting from the aerodynamic representation used.

2. The exact solution of the uncoupled control equation followed by the substitution of these values in place of the Runge-Kutta values. This is an optional feature and, when used, will persist only for a small, specified amount of time.

3. The values of the forcing functions are calculated prior to computing new response values.

4. Response values are written on binary tape for use in Program B and are plotted if desired.

5. Program A makes use of a steady-state algorithm to determine whether to stop the run. This feature may be suppressed in which case the run will continue for a specified amount of problem time.

A. Input

The first three cards of the data deck contain alphabetic information for heading formats. These cards are invariant.

After the three heading cards are the cards for the various cases to be run. Each case requires a basis of four cards, which are numbered 1 to 4 in the description below and any of the supplementary card sequences a, b, c, d, or e as indicated by information on the four basic cards.

The card dl must be inserted following card No. 2 if JGO on card No. 1 equals 4. If JGO equals 3, both cl and dl must be used. A JGO of 2 requires the sequence bl to b55 and cl and dl. If JGO is 1, the entire sequence of a, b, c, and d supplementary cards must be inserted following card No. 2.

The card el must be inserted following card No. 3 if TBETA ≥ DEL1. (Both these variables are on card No. 3.) The el card is read by subroutine BETA. This subroutine may be suppressed by setting TBETA equals 0.

The first case run in a given machine load must have JGO equals 1 in order to define the quantities read in on cards a1 to a9, b1 to b55, c1, and d1. Subsequent runs, however, may be run under the assumption that some or all of these quantities are unchanged. Broadly speaking, the choice of JGO follows the following outline:

JGO = 1 is used only on the first run of a job.

JGO = 2 corresponds to a change in flight time. Missile parameters which vary with altitude band are to be changed.

JGO = 3 corresponds to choosing a different set of responses for the computation. In other words the number of bending equations used will be changed or else the swivel engine equation will be added or deleted.

JGO = 4 corresponds to a change in the aerodynamic forcing function. These functions are controlled by the code K.

JGO = 5 corresponds to a change in time increment.

JGO = 6 is a signal that the last run has been computed.

Data required on the various cards and corresponding formats are shown below:

Card No.	Columns	Format	Format
1	1-4	I4	JBNO
	5-8	I4	JBNO1
	9-12	I4	JBNO2
	13-16	I4	JBNO3
	17-20	I4	JGO
2	1-2	I2	KKKKKK(1)
	3-4	I2	KKKKKK(2)
	5-6	I2	KKKKKK(3)
	7-8	I2	KKKKKK(4)
	9-10	I2	KKKKKK(5)
	11-12	I2	KKKKKK(6)
	13-14	I2	KKKKKK(7)
	15-16	I2	KKKKKK(8)
	17-18	I2	KKKKKK(9)
	19-20	I2	KKKKKK(10)
	21-68	8A6	ABCDE(1-8)

Card No.	Columns	Format	Symbol
3	1-4	I4	INCPR
	9-12	I4	JRUNPR
	13-18	F6.0	DEL1
	19-24	F6.0	DEL2
	25-30	F6.0	DEL3
	31-36	F6.0	TBETA
	37-42	F6.0	TCHGE1
	43-48	F6.0	TCHGE2
	49-54	F6.0	TEND
	55-60	F6.0	TLAG
	61-70	E10.4	TEST
4	1-4	I4	KLYDE
a1	1-4	I4	KPRINT
	5-8	I4	KK
	9-12	I4	KTB
	13-16	I4	KPR1
	17-20	I4	KPR2
	21-29	F9.4	AAT
	30-38	F9.4	ABT
a2	1-72	8F9.4	BE(J)
a3	1-72	8F9.4	RA(J)
a4	1-72	8F9.4	EX(J)
a5-a9	8-71	7X4E16.7	R(J)
b1	1-4	I4	KPRIN1
b2-b37	8-71	7X4E16.7	R(J)
b38	8-23	7XE16.7	R(165)
b39	1-15	E15.7	UM
	16-30	E15.7	U
	31-45	E15.7	Q
	46-60	E15.7	XGX

Card No.	Columns	Format	Symbol
b40-b55	1-15	E15.7	AA(J,I)
	16-30	E15.7	BB(J,I)
	31-45	E15.7	CC(J,I)
c1	1-4	I4	M
	5-8	I4	L
	9-12	I4	KPRIN2
	13-16	I4	KPRIN3
d1	1-4	I4	K
e1	1-13	E13.7	RR(1)
	14-26	E13.7	RI(1)
	27-39	E13.7	RR(2)
	40-52	E13.7	RI(2)
	53-65	E13.7	RR(3)
	66-78	E13.7	RI(3)

Card No. 1

JBNO = run identifier.
JBNO1 = month (1-12).
JBNO2 = day of month.
JBNO3 = year.
JGO = control symbol explained in text.

Card No. 2

KKKKKK(1 to 10) = plot control variables for each of the responses 1 to 10. A value of 1 causes plot to be made. Zero or blank suppresses it.

ABCDE(1 to 8) = 48 characters to describe the case plotted. The word "unit" is understood to precede the words in this array. For example, the characters might be IMPULSE, INST. IMMERSION, -- F.T. = 60 sec. The word "unit" ahead of "impulse" will be furnished by the program.

- 9 -

Card No. 3

INCPR = number of increments between response print-outs.

JRUNPR = control code for printing Runge-Kutta calculations prior to correction in subroutine BETA. A "1" causes printing; a "2" suppresses it.

DEL1 = initial time increment.

DEL2 = time increment after time exceeds TCHGE1.

DEL3 = time increment after time exceeds TCHGE2.

TBETA = the last time at which subroutine BETA is used to correct the Runge-Kutta values.

TCHGE1 = transition time when time increment is first increased.

TCHGE2 = transition time when time increment is last increased.

TEND = time at which program unconditionally terminates a case.

TLAG = time at start of case. (This must be zero.)

TEST = factor used to test whether responses have reached steady-state values.

Card No. 4

KLYDE = control code to determine how to terminate the case. A "2" causes the case to terminate if the steady-state condition is met. A "1" causes the case to continue until time = TEND.

Card No. a1

KPRINT = print code. A "2" causes R(1 to 20) to be printed. A "1" suppresses them.

KK = number of missile stages.

KTB = $0.1/\Delta\bar{\tau}$. Increment size in G, H, I integrations is 0.1/KTB.

KPR1 = print code. A "1" causes G, H, I tables to be printed. A zero suppresses print-out. A "2" causes asymptotic values only to be printed.

KPR2 = print code. A "1" causes partial and total forcing functions to be printed. A "2" causes only totals to be printed and a zero suppresses both.

AAT and ABT are constants determining cutoff point $\bar{\tau}_{CN}$ for G, H, I integrations. $\bar{\tau}_{CN}$ = AAT-ABT ln α_N where α_N is the angle of the Nth missile conical section.

Card No. a2

BE(J) = semi-vertex angle (rad.) of the Jth missile section. (J = 1,KK.)

Card No. a3

RA(J) = radius (meters) of the Jth cylindrical portion of missile. (J = 1,KK).

- 10 -

Card No. a4

    EX(J) = distance from nose (meters) to the front and rear of respective
           missile conical sections. (J = 1,2*KK-1).

Cards Nos. a5 to a9

    R(J) = constant missile parameters. ((J = 4n-3,4n), n = 1,5).
        (see Table I).*

Card No. b1

    KPRIN1 = print code. A "2" causes R(21 to 165) to be printed. A "1"
          suppresses them.

Cards Nos. b2 to b37

    R(J) = variable missile parameters. ((J = 4n-3,4n), n = 6,41).
        (see Table I).*

Card No. b38

    R(165) = last entry in R array. (see Table I).*

Card No. b39

    UM = Mach number.
     U = missile velocity (meters/second).
     Q = product of dynamic pressure and four times missile base area (kg.).
  XGX = center of gravity location measured from nose (meters).

Cards Nos. b40 to b55

    The Ith bending mode in the region of the Jth conical section is
represented by $CC(J,I)X^2 + BB(J,I)X + AA(J,I)$. The missile sections are
numbered from the nose rearward. Coefficients are read in the sequence
((J = 1,4), I = 1,4).**

---

* The units of the parameters presented in Table I are in the MKS system.
   Force is given in units of kilograms.

** If fewer than four missile stages are used, blank cards should be added
    to make 16 cards in all since the program reads these coefficients for
    four stages.

TABLE I

DEFINITION OF PARAMETERS IN R(J) ARRAY

R(J)	Parameter	R(J)	Parameter	R(J)	Parameter	R(J)	Parameter
1	$\bar{a}_o$	18	θ_E	35	ω_{S2}	52	$\bar{G}_1$
2	$\bar{a}_1$	19	k_E	36	m_{S1}	53	D_1
3	$\bar{a}_2$	20	C_E	37	m_{S2}	54	$\bar{D}_1$
4	$\bar{a}_3$	21	U	38	$(X_{S1}-X_g)$	55	H
5	$\bar{a}_4$	22	Q	39	$(X_{S2}-X_g)$	56	$\bar{H}_1$
6	$\bar{a}_5$	23	m	40	ω_{B1}	57	E_1
7	$\bar{a}_6$	24	I_{cg}	41	T_1	58	$\bar{E}_1$
8	g_{S1}	25	b_o	42	$Y_1(X_E)$	59	A_{11}
9	g_{S2}	26	a_o	43	$Y_1(X_{S1})$	60	B_{11}
10	F_o	27	a_1	44	$Y_1(X_{S2})$	61	C_{11}
11	J_o	28	F	45	$Y_1(X_v)$	62	ω_{B2}
12	g_{B1}	29	(X_E-X_g)	46	$Y_1'(X_E)$	63	T_2
13	g_{B2}	30	(X_v-X_g)	47	$Y_1'(X_{S1})$	64	$Y_2(X_E)$
14	g_{B3}	31	J_1	48	$Y_1'(X_{S2})$	65	$Y_2(X_{S1})$
15	g_{B4}	32	J_2	49	$Y_1'(X_v)$	66	$Y_2(X_{S2})$
16	m_E	33	F_2	50	$Y_1'(X_\emptyset)$	67	$Y_2(X_v)$
17	S_E	34	ω_{S1}	51	G_1	68	$Y_2'(X_E)$

TABLE I (Continued)

R(J)	Parameter	R(J)	Parameter	R(J)	Parameter	R(J)	Parameter
69	$Y'_2(X_{S1})$	87	C_{12}	105	D_3	123	C_{31}
70	$Y'_2(X_{S2})$	88	C_{21}	106	$\bar{D}_3$	124	C_{32}
71	$Y'_2(X_v)$	89	C_{22}	107	H_3	125	C_{33}
72	$Y'_2(X_\emptyset)$	90	F_1	108	$\bar{H}_3$	126	ω_{B4}
73	G_2	91	G_g	109	E_3	127	T_4
74	$\bar{G}_2$	92	ω_{B3}	110	$\bar{E}_3$	128	$Y_4(X_E)$
75	D_2	93	T_3	111	A_{13}	129	$Y_4(X_{S1})$
76	$\bar{D}_2$	94	$Y_3(X_E)$	112	A_{23}	130	$Y_4(X_{S2})$
77	H_2	95	$Y_3(X_{S1})$	113	A_{31}	131	$Y_4(X_v)$
78	$\bar{H}_2$	96	$Y_3(X_{S2})$	114	A_{32}	132	$Y'_4(X_E)$
79	E_2	97	$Y_3(X_v)$	115	A_{33}	133	$Y'_4(X_{S1})$
80	$\bar{E}_2$	98	$Y'_3(X_E)$	116	B_{13}	134	$Y'_4(X_{S2})$
81	A_{12}	99	$Y'_3(X_{S1})$	117	B_{23}	135	$Y'_4(X_v)$
82	A_{21}	100	$Y'_3(X_{S2})$	118	B_{31}	136	$Y'_4(X_\emptyset)$
83	A_{22}	101	$Y'_3(X_v)$	119	B_{32}	137	G_4
84	B_{12}	102	$Y'_3(X_\emptyset)$	120	B_{33}	138	$\bar{G}_4$
85	B_{21}	103	G_3	121	C_{13}	139	D_4
86	B_{22}	104	$\bar{G}_3$	122	C_{23}	140	$\bar{D}_4$

TABLE I (Concluded)

$R(J)$	Parameter	$R(J)$	Parameter
141	H_4	159	C_{14}
142	$\overline{H}_4$	160	C_{24}
143	E_4	161	C_{34}
144	$\overline{E}_4$	162	C_{41}
145	A_{14}	163	C_{42}
146	A_{24}	164	C_{43}
147	A_{34}	165	C_{44}
148	A_{41}		
149	A_{42}		
150	A_{43}		
151	A_{44}		
152	B_{14}		
153	B_{24}		
154	B_{34}		
155	B_{41}		
156	B_{42}		
157	B_{43}		
158	B_{44}		

Card No. c1

        M = number of bending equations used (0, 1, 2, 3, or 4).

        L = control code. A "2" causes swivel engine equation to be used.
           A "1" suppresses it.

KPRIN2 = print code. A "2" causes coefficients of the differential
           equation to be printed. A "1" suppresses printing.

KPRIN3 = print code. A "2" causes the inverse of the matrix of second
           derivative coefficients to be printed. A "1" suppresses
           printing.

Card No. d1

        K = a code defining aerodynamic forcing function. The values of K
           correspond as follows:

        K = 1 is unit step - instantaneous immersion.
        K = 2 is unit impulse - instantaneous immersion.
        K = 3 is unit step - pure penetration.
        K = 4 is unit impulse - pure penetration.
        K = 5 is unit step - penetration with lift growth.
        K = 6 is unit impulse - penetration with lift growth.

Card No. e1

        RR(1 to 3) = distinct real parts of the roots of the homogeneous un-
           coupled sixth order control equation.

        RI(1 to 3) = magnitudes of distinct imaginary parts of the roots of the
           homogeneous uncoupled sixth order control equation.

B. Output

      The amount of output is controlled by input parameters. First of
all, if JGO is chosen so that some of the preliminary calculations are skipped,
the results of these calculations are the same and will not be printed.

      If the G, H, and I tables are calculated the amount of output depends
on KPR1. If KPR1 is zero, the tables are suppressed. If KPR1 is two, steady-
state values only are printed. If KPR1 is one, maximum printout is given with
$\bar{\tau}$ values ranging 0(0.1)5(0.2)10(0.5)τ_∞ where τ_∞ is the time, $\bar{\tau}$, when G, H,
and I integrals have reached asymptotic values.

Output of the forcing functions is under the control of KPR2. If KPR2 is zero, no forcing functions are printed. If KPR2 is two, total forces only are printed. If KPR2 is one, the contributions from each missile section as well as totals are printed. After the forcing functions have reached steady state, they are deleted. There are no forcing functions for the sloshing and control equations.

Printout of the part of the R array which is independent of flight time is controlled by the variable KPRINT. If this variable is two, the program prints R(1 to 20); if KPRINT is one, printing is suppressed.

Printout of the part of the R array which depends on flight time is controlled by the variable KPRIN1. If this variable is two, the program prints R(21 to 165); if KPRIN1 is one, printing is suppressed.

Printout of the coefficients of the differential equations to be solved is controlled by KPRIN2. The coefficients are printed out when this variable is two and suppressed when it is one. The coefficients, if printed, are in the form of three matrices, a 10 by 10 and two 10 by 12's. The rows and columns of each of the matrices correspond respectively to the equations and variables shown below: (Symbols are defined in Volume II.)

Row	Equation
1	Fourth bending
2	Third bending
3	Second bending
4	First bending
5	Translation
6	Rotation
7	First sloshing
8	Second sloshing
9	Control deflection
10	Swivel engine deflection

Column	Second Derivative Coefficient	First Derivative Coefficient	Linear Coefficients
1	$\ddot{\eta}_4$	$\dot{\eta}_4$	η_4
2	$\ddot{\eta}_3$	$\dot{\eta}_3$	η_3
3	$\ddot{\eta}_2$	$\dot{\eta}_2$	η_2
4	$\ddot{\eta}_1$	$\dot{\eta}_1$	η_1
5	$\ddot{y}_0$	$\dot{y}_0$	y_0
6	$\ddot{\phi}$	$\dot{\phi}$	ϕ
7	$\ddot{\varsigma}_1$	$\dot{\varsigma}_1$	$\ddot{\varsigma}_1$
8	$\ddot{\varsigma}_2$	$\dot{\varsigma}_2$	$\bar{\varsigma}_2$
9	β_c^{VI}	β_c^{V}	β_c^{IV}
10	$\ddot{\beta}_E$	$\dot{\beta}_c$	β_c
11	-	$\dddot{\beta}_c$	$\ddot{\beta}_c$
12	-	$\dot{\beta}_E$	β_E

The inverse of the second derivative coefficient matrix is printed out if KPRIN3 is two. The format is the same as that of the second derivative coefficients themselves. If KPRIN2 is one, printout of the inverse is suppressed.

The responses may be printed out after each time increment, or they may be suppressed until several increments have been made. The variable INCPR determines how many time increments are made between printing of responses. When the time increment is changed at the various transition times, the printout interval is changed correspondingly with the number of intervals between printout remaining the same, regardless of the size of the intervals.

Responses are printed in three columns, the second and third columns being first and second derivatives of the response shown in the first column. The bending responses are given first, beginning with the highest frequency mode. These are followed by translation, rotation and the two sloshing responses. The remaining rows of output relate to the control equation, which

is of sixth order, and the swivel engine equation. Because of an interchange of notation swivel engine deflection, if it is used, is labeled BETAC, and control deflection is labeled BETAE. Two dummy variables N and P are introduced to represent second and fourth derivatives respectively of control deflection.

A binary indicial and impulsive response tape (A4) is also generated which contains responses of the coordinates, but not their derivatives, at every time where responses were calculated. The number of points for which responses are stored on the binary tape is greater than the corresponding number of points on the print tape by a factor INCPR.

C. Running Time Estimates and Operating Instructions for Program A

Program A was run for eight flight time bands. Each band was 20 sec. of real time. In each band the responses of seven generalized coordinates were computed for six different aerodynamic forcing functions. The computations averaged 25 min. per band with each 32nd response value printed. Time increments (seconds) are given in Table I of Volume II. Typical values are 0(0.0005)0.02(0.001)0.45(0.003)20.

This program requires a reserve tape, A4, and the normal print tape, B1. A plot tape, B8, is also needed if plots from this program are called for. If no plots are required, the program still selects B8 at the end of the program to write end-of-file and rewind.

D. Description of Subroutines of Program A

The relationship between the main program and the various subroutines used is shown in Fig. 2. A brief description of the purpose of the various subroutines used in Program A is given below. Flow charts of the principal subroutines are given in Appendix I.

GRAFT determines which quantities are to be plotted and calls the actual plotting routine QUIK3V.

INCØND assigns initial values of missile responses, based on the aerodynamic forcing function used.

RUNEND determines whether run should terminate by calculating JSTØP equals 1 for continue or JSTØP equals 2 for halt. If KLYDE equals 1, JSTØP will equal 2 only when time (T) exceeds some prescribed number (TEND). If KLYDE equals 2, satisfaction of a steady-state algorithm will also terminate the run. KLYDE is read when RUNEND is entered for the first time.
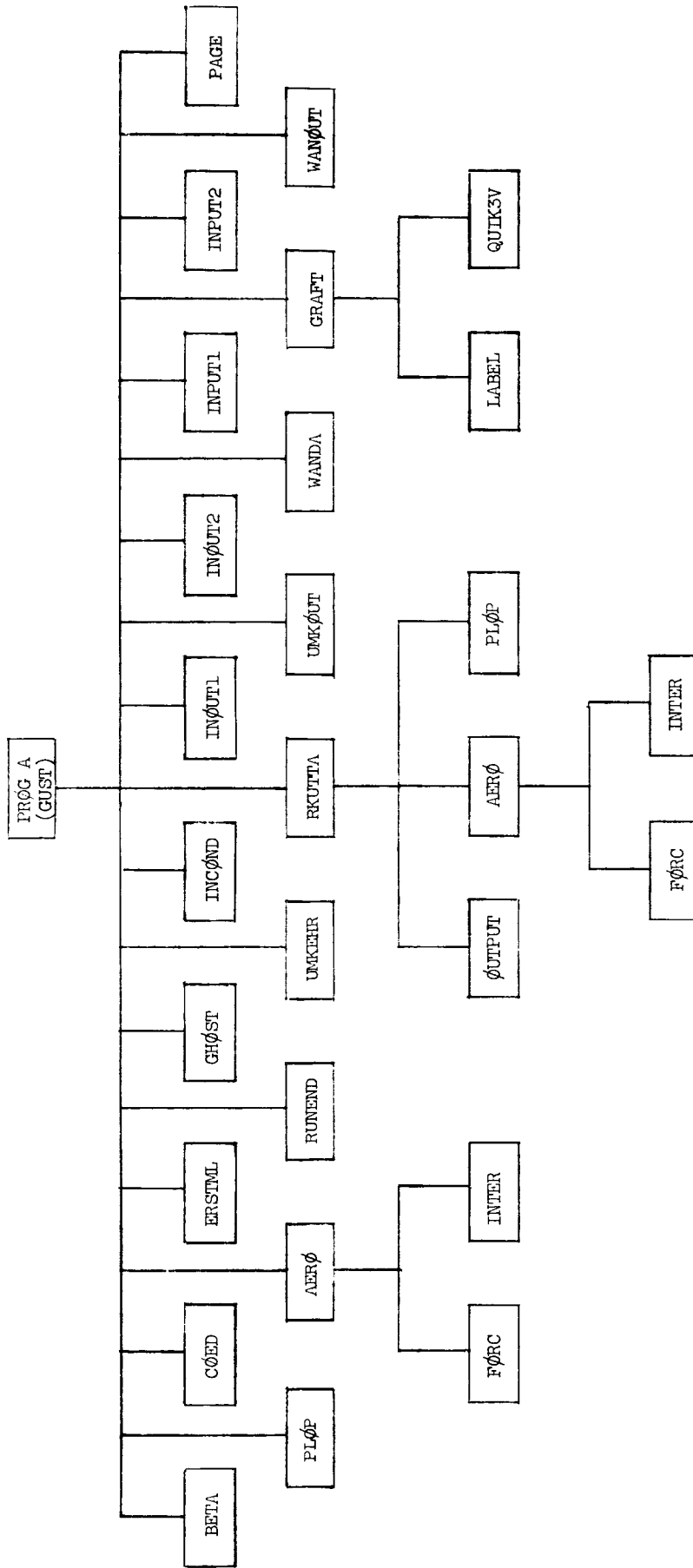
Fig. 2 - Hierarchy of Subroutines Used in Program A

RKUTTA performs the following:

1. Calls AERO for forcing function values.

2. Uses method of Runge-Kutta to calculate next response values.

3. Advances clock.

4. Determines time for output and calls ØUTPUT.

5. Calls PLØP.

GHOST computes and stores tables of the integral $\int_{o}^{\bar{\tau}} \dfrac{1-fo(\tau)}{(1+\alpha\tau)^{n}}\, d\tau$

for $n = 3,4$ and 5. The integration procedure uses a modified form of the trapezoidal rule. Printout of the computed tables is optional.

COED computes and stores a 4 by 11 array of coefficients required for the aerodynamic calculations.

INTER interpolates in the tables generated by GHOST for values of the integrals and (optionally) the derivatives of the integrals.

FORC computes the contribution of one missile section to the aerodynamic forcing functions of the equations of motion.

AERO coordinates computation of the aerodynamic forcing functions for a specified time. FORC is called successively for each missile section and the individual contributions are summed for total. Printout of the forcing functions is optional.

INPUT1 reads:

1. Missile parameters which normally do not change.

2. Quantities pertaining to the G, H, and I integrations.

3. Fixed point numbers which determine whether the parameters and the integration results are written on the output tape.

INPUT2 reads:

    1. Missile and atmospheric parameters which are apt to change between runs.

    2. A fixed point number which controls the printing of the missile and atmospheric parameters.

    INØUT1 writes unchanging missile parameters (R(1)-R(20)) on output tape.

    INØUT2 writes variable missile and atmospheric parameters (R(21)-R(165)) on output tape.

    ERSTML reads the first three data cards, which contain heading information for the plots.

    LABEL sets up the heading information for the particular responses which are being plotted.

    UMKEHR inverts the matrix $\begin{bmatrix} A \end{bmatrix}$ of coefficients of second derivatives.

    WANDA computes the matrices A, B, and C.

    BETA solves the uncoupled control equations in the vicinity of $t = 0$ and substitutes these solutions for the Runge-Kutta values.

    WANØUT writes the quantities calculated in subroutine WANDA on the output tape, namely:

    1. A(10,10), the coefficients of the second derivatives.

    2. B(10,12), the coefficients of the first derivatives.

    3. C(10,12), the coefficients of the responses.

    UMKØUT writes $\begin{bmatrix} A \end{bmatrix}^{-1}$, as calculated in subroutine UMKEHR, on the output tape.

    ØUTPUT writes the missile indicial and impulsive responses on the output tape.

PAGE turns the page.

PLOP assigns the plotting increments, organizes the quantities to be plotted into a form compatible with the QUIK3V subroutine.

IV. DISCUSSION OF PROGRAM B (DECK NAME DUHAMM)

The purpose of Program B is to calculate missile responses for a selected wind profile by evaluation of the superposition integral

$$R = \int_0^T W(\tau)I(T-\tau)d\tau$$

where

R = missile response.

$W(\tau)$ = wind profile as function of time.

$I(T-\tau)$ = unit impulse response with shifted argument .

The wind profile is available as a function of altitude and the unit impulse as a function of time measured from the instant of application of the impulsive gust. In both instances the data are in the form of discrete point functions stored on binary tape.

The superposition integral is evaluated using the trapezoidal rule. For this integration the available point function of altitude, $W(h)$, is transformed to a time function by assuming the missile to be flying at constant velocity U .

The response at a particular altitude, $R(h)$, is calculated by choosing $W(h)$ at the corresponding altitude as $W(T)$ for the integration. To facilitate calculation of $R(h)$ at many altitudes the impulsive responses are processed in time segments $\Delta h/U$ where Δh is the preset (uniform) altitude spacing at which the response is to be evaluated. Appreciable condensation of the impulsive response data is obtained in this manner at the outset.

A. Input

Program input consists of a series of cards, the impulsive response tape, and the wind profile tape. Input cards are numbered between one and seven in column two with other format as follows:

Card No.	Columns	Format	Symbol
1	3-12	F10.0	U
	23-26	I4	NTAPE
2	23-26	I4	K
3	23-26	I4	NR
	27-28	I2	NRES
	29-48	I2	KT(J)'s
4	3-12	F10.0	ALTI
	23-26	I4	NPRO
	27-28	I2	NUM1
	29-30	I2	NUM2
5	3-12	F10.0	ALMN
	13-22	F10.0	ALMX
	23-26	I4	NDEL
6	23-26	I4	KTT
7	23-26	I4	LTAPE
	27-28	I2	KPAUSE
	29-30	I2	NWIND
	49-54	A6	REEL

Card No. 1

U = missile velocity in meters per second.
NTAPE = logical number of impulsive response tape.

Card No. 2

K = code number identifying the aerodynamic theory used (see Program A description).

<u>Card No. 3</u>

KT(J), J = 1,10 , are identification numbers assigned to the various missile coordinate responses as indicated in Table II.

TABLE II

<u>NUMBERING SCHEME FOR RESPONSES AS REFERENCED IN PROGRAMS B AND C</u>

<u>Number</u>	<u>Response</u>	<u>Response Symbol</u>
1	Translation	y_0
2	Rotation	ϕ
3	First bending	η_1
4	Second bending	η_2
5	Third bending*	η_3
6	Fourth bending*	η_4
7	First sloshing	ζ_1
8	Second sloshing	ζ_2
9	First control (control deflection)	β_C
10	Second control (swivel engine deflection)*	β_E

---

* These responses were not computed in the runs made to date.

NRES designates how many of the 10 responses are to be used in the superposition integral. By reading in NRES and KT(J) for J = 1 to NRES, the responses to be processed are identified. NR, an integer $\neq$ 0, is a measure of the altitude spacing Δh at which responses are to be calculated. For given K all of the responses selected by the KT(J) are simultaneously processed in time segments $\Delta h/U$. Since Δh may vary from response to response, (that is, from one KT(J) to another) the processing should be done using the smallest Δh of interest (note that Δh is restricted to distinct values 25/k meters, k = an integer). Thus, NR should be made equal to the k corresponding to Δh_{min} (for further clarification see NDEL, Card No. 5). For $\Delta h \geq$ 25 meters, NR = 1.

Card No. 4

NPRO = number of wind velocity points to be stored at 25 meter altitude
increments.
ALTI* = lowest altitude at which nonzero wind data are stored. (This must
be an altitude appearing on the wind profile tape.)
NUM1 = word number in wind profile tape record to be stored. (This may
be 2, 3, 4, or 5. See remarks on the profile tape.)
NUM2 indicates how many zeros are to be stored at the low altitute end
of the profile array. Ten x MUM2 zeros are stored.

Card No. 5

ALMN = minimum altitude at which response is to be calculated. The
program shifts ALMN to the next lower wind data point.
ALMX = maximum altitude at which response is to be calculated. The pro-
gram shifts ALMX to the next higher wind data point.
NDEL = responses will be calculated at altitude spacing of 25 x NDEL/NR
meters.

Card No. 6

KTT identifies the response to be calculated, namely the one
corresponding to KT(KTT). After return from subroutine INDRES KTT = 1 is
understood and a number 6 card is optional. For subsequent runs the 6 card
is used to cycle through the responses to be calculated.

Card No. 7

The 7 card may be used optionally to write on line instructions for
mounting the indicial and impulsive response tapes. It is suggested the pro-
gram listing be consulted for full details. LTAPE is the logical number of
the tape to be changed. KPAUSE is zero if computation proceeds while the tape
is changed and nonzero if computation halts. NWIND $\neq$ 0 will cause the
appropriate tape to be rewound. REEL is the reel number of the tape to be
mounted.

When the program is first loaded, cards 1 through 5 followed by a
blank are required to initiate a run. (A run consists in calculating a

---

* All altitudes in meters.

response, say rotation, at a series of uniformly spaced altitudes.) Subsequent runs are made by reading in only those cards containing information to be changed. Each set of data must be followed by a blank. A card with the number 9 in column two must immediately precede the trailing blank of the last set of data to be run. This card causes a terminal record to be written on the binary output tape that informs Program D of the end of data.

Control indices are set internally so that in consecutive runs the program performs only the operations affected by the data changes. An oversight in programming these control indices makes it necessary to read in a 5 card whenever a 4 card is read, even when the 5 card does not change. This shortcoming can be removed by adding a statement in the DUHAMM routine (see comment cards in program listing).

The indicial and impulsive response tape is the binary tape written by Program A. If this tape contains more than one case, the cases are assumed to be ordered according to the value of K , the code determining aerodynamic forcing functions. The sequence of K values expected is 2, 4, 6, 1, 3, 5. Any of these K's may be deleted but permutations of the order will cause Program B to fail.

The profile tape used in the present analysis must be written in a format suitable for reading into a FORTRAN IV program, i.e., with a code word on the front of each record giving the number of words in the physical record, etc. The records must all contain five words excluding this code word, and any records after the first 804 are ignored. The first word of each record is altitude in meters. The next two words are zonal (W-E) and meridinanal (S-N) components respectively for the first wind profile. The last two words are similar velocity components for a second profile.

Altitude difference between successive records is assumed to be 25 meters. The subroutine which reads the profile searches the tape until it finds a record having an altitude equal to the given initial altitude (ALTI) and then stores corresponding velocity values until NPRO values have been stored. The variable NUM1, which must be 2, 3, 4, or 5, indicates which word in each of the profile tape records is the velocity component desired.

The inclusion of one or more alphameric heading records on the front of the profile tape will not affect the program provided the records contain five words. Since the program searches for the starting altitude, the heading records will be skipped.

B. Output Description

A binary output tape is produced for input to Program D and tabulated output is printed. The printed output consists of a heading identifying: (1) aerodynamic theory; (2) flight time; (3) response; and (4) wind profile (NUM1 of input card 4). Following the heading altitude and calculated response are tabulated in five double columns.

The first record of the binary output tape contains identification information on the first data run. Subsequent records each contain 125 values of the computed responses in the order of calculation, i.e., by rows in the printed output. Successive runs write an identification record and data records as above. A terminal record follows the data records of the last run to inform Program D of end of data.

C. Running Time Estimates and Operating Instructions for Program B

Program B was run for five flight times each using two profiles. Seven coordinate responses were found for each of the six aerodynamic forcing functions. A typical run where each response was calculated at 440 points took 40 min.

This program requires that the profile tape be mounted on unit A6 and the indicial and impulsive response tape or tapes on the units indicated on the input cards. However, if the NASA test profile is used, deck TESTPR should replace deck PROFIL in the program and the profile tape is not needed. The program generates a normal print tape, B1, and a binary reserve tape, A5, containing wind responses to be read into Program D. A scratch tape, B4, is also used.

D. Description of Subroutines of Program B

The relationship between the main program and the various subroutines used is shown in Fig. 3. A brief description of the purpose of the various subroutines used in Program B is given below. Flow charts of the principal subroutines are given in Appendix II.

INDRES processes the impulsive responses in prescribed time segments as discussed earlier and writes the processed data on scratch tape.

FINDEN moves the impulsive response tape into position for reading the desired set of data.
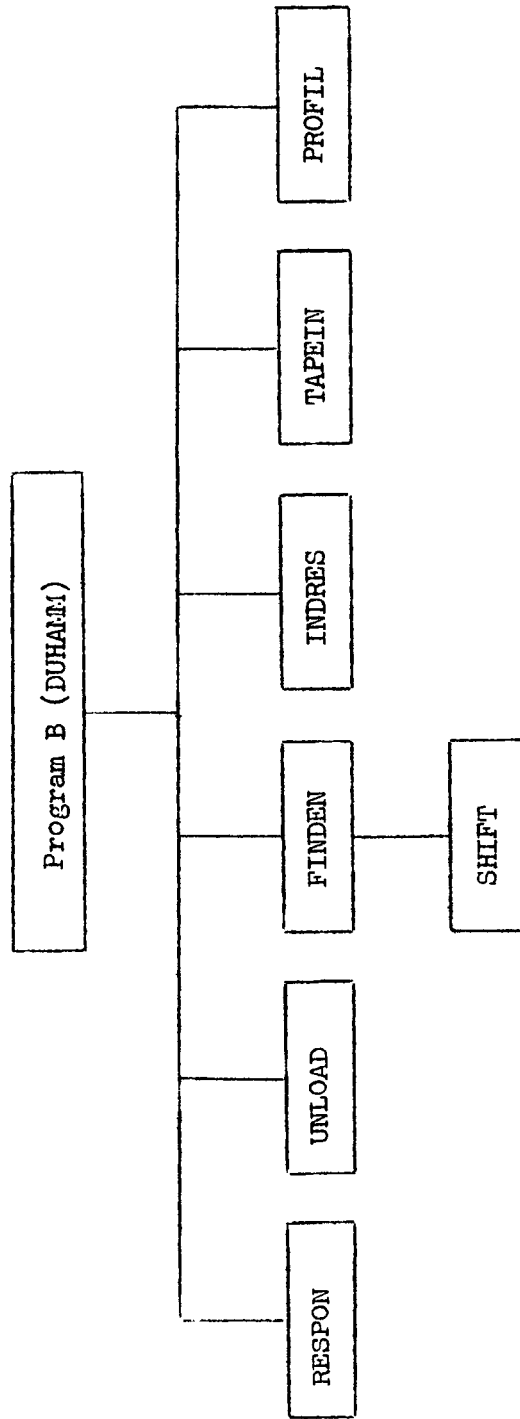
Fig. 3 - Hierarchy of Subroutines Used in Program B

RESPON calculates a response at one altitude by integrating the superposition integral.

TAPEIN reads and stores data from the scratch tape generated by INDRES.

SHIFT converts an integer from FORTRAN II to FORTRAN IV format in the computer (written in MAP)

PROFIL reads the required wind velocities from the wind profile tape, inserts zeros ahead of the values read and computes altitude values to correspond with the velocities.

UNLOAD rewinds the indicated tape. (This routine should be modified to rewind and unload the tape.)

V. DISCUSSION OF PROGRAM C (DECK NAME INALYS)

Program C is a routine to analyze the indicial and impulsive response data. The program works with those responses requested and locates maxima, minima, and crossings of zero (or any other value requested). In addition, it assembles the response data to be plotted and calls the standard NASA plot subroutine, QUIK3V, which produces a tape to be used by the SC4020.

A. Input

The program requires, in addition to the binary tapes produced by Program A, certain control information punched on data cards. The data cards are in a format which is compatible with Program B, since much of the same information is required. A deck of data cards will consist of one or more decklets, each of which contains a variable number of cards. Each card is identified by a digit (card number) in column 2. Normally, a decklet will consist of cards 1 and 2, a variable number of card 8's, an optional card 7, and followed by a card 0 (or blank). The details of the data cards are summarized below.

Card No.	Columns	Format	Symbol
1	23-26	I4	NTAPE
2	23-26	I4	K1
7	23-26	I4	I2
7	27-28	I2	I3
7	29-30	I2	I4
7	49-54	A6	A1
8	27-28	I2	N1
8	29-30	I2	N2
8	3-12	F10.0	AVE(N1)
8	13-22	F10.0	AVE(N2)
8	31-32	I2	NTH

Card No. 1 contains the logical tape number (e.g., 9) which holds the binary indicial and impulsive response tape.

Card No. 2 specifies whether the unit step (K1 = 1) or unit impulse (K1 = 2) responses are to be used.

Card No. 7 is needed only if many binary tapes are to be analyzed during a single job. It causes on-line messages and operator action pauses to occur, to allow for tape changes. See the program listing for details of the data on this card.

Card No. 8 indicates two responses to be analyzed, and the corresponding values (AVE), the crossings of which will be tabulated. The responses are considered to be represented by the integers as shown in Table II (see section on Program B). As many cards of this format as are necessary may be used. N1 and N2 may be the same, if an odd number of responses are to be analyzed. N1 and N2 must be in the range 1 to 10. The last of the card 8's should have a value of NTH, which indicates that every n^{th} point on the binary tape will be plotted. If NTH is not specified, it is taken as 5. In any case, no more than 1189 points will be plotted on a given curve.

Card 0 (blank) indicates the end of a decklet, and must be present.

Cards 3 to 6 are ignored by this program since they contain data pertinent only to Program B.

Card 9 is the last card in the data deck, and indicates end of job to the program. Note: it does not replace card 0; both must be present.

B. Output

For each decklet of input data, 3N pages of output and 3N plots will be produced, where N is the number of responses requested via card 8's. (The factor 3 arises since the three different types of aerodynamics discussed in Volume II are analyzed.)

Each page of output contains identifying information followed by a table of three columns. The first column is the time, the second is the value of the response, and the third is the event (maximum, minimum, or crossing). The values listed are not exact, but are those values existing on the binary tape which immediately precede (in time) the event. No more than 60 events are tabulated.

The plots are produced by the SC4020 from a plot tape produced by the program. Each plot is labeled and is self-explanatory. See Volume II, Section III-C for samples of the output from this routine.

C. Running Time Estimates and Operating Instructions for Program C

Program C required about 3 min. of computer time to process each of the response tapes generated by Program A. The total number of graphs and tables produced was 42, i.e., seven responses for six aerodynamic forcing functions.

This program requires that the indicial and impulsive response tapes to be processed be mounted on the units indicated on the input cards. The program generates a normal print tape, B1, and the plot tape, A8. The program will select unit A5 at the end of job to write end of file.

The program deck should be preceded by four cards to ready the plot tape. These cards are:

Column 1	Column 16
$ IBSYS	
$ ATTACH	A8
$ AS	SYSCK2, LOW
$ EXECUTE	IBJOB

D. Description of Subroutines of Program C

The relationship between the main program and the various subroutines used is shown in Fig. 4. A brief description of the purpose of the various subroutines used in Program C is given below. Flow charts of the principal subroutines are given in Appendix III.
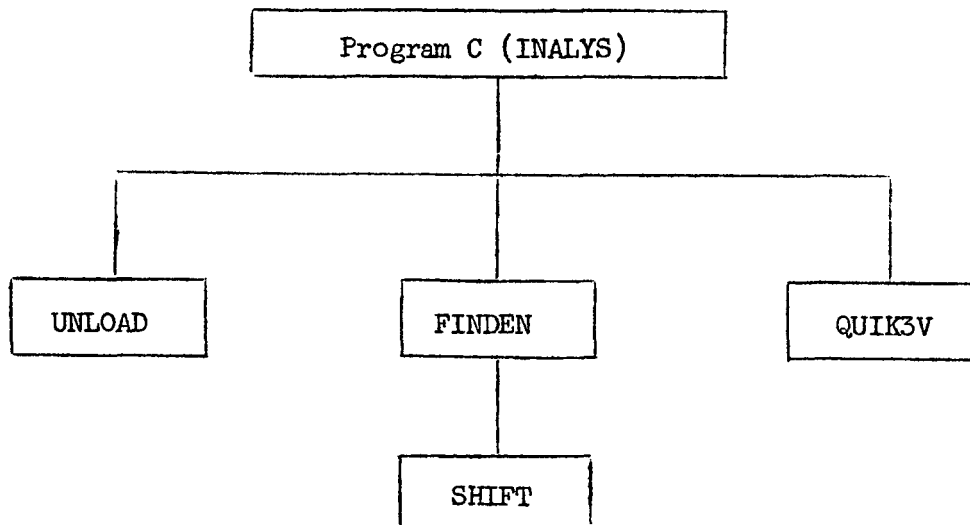
Fig. 4 - Hierarchy of Subroutines Used in Program C

FINDEN positions the indicial and impulsive response tape for reading, and reads identifying information from it.

SHIFT converts an integer from FORTRAN II to FORTRAN IV format in the computer (written in MAP).

UNLOAD rewinds and unloads a tape. (A dummy routine which simply rewinds was used.)

QUIK3V is part of a general plotting routine which prepares data for the SC4020.

VI. DISCUSSION OF PROGRAM D (DECK NAME WNDANL)

Program D reads in the binary tape generated by Program C and produces a plot tape for the SC4020 as well as print tape containing a summary of all maxima and minima and axis crossings for each response. A dummy record written at the end of the binary tape by Program C signals the end of the program.

In its present form Program D can process only one binary tape per job. However, linkages were included which were intended for use in converting the program so that several different wind response tapes could be processed with only one machine load. These linkages are indicated by comment cards in the program source deck.

A. Input

The only input for Program D consists of a binary tape written by Program C. This is mounted on unit A5 (logical tape 8).

B. Output

Program output consists of a plot tape A8 and a print tape B1 (logical 6). Samples of the output may be seen in Volume II, Section IV.

The profile identification in the heading uses the designation "PROFILE 1" to denote the velocity profile whose components are in words 2 and 3 of each record of the profile tape. The other profile is denoted as profile 2. If a distinction between responses for each component of a given profile is desired, this distinction will have to be carried in the alphabetic heading information, or a program change will be necessary.

The point printed at a crossing is the first point having the new sign, whether or not this response is actually smaller in magnitude than the last response having the old sign.

C. Running Time Estimates and Operating Instructions for Program D

Program D plots and analyzes the wind-induced response data written on binary tape by Program B at the rate of about 30 graphs per minute.

The program requires that the wind-induced response tape to be processed be mounted on unit A5. A normal print tape, B1, and the plot tape, A8, are generated. At the end of the job A6 and A7 may be selected to write end of file and rewind.

The program deck should be preceded by four cards to ready the plot tape. These cards are:

Column 1	Column 16
$ IBSYS	
$ ATTACH	A8
$ AS	SYSCK2, LOW
$ EXECUTE	IBJOB

D. Description of Subroutines for Program D

The relationship between the main program and the various subroutines used is shown in Fig. 5. A brief description of the purpose of the various subroutines used in Program D is given (p. 35). Flow charts of the principal subroutines are given in Appendix IV.
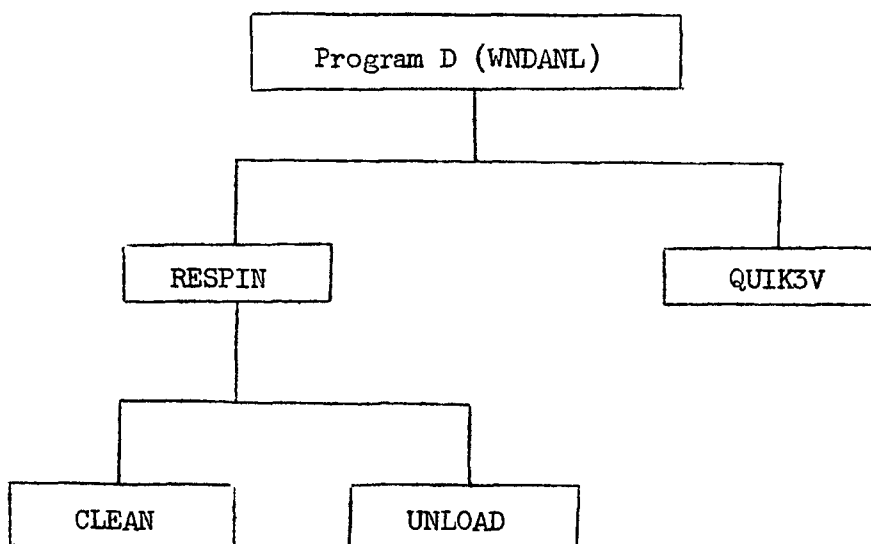
Fig. 5 - Hierarchy of Subroutines Used in Program D

RESPIN is used to read the wind-induced responses from the binary input tape.

QUIK3V is a plot routine from the library of NASA's IBSYS processor, which produces a plot tape for the SC-4020.

UNLOAD is a dummy routine which rewinds but does not unload the tape on the logical unit corresponding to the subroutine argument.

CLEAN is a routine from the processor library, which presumably closes all output files.

APPENDIX I

<u>FLOW DIAGRAMS OF MAJOR ROUTINES FROM PROGRAM A</u>
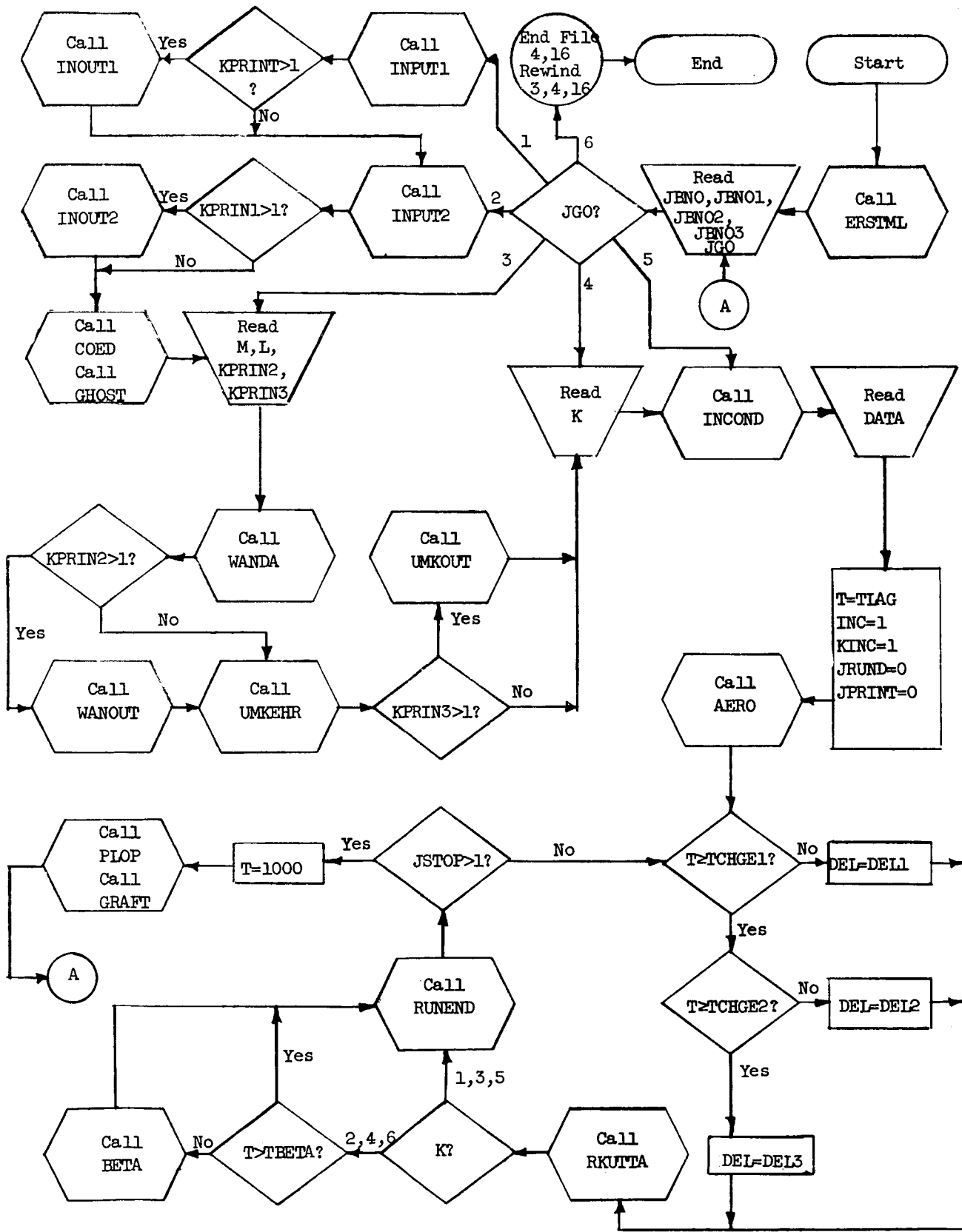
Fig. 6 - Flow Diagram for Program A (GUST)
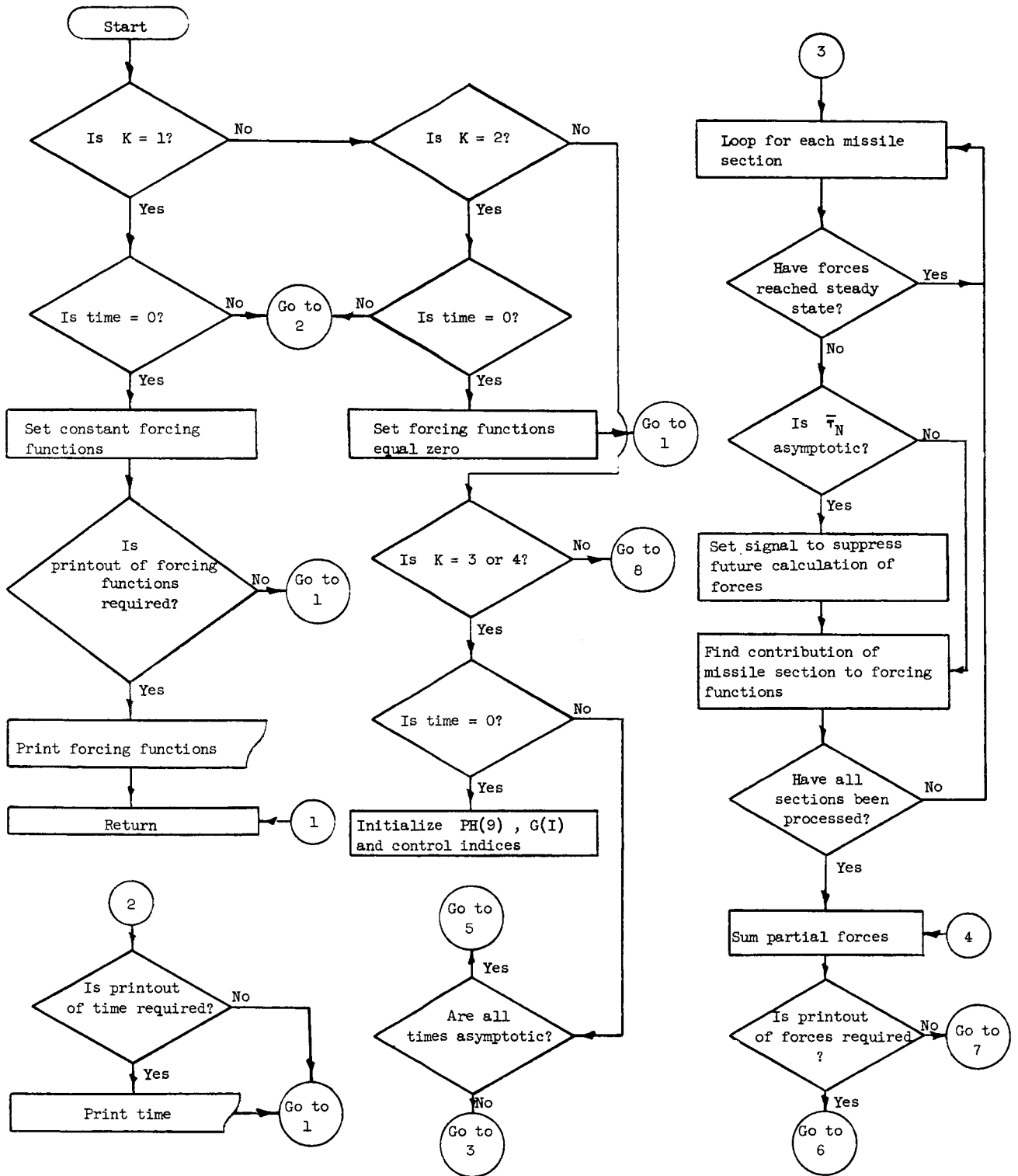
Fig. 7 - Flow Diagram for Subroutine AERO
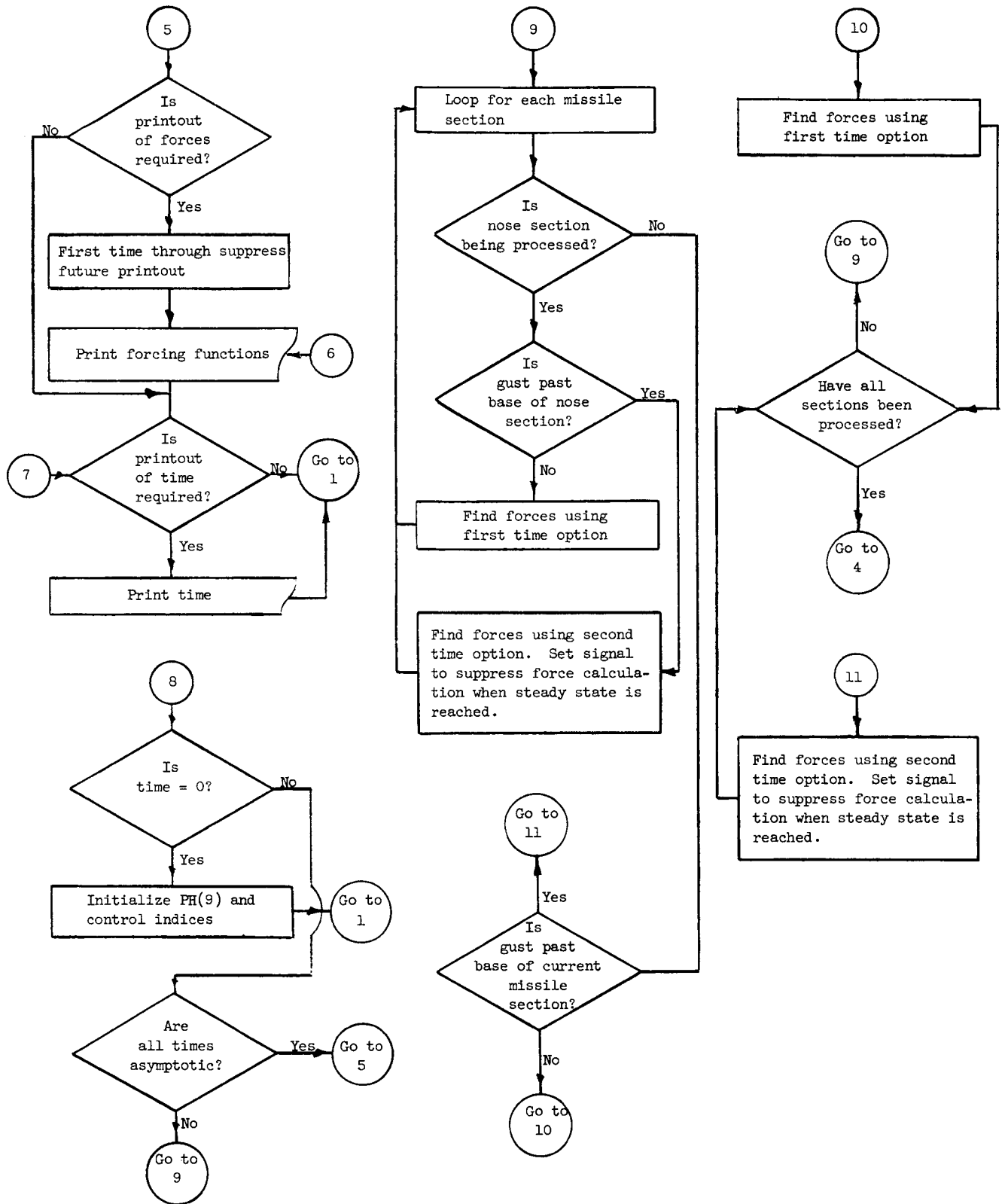
Fig. 7 (Continued) - Flow Diagram for Subroutine AERO
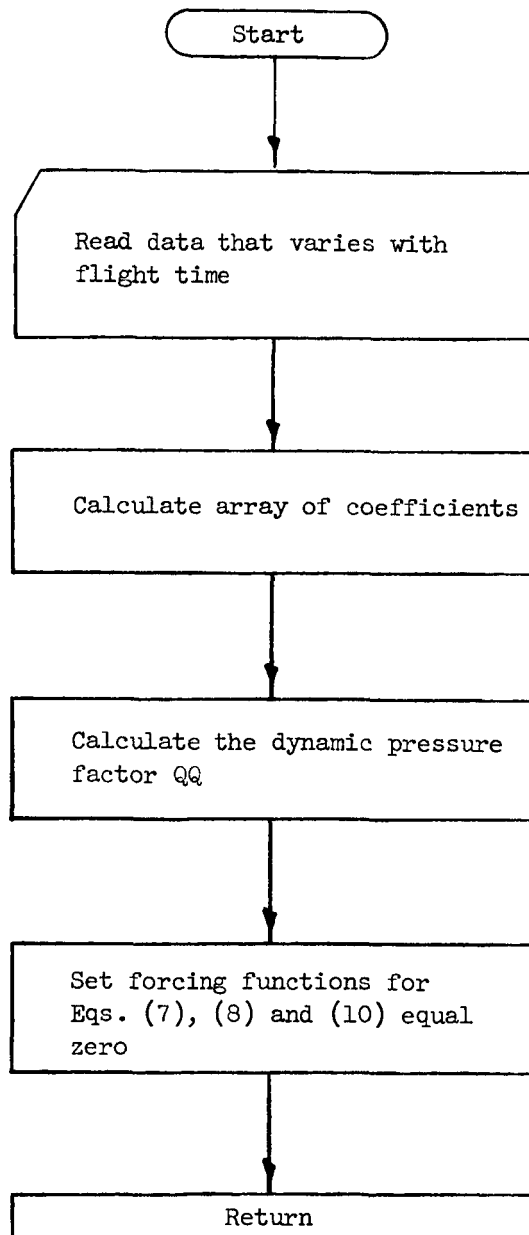
Fig. 8 - Flow Diagram for Subroutine COED
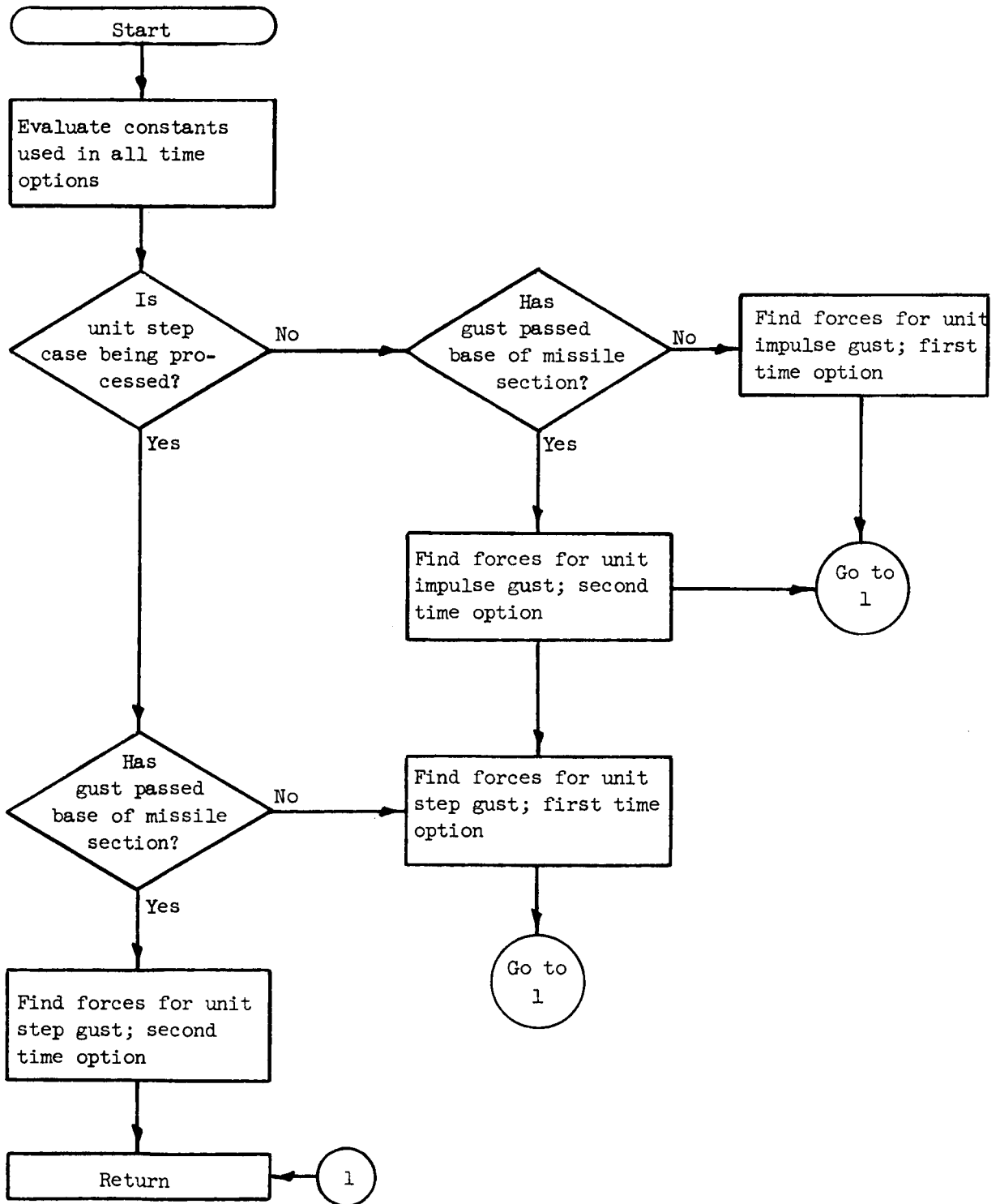
Fig. 9 - Flow Diagram for Subroutine FORC
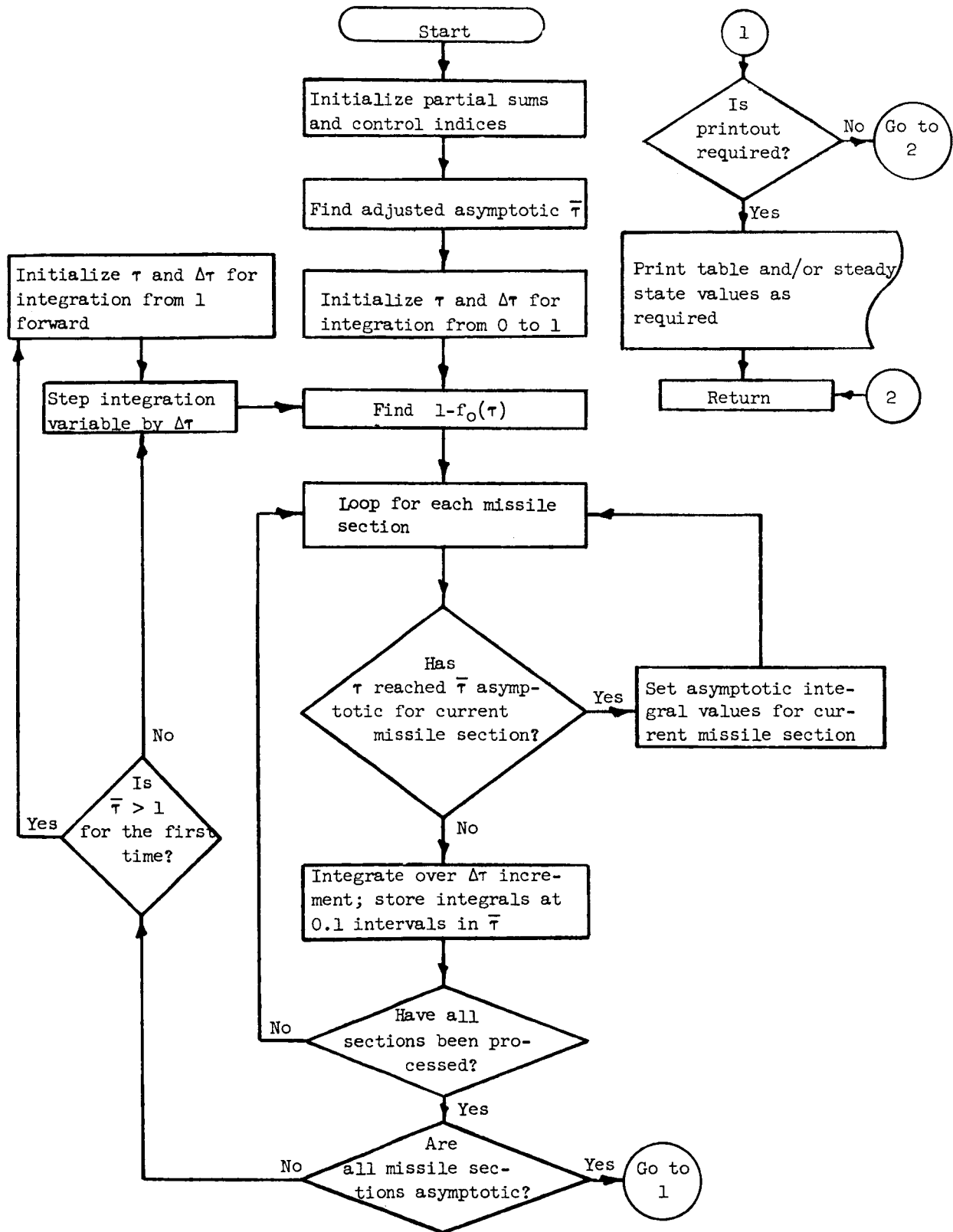
Fig. 10 - Flow Diagram for Subroutine GHOST
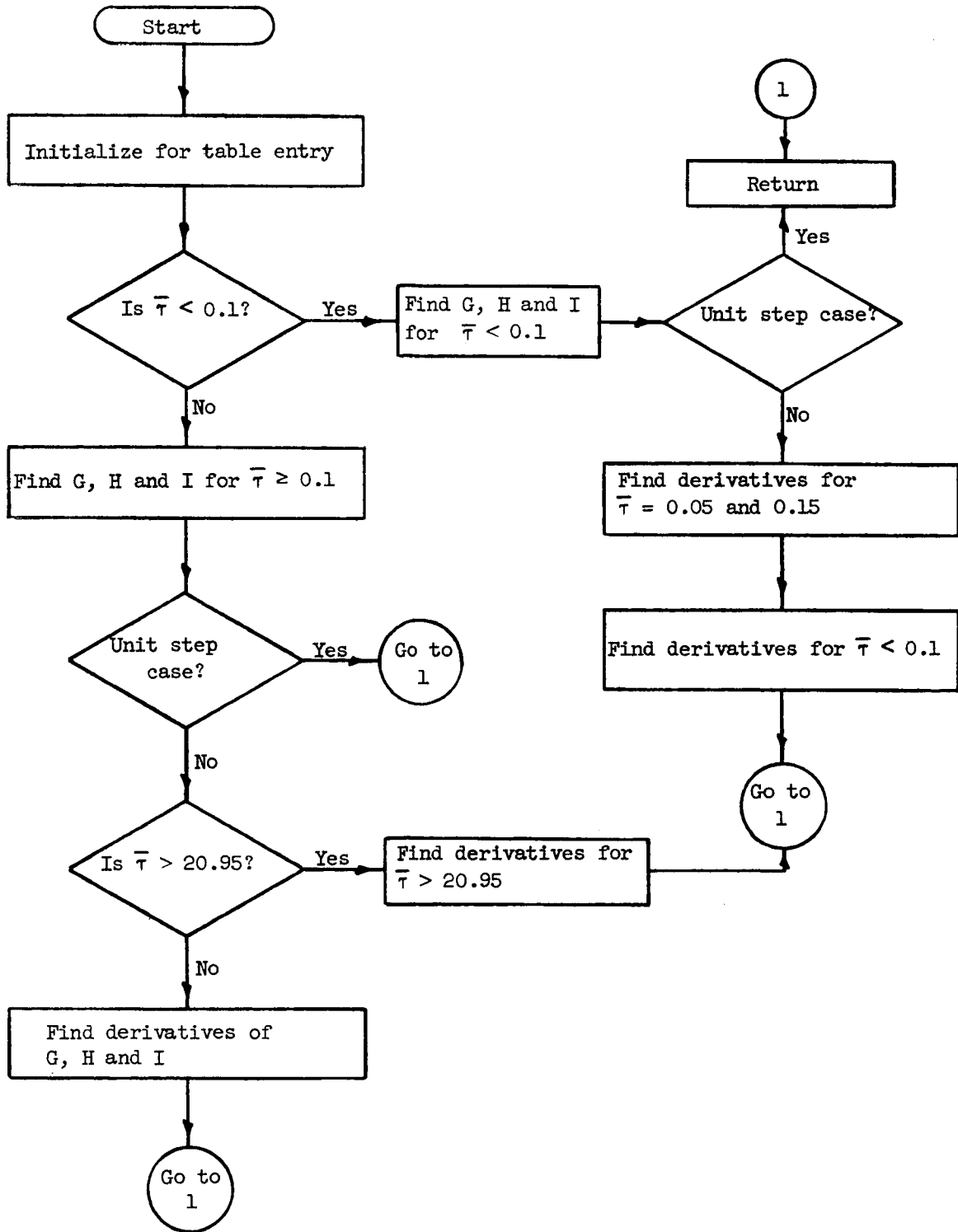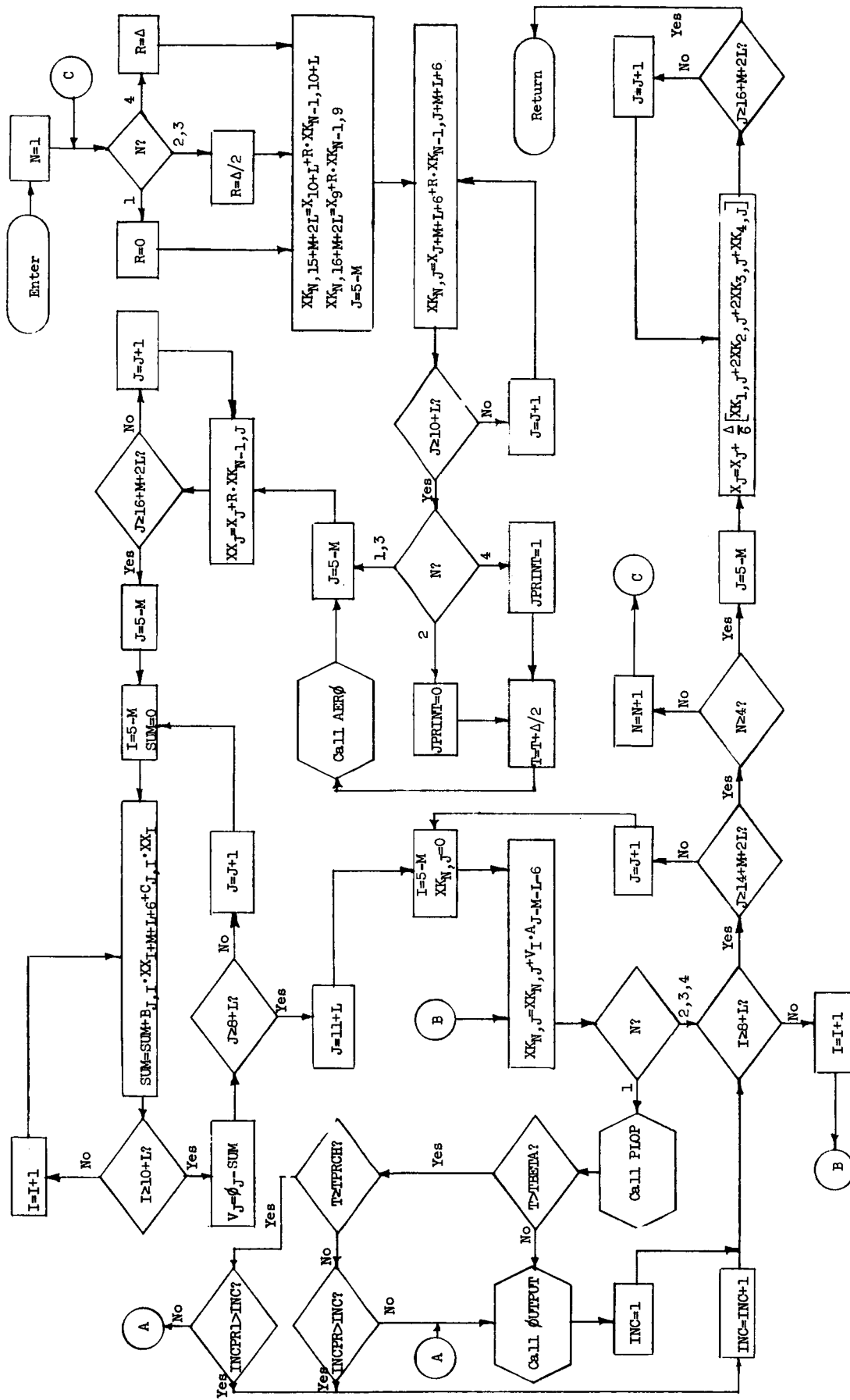
Fig. 11 - Flow Diagram for Subroutine INTER
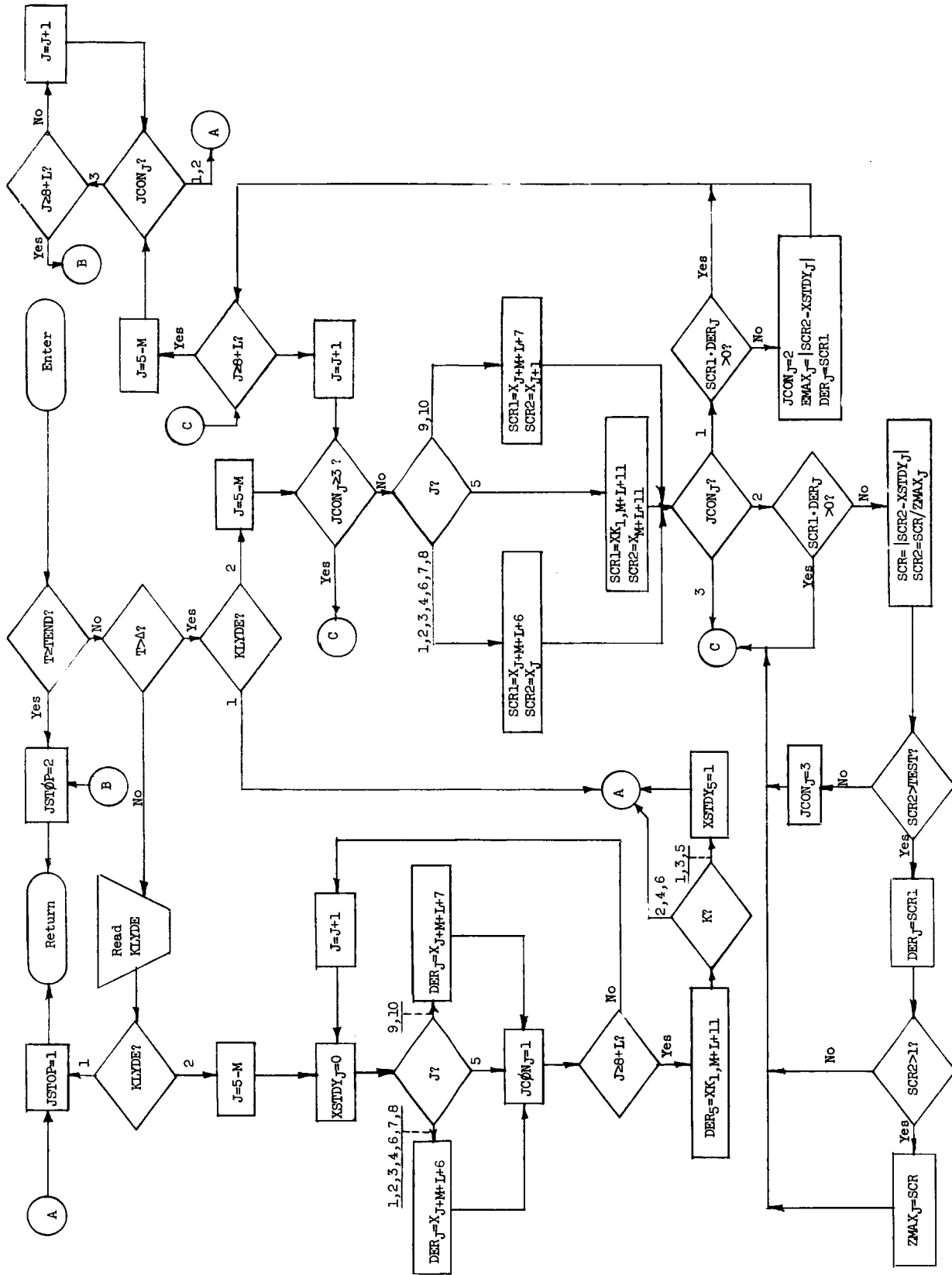
Fig. 12 - Flow Diagram for Subroutine RKUTTA

Fig. 15 - Flow Diagram for Subroutine RUNEND

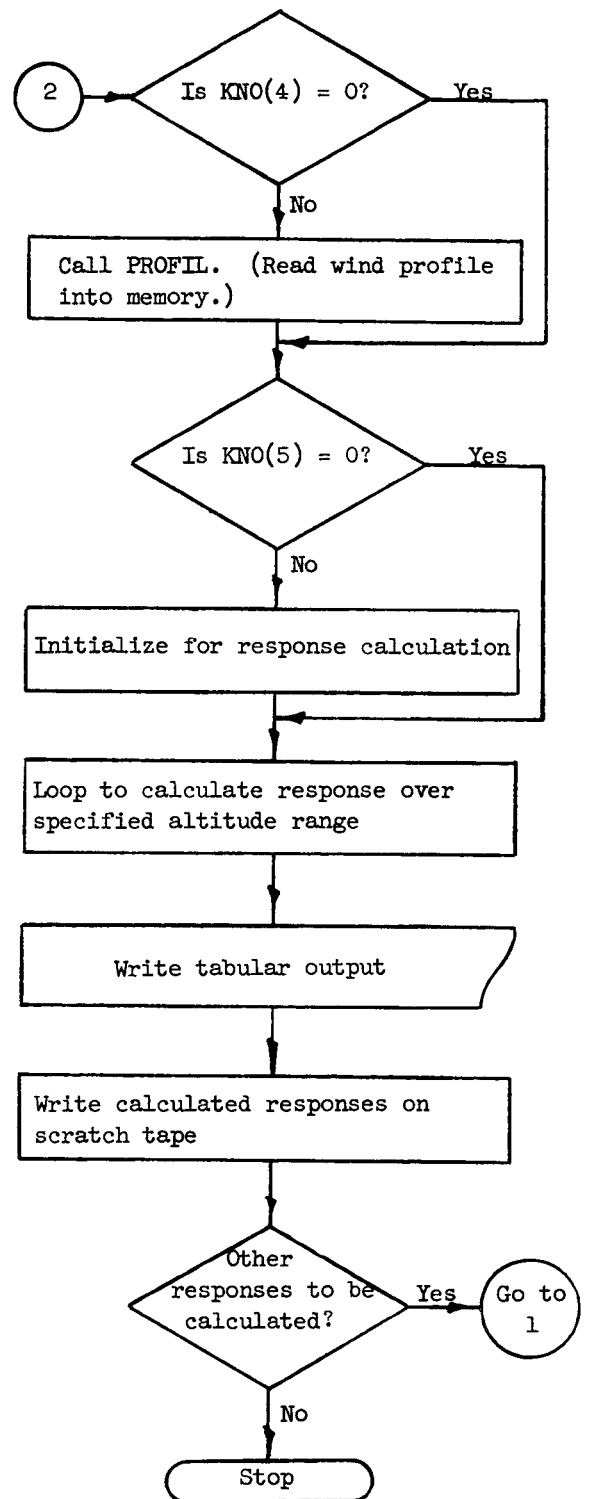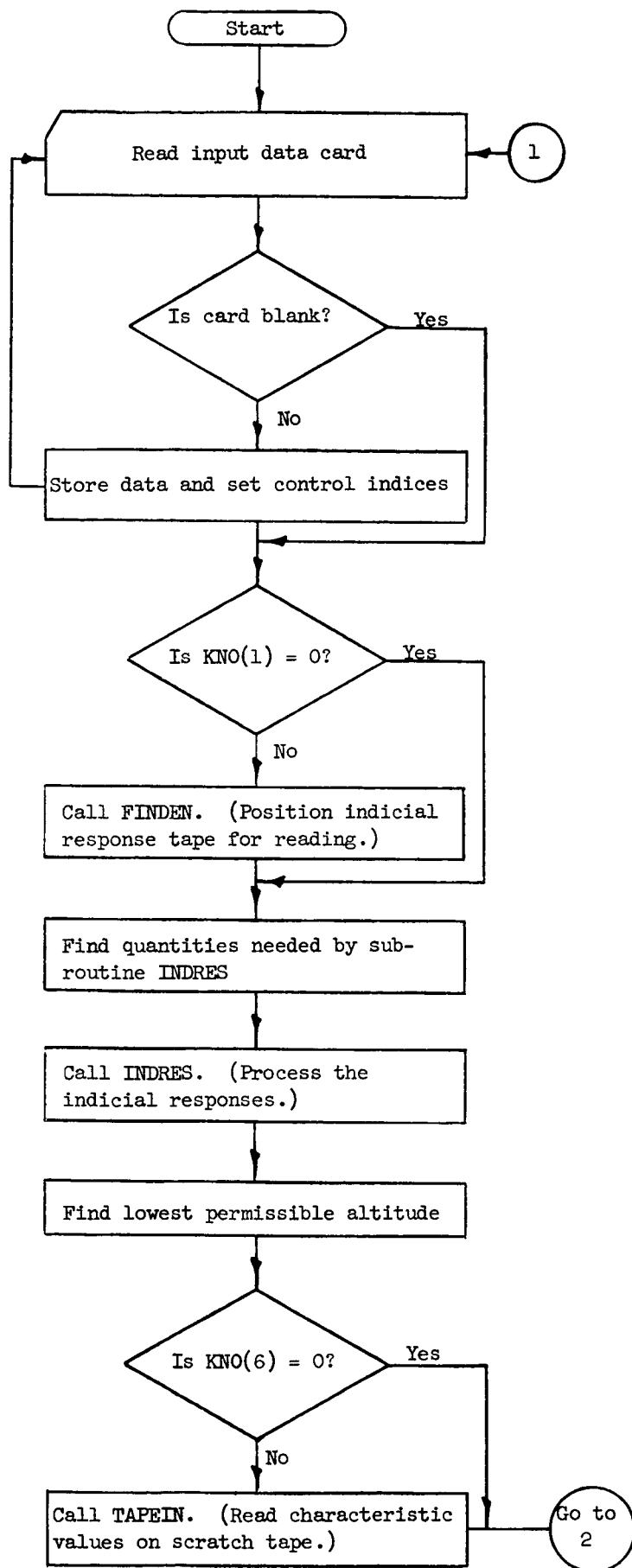APPENDIX II

FLOW DIAGRAMS OF MAJOR ROUTINES FROM PROGRAM B
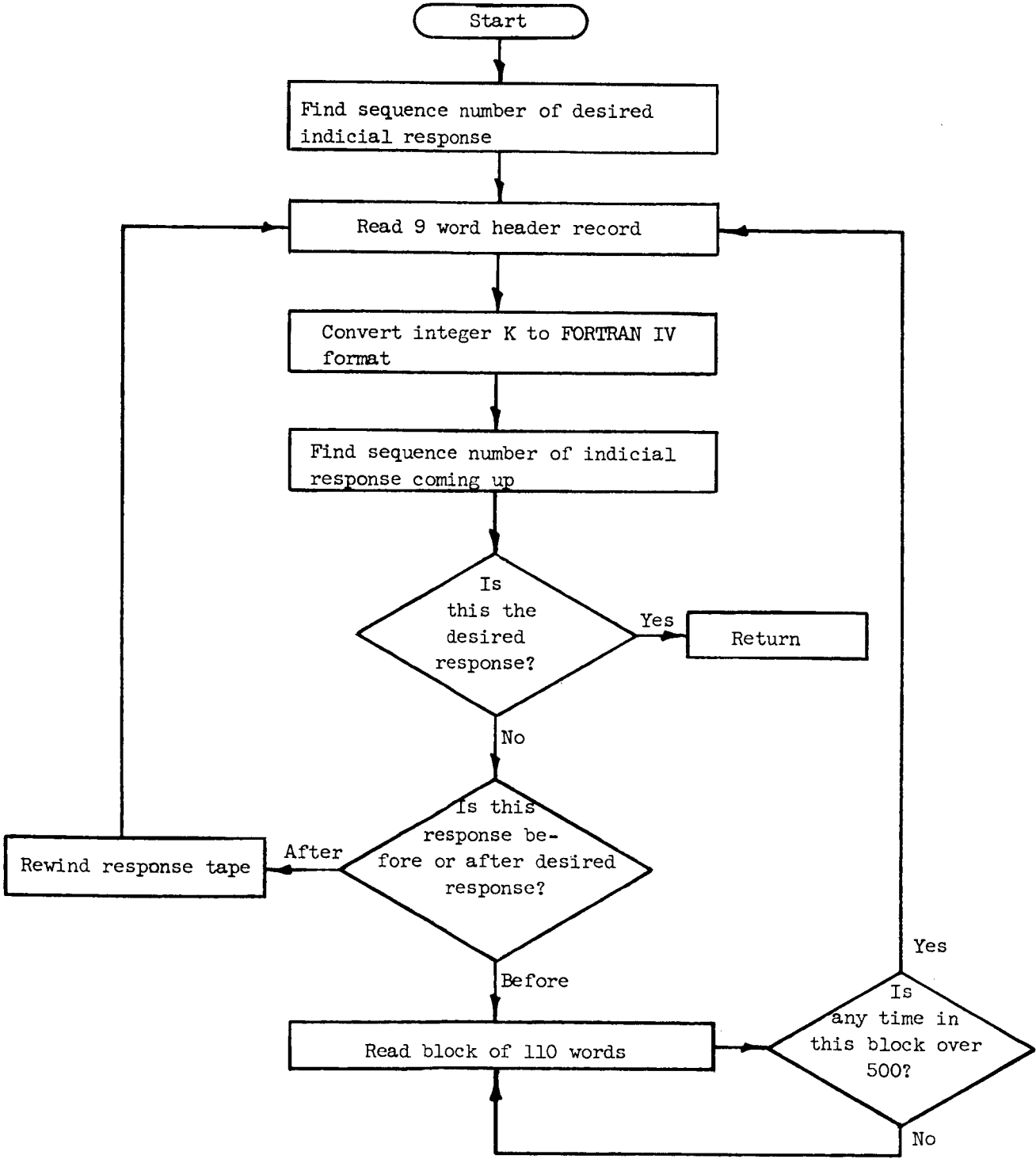
Fig. 14 - Flow Diagram for Program B (DUHAMM)

Fig. 15 - Flow Diagram for Subroutine FINDEN

Start

Initialize program variables and control indices

Read one record of indicial response reserve tape

Is First time read = 0? — No

Yes

Initialize for processing the indicial responses

Loop to process indicial responses

Is current time last to be processed? — Yes → Go to 1

No

Does current time overlap preset time interval? — Yes → Go to 2

No

Process the indicial responses

Have all responses in storage been processed? — No

Yes

---

1 → Set signal to suppress further processing

2 → Are unit step responses being processed? — No

Yes

Complete the processing for this time interval

Store characteristic values for first indicial response for this time interval

Write all characteristic values for this time interval on scratch tape

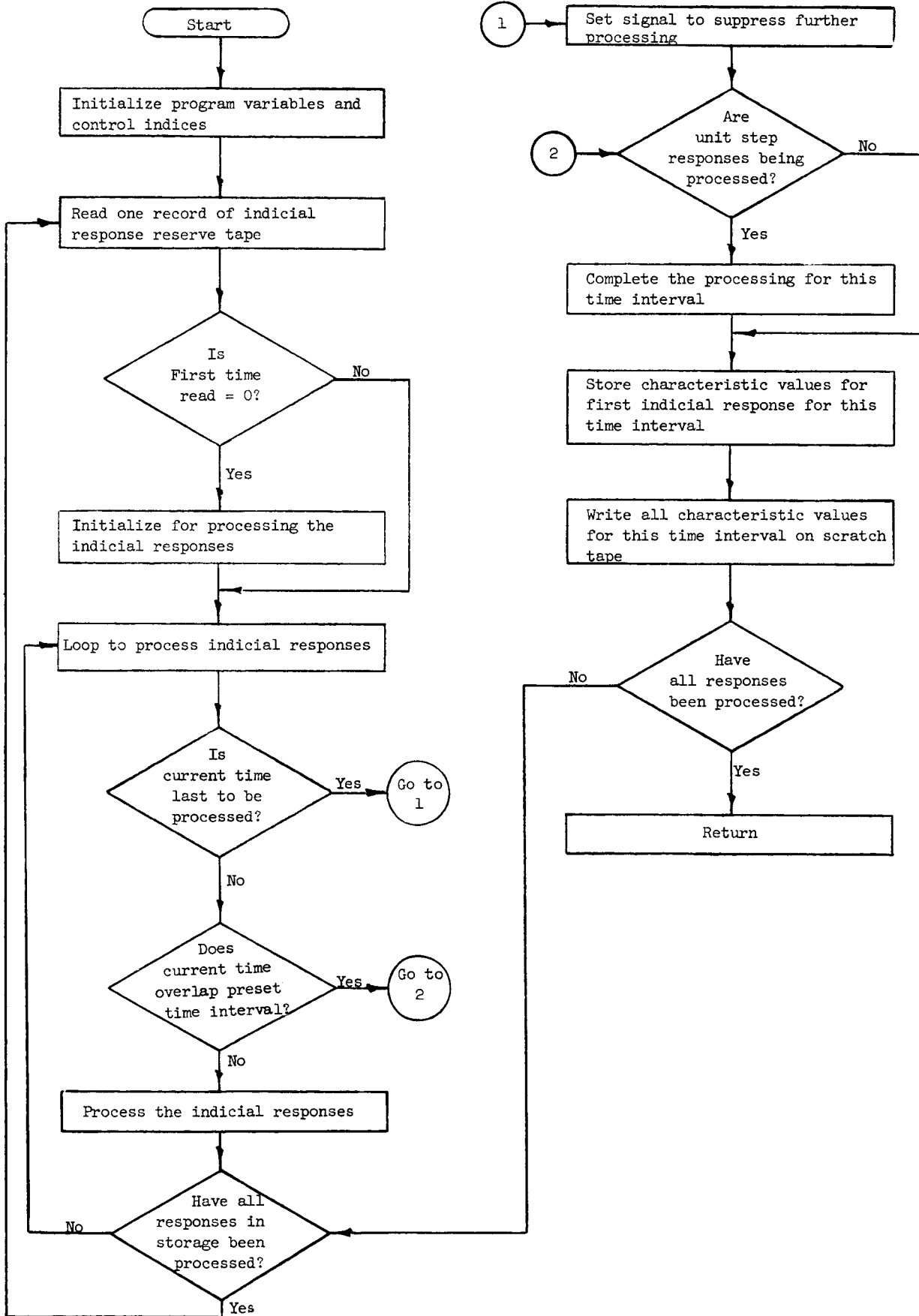Have all responses been processed? — No

Yes

Return

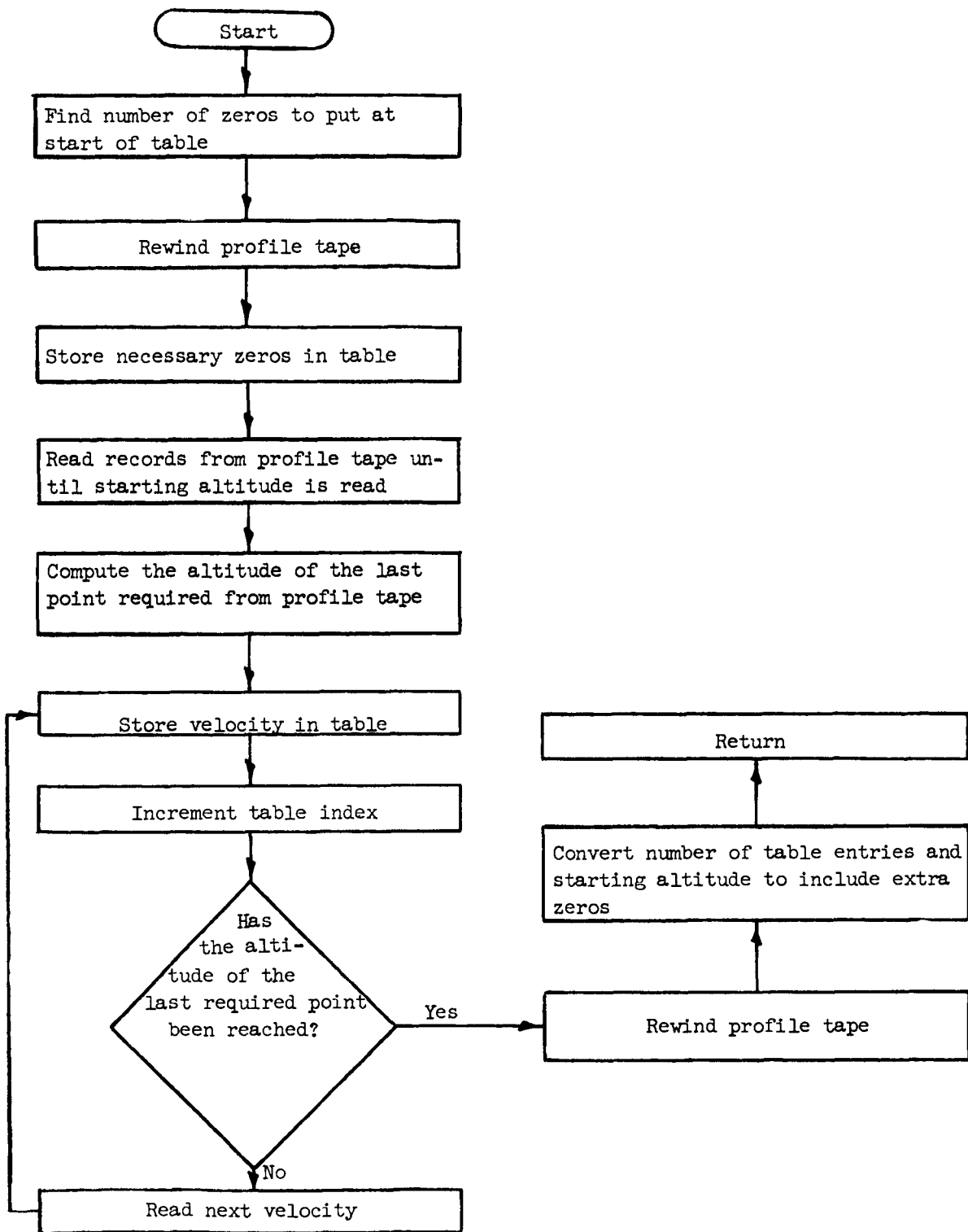Fig. 16 - Flow Diagram for Subroutine INDRES

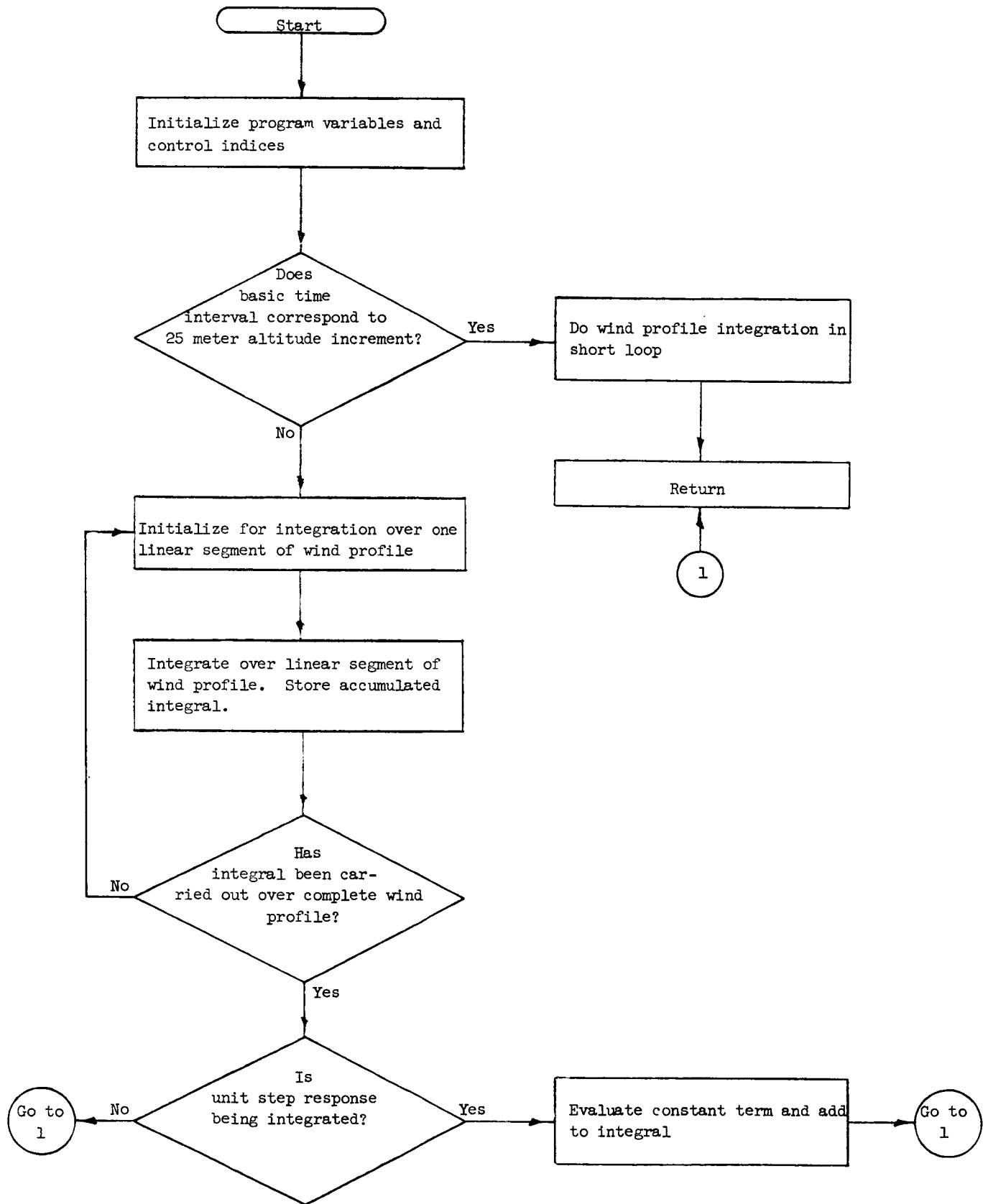Fig. 17 - Flow Diagram for Subroutine PROFIL

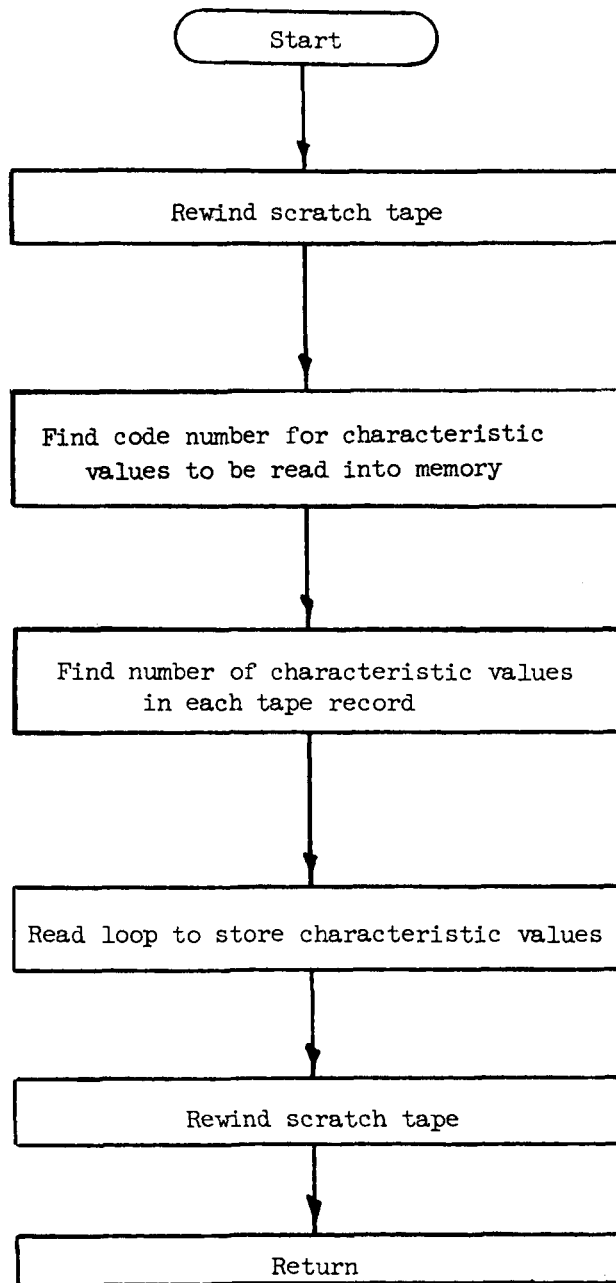Fig. 18 - Flow Diagram for Subroutine RESPON

Fig. 19 - Flow Diagram for Subroutine TAPEIN

APPENDIX III

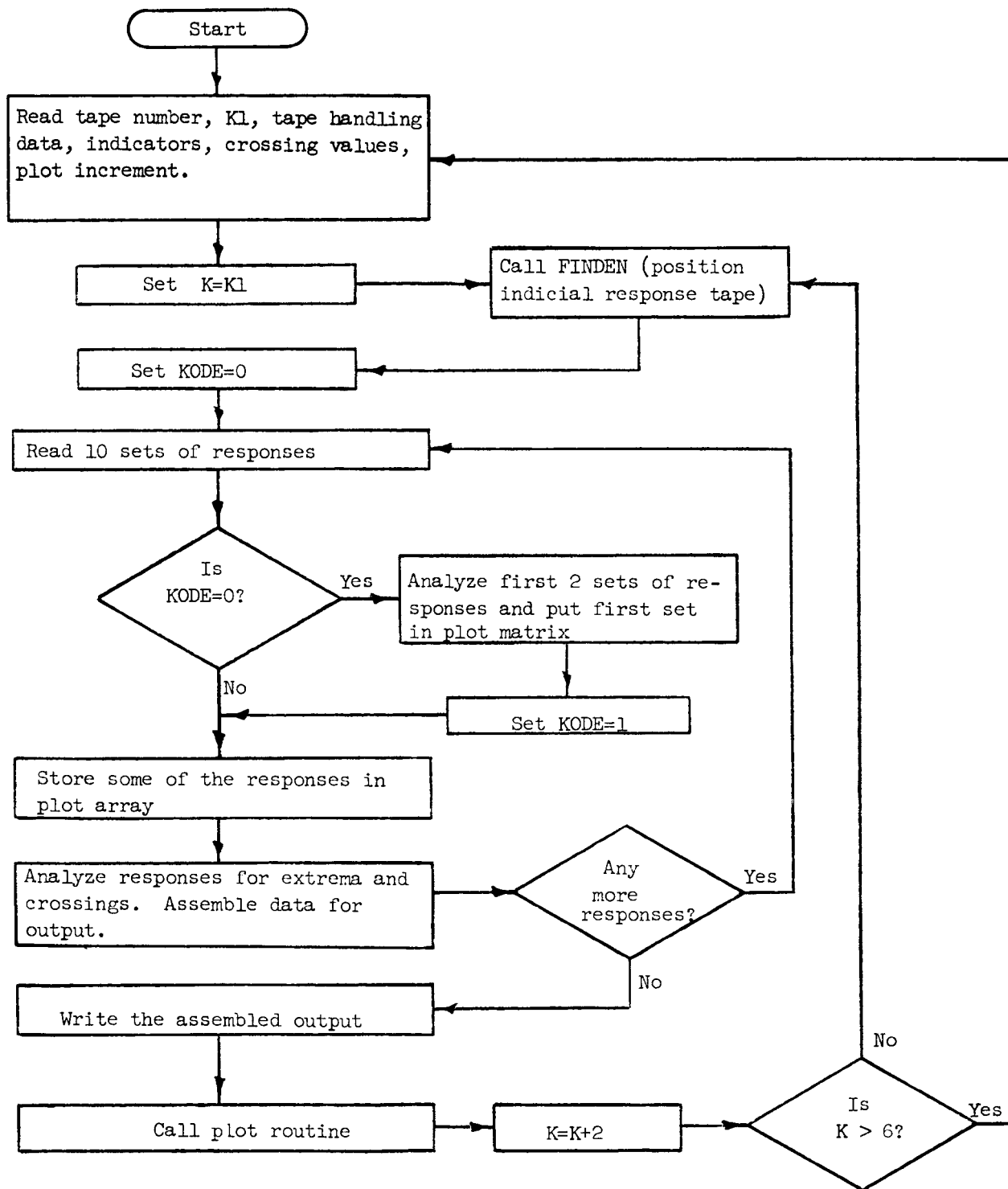<u>FLOW DIAGRAM FOR PROGRAM C (MAIN PROGRAM)</u>

Fig. 20 - Flow Diagram for Program C (INALYS)

APPENDIX IV

FLOW DIAGRAMS FOR MAJOR ROUTINES FROM PROGRAM D

Start

Set logical binary tape number

Set up permanent word in PLOT label arrays

Read next response from binary tape

Finish PLOT label array setup

Set up array of altitudes corresponding to responses

Call PLOT routine

Write headings on output tape

Set J=2

Has the last R(J) been processed?

Yes — No

Do the responses R(J) and R(J-1) have the same sign?

Yes — No

Write axis crossing

Is J > 2?

Yes — No

J=J+1

Is R(J-1) closer to zero than both adjacent R's?
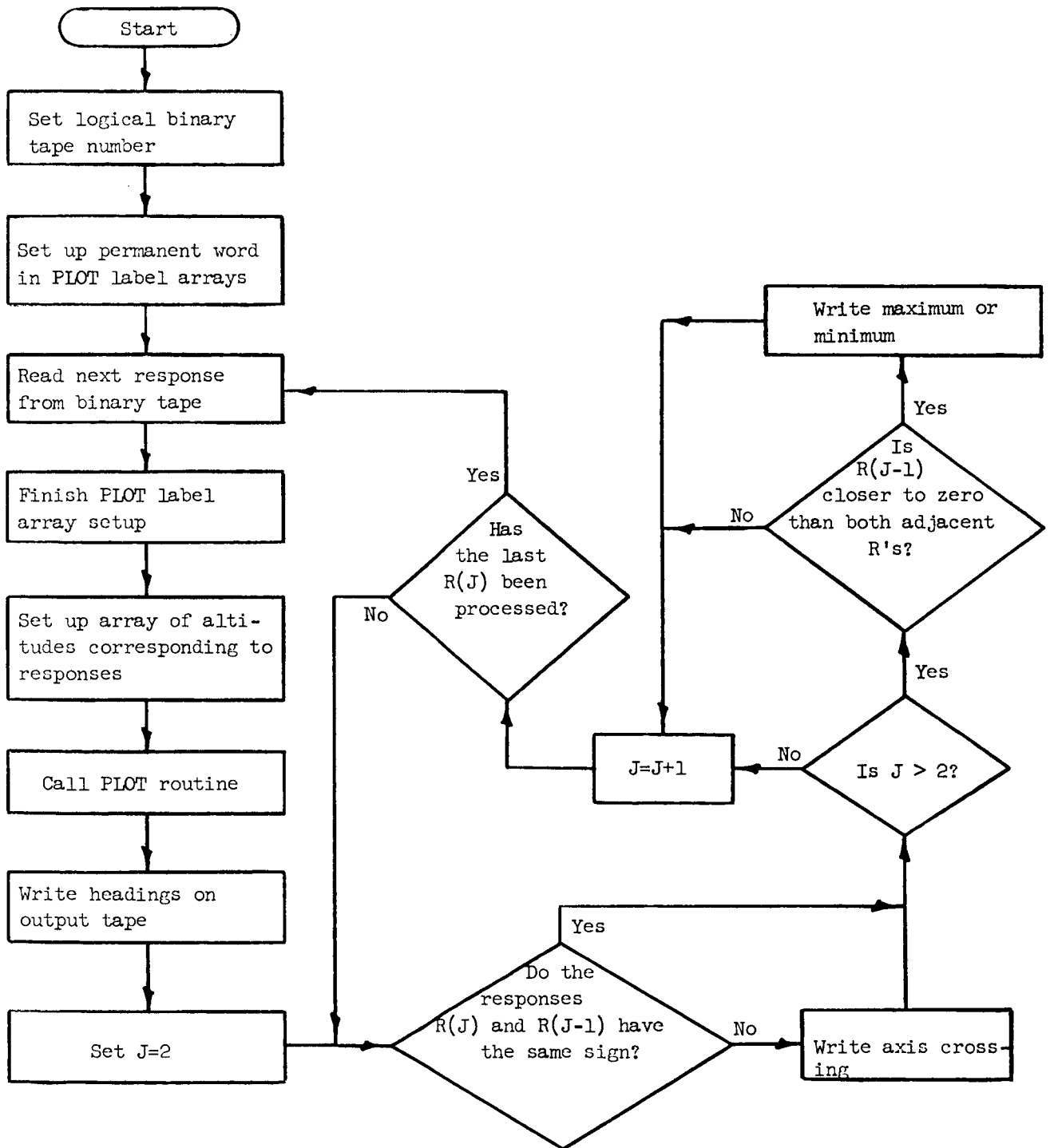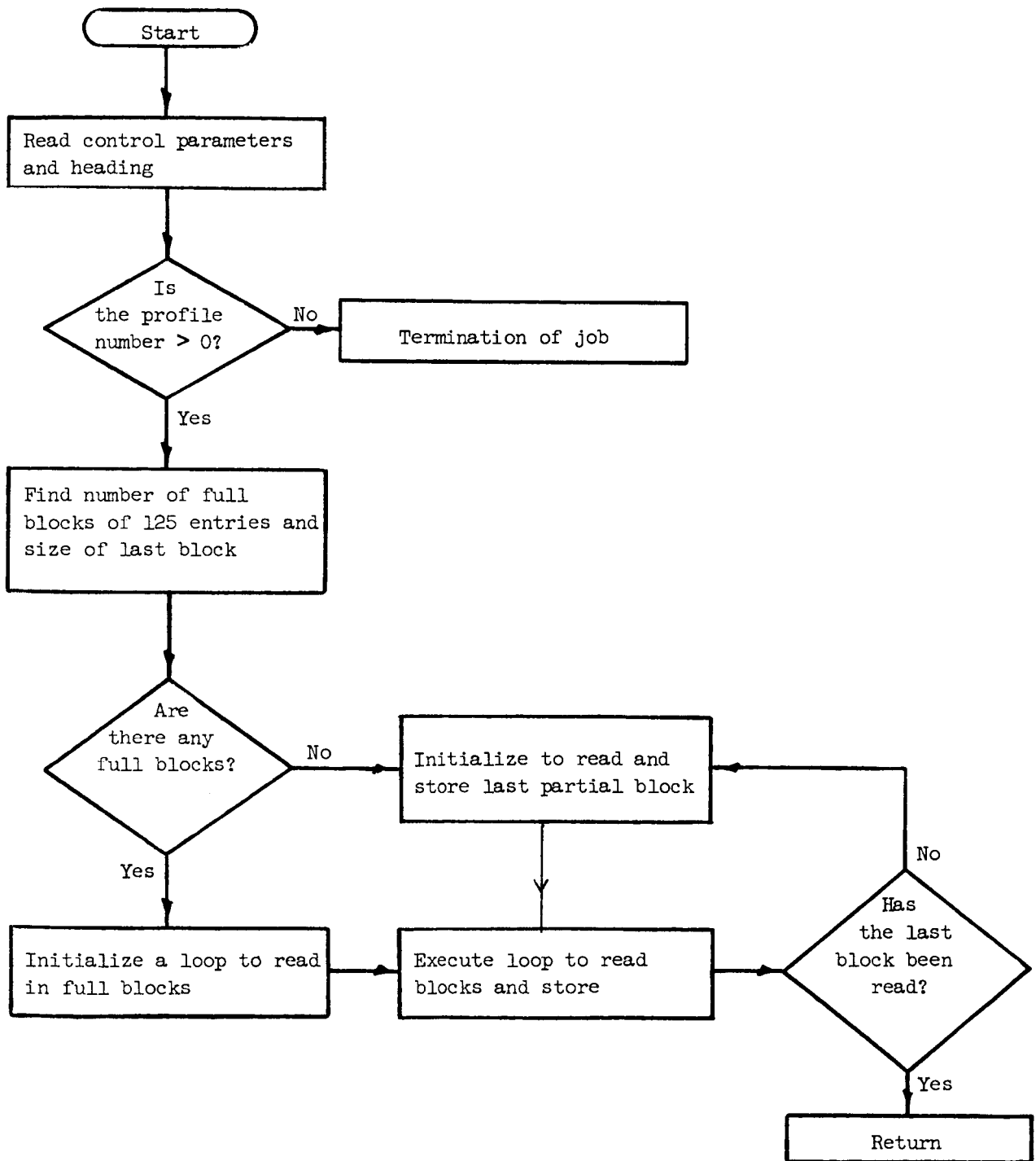
Yes — No

Write maximum or minimum

Fig. 21 - Flow Diagram for Program D (WNDANL)

Fig. 22 - Flow Diagram for Subroutine RESPIN