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A METHOD FOR DETERMINING THE RESPONSE OF SPACE SHUTTLE TO ATMOSPHERIC TURBULENCE

VOLUME II ✦ COMPUTER PROGRAM DESCRIPTION AND USAGE INSTRUCTIONS

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GENERAL DYNAMICS
Convair Aerospace Division

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A METHOD FOR DETERMINING THE RESPONSE OF SPACE SHUTTLE TO ATMOSPHERIC TURBULENCE

VOLUME II COMPUTER PROGRAM DESCRIPTION AND USAGE INSTRUCTIONS

December 1971

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GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

Prepared by
CONVAIR AEROSPACE DIVISION OF GENERAL DYNAMICS
San Diego, California

FOREWORD

This report presents user instructions for the computer program developed under Contract NAS8-26363 for NASA George C. Marshall Space Flight Center under the technical direction of the Aero-Astrodynamics Laboratory, Dynamics and Control Division. Dr. S. Winder is the technical monitor. The study is being performed by Convair Aerospace Division of General Dynamics under the direction of Mr. R. Huntington, project leader. Mr. R. Haller, co-author of this volume, was responsible for the computer program development.

The authors are indebted to Mr. R. Peloubet for his assistance in developing the computer program and to Mr. J. Kramer for converting the program to run on the Univac 1108 Computer.

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TABLE OF CONTENTS

Section			Page
1	INTRODUCTION		1-1
2	PROGRAM USAGE INSTRUCTIONS		2-1
	2.1	GENERAL INSTRUCTIONS	2-1
	2.2	PART 0 — SAS DEFINITION	2-4
	2.2.1	Deck 10	2-4
	2.2.2	Deck 100	2-6
	2.2.3	Deck 110	2-7
	2.2.4	Decks 120 Through 170	2-10
	2.2.5	Deck 180	2-10
	2.2.6	Deck 190	2-11
	2.2.7	Decks 200 Through 790	2-12
	2.2.8	Deck 900	2-13
	2.3	PART 1 — RESPONSE OF GENERALIZED COORDINATES	2-15
	2.3.1	Deck 000	2-15
	2.3.2	Deck 100	2-18
	2.3.3	Deck 110	2-20
	2.3.4	Deck 111	2-20
	2.3.5	Deck 112	2-22
	2.3.6	Deck 113	2-22
	2.3.7	Deck 120	2-22
	2.3.8	Deck 121	2-23
	2.3.9	Decks 122, 123, 124	2-23
	2.3.10	Deck 160	2-24
	2.3.11	Deck 161	2-25
	2.3.12	Decks 162, 163, 164	2-25
	2.3.13	Deck 165	2-26
	2.3.14	Altitude Considerations	2-27
	2.3.15	Correction Factors for Q_{rs} and Q_{rf} Terms	2-27
	2.3.16	Interpolation Constants	2-28
	2.3.17	Reduction of Degrees of Freedom	2-29
	2.3.18	Determinant of The A Matrix	2-31
	2.4	PART 2 — TRANSFER FUNCTION RESPONSE	2-32
	2.4.1	Deck 200	2-33
	2.4.2	Deck 210	2-35
	2.4.3	Deck 211	2-35
	2.4.4	Deck 220	2-35
	2.4.5	Deck 230	2-36

Section		Page
2.4.6	Deck 240	2-37
2.4.7	Deck 241	2-37
2.4.8	Decks 242, 243, 244	2-38
2.4.9	Decks 245 and 246	2-39
2.4.10	Deck 250	2-39
2.4.11	Correction Factors for The $\overline{F}$ Terms	2-40
2.4.12	Interpolation Constants	2-41
2.4.13	Calculating A New Set of Transfer Functions	2-41
2.5	PART 3 — RESPONSE TO A RANDOM INPUT	2-43
2.5.1	Deck 300	2-44
2.5.2	Deck 301	2-46
2.5.3	Deck 302	2-47
2.5.4	Deck 303	2-47
2.5.5	Deck 304	2-47
2.5.6	Deck 305	2-48
2.5.7	Decks 306-308	2-49
2.5.8	Deck 309	2-49
2.5.9	Deck 320	2-49
2.5.10	Calculation of $\overline{A}$, N_o, and N_1	2-50
2.5.11	Vary The Maximum Frequency in Computing $\overline{A}$ and N_o	2-50
2.6	PART 4 — RESPONSE TO A DISCRETE INPUT	2-52
2.6.1	Deck 400	2-53
2.6.2	Deck 408	2-57
2.6.3	Deck 409	2-58
2.6.4	Deck 410	2-58
2.6.5	Deck 420	2-58
2.6.6	Maximum Frequency Used in The Fourier Series	2-60
2.6.7	Gust Time History	2-60
2.6.8	Interpolation of Transfer Functions	2-60
2.7	PART 5 — PLOT RESULTS	2-61
2.7.1	Deck 500	2-61
2.7.2	Deck 510	2-61
2.7.3	Deck 520	2-63
2.7.4	Deck 530	2-64
2.7.5	Deck 540	2-66
2.7.6	Deck 550	2-68
2.8	PROGRAMMED ERROR PRINTOUT	2-71
2.8.1	Error Levels	2-71
2.8.2	Error Number Definition	2-72

TABLE OF CONTENTS, Contd

Section		Page
2.9	MAGNETIC TAPE INPUT/OUTPUT	2-80
3	REFERENCES	3-1
Appendix		
A	INTERPOLATION PROCEDURE	A-1
B	FLOW CHART OF READ SUBROUTINES	B-1
C	FLOW CHART OF CHECKING SUBROUTINES	C-1

LIST OF ILLUSTRATIONS

Figure		Page
2-1	Basic Program Flow	2-3
2-2	Part 1 through Part 5 Functional Flow Chart	2-16
2-3	Part 1 Flow Chart	2-19
2-4	Part 2 Flow Chart	2-34
2-5	Part 3 Flow Chart	2-45
2-6	Part 4 Flow Chart	2-54
2-7	Part 5 Flow Chart	2-62
2-8	Grid Use For Plotting Transfer Functions	2-65
2-9	Grid Used For Plotting PSD Functions	2-67
2-10	Grid Used For Plotting Time Histories	2-69

SUMMARY

This report describes a computer program which calculates the response of an elastic aerospace vehicle to random and discrete turbulence. Although this volume is self-contained, Volume I presents a more detailed discussion of the theory, application, and interpretation of results.

The program uses vibration modes as generalized coordinates. Inputs to the program include modal information, generalized aerodynamic forces, flight data, stability augmentation system description, and description of the disturbing function. Program outputs include tabulations of the ratio of root-mean-square response to root-mean-square turbulence and response upward zero crossings per second, and SC4020 plots of transfer functions, response power spectral densities, and Nyquist stability traces.

SECTION 1

INTRODUCTION

This report describes a computer program which calculates the response of an elastic aerospace vehicle to random and discrete turbulence. Although this volume is self-contained, Volume I (Reference 1) presents a more detailed discussion of the theory, application, and interpretation of results.

The program, written in FORTRAN IV language, uses vibration modes as generalized coordinates. Inputs to the program include modal information, generalized aerodynamic forces, flight data, stability augmentation system (SAS) description, and description of the disturbing function. Program outputs include tabulations of $\bar{A}$ (ratio of rms response to rms turbulence) and N_0 (response upward zero crossings per second) and SC4020 plots of transfer functions, response power spectral densities (PSD), and Nyquist stability traces.

The program is dimensioned to have the capability for: 20 generalized coordinates (modes), 20 structural response parameters, 20 reduced frequencies, and 10 interpolated points between input reduced frequencies (for a total of 210 response frequencies).

The following features add to the usefulness of the program:

a. Most large data blocks can be input or output on magnetic tape.

b. Most of the equations contain input scalar multipliers.

c. Several standard input power spectral density functions are available in the program, and in addition the user may construct his own, using straight line segments.

d. Several common time varying forces are available, or the user may construct his own.

e. Extensive use is made of the SC4020 Plotter.

f. A comprehensive error routine assists in finding input errors.

g. Provisions are made to compute quasi-steady forces from steady-state aerodynamic input data.

h. Ten types of control system elements are available for defining the SAS.

SECTION 2

PROGRAM USAGE INSTRUCTIONS

2.1 GENERAL INSTRUCTIONS

The digital computer program is divided into six main parts:

Part 0. Computes the dynamic matrix representing the vehicle stability augmentation system (SAS).

Part 1. Interpolates the aerodynamic terms and calculates the response of the generalized coordinates.

Part 2. Computes the transfer functions.

Part 3. Determines the response to a random input.

Part 4. Calculates the response to a discrete input.

Part 5. Plots the results of Parts 2, 3 and/or 4 on the SC 4020 Plotter.

The program is set up such that Part 0 is run independently and Parts 1 through 5 are run independently or in series.

The input to the program can consist of problem cards, and magnetic tape. The program output consists of user specified combinations of the following:

a. Printed information

b. Punched cards

c. Magnetic tape

d. SC 4020 plots

The card input to this program is read in individual data blocks called "decks". Each deck is composed of a collection of related data items. The input data to the program consists of a combination of decks, the specific combination depending on the flow options exercised in the program. Each deck is given a "deck number" (100, 110, 212, etc.).

The deck number is entered as the first number of the data block and is the only number listed on that card (with the exception of deck 010). The deck number tells the program what information is to be read and directs the flow of the program to the routine needed to read the data. Only data decks required for the particular analysis need be supplied. (Unnecessary decks may be included in the data.) Data decks are input to the program in order of increasing deck number.

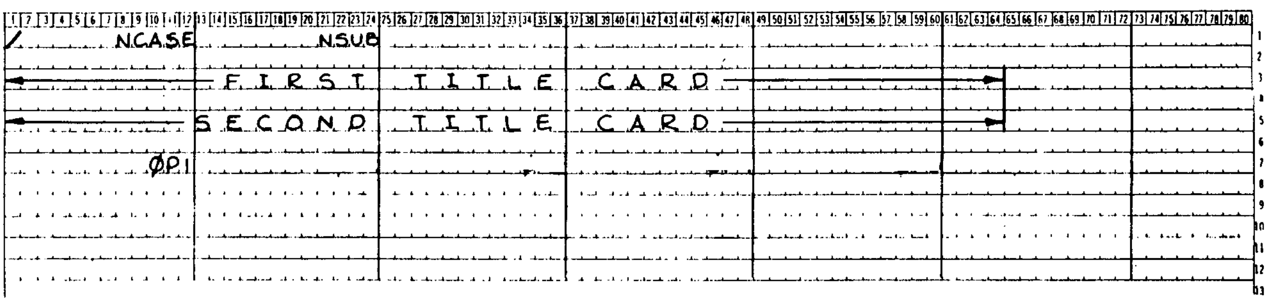
The program uses the deck numbers to detect input errors. For example, if too few or too many numbers are supplied in any given deck, the program will then read a number that is not a legitimate deck number and notify the user that an error has been made.

After reading all of the first case data, the program checks to insure that sufficient information has been supplied to execute the problem. In succeeding subcases, only the decks that supply new information to the program need be supplied. The following examples illustrate this point:

a. The altitude is to be changed on a ride quality problem. The only deck that must be resupplied for this subcase is Deck 000 which supplies the new atmospheric data and Deck 100 which must be included whenever Part 1 of the program is used.

b. In a random response problem, the scale of turbulence is to be changed in a subcase. The only deck that need be supplied is the deck listing the scale of turbulence.

The first four data cards shown below must always be included in the data for all cases and subcases.



CARD 1. The first card contains a slash (/) in column 1, case number (NCASE) right adjusted to column 12, and subcase number (NSUB) right adjusted to column 24. The case and subcase are arbitrary and are used for identification only. Each subcase is a modification of the preceding subcase.

CARDS 2 and 3. The second and third cards are general titles and are contained in columns 1 through 64.

CARD 4. The fourth card contains an option number (ØP1) which controls the flow of the program. As shown in Figure 2-1, if ØP1 = 10 the input for Part 0 is read. If ØP1 $\neq$ 10 the input for Parts 1 through 5 is read. Additional information contained on this card is explained in the appropriate sections of this report.

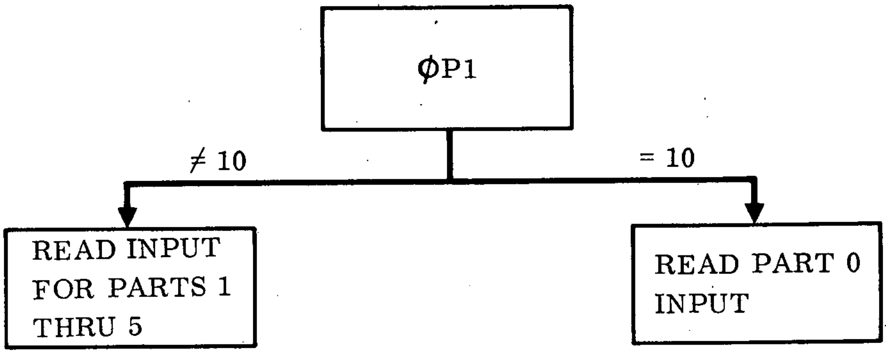
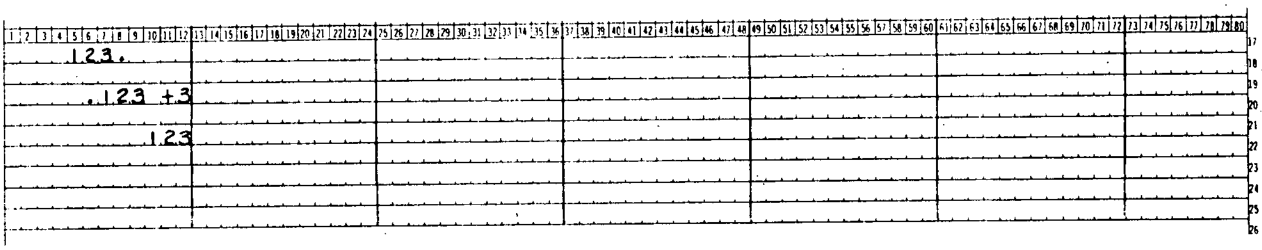


Figure 2-1. Basic Program Flow

For consistency, all numerical data is read into the program in 6E12.0 format. Matrices are input either by row or column, which ever is specified. Each row (column) begins on a new card. Data, such as deck numbers, may be input in integer from without a decimal point by right adjusting the number within the prescribed field. For example, the deck number 123 may be input in any of the three ways shown below.



The only other general comment about the input data that applies at this point is that the last card in each subcase, when running any of Parts 1 through 5, must contain the number 990 in the first 12-column field. The purpose of this card is to let the program know that no further information will be supplied for this subcase.

A discussion of each part of the program along with a detailed description of the input is contained in the following sections. Each section has a simplified logic flow chart indicating what data decks must be supplied and what calculations will be made for each flow path.

The input data are listed in the following sections by deck number. The required input quantities for each deck are enclosed in a box, each line of data corresponding to a card. These boxes will be found throughout this report interspersed with equations and text where appropriate.

2.2 PART 0 — SAS DEFINITION

This part of the program computes a dynamic matrix that accounts for the effects of a stability augmentation system (SAS). This matrix is then added to the unaugmented vehicle dynamic matrix, the resulting total matrix representing the elastic vehicle with an SAS.

When an SAS is used, the equation for the generalized coordinates $\overline{q}(\omega)$ can be written

$$\{\overline{q}(\omega)\} = - \left[[A(\omega)] + [H\Delta(\omega)]\right]^{-1} \{A_f(\omega)\} \tag{1}$$

where

- $[A(\omega)]$ is the dynamic matrix of the unaugmented vehicle,
- $[H\Delta(\omega)]$ is the dynamic matrix that is caused by the SAS, and
- $\{A_f(\omega)\}$ are the generalized forces in the system.

2.2.1 DECK 10. The first card in this deck corresponds to Card 4 described in Section 2.1. The first word, in addition to being the deck number, is also the option number (ØP1).

10	U	b_r	NQ	NKI
NCS	OLS	QRSIN		
K(1)	K(2)	. . .	K(NKI)	(When QRSIN < 2)
TAPJOB	TAPPROB			(When QRSIN = 2)

U = the velocity (ft/sec) used in defining the K terms.

b_r = reference length (input as inches) used in defining the K terms.

NQ = the number of modes, $(1 \leq NQ \leq 20)$.

NKI = the number of reduced frequencies supplied, $(1 \leq NKI \leq 210)$.

NCS = the Number of Control Surfaces, or independent loops in the SAS, $(1 \leq NCS \leq 8)$,

= 1 supply Decks 100–190 (For example, symmetric motion - elevator only),

= 2 supply Decks 100–190, 200–290 (For example, anti-symmetric motion - ailerons and rudder),

= 3 or 8 supply appropriate decks. This case would probably only be used when trim tabs are controlled by the SAS, or when the OLS option is used to compute open loop transfer functions for various combinations of constants.

OLS = Open Loop Stop

= 0 do NOT stop after computing the $G(\omega)$ vector,

= 1 STOP after computing the open loop transfer function,

= 2 same as 1 above, except the $G(\omega)$ vector for the various control surfaces will be punched in a form compatible with the $\bar{F}$ terms. The first card number will be QPUNJOB supplied for the first control surface. The form of the punched output cards is as follows:

$$\begin{bmatrix} \lfloor G, 0 \rfloor & \text{CSH1} \\ \lfloor G, 0 \rfloor & \text{CSH2} \\ \vdots & \\ \end{bmatrix}_{K(1)}$$

$$\vdots$$

$$\begin{bmatrix} \lfloor G, 0 \rfloor & \text{CSH1} \\ \lfloor G, 0 \rfloor & \text{CSH2} \\ \vdots & \\ \end{bmatrix}_{K(NKI)}$$

QRSIN = input Q_{rs} option,

= 0 do not input the Q_{rs} terms,

= 1 input the regular Q_{rs} terms in Deck 900. The program will add them to the $H\Delta$ matrix; the sum is the final Q_{rs} matrix,

= 2 input the regular Q_{rs} terms on tape (unit 12).

K(i) = reduced frequencies, $K(i) = \omega_i b_r/U$, where b_r is the reference length (BR) measured in feet, and U is the velocity (U).

TAPJOB = Case number of Q_{rs} input tape.

TAPPROB = Subcase number of Q_{rs} input tape.

2.2.2 DECK 100. Deck 100 supplies general data for the first control surface, (normally for symmetric motion there will only be one control surface, NCS = 1). The input format is:

100			
NPICKUP			
GPRINT	GPUNJOB	GPROB	GCARD
HDPRINT	HDPUNJOB	HPROB	HCARD

NPICKUP = the Number of PICKUPs that are sensed by the No. 1 control surface, ($1 \leq$ NPICKUP ≤ 7). (For example, if acceleration and angular velocity are sensed by the SAS, then NPICKUP = 2.)

GPRINT = 0 do not print the G vector,

$\geq$ 1 print the G vector for the first GPRINT K values

GPUNJOB = 0 do not punch the G vector. Read PROB and CARD but do not use,
If GPUNJOB < 0 punch the G vector, and start numbering with GPUNJOB.
Note: If OLS = 2, then G vector will be punched in the form above.

= 1 punch the G vector (with this case number) in the following form

$\lfloor G(\omega), 0, 0 \rfloor$

= JOB the case number of the punched cards will be JOB, ($2 \leq$ JOB ≤ 99999).

PROB = Subcase number for punched cards

= 0 use subcase number of this subcase

= PN subcase number (col. 74-75) of punched cards will be PN, ($1 \leq$ PN ≤ 99).

CARD = 0 start card number with 1

= NC start card number (col. 76-80) with NC, $(1 \leq NC \leq 99999)$.

HDPRINT = 0 do not print the H_Δ matrix,

= 1 print the H_Δ matrix for the first HDPRINT K values.

HDPUN = 0 do not punch the H_Δ matrix,

= 1 punch the H_Δ matrix and start numbering with HDPUN.

2.2.3 DECK 110. Deck 110 is always supplied, and gives information on the first pickup point and the transfer function, H(K), for the first point. The precoded elements available to define H(K) are listed in Table 2-1 along with the required inputs. In Table 2-1, the C_i terms are real constants defined as:

$$C_1 = CN_1/CD_1, \quad C_2 = CN_2/CD_2, \quad \text{etc.}$$

If $CD_i = 0.0$, then the program sets $C_i = 0.0$.

The Laplace operator, s, is defined as $i\omega$, where

$$i = \sqrt{-1}$$

and ω is frequency in radians per second. Therefore,

$$s^2 = -\omega^2.$$

Table 2-1. Precoded Transfer Function Elements

EQH	Element	Input Constants
1	$C_1\ (1 + 0i)$	CN_1, CD_1 (NC = 1)
2	$C_1\ (0 + 1i)$	CN_1, CD_1 (NC = 1)
3	$\dfrac{C_1}{C_2 s + C_3}$	CN_1, CD_1, ... CN_3, CD_3 (NC = 3)
4	$\dfrac{C_1 s + C_2}{C_3 s + C_4}$	CN_1, CD_1, ... CN_4, CD_4 (NC = 4)

Table 2-1. Precoded Transfer Function Elements (Continued)

EQH	Element	Input Constants
5	$\dfrac{C_1}{C_2 s^2 + C_3 s + C_4}$	CN_1, CD_1, ... CN_4, CD_4 (NC = 4)
6	$\dfrac{C_1 s^2 + C_2 s + C_3}{C_4 s^2 + C_5 s + C_6}$	CN_1, CD_1, ..., CN_6, CD_6 (NC = 6)
7	$\dfrac{C_1 s^2 + C_2 s + C_3}{(C_4 s + 1)(C_5 s + 1)}$	CN_1, CD_1, ... CN_5, CD_5 (NC = 5)
8	$\dfrac{(C_1 s + C_2)(C_3 s + 1)}{(C_4 s + 1)(C_5 s + 1)}$	CN_1, CD_1, ... CN_5, CD_5 (NC = 5)
9	$\dfrac{C_1}{\left(\frac{s}{\omega_0}\right)^2 + 2\gamma_1\left(\frac{s}{\omega_0}\right) + 1}$	C_1, ω_0, γ_1 (All Real)
10	$\dfrac{\left(\frac{s}{\omega_0}\right)^2 + 2\gamma_0\left(\frac{s}{\omega_0}\right) + 1}{\left(\frac{s}{\omega_0}\right)^2 + 2\gamma_1\left(\frac{s}{\omega_0}\right) + 1}$	ω_0, γ_0, γ_1 (All Real)

110				
NBB	HSET	HPRINT	A	P
Z1(1)	Z1(2)	... Z1(NQ)		
EQH(1)	MA(1)			
CN_1	CD_1	... CN_{NC}, CD_{NC}		
EQH(2)	MA(2)			
CN_1	CD_1	... CN_{NC}, CD_{NC}		
.				
.				
EQH(NBB)	MA(NBB)			
CN_1	CD_1	... CN_{NC}, CD_{NC}		

NBB = the Number of transfer function elements that are required to calculate H(K), $(1 \leq NBB \leq 50)$.

HSET = option for setting initial value of H(K),

= 1 set H(K) = 1.0 + 0i,

= 2 use the previous value of H(K) as the initial value. This option can not be used on the first pickup point. Thus for Deck 110 HSET = 1.

HPRINT = 0 do not print the H(K) function,

= 1 print the H(K) function for the first HPRINT K values.

A = input multiplying constant for Z1.

P = power of the time derivative, $(i\omega)^P$

= 0 displacement,

= 1 velocity, (d/dt),

= 2 acceleration, (d^2/dt^2).

Zi(r) = the displacement or angle at pickup point No. 1 for the rth mode shape. Supply NQ numbers, r = 1, 2, ..., NQ.

The above numbers supply geometrical data for pickup point No. 1. The following numbers supply information used to compute H(K), and are supplied NBB times:

EQH(1) = the equation number used to compute the first value of HN2(K), ($1 \leq$ EQH ≤ 10). See Table 2-1 for a list of the available equations.

MA(1) = 1 multiply the HN2(K) value just computed by the previous value of H(K).

= 2 add the HN2(K) value just computed to the previous value of H(K).

NOTE: If HSET = 1, then the value of H(K) is originally set equal to 1.0 + 0i on the first calculation; this will be the "previous" value.

CN, CD = constants used to compute transfer functions (see Table 2-1).

2.2.4 DECKS 120 THROUGH 170.

DECK 120. The format of Deck 120 is identical to Deck 110. Deck 120 is supplied when two or more pickup points are used, NPICKUP ≥ 2, and gives the information necessary to account for the second pickup point.

DECK 130. Same as Deck 120; supply when NPICKUP ≥ 3.

DECK 140, 150, 160, 170. Same as Deck 120; supply depending on the value of NPICKUP.

2.2.5 DECK 180. This deck supplies information necessary to calculate the transfer function that works on the final control surface deflection.

180			
NBB8	H8PRINT	A8	
EQH(1)	MA(1)		
CN_1	CD_1 ...	CN_{NC}	CD_{NC}
.	.		
.	.		
EQH(NBB8)	MA(NBB8)		
CN_1	CD_1 ...	CN_{NC}	CD_{NC}

NBB8 = the number of elements that are required to calculate H(K), ($1 \leq$ NBB8 ≤ 50).

H8PRINT	= 0 do not print the H(K) transfer function, ≥ 1 print H(K).
A8	= input multiplying constant for H(K).
EQH(1), MA(1), etc.	= same as defined in Deck 110.

2.2.6 DECK 190. This deck is supplied when OLS = 0, and gives the mass and aerodynamic data for a unit control surface motion for surface No. 1.

```
190
MMULT        QOPT      QMULT
MRD(1)       MRD(2)    ...              MRD(NQ)
CLD          ST                                    } Supply if
HT(1)        HT(2)     ...              HT(NQ)     } QOPT = 1
QRD(1, 1)    ...       QRD(NQ, 1)    }
             .                       }  Supply if QOPT = 2.
             .                       }  Input as complex
                                     }  numbers.
QRD(1, NKI)) ...       QRD(NQ, NKI)  }
```

MMULT = real constant multiplier for the MRD terms.

QOPT = 1 compute the QRD terms,

= 2 input the QRD terms,

= 3 the QRD terms are read from unit 12 behind the Q_{rs} terms

QMULT = real constant multiplier for either the computed or input QRD terms.

MRD(r) = inertia terms due to the control surface rotation,

$$= \frac{1}{4\rho b_r^3} \iint h_r(x, y) h_c(x, y)\, m(x, y)\, dxdy$$

$h_r(x, y)$ = the rth mode shape, r = 1, 2, ..., NQ.

$h_c(x, y)$ = deflection shape of unit amount of rigid body control surface rotation.

If QOPT = 1, then a real set of QRD terms will be computed from the following equation:

$$QRD(r, i) = \frac{1}{4\rho b_r^3 \omega_i^2} HT(r)\ L_T \tag{2}$$

where

b_r = reference length (feet)

HT(r) = deflection of the rth mode at the center of pressure of the control surface, feet.

L_T = real tail lift due to a unit control surface rotation,

= $1/2\rho U^2 S_T C_{L_\delta}$

ω_i = $(U/b_r)\ K(i)$

If QOPT = +2, then a complex set of QRD terms is input. These terms are defined as

$$QRD(r, i) = \frac{1}{4\rho b_r^3 \omega_i^2} \iint h_r(x, y)\ \Delta p_c(x, y)\ dxdy \tag{3}$$

where

$\Delta p_c(x, y)$ = complex pressure due to a unit control surface rotation.

2.2.7 DECKS 200 THROUGH 790.

DECKS 200-290. These decks are supplied when more than one control surface (NCS $\geq$2) is activated by the SAS; for instance, antisymmetric motion, where the ailerons and rudder are moved. The 100 series decks would then describe the aileron system, and the 200 series decks would describe the rudder system. The format for the 200 series decks is identical to the 100 decks.

DECKS 300-390. Same as Decks 200-290, except they are supplied when three or more control surfaces are activated, NCS $\geq$ 3.

DECKS 400-790. Same as Decks 200-290. Supply necessary decks according to the value of NCS.

2.2.8 DECK 900. This deck is supplied when QRSIN (Deck 010) is greater than 0, and gives "regular" Q_{rs} terms that are added to the H_{Δ} terms previously computed.

900			
QRSM	HDMULT		
QPRINT	QPUNJOB	PROB	CARD
QTAPE			
QRS(1, 1)	QRS(1, NQ)	Input when QRSIN = 1. Input as complex numbers.	
.			
.			
.			
.			
.			
QRS(NQ, 1)	QRS(NQ, NQ)		

QRSM = Q_{rs} multiplier. All of the input Q_{rs} terms are multiplied by this real constant.

HDMULT = H_{Δ} multiplier

QPRINT = 0 do not print the final Q_{rs} matrix,

= N print the Q_{rs} matrix for the first N values of K,

QPUNJOB = 0 do not punch the final Q_{rs} matrix. Read PROB and CARD but do use,

= 1 punch the final Q_{rs} matrix (with this case number) and start numbering with CARD.

= JOB the case number of the punched cards will be JOB, ($2 \leq JOB \leq 99999$).

PROB = subcase number for the punched cards

= 0 use subcase number of this subcase

= PN subcase number to be punched in cards, ($1 \leq PN \leq 99$).

CARD = 0 start card number with 1,

= NC start card number (col. 76-80) with NC, ($1 \leq NC \leq 99999$).

QTAPE = 0 do not tape the final Q_{rs} matrix,

$\geq$ 1 tape the final Q_{rs} matrix.

A single tape will be produced from each computer run. The Q_{rs} matrix is written on unit 9.

The equation used to calculate the total Q_{rs} matrices is

$$[Qrs(K)] = (QRSM)\,[Qrs(K)]_{input} + (HDMULT)\,[H_{\Delta}(K)]$$

2.3 PART 1 – RESPONSE OF GENERALIZED COORDINATES

The gust response part of the program consists of Parts 1 through 5. The first card (corresponding to card 4 in Section 2.1), contains five option numbers as defined in the flow chart of Figure 2-2.

OP1	OP2	OP3	OP4	OP5

2.3.1 DECK 000. This deck supplies information relating the basic size of the subcase. It must be the first deck supplied in any subcase that contains data for Parts 1 through 5 of the program.

0					
MACH	ALT	GW	SWEEP	PA	CG
b_r	ρ	a			
NQ	NDOF	NK	IP		
JOB	PROB	Supply if OP1 = 2 ($\overline{q}$ on tape)			

MACH = Mach number

ALT = altitude, feet, used for output identification only

GW = gross weight, used for output identification only

SWEEP = sweep angle, used for output identification only

PA = pitch axis, inches, used for output identification only

CG = center of gravity, inches, used for output identification only

b_r = reference length, inches, used in defining the reduced frequencies

ρ = atmospheric density, slugs/ft^3

a = speed of sound, ft/sec.

NQ = the number of generalized coordinates $1 \le NQ \le 20$

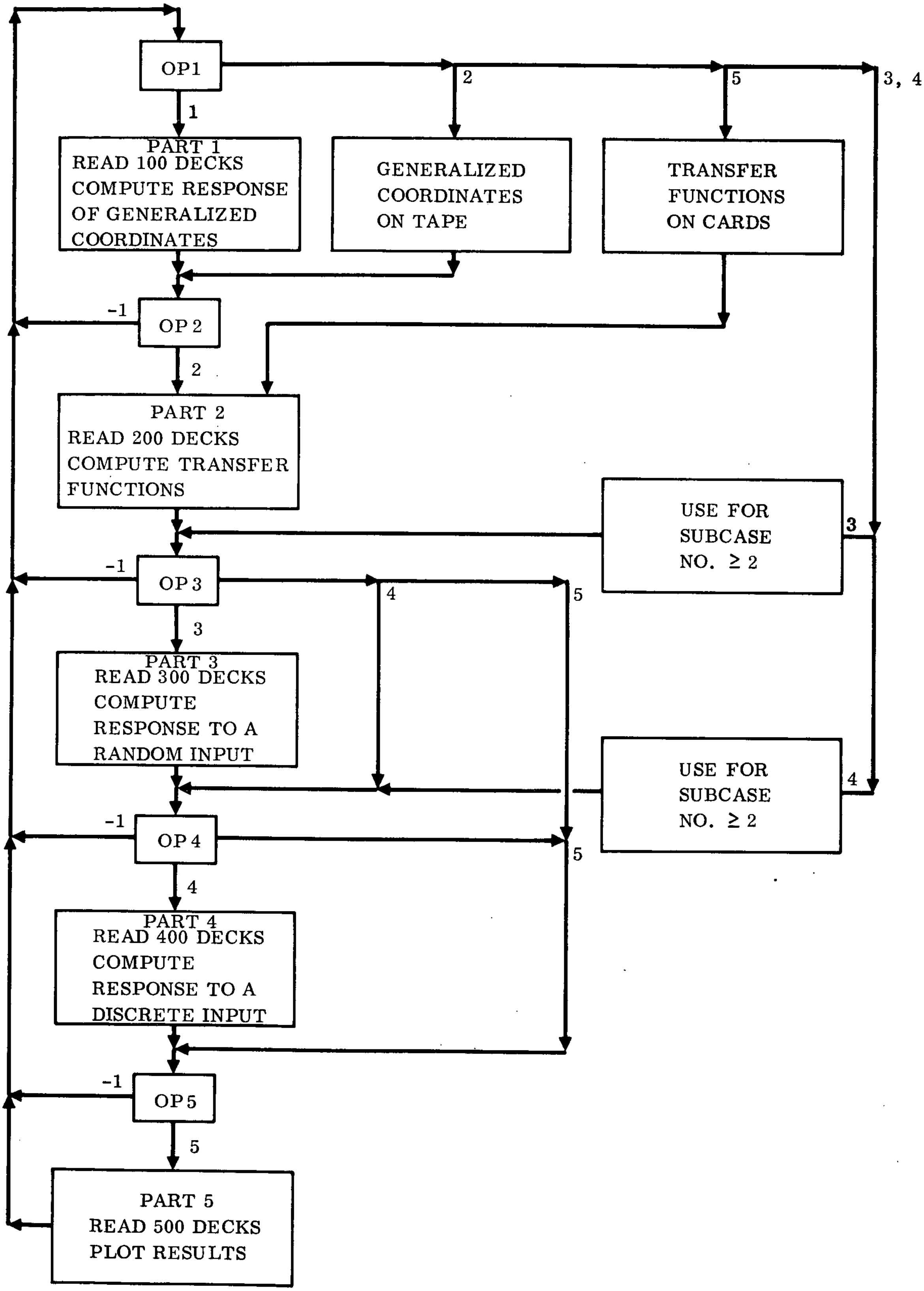


Figure 2-2. Part 1 through Part 5 Functional Flow Chart

NDOF = option for reduction of degrees of freedom
$0 \le |NDOF| \le 5$

= 0, use all NQ coordinates, no reduction in size

= N, there will be N sets of reduced matrices

= N, there will be N sets of reduced matrices and do not use the original NQ set

NK = number of reduced frequencies
$5 \le NK \le 20$ if $IP = 0$
$1 \le NK \le 210$ if $IP \neq 0$

IP = number of interpolation points $-10 \le IP \le 10$
the final number of frequencies after interpolation is
$NKI = |IP| \, (NK-1)+NK$

JOB and PROB are the case and subcase, respectively, from which the generalized coordinate tape was obtained.

For any arbitrary harmonic forcing function such as that produced by an electro mechanical vibrator, a sinusoidal gust, or an oscillating control surface, the equations of motion can be expressed in terms of generalized coordinates. In matrix notation this becomes

$$\begin{Bmatrix} \bar{q}_1 \\ \bar{q}_2 \\ \cdot \\ \cdot \\ \cdot \\ \bar{q}_n \end{Bmatrix} = - \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & & \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ A_{n1} & \cdots & \cdots & A_{nn} \end{bmatrix}^{-1} \begin{Bmatrix} A_{1f} \\ A_{2f} \\ \cdot \\ \cdot \\ \cdot \\ A_{nf} \end{Bmatrix} \tag{4}$$

or

$$\{\bar{q}\} = - [A]^{-1} \{A_f\} \tag{5}$$

where

$$A_{rr} = \left[1 - \left(\frac{\omega_r}{\omega}\right)^2 (1 + ig_r) - i2\gamma_r\left(\frac{\omega_r}{\omega}\right)\right] M_{rr} + Q_{rr} \qquad r = s$$

$A_{rs} = M_{rs} + Q_{rs} \qquad r \neq s$

$A_{rf} = M_{rf} + Q_{rf}$

ω = exciting frequency (rad/sec)

ω_r = natural frequency of the r^{th} mode (rad/sec)

g_r = structural damping coefficient of r^{th} mode

γ_r = ratio of viscous damping to critical damping for mode r

n = number of generalized coordinates $1 \leq n \leq 20$

M_{rs} = generalized mass divided by $4\rho b_r^3$

M_{rf} = generalized mass of forcing function divided by $4\rho b_r^3$

Q_{rs} = generalized force of the oscillating airplane divided by $4\rho b_r^3 \omega^2$

Q_{rf} = generalized force of the disturbance divided by $4\rho b_r^3 \omega^2$

b_r = reference length (feet)

$i = \sqrt{-1}$

Part 1 of the program solves Equation 5 for the response of the generalized coordinates for each specified input frequency, ω.

2.3.2 DECK 100. This deck supplies the input/output options for Part 1. This deck must be supplied in every gust response type subcase in which Part 1 is used.

100					
OP11	QRSIN	QRSPRINT	DET	QRFIN	QRFPRINT
QPRINT	QPUNCH				

The functions of OP11, QRSIN, and QRFIN are shown in Figure 2-3.

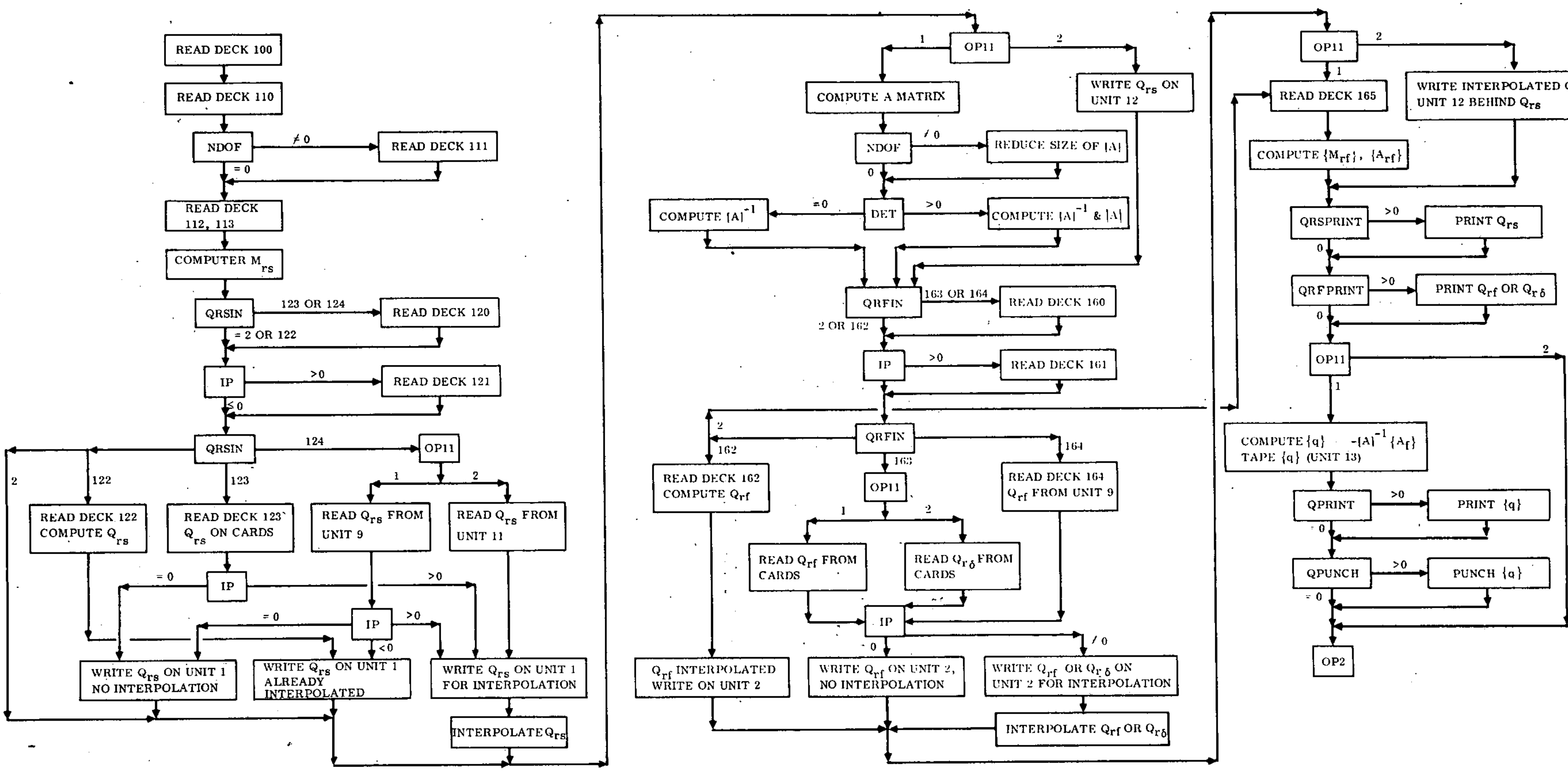


Figure 2-3. Part 1 Flow Chart

QRSPRINT = 0   do not print Q_{rs} terms

= N   print first N Q_{rs} matrices

DET > 0   find the determinant of the A matrix and multiply it by DET

= 0   do not find the determinant

QRFPRINT = 0   do not print Q_{rf} terms

= N   print first N Q_{rf} vectors

QPRINT = 0   do not print $\bar{q}$

= N   print first N $\bar{q}$ vectors

QPUNCH = 0   do not punch $\bar{q}$

= N   punch $\bar{q}$ terms and start numbering the cards with N where N is a 7 digit number specifying the subcase and sequence number desired on the cards. For example, N = 5200008 would punch a subcase number of 52 and sequence number the cards starting with 00008.

2.3.3 DECK 110. This deck supplies the non-dimensioned reduced frequencies.

110
K_1 K_2 . . . . K_{NK}

where

$$K_i = \frac{b_r \omega_i}{U} \qquad 0 \le K_i \le K_{i+1} \tag{6}$$

The velocity U is computed in the program from the Mach number and speed of sound supplied in Deck 000.

2.3.4 DECK 111. Deck 111 is input when NDOF $\neq$ 0 and supplies the information needed to reduce the size of the A matrix. The size of the A matrix is reduced by eliminating certain rows and columns. Deck 111 will supply numbers to indicate which row(s) and column(s) are to be eliminated.

111

N

DOF_1

E_1 $\quad E_2$ $\;\cdots\cdots\;$ E_{NQ-DOF_1}

DOF_2

E_1 $\quad E_2$ $\;\cdots\cdots\;$ E_{NQ-DOF_2}

.

.

DOF_N

E_1 $\quad E_2$ $\;\cdots\cdots\;$ E_{NQ-DOF_N}

Supply if $N \neq -1$ or -2

If N = -1, the program assumes that the response is symmetric and that the two rigid modes were supplied first and will compute the response for 1 and 2 degrees of freedom, respectively. The rigid body vertical translation mode must be supplied first in the Q_{rs} and Q_{rf} matrices to obtain the translation response only. If N = -2, the program assumes that the response is antisymmetric and that the three rigid body modes were supplied first and will compute the response for 1 and 3 degrees of freedom, respectively. The rigid body lateral translation mode must be supplied first in the Q_{rs} and Q_{rf} matrices to obtain the translation response. In order to use N = -1 or -2, NDOF must be equal = ±2. If NDOF = +2, the response for the NQ set will be computed in addition to the subsets. If NDOF = -2, the response for the subsets only will be computed.

If $N \neq -1$ or -2, then the specific row(s) and column(s) to eliminate must be supplied in the format shown above.

DOF_i = the size of the reduced A matrix $1 \le DOF_i \le NQ$
(Each DOF_i must be supplied on a card by itself)

E_j = the row and column to eliminate from the A matrix. The E numbers always refer to the original NQ x NQ A matrix $1 \le E_j \le NQ$

See Section 2.3.17 for a further explanation of the reduction of degrees of freedom.

2.3.5 DECK 112. This deck supplies basic data needed to compute the A matrix.

112			
ω_1	ω_2	....	ω_{NQ}
g_1	g_1	....	g_{NQ}
γ_1	γ_2	....	γ_{NQ}

ω_i = the natural frequency of the i^{th} mode, rad/sec

g_i = the structural damping coefficient of the i^{th} mode

γ_i = the viscous damping coefficient of the i^{th} mode

2.3.6 DECK 113. This deck supplies the generalized mass terms.

113		
C_M		
M_{rs} (1,1)	.....	M_{rs} (NQ,1)
M_{rs} (1,NQ)	.....	M_{rs} (NQ,NQ)

C_M is a multiplying constant to be applied to the M_{rs} terms. The quantity stored for the M_{rs} terms in the computer is

$$\left[\overline{M}_{rs}\right] = C_M \left[M_{rs}\right]$$

$\overline{M}_{rs}$ is the sea level generalized mass matrix (see Section 2.3.14 for the use of the M_{rs} terms).

2.3.7 DECK 120. Deck 120 consists of constants to adjust or correct the input Q_{rs} terms.

120		
T120		
C		(T120 = 1)
$C_1, C_2 \ldots C_{NK}$		(T120 = 2)
$C_R(1,1), C_I(1,1) \ldots\ldots C_R(NQ,1), C_I(NQ,1)$		(T120 = 3)
$C_R(1,NQ), C_I(1,NQ) \ldots C_R(NQ,NQ), C_I(NQ,NQ)$		

See Section 2.3.15 for the use of C correction terms.

2.3.8 DECK 121. Deck 121 is input when IP > 0 and QRSIN = 123 or 124 and supplies the interpolation coefficients to be used with the Q_{rs} terms.

121	
T121	
$K_R(1,1) \ldots\ldots K_R(NQ,1)$	Supply if T121 $\neq$ -1 or -2
$K_R(1,NQ) \ldots\ldots K_R(NQ,NQ)$	
$K_I(1,1) \ldots\ldots K_I(NQ,1)$	
$K_I(1,NQ) \ldots\ldots K_I(NQ,NQ)$	

The K_R and K_I matrices consist of integer constants between -9 and 9.

If T121 = -1 or -2, the program will set up the interpolation constants needed for a symmetric (T121 = -1) or antisymmetric (T121 = -2) analysis. The program will set the first column of the K_R matrix equal to zero and all other columns equal to 2. The whole K_I matrix is set equal to 1. (See Section 2.3.16 for the use of the interpolation constants.)

2.3.9 DECKS 122, 123, 124. Only one of these decks is input. The particular deck to input depends on the value of QRSIN supplied in Deck 100.

If QRSIN = 122, the Q_{rs} terms will be computed from the information supplied in Deck 122.

122			
C_1	P_1	C_2	P_2
Q (1,1)	Q (NQ,1)	Q (2NQ,1)	
Q (1,NQ)	Q (NQ,NQ)	Q (2NQ,NQ)	

where C_1, C_2, P_1, and P_2 are real constants and Q is a complex matrix.

The complex Q_{rs} terms will be computed from the following equation:

$$\left[Q_{rs}(\omega_j)\right] = C_1 \, \omega_j^{P_1} R \left[Q\right] + i \, C_2 \, \omega_j^{P_2} \; I \left[Q\right] \tag{7}$$

where R and I represent the real and imaginary parts and ω_j is computed from the reduced frequencies of Deck 110 by

$$\omega_j = U K_j / b_r \tag{8}$$

The Q_{rs} terms will be computed for each of the NKI reduced frequencies and no interpolation will be made.

If QRSIN = 123, the complex Q_{rs} terms will be input on cards in Deck 123.

123		
Q_{rs} (1,1)	Q_{rs} (2 x NQ,1)	Repeat NK times
Q_{rs} (1,NQ)	Q_{rs} (2 x NQ,NQ)	

If QRSIN = 124, the complex Q_{rs} terms will be supplied on tape (unit 9 or 11).

124	
JOB	PROB

JOB and PROB are the case and subcase number from which the Q_{rs} tape was generated.

2.3.10 DECK 160. Deck 160 supplies correction factors to be applied to the Q_{rf} terms.

160		
T160		
C_f		(T160 = 1)
C_f (1)	C_f (NK)	(T160 = 2)
C_{Rf} (1), C_{If} (1) . . .	C_{Rf} (NQ), C_{If} (NQ)	(T160 = 3)

See Section 2.3.15 for the use of the C_f correction terms.

2.3.11 DECK 161. Deck 161 is input when IP $\neq 0$ and supplies the interpolation coefficients to be used with the Q_{rs} terms.

161		
T161		
K_{Rf} (1)	K_{Rf} (NQ)	Supply if T161 $\neq -1$
K_{If} (1)	K_{If} (NQ)	

K_{Rf} and K_{If} are integer constants between -9 and 9.

If T161 = -1, the program will set $K_{Rf} = 2$ and $K_{If} = 1$. If T161 $\neq -1$, the K_R and K_I vectors must be supplied. (See Section 2.3.16 for the use of the interpolation constants.)

2.3.12 DECKS 162, 163, 164. Only one of these decks will be input. The particular deck to be input depends on the value of QRFIN supplied in Deck 100.

If QRFIN = 162, the Q_{rf} terms will be computed from the information supplied in Deck 162.

162					
C_{11}	C_{12}	C_{13}	P_1	C_{21}	C_{22}
C_{23}	P_2				
Q_f (1)	Q_f (NQ)	(Enter as complex numbers)			

C_{ij} and P_i are real constants and Q_f is a complex vector.

The complex Q_{rf} terms will be computed from the following equation:

$$\{ Q_{rf}(\omega_j) \} = C_{11}\, \omega_j^{P_1} \left[C_{12} + \cos(C_{13}\omega_j) \right] R \{ Q_f \}$$

$$+ \; i\, C_{21}\, \omega_j^{P_2} \left[C_{22} + \sin(C_{23}\, \omega_j) \right] I \{ Q_f \} \tag{9}$$

where R and I represent the real and imaginary parts. The Q_{rf} terms will be computed for each of the NKI reduced frequencies and no interpolation will be made.

If QRFIN = 163, the complex Q_{rf} or $Q_{r\delta}$ terms will be input on cards in Deck 163.

163	
Q_{rf} (1) . . . . Q_{rf} (NQ)	Enter as complex numbers. Repeat NK times

If QRFIN = 164, the complex Q_{rf} terms will be input on tape (unit 9).

164	
JOB	PROB

JOB and PROB are the case and subcase number from which the Q_{rf} terms were generated.

2.3.13 DECK 165. This deck supplies the generalized mass terms associated with the forcing function.

165
M
M_{rf} (1) . . . . M_{rf} (NQ)

M is a multiplying constant to be applied to the M_{rf} terms. The quantity that will be stored for the M_{rf} terms in the computer is

$$\{ \overline{M}_{rf} \} = M \{ M_{rf} \}$$

where $\overline{M}_{rf}$ is the sea level M_{rf} terms.

2.3.14 ALTITUDE CONSIDERATIONS. The generalized mass terms supplied in Decks 113 and 165 and the Q_{rf} terms computed or supplied in Decks 162, 163, and 164 are assumed to have been computed at sea level. When these terms are used in the computation of the response of the generalized coordinates, they are adjusted to the altitude supplied in Deck 000 by the following equations:

$$[M_{rs}]_{ALT} = \rho_o/\rho_{ALT}\,[\overline{M}_{rs}]_{SL} \tag{10}$$

$$\{M_{rf}\}_{ALT} = \rho_o/\rho_{ALT}\,\{\overline{M}_{rf}\}_{SL} \tag{11}$$

$$\{Q_{rf}\}_{ALT} = a_{SL}/a_{ALT}\,\{Q_{rf}\}_{SL} \tag{12}$$

where

ρ_o = air density at sea level

ρ_{ALT} = air density at the altitude supplied in Deck 000

a_{SL} = velocity of sound at sea level

a_{ALT} = velocity of sound at the altitude supplied in Deck 000

If any of these terms have been computed at some altitude other than sea level, they must be adjusted to sea level by the multiplier supplied with each deck.

2.3.15 CORRECTION FACTORS FOR Q_{rs} AND Q_{rf} TERMS. The Q_{rs} and Q_{rf} terms used in the computation of the response of the generalized coordinates will be multiplied by the correction factors supplied in Decks 120 and 160. If the Q_{rs} and Q_{rf} terms were computed from Decks 122 or 162, they will not be corrected.

For T120 = 1 , T160 = 1

$$\left[Q_{rs_i}(K)\right] = C\left[Q_{rs_i}(K)\right] \tag{13}$$

$$i = 1, NK$$

$$\left\{Q_{rf_i}(K)\right\} = C_f\left\{Q_{rf_i}(K)\right\} \tag{14}$$

where C and C_f are real constants.

For T120 = 2 , T160 = 2

$$\left[Q_{rs_i}(K)\right] = C_i(K)\left[Q_{rs_i}(K)\right] \tag{15}$$

$$i = 1, NK$$

$$\left\{Q_{rf_i}(K)\right\} = C_{f_i}(K)\left\{Q_{rf_i}(K)\right\} \tag{16}$$

where $C_i(K)$ and $C_{f_i}(K)$ are frequency dependent constants.

For T120 = 3 , T160 = 3

$$\left[Q_{rs_i}(K)\right] = \left[C_R\right] * R\left[Q_{rs_i}(K)\right] + \left[C_I\right] * I\left[Q_{rs_i}(K)\right] \tag{17}$$

$$i=1, NK$$

$$\left[Q_{rf_i}(K)\right] = \left[C_{Rf}\right] * R\left[Q_{rf_i}(K)\right] + \left[C_{If}\right] * I\left[Q_{rf_i}(K)\right] \tag{18}$$

where * signifies an element multiplication and NOT a matrix multiplication.

All corrections are applied to the Q_{rs} and Q_{rf} terms before interpolation and T120 need not equal T160. The quantities stored for the Q_{rs} and Q_{rf} terms will include the correction factor.

2.3.16 INTERPOLATION CONSTANTS. If IP is greater than zero, the interpolation procedure described in Appendix A is used to interpolate for additional sets of Q_{rs} terms. This interpolation method is also used on the Q_{rf} term when IP $\neq 0$. The additional Q terms are interpolated at IP equally spaced increments of K between each pair of adjacent supplied reduced frequencies.

Some of the Q terms are nearly constant, some are nearly proportional to K^{-1} and some are nearly proportional to K^{-2}. The interpolation is therefore improved by interpolating the term $\bar{Q}$ instead of Q, where $\bar{Q}$ is defined as:

$$R\left(\bar{Q}_{rs_i}(K)\right) = K^{\left(K_{R_{rs}}\right)} R\left(Q_{rs_i}(K)\right) \tag{19}$$

$$i = 1, NK$$

$$I\left(\bar{Q}_{rs_i}(K)\right) = K^{\left(K_{I_{rs}}\right)} I\left(Q_{rs_i}(K)\right) \tag{20}$$

$$R\left(\overline{Q}_{rf_i}(K)\right) = K^{\left(K_{Rf}\right)_r} R\left(Q_{rf_i}(K)\right) \tag{21}$$

$$i = 1, NK$$

$$I\left(\overline{Q}_{rf_i}(K)\right) = K^{\left(K_{If}\right)_r} I\left(Q_{rf_i}(K)\right) \tag{22}$$

where the K_R, K_I, K_{Rf}, and K_{If} are the integer constants supplied in Decks 121 and 161.

After the interpolation, the $\overline{Q}$ terms are converted back to Q terms by the following:

$$R\left(Q_{rs_i}(K)\right) = R\left(\overline{Q}_{rs_i}(K)\right) K^{\left(-K_{R}\right)_{rs}} \qquad i = 1, NK \tag{23}$$

etc.

Q(K) is now composed of both the input and interpolated values.

The interpolated Q terms are stored in the same storage locations as the original Q terms, hence the supplied Q terms will not be available for use in a later subcase (however, the interpolated Q term will be).

2.3.17 <u>REDUCTION OF DEGREES OF FREEDOM</u>. If NDOF $\neq$ 0, the size of the A matrix will be reduced by eliminating certain rows and columns.

If NDOF is positive, a solution will be obtained for both the original size A matrix (NQ x NQ) and NDOF reduced A matrices.

If NDOF is negative, only |NDOF| solutions will be obtained. No solution will be found for the original size A matrix.

The procedure used to eliminate the specified rows and columns can best be shown by an example. Let

NQ = 4 and NDOF = 2

and Deck 111 be input as follows

111		
2		(N)
3		(DOF_1)
1		(E_1)
2		(DOF_2)
2	4	(E_1, E_2)

Since NDOF is positive, three solutions will be found. The first solution is based on the original 4 x 4 A matrix.

$$\begin{bmatrix} A_{11} & A_{12} & A_{13} & A_{14} \\ A_{21} & A_{22} & & \cdot \\ A_{31} & & & \cdot \\ A_{41} & \cdots & \cdots & A_{44} \end{bmatrix}$$

The second solution will be found from a 3 x 3 matrix which is obtained by eliminating the first row and column from the original A matrix.

$$\begin{bmatrix} A_{22} & A_{23} & A_{24} \\ A_{32} & A_{33} & A_{34} \\ A_{42} & A_{43} & A_{44} \end{bmatrix}$$

The third solution will be based on a 2 x 2 matrix obtained by eliminating the second and fourth rows and columns from the original A matrix.

$$\begin{bmatrix} A_{11} & A_{13} \\ A_{31} & A_{33} \end{bmatrix}$$

In the above example, if NDOF had been equal to -2, then only the solution for the 3 x 3 and 2 x 2 A matrices would have been found.

2.3.18 DETERMINANT OF THE A MATRIX. If DET > 0, the elements of the A matrices are multiplied by DET and the determinants of the A matrices will be found. If the size of the A matrix has been reduced, then the determinants of the reduced size matrices will also be found.

The determinant of A is in the form of a complex number and also as a scaled magnitude

$$M(\omega) = \mathrm{Log}_{10} (\omega^2 \| A \|)$$

and a phase angle that is 180° from the actual phase angle of $|A|$. SC 4020 plots of $|A|$ will be output in two polar coordinate forms and in terms of scaled magnitude and phase angle.

2.4 PART 2 - TRANSFER FUNCTION RESPONSE

The response (acceleration, displacement, load, etc.) due to a harmonic input can be formulated as a function of the generalized coordinates. For some given response point l and excitation frequency ω, the transfer function is expressed as

$$H_l(\omega) = \sum_{j=1}^{n} \left[(i\,\omega)^P F_{jl} + \overline{F}_{jl}(\omega) \right] \overline{q}_j(\omega) + \overline{F}_{fl}(\omega) + (i\,\omega)^P F_{fl} \tag{24}$$

For a number of different response points, Equation 24 can be expressed in matrix notation as

$$\{H(\omega)\}_L = \left[\left[\diagdown (i\omega)^P \diagdown \right] \left[F_j \mid F_f \right] + \left[\overline{F}_j(\omega) \mid \overline{F}_f(\omega) \right] \right] \left\{ \begin{array}{c} \overline{q}(\omega) \\ \hline 1 \end{array} \right\} \tag{25}$$

where

L	=	number of response points, $1 \le L \le 20$
n	=	number of generalized coordinates (same as Part 1), $1 \le n \le 20$
m	=	number of $\overline{F}$ terms, $0 \le m \le 20$
ω	=	exciting frequency of the harmonic input
$(i\omega)^P F$	=	inertia component of the frequency response
$\overline{F}_j(\omega)$	=	load, stress, etc. resulting from the structure being deformed in the j^{th} mode shape
$\overline{F}_f(\omega)$	=	load, stress, etc. due to the unit amplitude forcing function.
$\overline{q}(\omega)$	=	response of the generalized coordinates

Part 2 solves Equation 25 for each exciting frequency used to compute the response of the generalized coordinates. If the degrees of freedom were reduced in the computation of the generalized coordinates, transfer functions are also computed for the reduced sizes.

The input data required to run Part 2 consists of the following:

a. Data supplied in Deck 000 (see Section 2.3.1)

b. The generalized coordinates computed in Part 1 or supplied on an input tape

c. A list of the reduced frequencies supplied in Deck 110

d. If NDOF $\neq$ 0, the information of Deck 111 must be supplied. (If the generalized coordinates are supplied on tape, the reduced frequencies and the information of Deck 111 will be read from the tape.)

e. Data input in this section.

Figure 2-4 is the flow chart for the input to Part 2.

2.4.1 DECK 200. This deck supplies the I/O options for Part 2. This deck must be supplied before any other 200 series deck can be read.

200					
LMAX	NF	NFB	FBIN	FBPRINT	D245
D250	HPRINT	NPUNCH			

where

LMAX = total number of output response points, $(1 \leq \text{LMAX} \leq 20)$

NF = size of the input F matrix, $(1 \leq \text{NF} \leq \text{LMAX})$ NF = 0 if OP1 = 5

NFB = size of the input $\overline{F}$ matrix, $(0 \leq \text{NFB} \leq 20)$

FBIN = $\overline{F}$ matrix input option (see flow chart)

FBPRINT = N print the first N $\overline{F}$ matrices

D245 > 0 input either Deck 245 or 246

D250 > 0 input Deck 250

HPRINT = N print the transfer functions for the first N frequencies.

HPUNCH = N punch the transfer functions sequentially, numbering each card starting with N where N is an integer specifying the desired subcase and sequence number.

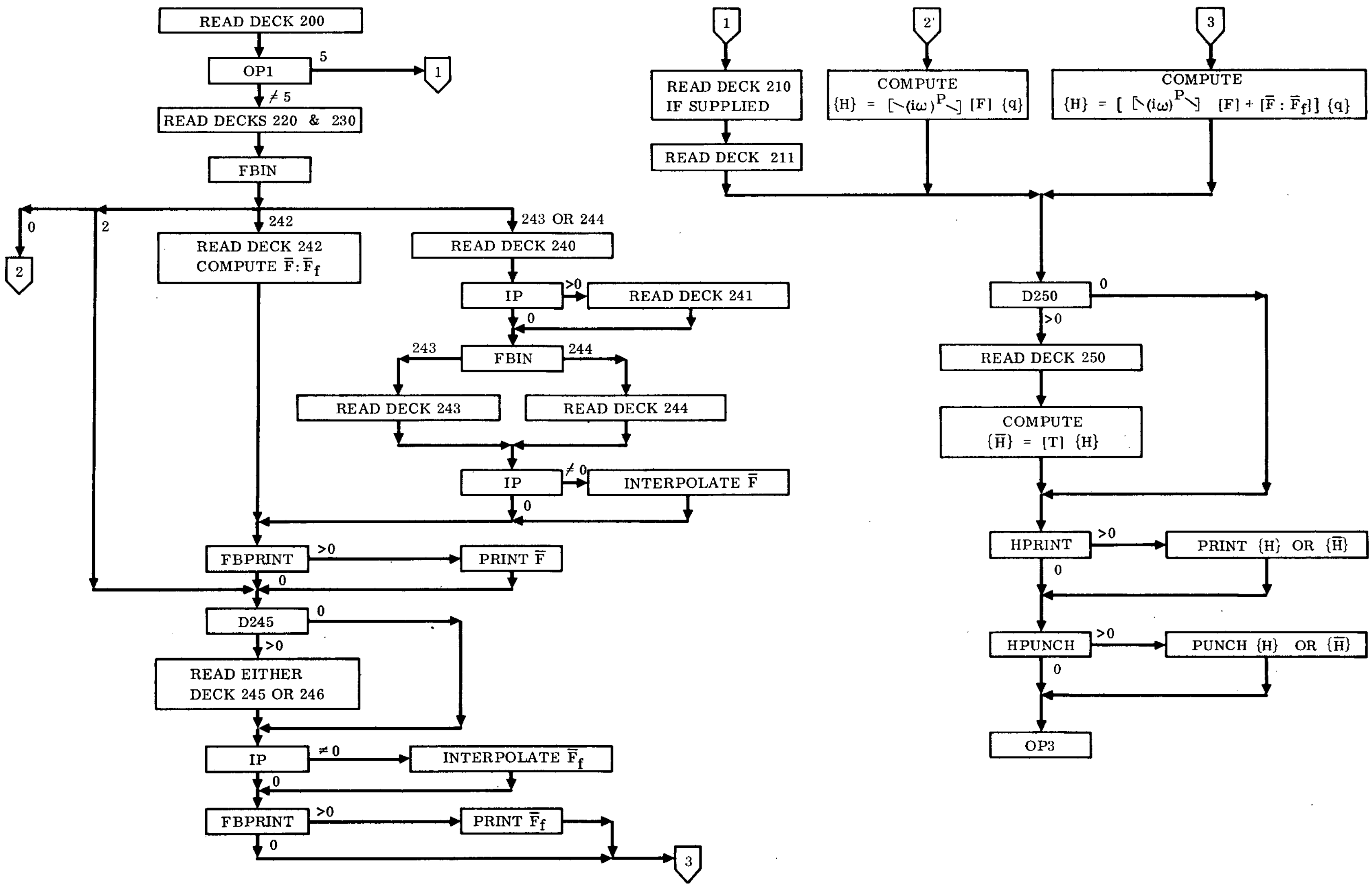


Figure 2-4. Part 2 Flow Chart

If OP1 = 5, the transfer functions will be input on cards instead of computed. If the transfer functions are input on cards, the reduced frequencies must be supplied in either Deck 110 or 210.

2.4.2 DECK 210. This deck supplies the reduced frequencies to be used with the transfer functions if they are input.

210				
K_1	K_2	K_3	. . .	K_{NKI}

Deck 210 is similar to Deck 110 except that NKI values of K must be supplied. NKI is the number of reduced frequencies after interpolation and is defined by NKI = |IP| (NK-1) + NK (See Section 2.3.1).

2.4.3 DECK 211. This deck is used to supply the transfer functions on cards. (The K's must have been supplied in Deck 110 or 210 to use this option.)

$$
\begin{array}{l}
211 \\
\left.\begin{array}{l}
H_1\ (\omega_1) \cdot \cdot \cdot \cdot \ H_1\ (\omega_{NKI}) \\
\quad \cdot \\
\quad \cdot \\
\quad \cdot \\
H_{LMAX}\ (\omega_1) \cdot \cdot \ H_{LMAX}\ (\omega_{NKI})
\end{array}\right\} \text{Enter as complex numbers}
\end{array}
$$

where H_L (ω_j) is the complex transfer function for the L^{th} response point at ω_j.

2.4.4 DECK 220. This deck supplies the information needed to assemble the final F matrix

220		
L(1)	C(1)	P(1)
L(2)	C(2)	P(2)
.	.	.
.	.	.
L(LMAX)	C(LMAX)	P(LMAX)

L_i = integer number of the row in the F matrix to use for the i^{th} response point, $1 \leq L_i \leq NF$

C_i = real constant

P_i = integer constant

2.4.5 <u>DECK 230</u>. This deck supplies the F' terms used to assemble the final F matrix.

```
230
F' (1, 1) . . . . . F' (NQ + 1, 1)
    .
    .
F' (1, NF). . . . F' (NQ + 1, NF)
```

The final F matrix is assembled from the information in Deck 220 and 230 as follows:

$$\begin{bmatrix} F_{11} & F_{12} & \cdot\cdot & F_{1\ NQ+1} \\ F_{21} & F_{22} & \cdot\cdot & F_{2\ NQ+1} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ F_{LMAX\ 1} & F_{LMAX\ 2} & \cdot\cdot & F_{LMAX\ NQ+1} \end{bmatrix}$$

$$= \begin{bmatrix} C_1 F'_{11} & C_1\ F'_{12} & \cdot\cdot & C_1 F'_{1\ NQ+1} \\ C_2 F'_{21} & C_2\ F'_{22} & \cdot\cdot & C_2 F'_{2\ NQ+1} \\ \cdot & \cdot & & \\ \cdot & \cdot & & \\ C_{LMAX}\ F'_{LMAX\ 1} & C_{LMAX}\ F'_{LMAX\ 2} & \cdot\cdot & C_{LMAX}\ F'_{LMAX\ NQ+1} \end{bmatrix} \quad (26)$$

where L_i and C_i were supplied in Deck 220.

The final size of the F matrix is LMAX x (NQ+1).

If $\bar{F}$ terms are to be supplied and NFB $\neq$ LMAX, the F' terms associated with the $\bar{F}$ terms must be placed at the top of the final F matrix and in the same order as the corresponding $\bar{F}$ matrix.

2.4.6 <u>DECK 240</u>. This deck supplies correction factors to be used with the $\bar{F}$ terms.

240

T240

C(1) . . . . C(NFB) (T240 = 1)

$$\left.\begin{array}{l} C(1) \;.\;.\;.\;.\; C(NFB)\ (\text{for } \omega_1) \\ \quad \vdots \\ C(1) \;.\;.\;.\;.\; C(NFB)\ (\text{for } \omega_{NK}) \end{array}\right\} \quad (T240 = 2)$$

$$C(1)_{RL},\ C(1)_{IM}\ \ldots\ C(NQ+1)_{RL},\ C(NQ+1)_{IM} \left\{\begin{array}{l} (T240 = 3) \\ \text{Repeat} \\ \text{NFB times} \end{array}\right.$$

where

T240 = 0, 1, 2, 3

C = real constant defined in Section 2.4.11.

If T240 = 0, the program will set $\{C\}$ = 1. (T240 will be the only number supplied.)

2.4.7 <u>DECK 241</u>. This deck is supplied when IP $\neq$ 0 and supplies information needed to interpolate the $\bar{F}$ terms.

241

T241

$$\left.\begin{array}{ll} K_R(1) \;.\;.\;.\;.\;.\;. & K_R\ (NQ+1) \\ K_I(1) \;.\;.\;.\;.\;.\;. & K_I\ (NQ+1) \end{array}\right\} \quad (T241 = 1)$$

$$\left.\begin{array}{ll} K_R(1,1) \;.\;.\;.\;. & K_R\ (NQ+1, 1) \\ \vdots & \\ K_R(1,NFB) \;.\;.\;. & K_R\ (NQ+1,\ NFB) \\ K_I(1,1) \;.\;.\;.\;. & K_I\ (NQ+1, 1) \\ \vdots & \\ K_I(1,NFB) \;.\;.\;. & K_I\ (NQ+1,\ NFB) \end{array}\right\} \quad (T241 = 2)$$

where the K_R and K_I matrices contain integer constants between -9 and 9.

If T241 = 0, the program will set both $\lfloor K_R \rfloor$ and $\lfloor K_I \rfloor = \lfloor 0 \rfloor$. (T241 will be the only number supplied.) See Section 2.4.12 for the use of interpolation constants.

2.4.8 DECKS 242, 243, 244. Only one of these decks will be input, the particular deck depending on the value of FBIN supplied in Deck 200.

If FBIN = 242, the $\bar{F}$ terms will be computed by the program from the information supplied in Deck 242.

242				
C_1	P_1	C_2	P_2	
$\bar{F}(1, 1)$	$\bar{F}(NQ+1, 1)$			Enter as complex numbers
.				
.				
$\bar{F}(1, NFB)$ . . .	$\bar{F}(NQ+1, NFB)$			

The complex $\bar{F}$ terms will be computed from the following equation:

$$[\bar{F}(\omega)] = C_1 \, \omega^{P_1} \, R[\bar{F}] + i \, C_2 \, \omega^{P_2} \, I[\bar{F}] \tag{27}$$

in which C_1, C_2, P_1, P_2 are all real constants.

If FBIN = 243, the complex $\bar{F}$ terms will be input on cards.

243		
NFBF		Enter as complex numbers
$\bar{F}(1, 1, 1)$ . . .	$\bar{F}(II, 1, 1)$	
⋮		
$\bar{F}(1, NFB, 1)$ . .	$\bar{F}(II, NFB, 1)$	
$\bar{F}(1, 1, 2)$ . . .	$\bar{F}(II, 1, 2)$	
⋮		
$\bar{F}(1, NFB, 2)$ . .	$\bar{F}(II, NFB, 2)$	
⋮		
$\bar{F}(1, NFB, NK)$ . .	$\bar{F}(II, NFB, NK)$	

If NFBF $\neq$ 0, II = (NQ+1) and the $\overline{F}_f$ terms will be included in the $\overline{F}$ matrix.

If NFBF = 0, II = NQ and the $\overline{F}_f$ terms will not be included in the $\overline{F}$ matrix. The $\overline{F}_f$ terms must then be input in either Deck 245 or 246.

If FBIN = 244, the complex $\overline{F}$ terms will be input on tape (unit 10).

244		
NFBF	JOB	PROB

JOB and PROB are the case and subcase numbers from which the $\overline{F}$ tape was generated.

2.4.9 DECKS 245 AND 246. One of these decks must be supplied if D245 is greater than 0 or if NFBF in Deck 243 or 244 was equal to 0. If $\overline{F}_f$ terms were supplied in either Deck 243 or 244, they will be replaced by the new set of Deck 245 or 246. Deck 245 inputs the complex $\overline{F}_f$ terms on cards. Deck 246 is used if they are input from tape (unit 10).

245

$\overline{F}(1,1)$ . . . . $\overline{F}(\mathrm{NFB},1)$
.
.
$\overline{F}(1,\mathrm{NK})$ . . . $\overline{F}(\mathrm{NFB},\mathrm{NK})$

Enter as complex numbers

246	
JOB	PROB

JOB and PROB are the case and subcase from which the $\overline{F}_f$ tape was generated.

2.4.10 DECK 250. This deck is read when D250 > 0.

F

250			
LMAXF	NELEM		Enter T's as complex numbers.
NR_1	NC_1	T_1	
NR_2	NC_2	T_2	
.	.	.	
.	.	.	
.	.	.	
NR_{NELEM}	NC_{NELEM}	T_{NELEM}	

where

LMAXF = final number of output response points, $1 \le \text{LMAXF} \le 20$

NELEM = number of elements supplied $1 \le \text{NELEM} \le (\text{LMAXF} * \text{LMAX})$

NR_m = row number of the m^{th} element, $1 \le NR_m \le \text{LMAXF}$

NC_m = column number of the m^{th} element, $1 \le NC_m \le \text{LMAX}$

T_m = m^{th} complex element

See Section 2.4.13 for the use of Deck 250.

2.4.11 CORRECTION FACTORS FOR THE $\overline{F}$ TERMS. The $\overline{F}$, $\overline{F}_f$ terms will be corrected using the correction factors supplied in Deck 240 and the $\overline{F}$, $\overline{F}_f$ terms supplied in Decks 243, 244, 245, and/or 246. (No corrections will be made to the $\overline{F}$, $\overline{F}_f$ terms computed in Deck 242.)

For T240 = 0

$$[\overline{F}(\omega):\overline{F}_f(\omega)] = [\diagdown 1 \diagdown] \, [\overline{F}(\omega):\overline{F}_f(\omega)] \tag{28}$$

For T240 = 1

$$[\overline{F}(\omega):\overline{F}_f(\omega)] = [\diagdown C \diagdown] \, [\overline{F}(\omega):\overline{F}_f(\omega)] \tag{29}$$

where the C diagonal matrix is formed from the NFB real constants input in Deck 240.

For T240 = 2

$$[\bar{F}(\omega_i):\bar{F}_f(\omega_i)] = [\llcorner C(\omega_i) \lrcorner] \, [\bar{F}(\omega_i):\bar{F}_f(\omega_i)] \tag{30}$$

where

$$i = 1, 2, 3 \ldots NK$$

For T240 = 3

$$[\bar{F}(\omega):\bar{F}_f(\omega)] = [C_{RL}] * R\,[\bar{F}(\omega):\bar{F}_f(\omega)] + i\,[C_{IM}] * I[\bar{F}(\omega):\bar{F}_f(\omega)] \tag{31}$$

where * signifies an element multiplication and NOT a matrix multiplication.

All corrections are applied to the $\bar{F}$, $\bar{F}_f$ terms before interpolation.

2.4.12 INTERPOLATION CONSTANTS. If IP $\neq$ 0, the $\bar{F}$, $\bar{F}_f$ terms (if supplied) are interpolated by the same procedure used to interpolate the Q_{rs} terms. The interpolation constants are set up from Deck 241 as follows:

If T241 = 0 or 1

$$[K_R] = \begin{bmatrix} \lfloor K_R \rfloor \\ \lfloor K_R \rfloor \\ \cdot \\ \cdot \\ \lfloor K_R \rfloor \end{bmatrix} \text{NFB x (NQ + 1)} \tag{32}$$

Similarly, the K_I matrix is constructed from the K_I vectors.

If T241 = 2, then the K_R and K_I matrices are input.

2.4.13 CALCULATING A NEW SET OF TRANSFER FUNCTIONS. If D250 > 0, a new set of transfer functions are computed by multiplying the original transfer functions by a T matrix assembled from the information supplied in Deck 250.

Initially, each element of the complex T matrix is set to zero.

$$[T] = [0] \;\; \text{LMAXF x LMAX} \tag{33}$$

The final T matrix is assembled by inserting the T elements of Deck 250 in the appropriate rows and columns.

The new set of transfer functions are computed as follows:

$$\underset{\text{LMAXF}}{\{\bar{H}(\omega)\}} = \underset{\text{LMAXF x LMAX}}{[T]} \quad \underset{\text{LMAX x 1}}{\{H(\omega)\}} \tag{34}$$

where $\bar{H}(\omega)$ is the new set of transfer functions. $\bar{H}$ will be used in all further calculations using the transfer functions.

2.5 PART 3 – RESPONSE TO A RANDOM INPUT

Part 3 of this program computes the response to a random input. The response to a random input is defined in terms of statistical quantities such as the output power spectral density function; rms acceleration; rms bending moment; rms stress; etc.

The output power spectrum is a function of both the input spectrum and the frequency response function.

$$\phi_o(f) = \phi_i(f) \, |H(f)|^2 \tag{35}$$

where

$\phi_o(f)$ = output spectrum

$\phi_i(f)$ = input spectrum

$H(f)$ = frequency response function

The rms value is defined as

$$(\text{rms}) = \bar{A} = \sqrt{\int_{f_1}^{f_n} \phi_o(f)df} \tag{36}$$

where $\bar{A}$ is computed by numerical integration using the trapezoidal rule.

The characteristic frequency, computed in this section, is defined as

$$N_o = \frac{1}{2\pi} \sqrt{\int_{f_1}^{f_n} (2\pi f)^2 \phi_o(f)df \Big/ \int_{f_1}^{f_n} \phi_o(f)\, df}$$

which may be written as

$$N_o = \frac{1}{2\pi\bar{A}} \sqrt{\int_{f_1}^{f_n} (2\pi f)^2 \phi_o\,(f)\, df} \tag{37}$$

A third quantity of statistical use, N_1 is also computed in Part 3. Defined as the expected number of response peaks per second, N_1 is given by the equation

$$N_1 = \frac{1}{2\pi}\sqrt{\int_{f_1}^{f_n}(2\pi f)^4\,\phi_o(f)df \Big/ \int_{f_1}^{f_n}(2\pi f)^2\,\phi_o(f)df}$$

or,

$$N_1 = \frac{1}{\bar{A}N_o}\sqrt{\int_{f_1}^{f_n}(2\pi f)^4\,\phi_o(f)df} \tag{38}$$

The information needed to run Part 3 is listed as follows:

a. Data in Deck 000

b. Transfer functions from Part 2 or input on cards

c. List of the reduced frequencies, Deck 110 or 210

d. The reduction in degrees of freedom, Deck 111. (If NDOF $\neq$ 0)

e. Data from Deck 220. (This information is only used for printout)

f. Data input in this section.

Figure 2-5 shows the flow chart for Part 3.

2.5.1 DECK 300. This deck supplies the flow and I/O options for Part 3.

300					
TITLE3		(columns 2 through 65)			
ϕ_iOPT	ϕ_iPRINT	ϕ_oPRINT	ϕ_oPUNCH	D320	VFREQ
ANPRINT	ANPUNCH	ANPUNST			

where

TITLE3 is used in the printed output

ϕ_iOPT = 301, 302, . . . or 309. (Option for the input power spectrum.)

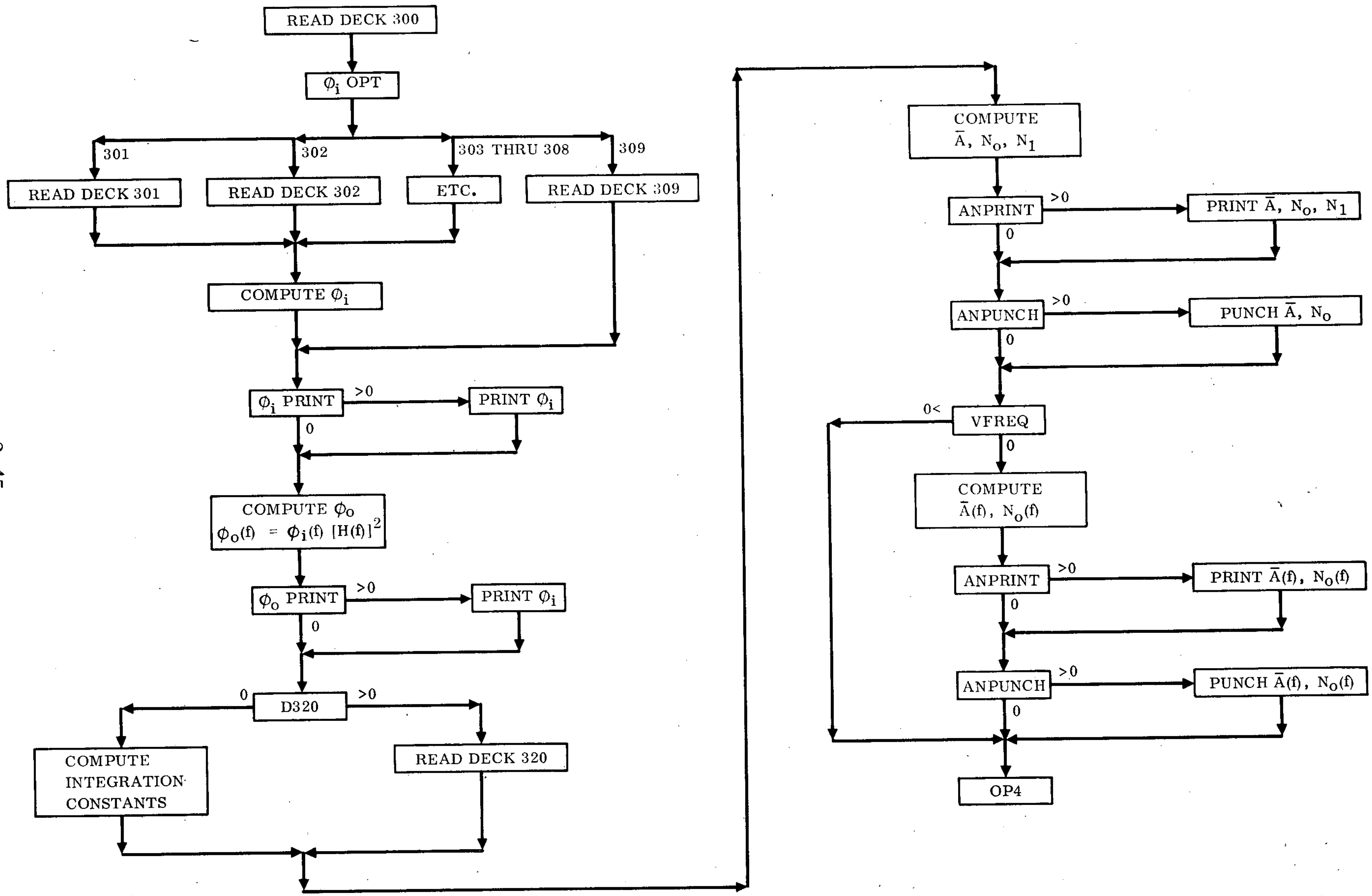


Figure 2-5. Part 3 Flow Chart

ϕ_iPRINT	> 0	Print input spectrum
ϕ_oPRINT	> 0	Print output spectrum for each response point
ϕ_oPUNCH	= N	If N > 0, punch the output power spectrum and sequentially number the cards starting with N
D320	> 0	Input Deck 320
VFREQ	> 0	Vary the maximum frequency used in calculating the $\bar{A}$ and N_o terms. The increment used will be every VFREQ value of frequency. (See Section 2.5.11.)
ANPRINT	> 0	Print the $\bar{A}$, N_o, N_1 values
ANPUNCH	= N	If N > 0, punch the $\bar{A}$ and N_o values and sequentially number the cards starting with N.
ANPUNST		If ANPUNCH > 0, punch the first ANPUNST sets of degrees of freedom. If ANPUNST is .LE.0 or .GE. to the total number of sets, all the $\bar{A}$ and N_o values will be punched.

2.5.2 DECK 301. The Dryden Spectrum is used for the input spectrum.

301
L

The input spectrum is computed from the following equation:

$$\phi_i(f) = \frac{2L}{U} \frac{\left[1 + 3\left(\frac{2\pi f L}{U}\right)^2\right]}{\left[1 + \left(\frac{2\pi f L}{U}\right)^2\right]^2} \tag{39}$$

where

L = scale of turbulence, feet L > 0

U = vehicle velocity, ft/sec (computed from data supplied in Deck 000)

2.5.3 DECK 302. The Von Karman Spectrum is used for the input spectrum.

302
L

The input spectrum will be computed from the following equation:

$$\phi_i(f) = \frac{2L}{U} \frac{\left[1 + \frac{8}{3}\left(1.339 \frac{2\pi f L}{U}\right)^2\right]}{\left[1 + \left(1.339 \frac{2\pi f L}{U}\right)^2\right]^{11/6}} \tag{40}$$

2.5.4 DECK 303. The "runway" spectrum is used for the input spectrum.

303			
A_1	A_2	A_3	A_4

The input spectrum is computed from the following equation:

$$\phi_i(f) = \left(A_1 + \frac{A_2}{U}\right)\left(A_3 \frac{2\pi f}{U}\right)^{A_4} \tag{41}$$

where

$A_1 \rightarrow A_4$ are real constants and $A_3 > 0$.

2.5.5 DECK 304. The input spectrum is computed from a power series:

304			
B			
A_1	A_2	. . . . . .	A_{16}

The following power series is used

$$\phi_i(f) = \frac{2\pi B\left(A_1 + A_2(2\pi f) + A_3(2\pi f)^2 \ . \ . \ . \ A_7(2\pi f)^6\right)^{A_8}}{\left(A_9 + A_{10}(2\pi f) + A_{11}(2\pi f)^2 \ . \ . \ . \ A_{15}(2\pi f)^6\right)^{A_{16}}} \tag{42}$$

where B and $A_1 \rightarrow A_{16}$ are real constants and A_8 & $A_{16} \geq 0$.

2.5.6 DECK 305. This deck is used to compute the crew sensitivity index.

305						
L	A	NT				
f_1	T_1	f_2	T_2	. . .	f_{NT}	T_{NT}

NT = number of input T_i and f_i points, $2 \leq NT \leq 25$

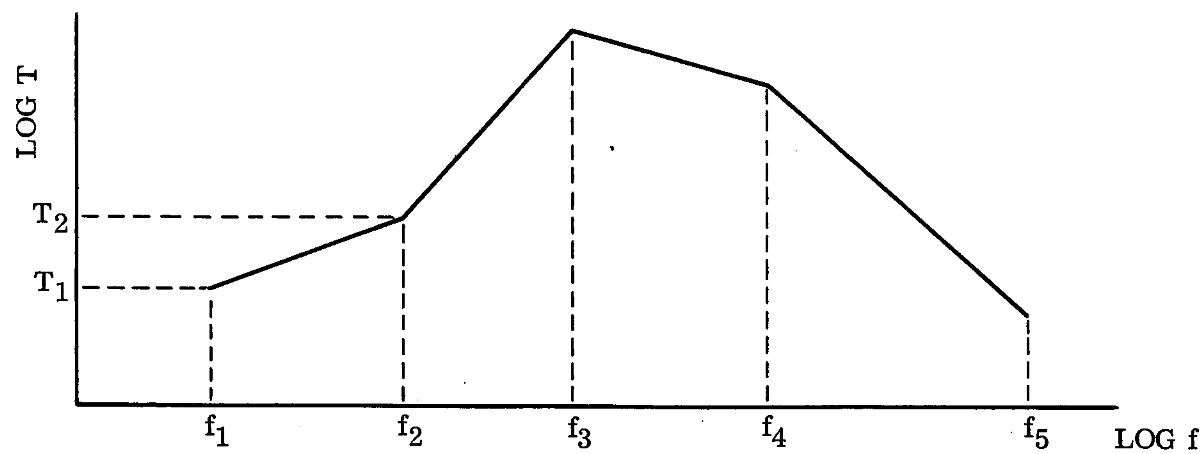
L = scale of turbulence, ft. $L > 0$

A = real constant

T_i = human transfer function defined at f_i frequency (cps)

$0 < f_i < f_{i+1}$ $\quad T_i > 0$

The human transfer function is defined as a series of straight line segments on a log-log plot as shown below:



For any point between f_i and f_{i+1}, the human transfer function is computed by

$$T(f) = e^{\ln C} \tag{43}$$

$$\text{where } C = \ln(f/f_1)\left[\frac{\ln\left(T_{i+1}/T_i\right)}{\ln\left(f_{i+1}/f_i\right)}\right] + \ln T_i$$

The input spectrum is now defined as

$$\phi_i(f) = \left[A\ \ T(f)\right]^2\ \phi_{VK}(f) \tag{44}$$

where $\phi_{VK}(f)$ is the Von Karman Spectrum for the input scale of turbulence, L.

NOTE

> f_1 need not be the lowest frequency used in the analysis or f_{NT} need not be the largest frequency used. The program disregards any values outside the first and last value of frequency used in the program. If f_{NT} is less than the largest T.F. frequency the program extends the last T(f) segment to the largest T.F. frequency.

2.5.7 <u>DECKS 306-308</u>. These deck numbers are left open for future additions.

2.5.8 <u>DECK 309</u>. This deck is used to input the power spectrum on cards.

309				
$\phi_i(f_1)$	$\phi_i(f_2)$	$\phi_i(f_3)$	. . . .	$\phi_i(f_{NKI})$

2.5.9 <u>DECK 320</u>. If Deck 320 is greater than zero, the integration constants used in computing $\bar{A}$, N_o, and N_1 are input in this deck.

320				
W_1	W_2	W_3	. . . .	W_{NKI}

If the integration constants are not input, they are computed by the program.

$$W_1 = 1/2\ (f_2 - f_1) \tag{45}$$

$$W_i = (f_{i+1} - f_{i-1}) \tag{46}$$

$$W_{NKI} = 1/2\,(f_{NKI} - f_{NKI-1}) \tag{47}$$

2.5.10 CALCULATION OF $\bar{A}$, N_o, AND N_1. The $\bar{A}$, N_o, and N_1 values are computed from the output power spectrums of each response point using numerical integration (trapezoidal rule).

$$\bar{A} = \sqrt{\int_{f_1}^{f_{NKI}} \phi_o(f)df} = \left[\sum_{j=1}^{NKI} \phi_{o_j} W_j\right]^{1/2} \tag{48}$$

$$N_o = \frac{1}{2\pi}\sqrt{\frac{\int_{f_1}^{f_{NKI}} (2\pi f)^2 \phi_o(f)df}{\int_{f_1}^{f_{NKI}} \phi_o(f)\,df}} = \frac{1}{2\pi\bar{A}}\left[\sum_{j=1}^{NKI} (2\pi f_j)^2 \phi_{o_j} W_j\right]^{1/2} \tag{49}$$

$$N_1 = \frac{1}{2\pi}\sqrt{\frac{\int_{f_1}^{f_{NKI}} (2\pi f)^4 \phi_o(f)df}{\int_{f_1}^{f_{NKI}} (2\pi f)^2 \phi_o(f)df}} = \frac{1}{\bar{A}N_o}\left[\sum_{j=1}^{NKI} (2\pi f_j)^4 \phi_{o_j} W_j\right]^{1/2} \tag{50}$$

Values of $\bar{A}$, N_o, and N_1 are computed for all response points and all variations in degrees of freedom.

2.5.11 VARY THE MAXIMUM FREQUENCY IN COMPUTING $\bar{A}$ AND N_o. If VFREQ is greater than zero, the maximum frequency is varied in the computation of $\bar{A}$ and N_o. (This option should be used if the convergence of either $\bar{A}$ or N_o is desired or if the contribution of each frequency band to the final $\bar{A}$ or N_o value is desired.) The program computes

$$\bar{A}_m = \left[\sum_{j=1}^{m} \phi_{o_j} W_j\right]^{1/2} \tag{51}$$

$$N_{o_m} = \frac{1}{A_m} \left[\sum_{j=1}^{m} (2\pi f_j)^2 \, \phi_{o_j} \, W_j \right]^{1/2} \tag{52}$$

where m ≤ NKI. For the first pass, m = VFREQ and on subsequent passes, the value of m is increased by VFREQ until m is equal to NKI. The value of W_m is adjusted to compensate for each new end point in the numerical integration.

Example:

VFREQ is an integer	VFREQ =	1; compute $\bar{A}$ and N_o for every frequency band.
	VFREQ =	2; compute $\bar{A}$ and N_o for every other frequency band
	etc.	

B

2.6 PART 4 – RESPONSE TO A DISCRETE INPUT

Part 4 of the program solves for the vehicle's response to a discrete input using Fourier series techniques.

The Fourier series representation of the forcing function can be expressed as

$$f(t) = a_o + \sum_{m=1}^{MAXM} \left[a_m \cos \bar{\omega}_m t + b_m \sin \bar{\omega}_m t \right] \tag{53}$$

where

$$\bar{\omega}_m = m\pi/T$$

$$a_o = \frac{1}{2T} \int_{-T}^{T} f(t)\, dt$$

$$a_m = \frac{1}{T} \int_{-T}^{T} f(t) \cos \bar{\omega}_m t\, dt$$

$$b_m = \frac{1}{T} \int_{-T}^{T} f(t) \sin \bar{\omega}_m t\, dt$$

The Fourier series representation of the forcing function has a period of 2T.

The response at a point due to a discrete input is expressed as

$$Z(t) = \sum_{m=1}^{MAXM} \left\{ \left[a_m H_R(\bar{\omega}_m) + b_m H_I(\bar{\omega}_m) \right] \cos \bar{\omega}_m t + \left[b_m H_R(\bar{\omega}_m) - a_m H_I(\bar{\omega}_m) \right] \sin \bar{\omega}_m t \right\} \tag{54}$$

where

$$H(\bar{\omega}_m) = \text{complex transfer function}$$

$$= H_R(\bar{\omega}_m) + i\,H_I(\bar{\omega}_m)$$

Frequently, it is desired to represent the forcing function in terms of the vehicle's velocity and size (reference length). A transformation is then made to the S axis where the relationship between S and t is

$$S = 12\,Ut/\bar{C} \tag{55}$$

where

U = vehicle velocity, ft/sec (obtained from Deck 000 data)

$\bar{C}$ = vehicle reference length, inches

Part 4 of this program is setup such that the forcing function can be expressed as a function of t or S. If the S axis is used for input, the program converts the S values to corresponding t values using equation 55 and all outputs are in units of time.

The vehicle's response to a discrete gust is computed for all response points and reductions in degrees of freedom.

The input data required to run Part 4 consists of the following:

a. Information in Deck 000

b. Transfer functions from Part 2 or input on cards

c. List of the reduced frequencies, Deck 110 or 210

d. Reduction in degrees of freedom, Deck 111. (If NDOF $\neq$ 0)

e. Information from Deck 220. (This information is only used for printout)

f. Data input in this section.

A flow chart for the input to Part 4 is shown in Figure 2-6.

2.6.1 DECK 400. This deck supplies the flow and I/O options for Part 4. This deck must be read before reading any other 400 series decks.

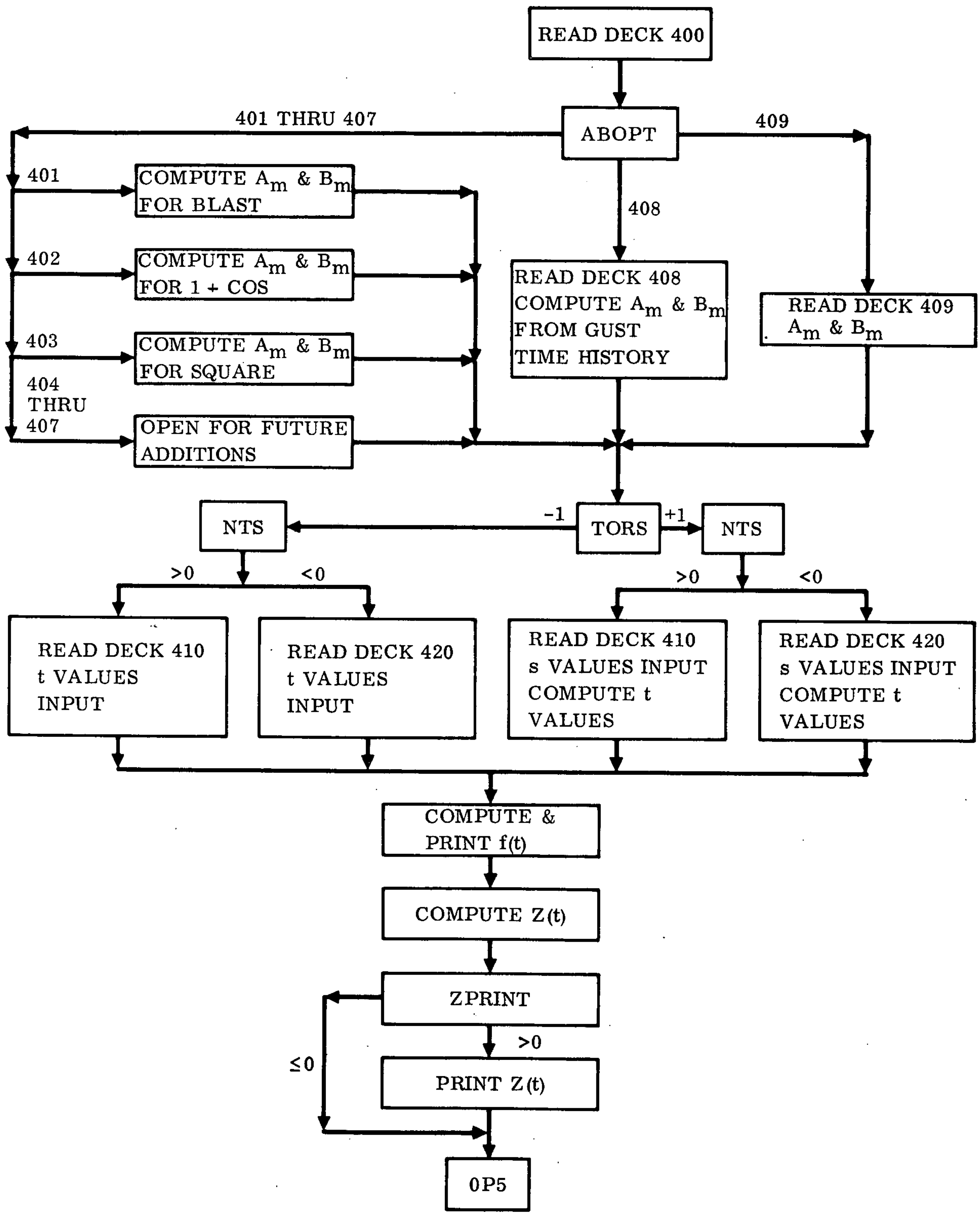


Figure 2-6. Part 4 Flow Chart

400 TITLE 4 (columns 2 thru 65) ABOPT NTS TORS ZPRINT T/S T/SEFF MAXM $\bar{C}$

where TITLE 4 is used to identify the printed output,

ABOPT = 401, 402, ... , or 409. (Input option for the A_m and B_m coefficients).

NTS = the number of time or S values supplied

= NTS supply Deck 410 $1 \le NTS \le 100$

= -NTS supply Deck 420 $1 \le NTS \le 5$

TORS = -1 time values will be supplied in Deck 410 or 420

= 1 S values will be supplied in Deck 410 or 420

ZPRINT > 0 print Z(t)

T/S = half period of forcing function T/S > 0

T/SEFF = half period of gust $0 < T/SEFF < T/S$

MAXM = maximum number of terms in the Fourier series $1 \le MAXM \le 100$

$\bar{C}$ = vehicle reference length, inches

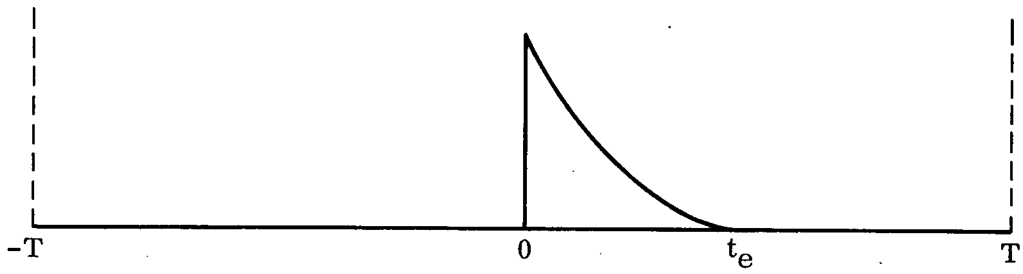
If ABOPT = 401, 402, or 403, the Fourier series coefficients are computed by the program. For convenience, define

$$te = T/SEFF \quad \text{and} \quad t = T/S \tag{56}$$

If ABOPT = 401, the Fourier series coefficients for a blast wave are computed.

$$f(t) = (1 - t/te)e^{-t/te}, \qquad 0 \le t \le te \tag{57}$$

$$f(t) = 0 \qquad t > te \tag{58}$$



$$a_o = \frac{te}{2T} e^{-1} \tag{59}$$

$$a_m = \frac{te}{T(1+C_m^2)^2} \left\{ e^{-1} \left[(1 - C_m^2) \cos C_m - 2C_m \sin C_m \right] + 2 C_m^2 \right\} \tag{60}$$

$$b_m = \frac{te}{T(1+C_m^2)^2} \left\{ e^{-1} \left[(1 - C_m^2) \sin C_m + 2 C_m \cos C_m \right] - C_m (1-C_m^2) \right\} \tag{61}$$

where

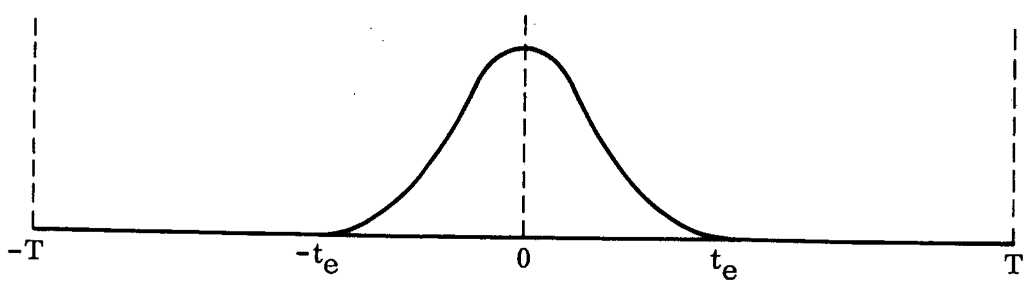
$$C_m = \bar{\omega}_m te$$

$$m = 1, 2, 3, \ldots \text{MAXM}$$

If ABOPT = 402, the Fourier series coefficients for a (1 + cos) gust are computed.

$$f(t) = 1/2 \left[1 + \cos (\pi t/te)\right] \quad -te \le t \le te \tag{62}$$

$$f(t) = 0 \qquad t < -te, \ t > te \tag{63}$$



$$a_o = te/2T \tag{64}$$

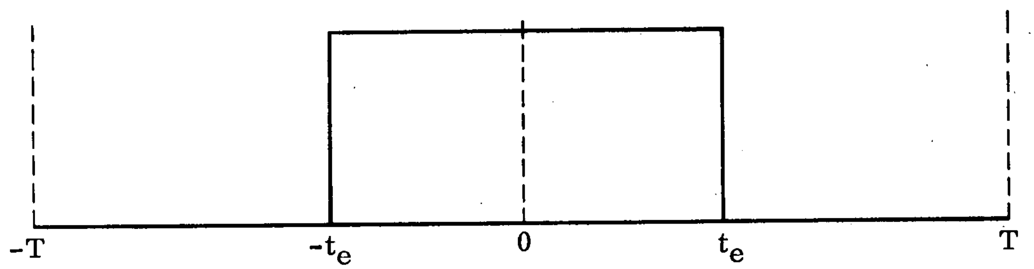
$$a_m = \frac{\sin(m\pi te/T)}{\left[1 - (mte/T)^2\right] m\pi} \tag{65}$$

$$b_m = 0 \tag{66}$$

If ABOPT = 403, the Fourier series coefficients for a square wave are computed.

$$f(t) = 1 \qquad -te \le t \le te \tag{67}$$

$$f(t) = 0 \qquad t < -t_e,\ t > t_e \tag{68}$$



$$a_o = te/T \tag{69}$$

$$a_m = \frac{2\sin(m\pi\ te/T)}{m\pi} \tag{70}$$

$$b_m = 0 \tag{71}$$

ABOPT = 404, 405, 406, and 407 have been left open for future additions and should not be used at this time.

2.6.2 DECK 408. The time history of the forcing function is input in this deck.

408			
NTFS		DELTAT	
F_1	F_2	F_3	F_{NTFS}

where

NTFS = the number of points defining the forcing function $20 \le NTFS \le 100$

DELTAT = time differential between the values of f(t) input

F_i = forcing function

The following assumptions are made on the input of this deck:

a. The first value of the forcing function is defined at time t = 0

b. The forcing function values are input at evenly spaced values of time, DELTAT

The program computes the Fourier series coefficients from the forcing function time history by numerical integration.

2.6.3 DECK 409. This deck is supplied if ABOPT = 409 and the Fourier coefficients are supplied as input data.

409			
a_o			
a_1	a_2	a_3	a_{MAXM}
b_1	b_2	b_3	b_{MAXM}

2.6.4 DECK 410. Deck 410 is supplied if NTS>0 and supplies the t or S values for which the response Z(t) is to be output.

410				
t_1	t_2	t_3	t_{NTS}	} TORS = -1
S_1	S_2	S_3	S_{NTS}	} TORS = 1

2.6.5 DECK 420. Deck 420 is supplied if NTS<0 and supplies the information needed to compute the t or S values for which the response Z(t) is to be output.

420			
T_1	DT_1	$TMAX_1$	
T_2	DT_2	$TMAX_2$	
.	.	.	TORS = -1
.	.	.	
T_{NTS}	DT_{NTS}	$TMAX_{NTS}$	

420			
S_1	DS_1	$TMAX_1$	
S_2	DS_2	$TMAX_2$	
.	.	.	TORS = 1
.	.	.	
S_{NTS}	DS_{NTS}	$TMAX_2$	

The t or S values are computed from the information in Deck 420 as follows:

$$t_1 = T_1$$

$$t_2 = T_1 + DT$$

$$t_j = T_1 + (j-1)\ DT_1$$

until

$$t_k \geq TMAX_1$$

$$t_{k+1} = T_2$$

$$t_{k+2} = T_2 + DT_2$$

etc.

If the total number of calculated t values exceeds 100, only the first 100 are used in the program.

If S values have been input in Deck 410 or 420, they are converted to t values by the following equation:

$$t_i = \frac{\bar{C}\, S_i}{12U} \tag{72}$$

2.6.6 MAXIMUM FREQUENCY USED IN THE FOURIER SERIES. The frequencies, $\bar{\omega}_m$, used in the Fourier series are defined by Equation 53 and

$$\bar{\omega}_{MAXM} = \frac{MAXM\, \pi}{T}$$

The value of $\bar{\omega}_{MAXM}$ cannot be larger than ω_{NK}. If it is, the value of MAXM will be reset such that

$$\bar{\omega}_{MAXM} \leq \omega_{NK}$$

This new value of MAXM will be used in all future calculations.

2.6.7 GUST TIME HISTORY. Along with Z(t), the program computes the Fourier series representation of the forcing function using Equation 53. When the results of Part 4 are plotted in Part 5, the Fourier series representation of the forcing function should be plotted to insure that sufficient terms have been used in the series.

2.6.8 INTERPOLATION OF TRANSFER FUNCTIONS. In the calculation of Z(t) for each response point, the corresponding transfer function for the frequencies $\bar{\omega}_m$ is needed. The values of $\bar{\omega}_m$ need not coincide with the frequencies at which the transfer functions were computed as the program interpolates for the required values. The procedure used is simply a linear interpolation with the real and imaginary components of the transfer function interpolated separately.

$$H_R(\bar{\omega}_m) = H_R(\omega_j) + \frac{\bar{\omega}_m - \omega_j}{\omega_{j+1} - \omega_j}\left[H_R(\omega_{j+1}) - H_R(\omega_j)\right] \tag{73}$$

where

$$\omega_j \leq \bar{\omega}_m \leq \omega_{j+1}$$

2.7 PART 5 – PLOT RESULTS

This section plots the results of Parts 2, 3, and/or 4 using the SC4020 Plotter. The following quantities, if previously computed, can be plotted:

a. Part 2. H(f)

b. Part 3. $\emptyset_i(f)$, $\emptyset_o(f)$, $\overline{A}(f)$, $N_o(f)$

c. Part 4. Time history of the forcing function and/or the time histories of the individual response points.

Each output plot is multiplied by an input constant. This constant can be used to change the units or as a correction factor.

Figure 2-7 shows the flow chart for the input to Part 5.

2.7.1 DECK 500. This deck supplies information specifying what results are to be plotted. It must be supplied before any other 500 series decks.

```
500

NPLOT2        NPLOT3        NPLOT4
```

where

NPLOT2 = number of plots for Part 2, $0 \leq NPLOT2 \leq 20$

NPLOT3 = number of plots for Part 3, $0 \leq NPLOT3 \leq 63$

NPLOT4 = number of plots for Part 4, $0 \leq NPLOT4 \leq 20$

2.7.2 DECK 510. This deck supplies the titles to be used with the plots and must be supplied.

510	
NTITLE1	
$TITLE_1$	The titles are supplied in columns 2 thru 60
$TITLE_2$	
.	
.	
$TITLE_{NTITLE_1}$	

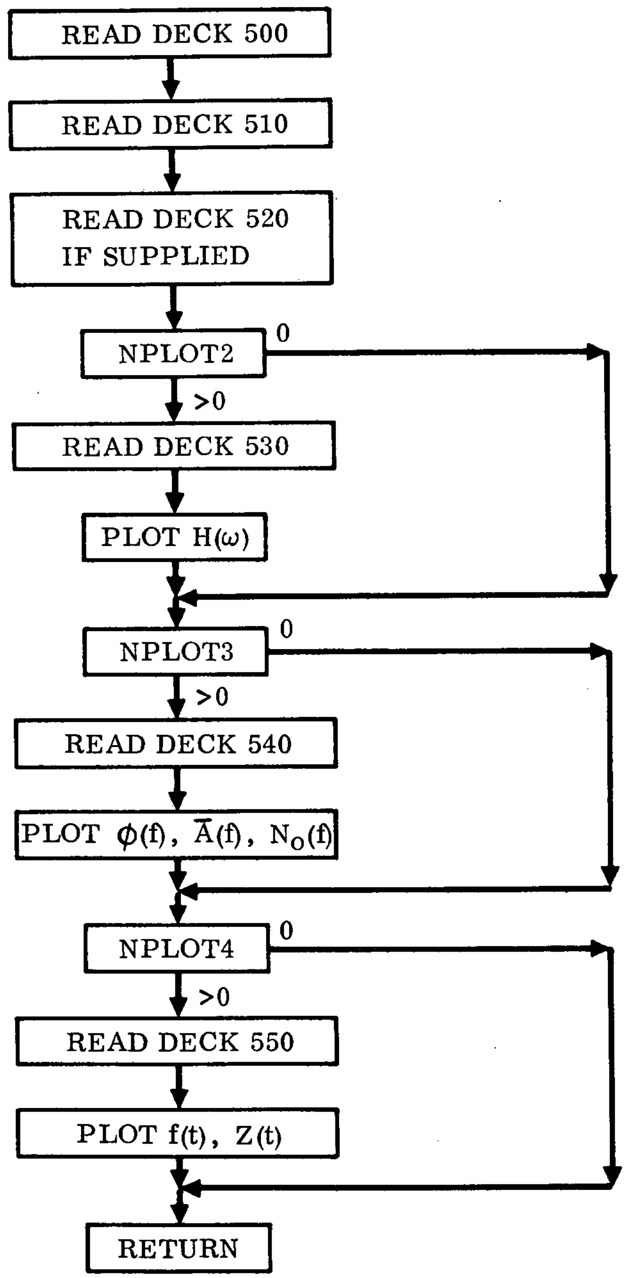


Figure 2-7. Part 5 Flow Chart

where

$NTITLE1$ = number of titles supplied in Deck 510

$6 \leq NTITLE1 \leq 100$

Individual titles can be changed in a later subcase by supplying an alternate form of Deck 510.

```
510

-NT

TITLE_NT        (Columns 2 thru 60)

-NT

TITLE_NT        (Columns 2 thru 60)

  .

  .
```

where

NT is the number of the title to be changed.

$1 \leq |NT| \leq NTITLE1$

$TITLE_{NT}$ will replace the previous title.

As many titles can be changed as desired, the only restriction is that Deck 510 must have been previously supplied in its original format.

2.7.3 DECK 520. This deck is optional and can be used to supply supplemental titles. The format for this deck is identical to Deck 510.

$$\begin{array}{l}
520 \\
NTITLE2 \\
\left.\begin{array}{l}
\quad TITLE_1 \\
\quad TITLE_2 \\
\quad\quad . \\
\quad\quad . \\
\quad TITLE_{NTITLE_2}
\end{array}\right\} \text{Columns 2 thru 60}
\end{array}$$

where

NTITLE2 = number of titles supplied in Deck 520

$1 \leq \text{NTITLE2} \leq 30$

Individual titles can be changed in a later subcase by exercising the same alternate form that was used with Deck 510.

2.7.4 DECK 530. This deck is input when NPLOT2 > 0 and supplies the information needed to plot the transfer functions. Figure 2-8 shows the type of plot that will be produced.

530			
1	GRID	NCPP	PLOT 1
T_1	T_2	T_6	
L_1	N_1	$MULT_1$	
.			
.			
L_{NCPP}	N_{NCPP}	$MULT_{NCPP}$	
2	GRID	NCPP	PLOT 2
T_1	T_2	T_6	
L_1	N_1	$MULT_1$	
.			
.			
NPLOT2	GRID	NCPP	PLOT NPLOT2
.			

where

GRID = 1 a linear scale is used for the Y axis

= 2 a log scale is used for the Y axis

NCPP = number of curves to plot on this plot. $1 \leq \text{NCPP} \leq 6$

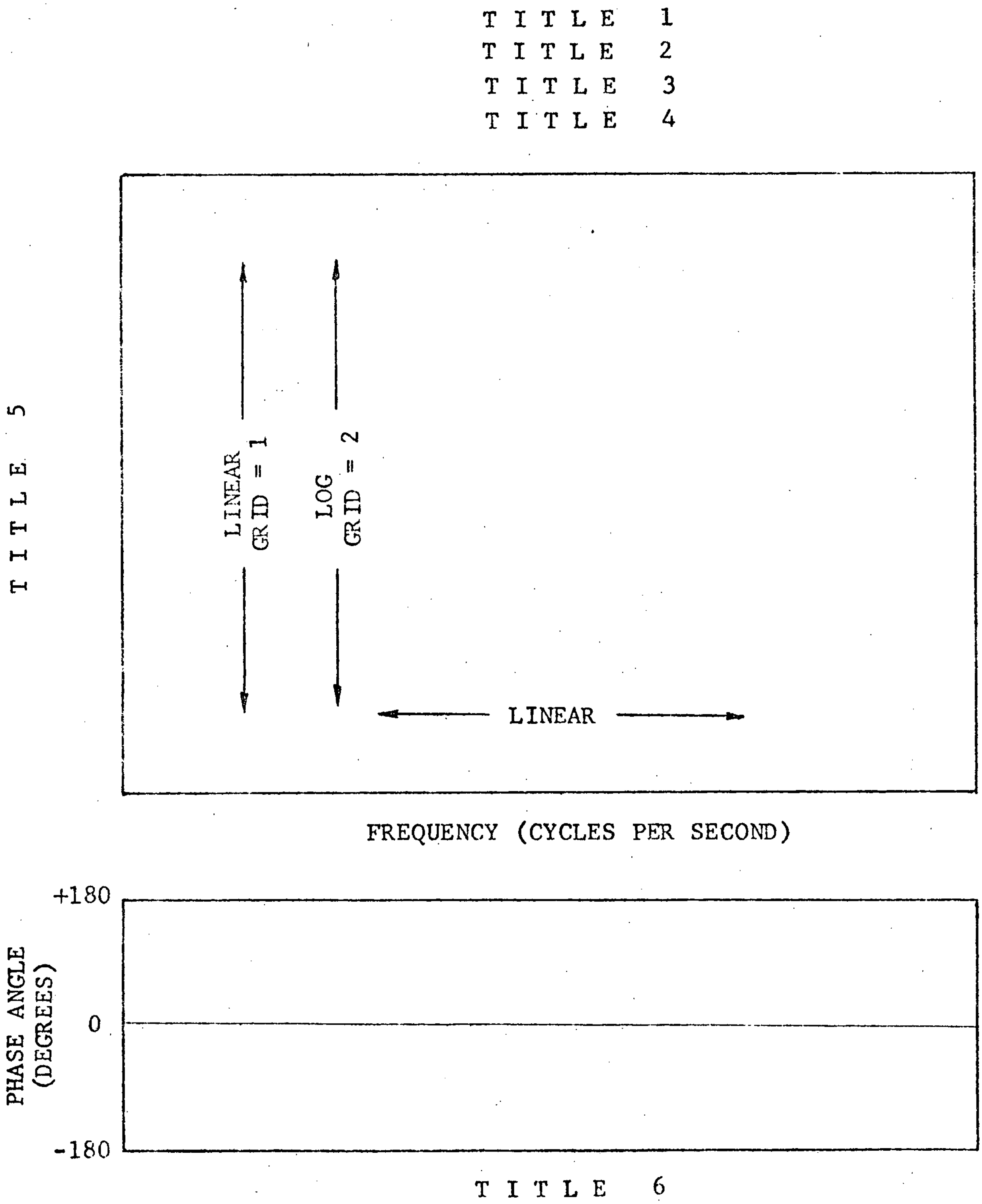


Figure 2-8. Grid Used For Plotting Transfer Functions

T_i = title numbers, see Figure 2-8

= + use title from Deck 510 $1 \le T_i \le 100$

= - use title from Deck 520 $1 \le |T_i| \le 30$

L_m = plot the L_m^{th} response point

$1 \le L_m \le$ LMAX (LMAXF if D250 > 0)

N_m = index for the degrees of freedom to use

$1 \le N_m \le$ NN where NN = 1 + NDOF when NDOF ≥ 0

NN = |NDOF| when NDOF < 0

$MULT_m$ = Multiplication factor for the m^{th} curve. (The multiplication factor will be applied to the magnitude of H and not the phase angle.)

NOTE

If the magnitude is zero at any frequency, the points are not plotted.

The plotting symbols used to plot each curve are as follows:

Curve No. 1 - X	Curve No. 4 - *
Curve No. 2 - 0	Curve No. 5 - $
Curve No. 3 - +	Curve No. 6 - □

2.7.5 DECK 540. This deck is input when NPLOT3 > 0 and supplies the information needed to plot the results of Part 3. The format for this deck is the same of that for Deck 530 but the functions of some of the variables are different.

When NCPP is greater than zero, the output power spectrum is plotted. The format of the input deck and function of the input variables will be the same as Deck 530 except that GRID is applied to the X axis instead of the Y axis. Figure 2-9 shows the type of plot produced.

When NCPP is equal to zero, the input power spectrum is plotted. Only L_1, N_1, and $MULT_1$ are supplied. L_1 and N_1 are read but not used or checked. The input power spectrum is multiplied by $MULT_1$.

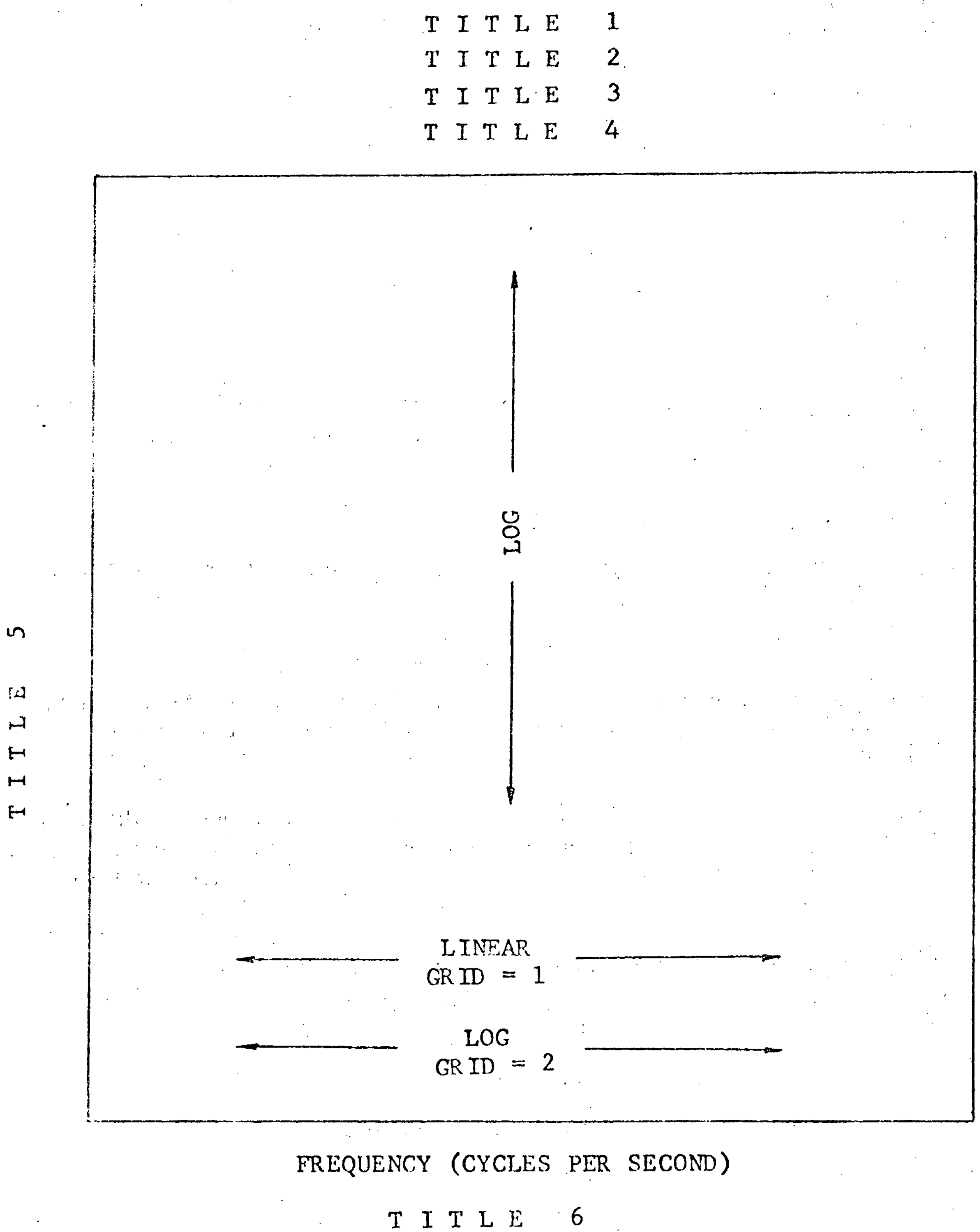


Figure 2-9. Grid Used For Plotting PSD Functions

When NCPP is less than zero, either $\bar{A}(f)$ or $N_o(f)$ is plotted. The input format is the same as that used for Deck 530 with $|NCPP|$ values of L, N, and MULT being supplied. The L_m and N_m values are used to locate the desired response point and degree of freedom. The $MULT_m$ constant determines whether to plot $\bar{A}(f)$ or $N_o(f)$.

$MULT_m = 1$ plot $\bar{A}(f)$

$MULT_m = 2$ plot $N_o(f)$

Neither $\bar{A}$ nor N_o is multiplied by $MULT_m$. The type of plot used is similar to Figure 2-9 but has a linear-linear grid. ($\bar{A}$ and N_o should not be plotted on the same plot.) VFREQ must be greater than zero to plot $\bar{A}$ and N_o.

2.7.6 DECK 550. This deck is input when NPLOT4 > 0 and supplies the information needed to plot the results of Part 4. The format for this deck is the same as that of Deck 530 with the following exceptions:

a. GRID is read but not checked or used.

b. NCPP must be between 1 and 3 (A maximum of three curves can be plotted on any given plot).

c. Nine title numbers are supplied instead of six.

The Fourier series representation of the forcing function can be plotted by setting $L_i = 1$ and $N_i = 0$. Figure 2-10 shows the type of plot produced from the results of Part 4.

The results of Parts 2, 3, and 4 are stored on a sequential I/O device. Although it is possible to plot the different response points in a random fashion, the most efficient procedure is to plot them in the same order as they are stored on the output device. This will eliminate rewinding and searching through the I/O device.

The results of Part 2 should be plotted in the following order:

Response point $L_m(1)$

First degree of freedom

Second degree of freedom

.

.

Last degree of freedom

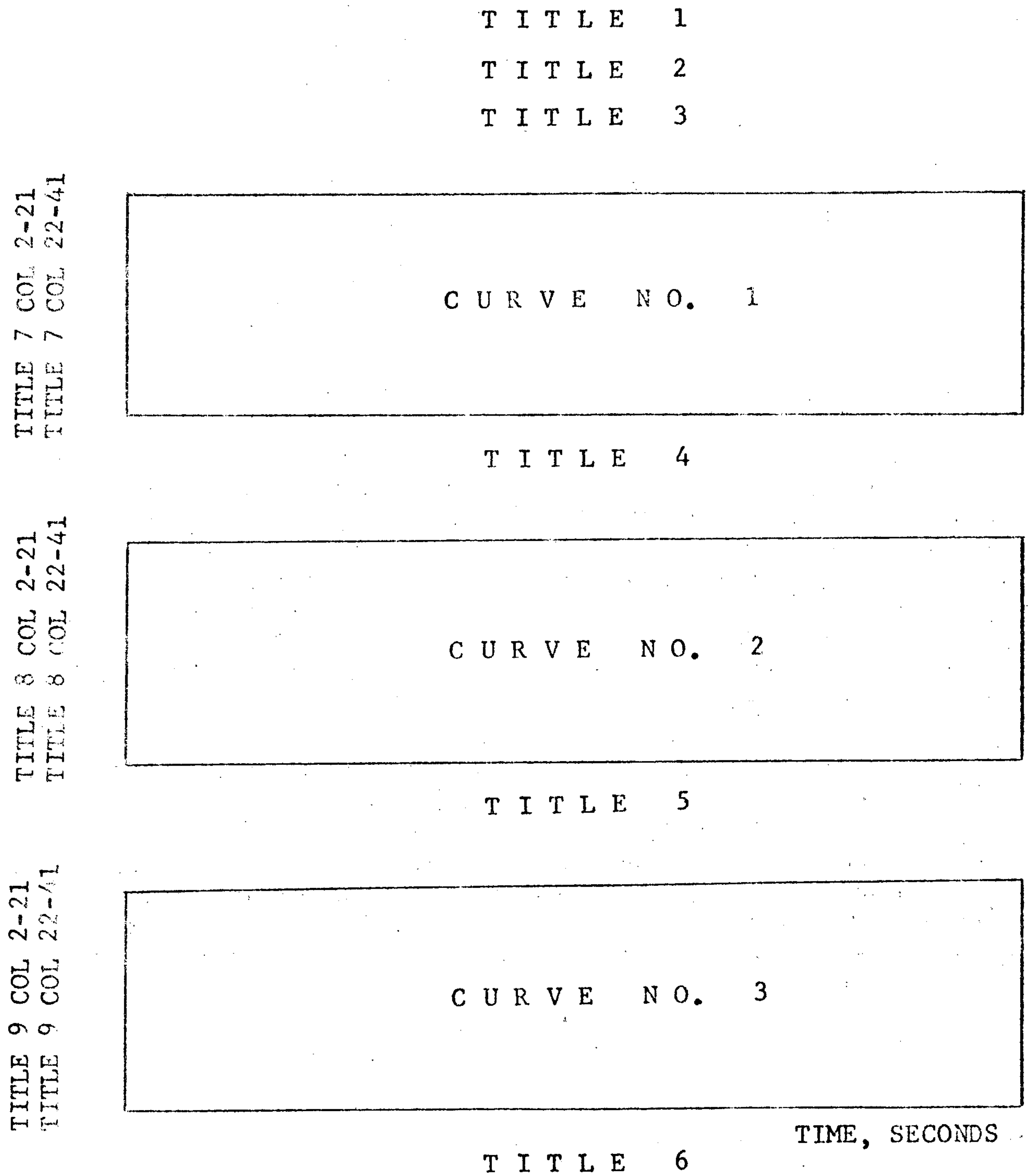


Figure 2-10. Grid Used For Plotting Time Histories

Response point $L_m(2)$

First degree of freedom

.

.

Response point $L_m(i)$

First degree of freedom

.

.

Last degree of freedom

Only selected output need be plotted, but in this order.

The results of Part 3 should be plotted in the same order as shown above with the following addition. The input power spectrum should be plotted first followed by all the output power spectra followed by all the $\bar{A}(f)$ and lastly, all the $N_o(f)$.

The results of Part 4 should be plotted in the same order as Part 2. If the Fourier series representation of the forcing function is desired, it should be plotted first.

If any of the curves are zero for any values of the independent variable, they are not plotted by the program.

On subcases, Deck 500 can be resupplied changing the number of output plots. If each of the plot options remain constant or are reduced in size, Decks 530, 540, and 550 need not be resupplied. (If the plot option is reduced in size, the curves that are plotted are the first supplied in the corresponding input deck. If the plot option is set to zero, no plots are made. It is possible to come back in even a later subcase and reset the plot option to what it originally was.) If the size of the plot option is increased, then the corresponding input deck must be resupplied to conform with the new subcase size.

2.8 PROGRAMMED ERROR PRINTOUT

When the program detects an error in the input data, an error message is printed. The format for the error message is shown below:

```
ERROR NUMBER =
LAST CARD READ =
N1 =                 N2 =
N3 =                 N4 =
N5 =                 N6 =
N7 =                 N8 =
TITLE 1
TITLE 2
MESSAGE STATING WHAT ACTION WILL
BE TAKEN
```

ERROR NUMBER - Designates what error has occurred.

N1-N8 - Diagnostic information pertinent to each error number.

2.8.1 <u>ERROR LEVELS</u>. The action that will be taken depends on the severity of the error. Four different error levels exist and are as follows:

<u>Error level 1.</u> This level is used for errors so severe that the job must be terminated.

<u>Error level 2.</u> A major error has occurred and it is impossible to continue reading the information in this subcases. The execution of this and the remaining subcases will not be attempted, but the data in the remaining subcases will be checked for further errors.

<u>Error level 3.</u> A major error has occurred and the execution of this and following subcases will not be attempted. The data in this and all following subcases will be checked for further errors.

<u>Error level 4.</u> A minor error has occurred of such a nature that the program will make an assumption as to the desired correction to be made (see the description of each error to determine what assumption was made). The execution of this and all following subcases will continue as long as no level 1, 2, or 3 errors have been or are encountered.

2.8.2 ERROR NUMBER DEFINITION

0.0 N1 was read for a deck number.

Level 2

0.1 One of main size variables in Deck 000 is incorrect.

N1 = NQ

N2 = NDOF

N3 = NK

N4 = IP

Level 2

0.2 $B_r \leq 0$.

Level 3

0.3 The number of frequencies (N1) on the $\overline{q}$ input tape does not equal NKI (N2) or the number of sets of degrees of freedom, NC (N3) does not equal (1 + NDOF) or (NDOF) (N4).

Level 3

0.4 N1 was read for Deck 000.

Level 2

0.5 No such error number.

0.6 During the computation of $\{\overline{H}\} = [T]\{H\}$, the file on the H input tape could not be located.

Level 1

100.1 Part 1 is being read and Deck 100 was not supplied. The deck number is N1.

Level 3

110.1 K_1 is 0, N1 $\rightarrow$ N8 = $K_1 \rightarrow K_8$.

Level 3

110.2 $K_{i-1} \geq K_i$, N1 $\rightarrow$ N8 = $K_{i-1} \rightarrow K_{i+7}$.

Level 3

111.1 DOF_i (N1) is either greater than NQ-1 or less than 1.

Level 2

111.2 E_i is either greater than NQ or less than 1, $N1 \rightarrow N8 = E_i \rightarrow E_{i+7}$

Level 3

111.3 The input option for Deck 111 (N1) specifies a standard reduction of degrees of freedom for rigid body motion but NDOF (N2) is not ±2.

Level 3

120.1 The input option for Deck 120 (N1) is not 1, 2, or 3.

Level 2

121.1 K_R or K_I (N1) is not between ±9.

Level 3

124.1 The number of rows (N1) on the Q_{rs} input tape does not equal NQ (N2) or the number of columns (N3) does not equal NQ or the number of frequencies (N4) does not equal NK (N5).

Level 3

124.2 NOP11 is not equal to 1 or 2.

Level 3

160.1 The input option for Deck 160 (N1) is not 1, 2, or 3.

Level 2

161.1 K_{Rf} or K_{If} (N1) is not between ±9.

Level 3

164.1 The number of rows (N1) on the Q_{rf} input tape does not equal NQ (N2), or the number of columns (N3) does not equal 1, or the number of frequencies (N4) does not equal NK (N5).

Level 3

200.1 One of the control numbers in Deck 200 is incorrect.

N1 = LMAX N2 = NF

N3 = NFB N4 = FBIN

Level 2

200.2 The program is attempting to read a 200 series deck without first reading Deck 200.

Level 2

210.1 K_1 is less than or equal to 0. $N1 \rightarrow N8 = K_1 \rightarrow K_8$.

Level 3

210.2 $K_{i-1} \geq K_i$, $N1 \rightarrow N8 = K_{i-1} \rightarrow K_{i+7}$.

Level 3

212.1 The number of frequencies (N1) on the H input tape is not equal to NKI (N2), or the number of response points (N3) is not equal to LMAX (N4), or the number of sets of degrees of freedom (N5) is not equal to (1 + NDOF or |NDOF|) (N6).

Level 3

220.1 L_i (N1) is either less than 1 or greater than NF.

Level 3

240.1 The input option for Deck 240 (N1) is not 0, 1, 2, or 3.

Level 2

241.1 The input option for Deck 241 (N1) is not 0, 1, or 2.

Level 2

241.2 K_i is not between ±9, $N1 \rightarrow N8 = K_i \rightarrow K_{i+7}$.

Level 3

244.1 The number of rows (N1) on the $\overline{F}$ input tape does not equal NFB (N2), or the number of columns (N3) does not equal (NQ or NQ+1 if NFBF $\neq$ 0) (N4), or the number of frequencies (N5) does not equal NK (N6).

Level 3

246.1 The number of rows (N1) on the $\overline{F}_f$ input tape does not equal NFB (N2), or the number of columns (N3) does not equal 1, or the number of frequencies (N4) does not equal NK (N5).

Level 3

250.1 Either LMAXF (N1) is not between 1 and 60 or NELEM (N2) is not between 1 and LMAX * LMAXF, (LMAX = N3).

Level 2

250.2 Either NR (N1) is not between 1 and LMAXF or NC (N2) is not between 1 and LMAX.

Level 2

300.1 The input power spectrum option (N1) is not between 301 and 309.

Level 3

300.2 VFREQ (N2) is greater than NKI, VFREQ will be set equal to 0.

Level 4

301.1 The scale of turbulence (N1) in Deck 301 or 302 is less than or equal to zero.

Level 3

303.1 A_3 (N1) is less than or equal to zero.

Level 3

304.1 Either A_8 (N1) or A_{16} (N2) is less than zero.

Level 3

305.1 The scale of turbulence (N1) is not greater than zero.

Level 3

305.2 NT (N1) is not between 2 and 25.

Level 2

305.3 The value of T listed (N1) is not greater than zero.

Level 3

305.4 f_i (N1) is either less than zero or greater than f_{i+1} (N2).

Level 3

30N.1 Where N = 6, 7, or 8. NPSDIN says to use one of the deck numbers that were left open.

Level 3

400.1 The program is attempting to read a 400 series deck without first having read deck 400.

Level 2

400.2 The gust input option (N1) is not between 401 and 409.

Level 3

400.3 NTS (N1) is either not between 1 and 100 or not between -1 and -5.

Level 2

400.4 T/S (N1) is less than or equal to zero, or T/SEFF (N2) is greather than T/S, or TORS (N3) is not ±1, or MAXM (N4) is not between 1 and 100, or $\bar{C}$ (N5) is less than or equal to zero.

Level 2

408.1 NTFS (N1) is not between 20 and 100.

Level 2

410.1 NTS (N1) is less than 1. (This value of NTS was to be used with Deck 420.)

Level 2

420.1 NTS (N1) is greater than or equal to 1. (This value of NTS was to be used with Deck 410.)

Level 2

500.1 The program is attempting to read a 500 series deck (N1) without having read Deck 500.

Level 2

500.2 NPLOT2 (N1) is not between 0 and 20, or NPLOT3 (N2) is not between 0 and 63, or NPLOT4 (N3) is not between 0 and 20.

Level 2

510.1 NTITLE1 (N1) is not between 6 and 100.

Level 2

510.2 The program is attempting to read Deck 510, option 2 without having read Deck 510, option 1 first.

Level 2

510.3 For Deck 510, option 2, NT (N1) is not between -1 and -NTITLE1 (N2). This title change will be skipped.

Level 4

520.1 NTITLE2 (N1) is not between 1 and 30.

Level 2

520.2 The program is attempting to read Deck 520, option 2 without having read Deck 520, option 1 first.

Level 2

520.3 For Deck 520, option 2, NT (N1) is not between -1 and -NTITLE2 (N2). This title change will be skipped.

Level 4

530.1 Plot number (N1) is not right, or GRID (N2) is not 1 or 2, or NCPP (N3) is not between 1 and 6.

Level 2

530.2 T_i is greater than 100, it will be set equal to 1. $N1 \rightarrow N6 = T_i \rightarrow T_{i+5}$.

Level 4

530.3 T_i is less than -30 or equal to 0, it will be set equal to -1. $N1 \rightarrow N6 = T_i \rightarrow T_{i+5}$.

Level 4

530.4 For the N1th plot, curve N2, L (N3), or N (N4) is either less than 1 or larger than the problem size. This curve will not be plotted.

Level 4

530.5 For the N1th plot, curve N2, MULT (N3) is less than zero. This will cause trouble on the log-linear plot. MULT will be set equal to 1.

Level 4

540.1 Plot number (N1) is not right or GRID (N2) is not 1 or 2.

Level 2

540.2 Same as 530.2

Level 4

540.3 Same as 530.3

Level 4

540.4 |NCPP| (N1) is greater than 6.

Level 2

540.5 Same as 530.4

Level 4

540.6 No such error number.

540.7 For the N1th plot, curve N2, MULT (N3) is less than zero. This will cause trouble on the log plot. MULT will be set equal to 1.

Level 4

550.1 Plot number (N1) is not right or NCPP (N3) is not between 1 and 3.

Level 2

550.2 Same as 530.2

Level 4

550.3 Same as 530.3

Level 4

550.4 Same as 530.4

Level 4

900.1 OP1 (N1) is incorrect.

Level 2

900.2 OP11 (N1) is not 1 or 2.

Level 2

900.3 QRSIN (N1) is not 2, 122, 123, or 124. It will be assumed to be 124 to continue checking the data but the execution of this problem will not be attempted.

Level 3

900.4 QRSIN (N2) says to use the Q_{rs} terms from a previous problem but the Q_{rs} terms were not supplied in a previous problem. N1 = OP11.

Level 3

900.5 QRFIN (N1) is not 2, 162, 163, or 164. It will be assumed to be 164 to continue checking the data but the execution of this subcase will not be attempted.

Level 3

900.6 QRFIN (N1) says to use the Q_{rf} terms from a previous subcase but the Q_{rf} terms were not supplied in a previous subcase.

Level 3

900.7 OP2 (N1) is not equal to -1 or 2. It will be set equal to 2.

Level 4

900.8 FBIN (N1) says to use $\bar{F}$ terms from a previous subcase, but the $\bar{F}$ terms were not supplied in a previous subcase.

Level 3

900.9 OP3 (N1) is not -1, 3, 4, or 5. It will be set equal to 3.

Level 4

901.1 Transfer functions are not available to work Part 3.

Level 3

901.2 Transfer function are not available to work Part 4.

Level 3

901.3 OP4 (N1) is not -1, 4 or 5. It will be set equal to 4.

Level 4

901.4 OP5 (N1) is not -1 or 5. It will be set equal to 5.

Level 4

901.5 The response of the generalized coordinates are not available to work Part 2.

Level 3

901.6 No such error number.

901.8 The number of files on input tape unit N1 is greater than the maximum of 20.

Level 3

2.9 MAGNETIC TAPE INPUT/OUTPUT

The program can accept a combination of up to five input/output (I/O) tapes. These tapes and the units on which they are mounted are listed below:

Unit	Contents	Label	Type
9	Q_{rs}/Q_{rf}	XXXXXXQXX	Input/output
10	$\overline{F}/\overline{F}_f$	XXXXXXFXX	Input only
11	Q_{rs}	XXXXXXAXX	Input/output
12	Q_{rs}	XXXXXXHXX	Input/output
13	$\overline{q}$	XXXXXXGXX	Input/output

The label is composed of a six digit case number, an alphabetic, and a two digit sub-case number.

If any of the I/O units are used as input, they cannot be used as output in a later sub-case. (It is not possible to write on an input tape.) If any of the I/O units are to be used as input in a second, third, etc. subcase but not in the first subcase, the case and subcase numbers of the files to be used should still be listed as input to the first case. This will not cause an error because the flow options in the first case will disregard the tape inputs. However, the program will have been alerted and will not attempt to write on any of these units. When the subcase is run in which the input tapes are actually used, the case and subcase numbers of the desired files should be input again.

The output from more than one subcase can be placed on each of the output tapes. The output from each subcase will be preceded by the case and subcase number from which it was generated. The output from up to 20 separate subcases can be placed on any given output tape.

SECTION 3

REFERENCES

1. Huntington, R. G., "A Method for Determining the Response of Space Shuttle to Atmospheric Turbulence, Volume I, Space Shuttle Turbulence Response," General Dynamics Convair Aerospace Division Report GDC-DDE 71-002, 1 November 1971.

APPENDIX A

INTERPOLATION PROCEDURE

The interpolation procedure used in Part 1 of the program is described below:

Given: $f(K_1), f(K_2), \ldots\ldots, f(K_{NK})$

where $K_1 < K_2 < \ldots . K_{NK}$

The problem is to interpolate between each successive value of K to determine

$$f\left[K_i + \left(\frac{m}{IP+1}\right)\Delta K_i\right] \qquad \begin{array}{l} i = 1, 2, \ldots, NK-1 \\ m = 1, 2, \ldots, IP \end{array}$$

where

$$\Delta K_i = K_{i+1} - K_i$$

The equation used to interpolate is

$$f\left[K_i + \left(\frac{m}{IP+1}\right)\Delta K_i\right] = f(K_i) - A_m F_i - C_i \Delta K_i^{\,2} B_m\left(1 - B_m^{\,2}\right) - C_{i+1}\Delta K_i^{\,2} A_m\left(1 - A_m^{\,2}\right)$$

where

$$A_m = \frac{m}{IP+1}$$

$$B_m = 1 - A_m$$

$$F_i = f(K_i) - f(K_{i+1})$$

$$C_1 = C_{NK} = 0$$

The C_i ($i = 2, 3, \ldots, NK-1$) coefficients are computed from the following matrix equation:

$$\{C\} = [D]^{-1}\{\Delta\}$$

where

$$\{C\} = \begin{Bmatrix} C_2 \\ C_3 \\ \cdot \\ \cdot \\ C_{NK-1} \end{Bmatrix}$$

The Δ vector is a function of the curve being interpolated.

$$\{\Delta\} = \begin{Bmatrix} F_2/\Delta K_2 \\ F_3/\Delta K_3 \\ \cdot \\ \cdot \\ F_{NK-2}/\Delta K_{NK-2} \\ F_1/\Delta K_1 \end{Bmatrix} - \begin{Bmatrix} F_3/\Delta K_3 \\ F_4/\Delta K_4 \\ \cdot \\ \cdot \\ F_{NK-1}/\Delta K_{NK-1} \\ F_2/\Delta K_2 \end{Bmatrix}$$

The D matrix, shown below, is a function of the independent variable, K.

$$D = \begin{bmatrix} \Delta K_2 & 2(\Delta K_2+\Delta K_3) & \Delta K_3 & 0 & 0 & 0 \\ 0 & \Delta K_3 & 2(\Delta K_3+\Delta K_4) & \Delta K_4 & 0 & 0 \\ 0 & 0 & \Delta K_4 & 2(\Delta K_4+\Delta K_5) & 0 & 0 \\ 0 & 0 & 0 & \Delta K_5 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot \ddots & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \ddots & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \ddots & \cdot & \cdot \\ 0 & 0 & 0 & 0 & \Delta K_{NK-3} & 0 \\ 0 & 0 & 0 & 0 & 2(\Delta K_{NK-3}+\Delta K_{NK-2}) & \Delta K_{NK-2} \\ 0 & 0 & 0 & 0 & \Delta K_{NK-2} & 2(\Delta K_{NK-2}+\Delta K_{NK-1}) \\ 2(\Delta K_1+\Delta K_2) & \Delta K_2 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$(NK-2) \times (NK-2)$

APPENDIX B

FLOW CHART OF READ SUBROUTINES

Figure B-1 presents the read subroutines in flow chart format.

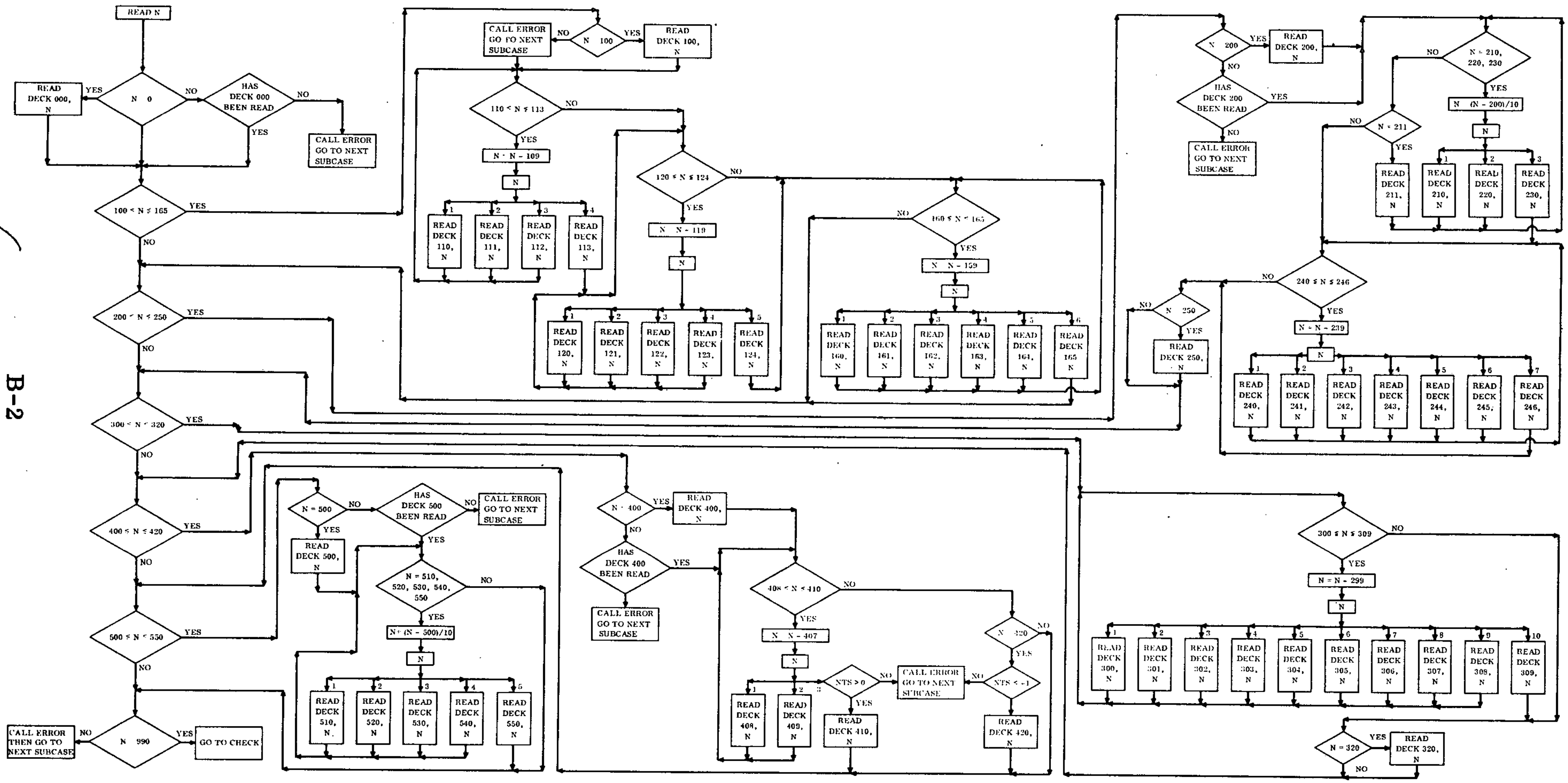


Figure B-1. Flow Chart of Read Subroutines

APPENDIX C

FLOW CHART OF CHECKING SUBROUTINES

Figure C-1 presents the checking subroutines in flow chart format.

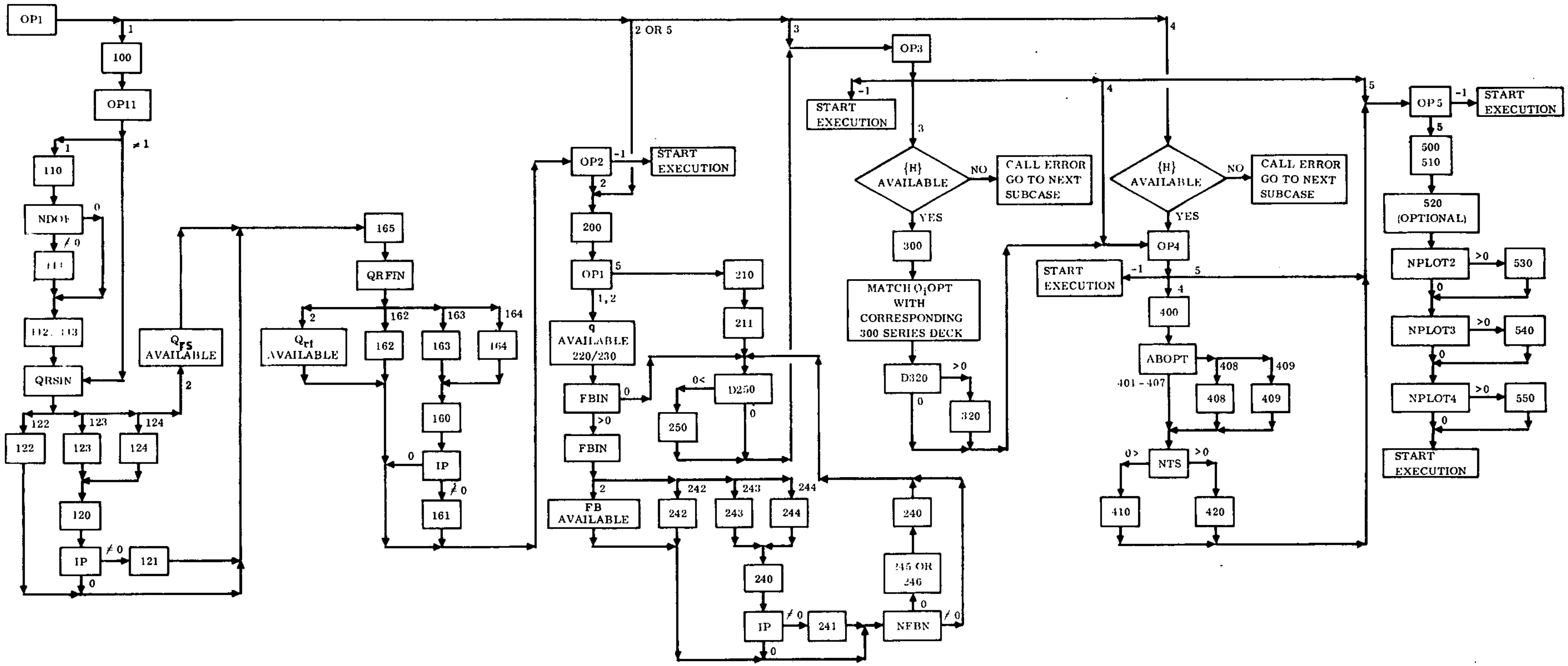


Figure C-1. Flow Chart of Checking Subroutines