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A STRUCTURAL WEIGHT ESTIMATION PROGRAM (SWEEP) FOR AIRCRAFT. VOLUME IV - MATERIAL PROPERTIES, STRUCTURE TEMPERATURE, FLUTTER AND FATIGUE

H. Haroldson, et al

Rockwell International Corporation

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20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

Three computer programs were written with the objective of predicting the structural weight of aircraft through analytical methods. The first program, the structural weight estimation program (SWEEP), is a completely integrated program including routines for airloads, loads spectra, skin temperatures, material properties, flutter stiffness requirements, fatigue life, structural sizing, and for weight estimation of each of the major aircraft structural components. The program produces first-order weight estimates

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and indicates trends when parameters are varied. Fighters, bombers, and cargo aircraft can be analyzed by the program. The program operates within 100,000 octal units on the Control Data Corporation 6600 computer. Two stand-alone programs operating within 100,000 octal units were also developed to provide optional data sources for SWEEP. These include (1) the flexible airloads program to assess the effects of flexibility on lifting surface airloads, and (2) the flutter optimization program to optimize the stiffness distribution required for lifting surface flutter prevention.

The final report is composed of 11 volumes. This volume (volume IV) contains the methodology, program description, and user's information for the use of material properties, flutter and temperature module, and fatigue module of SWEEP.

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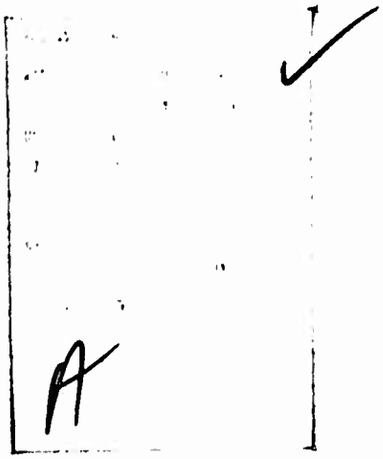

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Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

JAMES H. HALL, Colonel, USAF
Deputy for Development Planning

PREFACE

This report was prepared by Rockwell International Corporation, Los Angeles Aircraft Division, Los Angeles, California, under Contract F33615-71-C-1922, No. FX2826-71-01876/C093. The work was performed for the Deputy for Development Planning, Air Force System Command, Wright-Patterson Air Force Base, Ohio, and extended from September 1971 to June 1974.

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The final report was published in 11 volumes; the complete list is as follows:

Volume	
I	"Executive Summary"
II	"Program Integration and Data Management Module"
III	"Airloads Estimation Module"
IV	"Material Properties, Structure Temperature, Flutter, and Fatigue"
V	"Air Induction System and Landing Gear Modules"
VI	"Wing and Empennage Module"
VII	"Fuselage Module"
VIII	"Programmer's Manual"
IX	"User's Manual"
X	"Flutter Optimization Stand-Alone Program"
XI	"Flexible Airloads Stand-Alone Program"

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INTRODUCTION TO VOLUME IV

The Structural Weight Estimation Program (SWEEP) was developed as an aircraft structural prediction tool suitable for use in the preliminary design phase of vehicle synthesis. To insure prediction of realistic trend data, it considers many problem- and component-dependent criteria, tasks which are normally performed by different engineering disciplines. The functions of data development and assessment have been integrated into various program modules so that criteria and environment considerations are consistent. The purpose of this volume is to present methods and formulations and to discuss program routines that evaluate material properties, structure temperature, flutter, and fatigue.

1. Part 1 describes the material library files, data arrangement, development of stress-strain curves, and routines within the different program modules which process data from these files.

2. Part 2 describes the methodology and program of the flutter and temperature module. This module performs two basic tasks:

   a. Calculates structural temperatures at the various speeds and altitudes where loading and flutter analyses are performed.

   b. Determines the mach-altitude points most critical to the flutter evaluation of each lifting surface, and sets up the various flutter-related parameters and material properties to be used in the wing and empennage module flutter analyses. The module establishes these parameters for the following lifting surface configurations:

      (1) Wing

         (a) Swept
         (b) Unswept

      (2) Horizontal tail

      (3) Vertical tail

         (a) Conventional arrangement
         (b) T-tail arrangement

      Descriptions, autoflow charts, and program listings, of routines used to accomplish these tasks are included within Part 2.

5. Part 3 describes the methodology and program of the fatigue module. This module evaluates wing bending moment and cabin pressurization spectra, and determines the nominal spectrum stresses required to achieve the specified vehicle life. A correlation between design loads and spectrum loads is then used to establish allowable not-to-be-exceeded fatigue cutoff stresses. These allowables are used by the structural synthesis modules in sizing the structure. Wing spectrum loads are either user input data or are calculated by the airloads module. Derivation of these loads is presented in Volume III.

   Descriptions, autoflow charts, and program listings of the routines used by the fatigue module are included in Part 3.

PART 1

MATERIAL PROPERTIES

Section I

INTRODUCTION

The structural synthesis procedures of an analytical weight-estimating program are not only dependent upon the modeling of general structural geometries, design loads, and requirements, but also on the modeling of the physical and mechanical properties of the materials selected for the analysis. Material descriptions must be in a form that can be used to reflect their behavior under load so that structures can be synthesized to satisfy conditions of strength, stiffness, and stability. SWEEP includes a procedure to describe the physical and mechanical properties of materials selected for analysis of each air vehicle component. This is accomplished with a material library and special routines designed to provide required material descriptions for each weight estimating module. Updating and expansion of the data bank require only the addition of data sets describing the materials to be changed or added.

The material properties library consists of a maximum of 20 sets of material data stored, at run time, on mass storage files. This file includes a full range of physical and mechanical properties for structural materials such as aluminum, titanium, and steel. The various alloys, conditions, forms, or heat treats for each material are identified and described separately in individual records of the file. Each record includes material properties for one to six temperatures covering the normal operating temperature range of that material. An interpolation procedure in the evaluation routine is used to obtain the material properties for temperatures other than those described in the data set.

The material property library was compiled from data developed for various in-house preliminary design and contract proposal efforts. The data are similar to the information found in MIL-HDBK-5A, "Metallic Materials and Elements for Aerospace Vehicle Structures." This document can be used in the preparation of new data sets to expand the scope of the library.

Table 1 lists the materials found in the current SWEEP data bank. To allow for ease in identification, each material is listed by relative record number and descriptive title. This title is always included in the output data set describing the selected structural material for the individual vehicle components being analyzed. This identification of the material used is necessary because material alloy and form along with the source of the data must be easily associated with the structure and weight arrived at in each problem. Material properties at several operating temperatures after specific exposure at temperature are included in this file. These records can be selected when similar requirements are specified for a problem.

TABLE 1. MATERIALS INCLUDED IN THE LIBRARY

Material ID No.	Material Description	Density (lb/in^3)	Basis (Note 1)	Thickness (in.)	Temperature Range (° F)	Room Temp Properties (psi)	
						F_{CY}	F_{SU}
1	2024-T81 Al clad sheet	0.100	S	0.063-0.250	80	57,000	39,000
2	2024-T851 Al bare plate	0.100	S(2)	0.500-1.000	80-300	58,500	38,000
3	2024-T851 Al bare plate	0.100	S(3)	1.000-3.000	80-350	54,500	37,500
4	7075-T6 Al clad sheet	0.101	B	0.040-0.062	80	65,000	44,000
5	7075-T6 Al bare plate	0.101	B	0.250-0.500	80	71,000	47,000
6	7075-T6511 Al extrusion	0.101	A	3.000-4.000	80	66,000	45,000
7	7075-T7351 Al bare plate	0.101	S	0.250-0.500	80	56,000	39,000
8	7050-T7351 Al bare plate	0.102	Est	- -	80	66,000	42,200
9	2219-T851 Al bare sheet/plate	0.102	Est	0.250-2.000	80	48,000	36,000
10	7178-T6 Al clad sheet	0.102	B	0.045-0.249	80	75,000	48,000
11	7178-T6 Al bare sheet	0.102	B(4)	0.045-0.249	80-280	75,000	49,000
12	7079-T651 Al bare plate	0.099	A	0.250-1.500	80	63,000	42,000
13	6Al-4V Ti annealed sheet/plate	0.160	B(2)	-0.250	80-500	138,000	81,000
14	6Al-4V Ti annealed plate	0.160	S	0.187-4.000	80-350	126,000	76,000
15	9Ni-4CO-.2C steel sheet/plate	0.283	Est	- -	80	188,000	118,000
16	17-4PH (H900)	0.282	Est	- -	80	165,000	120,000
17	Rene 41 plate	0.298	B	0.187-	80-1600	113,000	118,000

NOTE

1. The basis A, B, and S are as defined in MIL-HDBK-5A.
2. After exposure to 290° F for 120 hours.
3. After exposure to 265° F for 390 hours.
4. After exposure to 280° F for 120 hours.

Section II

METHODOLOGY

AVAILABLE DATA

Each material properties data set or record consists of the following information:

- Identification number and descriptive title
- Density
- Modulus of elasticity at 80° F
- Fatigue parameter, reduction in area
- Crippling coefficients
- Stress-strain and strength data for different operating temperatures (from one to six temperature blocks can be included)
- Fatigue factors, fraction of ultimate tensile strength

An item-by-item description of these data can be found in Table 2.

CALCULATION PROCEDURES

INTERMEDIATE TEMPERATURES

Properties at temperatures other than those input are determined by linear interpolation or extrapolation if the data set has more than one temperature block. For records that include only one temperature, the properties for that temperature are used for all requested temperatures with an accompanying printed message to warn the user.

STRESS-STRAIN DIAGRAM

Stress-strain data are included at key points, and a continuous description for the desired temperature is provided by a least squares curve fit. Figure 1 shows a typical diagram. The lowest point (σ_{pl}, ϵ_{pl}) is the proportional limit, that point where the diagram first deviates from a straight line through the

TABLE 2. DESCRIPTION OF MATERIAL LIBRARY INPUTS BY RELATIVE LOCATION

TITLE CARD ONE 1-80 FOR COMMENTS. **MUST BE USED**
TWO 1-80 FOR COMMENTS. **MUST BE USED**

LOCATION	DESCRIPTION	
1	MATERIAL NUMBER-CHECK PROGRAM LIBRARY FOR NEXT NUMBER.	
2	MATERIAL DENSITY.	POUNDS/CUBIC INCH
3	YOUNG'S MODULUS AT 70 DEG. FAHRENHEIT	
4	SHEAR MODULUS AT 70 DEG. FAHRENHEIT	
5	REDUCTION IN AREA, FATIGUE PARAMETER.	
6	MATERIAL CRIPPLING COEFFICIENT	
	-FOR FLAT SHEET SIMPLY SUPPORTED AT TWO EDGES	
7	-FOR FLAT SHEET SIMPLY SUPPORTED AT ONE EDGE ONLY	
8-109	NOT USED	
110	TEMPERATURE OF MATERIAL FOR DATA IN LOCATIONS 111 THRU 154	
	*** TEMPERATURES IN DEGREES FAHRENHEIT ***	
111	MU - POISSON'S RATIO	
112	EC1 COMPRESSION STRAIN AT PROPORTIONAL LIMIT	INCH/INCH
113	EC5 COMPRESSION STRAIN AT YIELD POINT	INCH/INCH
114	FC1 COMPRESSION STRESS AT PROPORTIONAL LIMIT	PSI
115	FC2 COMPRESSION STRESS AT EC1 + (EC5 - EC1) * .25	PSI
116	FC3 COMPRESSION STRESS AT EC1 + (EC5 - EC1) * .50	PSI
117	FC4 COMPRESSION STRESS AT EC1 + (EC5 - EC1) * .75	PSI
118	FC5 COMPRESSION STRESS AT YIELD POINT	PSI
119	ET1 TENSION STRAIN AT PROPORTIONAL LIMIT	INCH/INCH
120	ET5 TENSION STRAIN AT YIELD POINT	INCH/INCH
121	FT1 TENSION STRESS AT PROPORTIONAL LIMIT	PSI
122	FT2 TENSION STRESS AT ET1 + (ET5 - ET1) * .25	PSI
123	FT3 TENSION STRESS AT ET1 + (ET5 - ET1) * .50	PSI
124	FT4 TENSION STRESS AT ET1 + (ET5 - ET1) * .75	PSI
125	FT5 TENSION STRESS AT YIELD POINT	PSI
126	FTU ULTIMATE TENSION STRESS	PSI
127	FSU ULTIMATE SHEAR STRESS	PSI
128	FBRU ULTIMATE BEARING STRESS	PSI

TABLE 2. DESCRIPTION OF MATERIAL LIBRARY TAPES BY RELATIVE LOCATION (CONT)

128	NOT USED
129	KFTU FATIGUE FACTOR - ENDURANCE LIMIT, KT=1, R=-1
130	- FUSELAGE SHELL BENDING
131	- FUSELAGE PRESSURE CYCLES, R=0
132	- WING AT SIDE OF FUSELAGE (SOF)
133	- WING OUTER PANEL STATION (WOS)
	INPUT FOR SECOND TEMPERATURE **OPTIONAL**
134	TEMPERATURE, MUST BE HIGHER THAN TEMPERATURE IN LOCATION 110
135	MU.
136	EC1 STRAIN AT P.L.
137	EC2 STRAIN AT YIELD
138	EC1
139	EC2
140	EC3
141	EC4
142	EC5
143	ET1 STRAIN AT P.L.
144	ET2 STRAIN AT YIELD
145	FT1
146	FT2
147	FT3
148	FT4
149	FT5
150	FTU
151	FSU
152	FBRU
153	NOT USED
154	KFTU - ENDURANCE LIMIT
155	- FUS. SHELL
156	- FUS. PRESSURE
157	- SOF
158	- WOS
	INPUT FOR THIRD TEMPERATURE **OPTIONAL**
159	TEMPERATURE, MUST BE HIGHER THAN TEMPERATURE IN LOCATION 134
160	MU.

TABLE 7. DESCRIPTION OF MATERIAL LIBRARY INPUTS BY RELATIVE LOCATION (CONT)

162	EC1 STRAIN AT P.L.
163	EC5 STRAIN AT YIELD
164	FC1
165	FC2
166	FC3
167	FC4
168	FC5
169	ET1 STRAIN AT P.L.
170	ET5 STRAIN AT YIELD
171	FT1
172	FT2
173	FT3
174	FT4
175	FT5
176	FTU
177	FSU
178	FBRU
179	NOT USED
180	NFTU - ENDURANCE LIMIT
181	- FUS. SHELL
182	- FUS. PRESSURE
183	- SCF
184	- WOS
	INPUT FOR FOURTH TEMPERATURE **OPTIONAL**
185	TEMPERATURE, MUST BE HIGHER THAN TEMPERATURE IN LOCATION 160
186	MU.
187	EC1 STRAIN AT P.L.
188	EC5 STRAIN AT YIELD
189	FC1
190	FC2
191	FC3
192	FC4
193	FC5
194	ET1 STRAIN AT P.L.
195	ET5 STRAIN AT YIELD
196	FT1

TABLE 2. DESCRIPTION OF MATERIAL LIBRARY INPUTS BY RELATIVE LOCATION (CONT)

197	FT6
198	FT7
199	FT8
200	FT9
201	FTR
202	FSU
203	FBRU
204	NOT USED
205	KFTU - ENDURANCE LIMIT
206	- FUS. SHELL
207	- FUS. PRESSURE
208	- SCF
209	- KT
	INPUT FOR FIFTH TEMPERATURE **OPTIONAL**
210	TEMPERATURE, MUST BE HIGHER THAN TEMPERATURE IN LOCATION 185
211	MU.
212	EC1 STRAIN AT P.L.
213	EC5 STRAIN AT YIELD
214	EC1
215	EC2
216	EC3
217	EC4
218	EC5
219	ET1 STRAIN AT P.L.
220	ET5 STRAIN AT YIELD
221	FT1
222	FT2
223	FT3
224	FT4
225	FT5
226	FTU
227	FSU
228	FBRU
229	NOT USED
230	KFTU - ENDURANCE LIMIT
231	- FUS. SHELL

TABLE 2. DESCRIPTION OF MATERIAL LIBRARY INPUTS BY RELATIVE LOCATION (CONCL)

2[illegible]		- FCS. PRESSURE
253		- SUF
254		- WOS
	INPUT FOR STATE TEMPERATURE	**OPTIONAL**
255	TEMPERATURE, MUST BE HIGHER THAN TEMPERATURE IN LOCATION 210	
256	MU.	
257	EC1 STRAIN AT P.L.	
258	EC2 STRAIN AT YIELD	
259	FC1	
260	FC2	
261	FC3	
262	FC4	
263	FC5	
264	ET1 STRAIN AT P.L.	
265	ET2 STRAIN AT YIELD	
266	FT1	
267	FT2	
268	FT3	
269	FT4	
270	FT5	
271	FTU	
272	FSU	
273	FBRU	
274	NOT USED	
275	KFTU - ENDURANCE LIMIT	
276	- FUS. SHELL	
277	- FUS. PRESSURE	
278	- SUF	
279	- WOS	

*** LAST CARD FOR EACH MATERIAL MUST HAVE A MINUS (-) IN COLUMN ONE(1)

*** LAST MATERIAL MUST BE A DUMMY
WITH 2 TITLE CARDS AND A 3RD CARD WITH MINUS IN COLUMN 1
AND ZERO (0.0) IN LOCATION 1

origin. The slope of the straight line portion of the diagram defines the modulus of elasticity, E.

$$E = \sigma_{PL}/\epsilon_{PL} \tag{1}$$

The highest point on the diagram (σ_Y, ϵ_Y) is the yield point; in this example, it is defined by the 0.002 strain offset method. The true yield stress would be used for materials which have a definite yield point. Three stress values, at equal strain increments between ϵ_{PL} and ϵ_Y are included to help define the curved portion of the diagram.

The general form of the equation used to approximate the stress-strain curve is:

$$\epsilon = \frac{\sigma}{E} + ae^{b\sigma} \tag{2}$$

where

ϵ = strain, inches per inch

σ = stress, pounds per square inch

E = modulus of elasticity, pounds per square inch

a = material dependent factor, inches per inch

b = material dependent factor, 1/psi

e = base of natural logarithms

The first term of the equation approximates the linear region of the curve, values below the proportional limit. The second term fits the plastic region of the diagram between the proportional limit and the "yield" point.

For a curve through the proportional limit, yield point, and point B, as shown in Figure 1, the factors a and b can be determined:

$$b = \frac{\ln\left(\frac{\Delta\epsilon_Y}{\Delta\epsilon_B}\right)}{\sigma_Y - \sigma_B} \tag{3}$$

$$a = e^{(\ln \Delta\epsilon_B - b\sigma_B)} \tag{4}$$

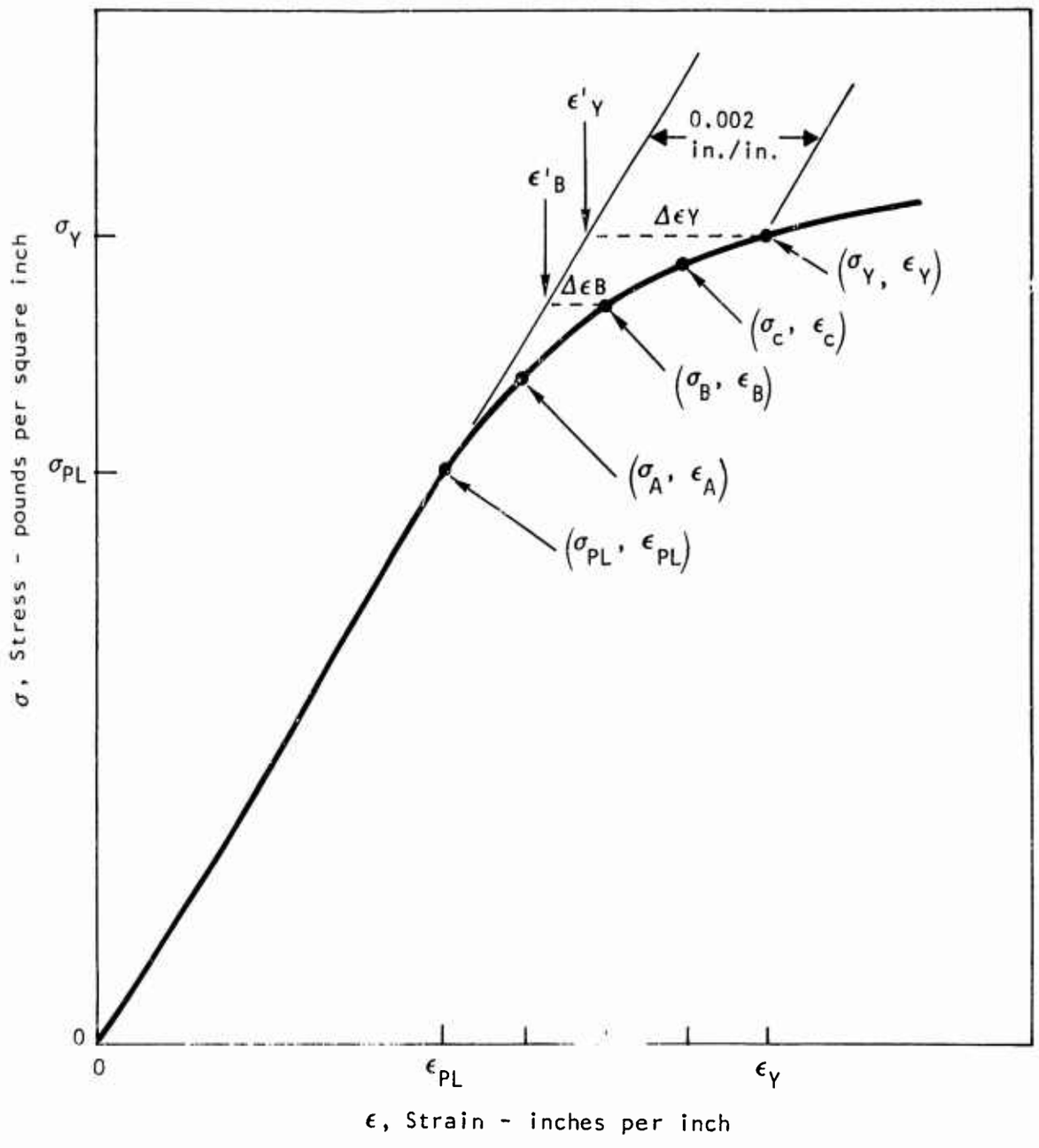


Figure 1. Stress-strain curve showing curve fit control points.

where

$$\Delta\epsilon_y = \epsilon_y - \frac{\sigma_y}{E} = \epsilon_y - \epsilon'_y$$

$$\Delta\epsilon_B = \epsilon_B - \frac{\sigma_B}{E} = \epsilon_B - \epsilon'_B$$

For points A and C, the same procedure is followed, and the best of the three is selected for the calculation of required parameters.

The slope of the curve at any point is the tangent modulus, E_T, and is obtained by differentiating equation 2.

$$E_T = \frac{d\sigma}{d\epsilon} = \frac{1}{\frac{d\epsilon}{d\sigma}} = \frac{1}{\frac{1}{E} + abe^{b\sigma}} \tag{5}$$

The secant modulus, E_S, is the value of stress divided by strain at any point on the curve.

$$E_S = \sigma/\epsilon \tag{6}$$

There properties are shown on a typical stress-strain diagram in Figure 2.

OTHER PROPERTIES

Other design properties may be obtained from the library:

- Poisons ratio, μ, used in the calculation of shear modulus:

$$G = E/2(1+\mu) \tag{7}$$

- Ultimate tensile stress
- Ultimate shear stress
- Ultimate bearing stress

A complete listing of the library data is included in the Users' Manual.

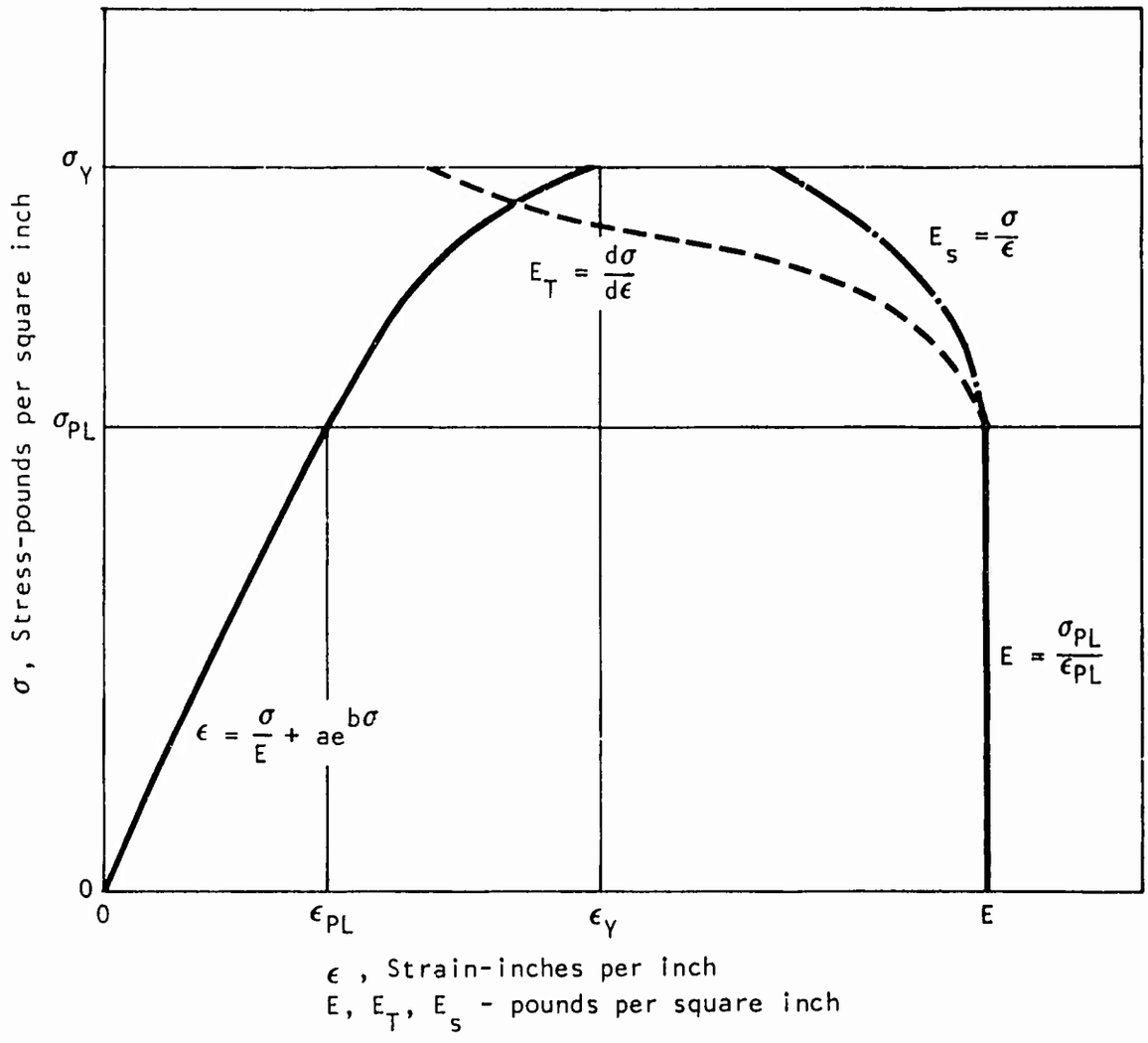


Figure 2. Stress-strain curve evaluation for elastic and plastic properties.

TABLE 5. MATERIAL LIBRARY DATA

MATERIAL NUMBER 1

2024-T81 AL CLAD SHEET 0.063 TO 0.249 IN. MIL-HDBK-5 S DATA EST.
SEE. TABLE 3.2.3..D(1) PAGE 258 8-30-72

1	1.0	0.100	10700000.0	4022000.0	.16
6	0.500	0.312			
110	80.0	0.33	0.0042523 36	0.0073271 02	45510.0
115	50300.0	53600.0	55700.0	57000.0	0.0042523 36
120	0.0073271 02	45500.0	50300.0	53600.0	55700.0
125	57000.0	65000.0	39000.0	127000.0	
130	0.225	0.76	0.50	1.0	1.0
255					

MATERIAL NUMBER 2

2024-T851 AL BARE PLATE 0.5 TO 1.0 IN. BEE-AEL.30/1.10
120 HRS AT 290 DEG MIL-HDBK-5 S DATA 10-24-62

1	2.0	0.100	10700000.0	4022560.0	0.16
6	0.500	0.312			
110	80.0	0.330	0.0043458	0.0074673	46500.0
115	52100.0	55200.0	57200.0	58500.0	0.0043458
120	0.0074673	46500.0	52100.0	55200.0	57200.0
125	58500.0	66000.0	39000.0	117000.0	
130	0.225	0.76	0.50	1.0	1.0
135	200.0	0.345	0.0041904 76	0.0072957 14	44000.0
140	49100.0	52300.0	54200.0	55500.0	0.0041904 76
145	0.0072957 14	44000.0	49100.0	52300.0	54200.0
150	55500.0	61500.0	35500.0	109000.0	
155	0.225	0.76	0.50	1.0	1.0
160	300.0	0.358	0.0038725 49	0.0068523 41	39500.0
165	44300.0	47000.0	48500.0	49500.0	0.0038725 49
170	0.0068523 41	39500.0	44300.0	47000.0	48500.0
175	49500.0	55000.0	31500.0	97500.0	
180	0.225	0.76	0.50	1.0	1.0
255					

TABLE 3. MATERIAL LIBRARY DATA (CONT'D)

MATERIAL NUMBER 3

2024-T851 AL PLATE 1.0 TO 3.0 IN. REF-RAE.8 2-5-70
330 MPS AT 265 DEG. MIL-HDBK-5 S VALUES PER ALCOA 2-09-70

1	3.0	0.100	10770000.0	4022560.0	1.16
6	0.500	0.312			
110	80.0	0.330	0.004150	0.007052	44500.0
115	49100.0	51900.0	53500.0	54500.0	0.004150
120	0.007052	44500.0	49100.0	51900.0	53500.0
125	54500.0	65000.0	37500.0	109000.0	
130	0.225	0.76	0.50	1.0	1.0
135	165.0	0.334	0.004095	0.007048	43000.0
140	47900.0	50500.0	52000.0	53000.0	0.004095
145	0.007048	43000.0	47900.0	50500.0	52000.0
150	53000.0	62500.0	36000.0	106000.0	
155	0.225	0.76	0.50	1.0	1.0
160	197.0	0.336	0.004048	0.006952	42500.0
165	47100.0	49700.0	51200.0	52000.0	0.004048
170	0.006952	42500.0	47100.0	49700.0	51200.0
175	52000.0	61000.0	35000.0	104000.0	
180	0.225	0.76	0.50	1.0	1.0
185	265.0	0.339	0.003883	0.006757	40000.0
190	44500.0	46900.0	48200.0	49000.0	0.003883
195	0.006757	40000.0	44500.0	46900.0	48200.0
200	49000.0	56500.0	32500.0	98000.0	
205	0.225	0.76	0.50	1.0	1.0
210	350.0	0.343	0.003550	0.006300	35500.0
215	39100.0	41500.0	42500.0	43000.0	0.003550
220	0.006300	35500.0	39100.0	41500.0	42500.0
225	43000.0	49000.0	28000.0	86000.0	
230	0.225	0.76	0.50	1.0	1.0
255					

TABLE 3. MATERIAL LIBRARY DATA (CONT'D)

MATERIAL NUMBER 4

7075-T6 AL CLAD SHEET 0.040 TO 0.062 IN. MIL-HDBK-5 B DATA EST.
REF. TABLE 3.2.7.0(C) PAGE 336 8-16-72

1	4.0	0.101	10700000.0	4022560.0	0.1B
6	0.509	0.312			
110	80.0	0.3305	0.00389852	0.0081304S	40000.0
115	51200.0	50000.0	52300.0	65000.0	0.00389852
120	0.0081304S	40000.0	51200.0	59000.0	62300.0
125	65000.0	73000.0	44000.0	133000.0	
130	0.225	0.76	0.500	1.0	1.0
-	255				

MATERIAL NUMBER 5

7075-T6 AL BARE PLATE 0.25 TO 0.50 IN. MIL-HDBK-5 B DATA EST.
REF. TABLE 3.2.7.0(B) PAGE 334 4-06-72

1	5.0	.101	10500000.0	3901000.0	0.1B
6	0.509	0.312			
110	80.0	.33	.005	.0087619	52500.0
115	59700.0	65000.0	68750.0	71000.0	.005
120	.0087619	52500.0	59700.0	65000.0	68750.0
125	71000.0	78000.0	47000.0	142000.0	
130	0.225	0.76	0.500	1.0	1.0
-	255				

TABLE 3. MATERIAL LIBRARY DATA (CONT.)

```
MATERIAL NUMBER   6

        7075-T6511 AL EXTRU. 3.0 TO 4.0 IN. MIL-HDBK-5 A DATA EST.
                   REF. TABLE 3.2.7.0(E) PAGE 340  3-26-72
          1 6.0          0.101        10500000.0   3901000.0    0.18
          6 0.500        0.312
        110 80.0         0.330        0.00514285?  0.0198285714 54000.0
        115 59100.0      62300.0      64450.0      66000.0      0.00514285?
        120 0.0098285714 54000.0      59100.0      62300.0      64450.0
        125 66000.0      81000.0      45000.0      87000.0
        130 0.225        0.76         0.500        1.0          1.0
        255
```

```
MATERIAL NUMBER   7

        7075-T7351 AL BARE PLATE 0.25 TO 0.50 IN. MIL-HDBK-5 S DATA EST.
                   REF. TABLE 3.2.7.0(B) PAGE 334  12-14-71
          1 7.0          .101         10500000.0   3901000.0    0.18
          6 0.500        0.312
        110 80.0         .33          .0043204     .0074369     44500.0
        115 49800.0      52800.0      54700.0      56000.0      .0043204
        120 .0074369     44500.0      49800.0      52800.0      54700.0
        125 56000.0      68000.0      39000.0      137000.0
        130 0.225        0.76         0.500        1.0          1.0
        255
```

MATERIAL NUMBER 8

7050-T7351 AL PARE PLATE
ESTIMATED DESIGN VALUE 2 MAY 1972

1	8.0	0.102	10500000.0	3300000.0	0.20
6	0.500	0.312			
110	80.0	0.33	0.005029	0.008301	52830.0
115	58200.0	63000.0	55100.0	66000.0	0.005029
120	0.008301	52800.0	58200.0	63000.0	65100.0
125	66000.0	76000.0	42200.0	87000.0	
130	0.225	0.76	0.500	1.0	1.0
255					

MATERIAL NUMBER 9

2219-T851 AL PARE SHEET AND PLATE 0.25 TO 2.0 IN.
CURVE DERIVED FROM T852 CURVE AND T851 CHART 12 JUNE 1972

1	8.0	.102	10500000.0	4000000.0	0.27
6	0.500	0.312			
110	80.0	.33	.00364	.00646	39360.0
115	43800.0	46300.0	47500.0	48000.0	.00364
120	.00646	39360.0	43800.0	46300.0	47500.0
125	48000.0	62000.0	36000.0	118000.0	
130	0.225	0.76	0.500	1.0	1.0
255					

TABLE 5. MATERIAL LIBRARY DATA (CONT)

MATERIAL NUMBER 10

7178-T6 AL CLAD SHEET 0.045 TO 0.249 IN. MIL-HDBK-5 B DATA EST.
REF. TABLE 3.2.3.3(C) PAGE 369 8-09-72

1	10.0	0.102	10500000.0	3901000.0	0.20
6	0.509	0.312			
110	80.0	0.33	0.004904761	0.009142857	51500.0
115	61000.0	67800.0	72500.0	75000.0	0.004904761
120	0.009142857	51500.0	61000.0	67800.0	72500.0
125	75000.0	80000.0	49000.0	153000.0	
130	0.225	0.76	0.50	1.0	1.0
255					

MATERIAL NUMBER 11

7178-T6 AL BARE SHEET 0.045 TO 0.249 IN. REF-EX-45 1-25-68
120 HRS AT 280 DEG. MIL-HDBK-5 B DATA

1	11.0	0.102	10500000.0	3901000.0	0.20
6	0.509	0.312			
110	80.0	0.330	0.004904761	0.009142857	51500.0
115	61000.0	67800.0	72500.0	75000.0	0.004904761
120	0.009142857	51500.0	61000.0	67800.0	72500.0
125	75000.0	81000.0	49000.0	153500.0	
130	0.225	0.76	0.500	1.0	1.0
135	280.0	0.355	0.005157894	0.008736842	49000.0
140	54600.0	59400.0	61400.0	64000.0	0.005157894
145	0.008736842	49000.0	54600.0	59400.0	61400.0
150	64000.0	59500.0	46000.0	113000.0	
155	0.225	0.76	0.50	1.0	1.0
255					

TABLE 3. MATERIAL LIBRARY DATA (CONT)

MATERIAL NUMBER 12

7079-T651 AL BARE PLATE 0.25 TO 1.50 IN. MIL-HDBK-5 A DATA EST.
REF. TABLE 3.2.8.0(D) PAGE 358 2-24-72

1	12.0	0.099	10500000.0	3900000.0	0.20
6	0.509	0.312			
110	80.0	0.330	0.0043810	0.008000	52800.0
115	52800.0	57900.0	61100.0	63000.0	0.0043810
120	0.0080	46000.0	52800.0	57900.0	61100.0
125	63000.0	71000.0	42000.0	114000.0	
130	0.225	0.76	0.500	1.0	1.0
255					

TABLE 5. MATERIAL LIBRARY DATA (CONT)

MATERIAL NUMBER 13

6AL-4V TI-1* SHT/PLATE T) .250 IN. REF-TEI.30/1.10 2-22-67
120 HRS AT 290 DEG. MIL-HDBK-5 B DATA

1	13.0	0.160	1640220.0	6165500.0	0.27
6	0.771	0.304			
110	80.0	0.330	0.007256	0.0104146	113000.0
115	127000.0	132000.0	135500.0	138000.0	0.007256
120	0.0104146	119000.0	127000.0	132000.0	135500.0
125	138000.0	132000.0	81000.0	250300.0	
130	0.28	0.70	0.50	1.0	1.0
135	200.0	0.336	0.0065397	0.0099365	103000.0
140	111600.0	113500.0	122200.0	125000.0	0.0065397
145	0.0099365	103000.0	111600.0	118500.0	122200.0
150	125000.0	126000.0	74500.0	250000.0	
155	0.28	0.70	0.50	1.0	1.0
160	245.0	0.33825	0.0065326	0.0097813	100375.0
165	103000.0	114400.0	117900.0	120275.0	0.0065326
170	0.0097813	100975.0	109000.0	114400.0	117900.0
175	120275.0	122500.0	72250.0	240550.0	
180	0.28	0.70	0.50	1.0	1.0
185	300.0	0.3410	0.0065232	0.0095828	98500.0
190	105300.0	109600.0	112600.0	114500.0	0.0065232
195	0.0095828	98500.0	105300.0	109600.0	112600.0
200	114500.0	117000.0	69500.0	229000.0	
205	0.28	0.70	0.50	1.0	1.0
210	500.0	0.351	0.0060932	0.0090609	95000.0
215	91200.0	95100.0	97400.0	98500.0	0.0060932
220	0.0090609	85000.0	91200.0	95100.0	97400.0
225	98500.0	107000.0	62500.0	209427.0	
230	0.28	0.70	0.50	1.0	1.0
255					

TABLE 5. MATERIAL LIBRARY DATA (CONT)

MATERIAL NUMBER 14

6AL-4V TI-A*PLATE 3/16 TO 4.0 IN. REF- SDM IIR-9.5.1.3.11
9-13-72 390 HRS AT 265 DEG. MIL-HDBK-5 S DATA

1	14.0	0.16	16400000.0	6165790.0	0.27
6	0.771	0.304			
10	0.040	0.332	0.030	0.040	0.080
110	80.0	0.33	0.0064634	0.0096829	106000.0
115	115000.0	121000.0	124000.0	126000.0	0.0064634
120	0.0096829	106000.0	115000.0	121000.0	124000.0
125	126000.0	130000.0	76000.0	245000.0	
130	0.23	0.70	0.50	1.0	1.0
135	165.0	0.334	0.0061635	0.00935849	98000.0
140	104000.0	112100.0	115300.0	117000.0	0.0061635
145	0.00935849	98000.0	104000.0	112100.0	115300.0
150	117000.0	121000.0	71500.0	234000.0	
155	0.23	0.70	0.50	1.0	1.0
160	197.0	0.336	0.00608280	0.00926114	95500.0
165	103700.0	108900.0	112200.0	114000.0	0.00608280
170	0.00926114	95500.0	103700.0	108900.0	112200.0
175	114000.0	118000.0	70000.0	228000.0	
180	0.23	0.70	0.50	1.0	1.0
185	265.0	0.339	0.005882	0.0089034	93000.0
190	98300.0	102500.0	105000.0	107000.0	0.005882
195	0.0089034	90000.0	98300.0	102500.0	105000.0
200	107000.0	112500.0	67000.0	216000.0	
205	0.23	0.70	0.50	1.0	1.0
210	350.0	0.343	0.0057432	0.0088243	85000.0
215	93500.0	97900.0	100000.0	101000.0	0.0057432
220	0.0088243	85000.0	93500.0	97900.0	100000.0
225	101000.0	106500.0	64000.0	202000.0	
230	0.23	0.70	0.50	1.0	1.0
255					

TABLE 3. MATERIAL LIBRARY DATA (CONT)

```
MATERIAL NUMBER 15

MATI NO 15    ONT-400-.20 STEEL  REF. TTB-9 MATERIALS MANUAL
                  BAR,SHEET,PLATE,FORGING
   1 15.0          0.283          29600000.0     11100000.0     0.65
   6 0.750         0.300
 110 80.0          0.30           0.004700       0.008351       139170.0
 115 160500.0      174500.0       183000.0       198000.0       0.004700
 120 0.008351      139170.0       160500.0       174500.0       183000.0
 125 198000.0      190000.0       118000.0       298000.0
 130 0.28          0.70           0.50           1.0            1.0
 255
```

```
MATERIAL NUMBER 16

MATI NO 16    17-4 PH STEEL     BAR,FORGING     REF.BRJHN TABLE B1
   1 16.0          0.282          27500000.0     11000000.0     0.45
   6 0.631         0.333
 110 80.0          0.272          0.004727       0.008000       130000.0
 115 148000.0      157000.0       162000.0       165000.0       0.004727
 120 0.00800       130000.0       148000.0       157000.0       162000.0
 125 165000.0      180000.0       120000.0       300000.0
 130 0.28          0.70           0.50           1.0            1.0
 255
```

TABLE 5. MATERIAL LIBRARY DATA (CONT)

MATERIAL NUMBER 17

```
     MATL NO 17   RENE 41  PLATE T. IS GREATER THAN 0.187  4/2/73
  DATA ESTIMATED FROM MIL-HDBK-5B  PP. 6-76 TO 6-81  EXPOSURE UP TO 1
       1 17.0          0.298        31600000.0   12100000.0   0.65
       6 0.700         0.300
     110 80.0          0.31         0.00275      0.0056       86000.0
     115 97000.0       103800.0     109000.0     113000.0     0.00275
     120 0.0056        86000.0      97000.0      103800.0     109000.0
     125 113000.0      170000.0     118000.0     253000.0
     130 0.28          0.7          0.5          1.0          1.0
     135 400.0         0.31         0.0028       0.0057       83000.0
     140 94000.0       101000.0     106000.0     109500.0     0.0028
     145 0.0057        83000.0      94000.0      101000.0     106000.0
     150 109500.0      158000.0     107400.0     240000.0
     155 0.28          0.7          0.5          1.0          1.0
     160 800.0         0.31         0.003        0.0059       82000.0
     165 93000.0       100000.0     104500.0     108000.0     0.003
     170 0.0059        82000.0      93000.0      100000.0     104500.0
     175 108000.0      153000.0     106000.0     227700.0
     180 0.28          0.7          0.5          1.0          1.0
     185 1200.0        0.31         0.0033       0.0063       81000.0
     190 92000.0       98500.0      103000.0     107000.0     0.0033
     195 0.0063        81000.0      92000.0      98500.0      103000.0
     200 107000.0      148000.0     105200.0     215000.0
     205 0.28          0.7          0.5          1.0          1.0
     210 1400.0        0.31         0.003        0.0058       67000.0
     215 75500.0       81000.0      85000.0      88000.0      0.003
     220 0.0058        67000.0      75500.0      81000.0      85000.0
     225 88000.0       127500.0     105000.0     202000.0
     230 0.28          0.7          0.5          1.0          1.0
     235 1600.0        0.31         0.0022       0.00475      37000.0
     240 43000.0       46000.0      47800.0      48500.0      0.0022
     245 0.00475       37000.0      43000.0      46000.0      47800.0
     250 48500.0       86700.0      64900.0      121400.0
     255 0.28          0.7          0.5          1.0          1.0
```

TABLE 3. MATERIAL LIBRARY DATA (CONCL)

```
MATERIAL NUMBER 00 --- DUMMY --- TO END LOAD

      DUMMY      DUMMY
LAST MATI
-           1 0.0
```

Section III

USING THE LIBRARY

GENERAL DISCUSSION

The synthesis modules use material properties in many equations in the determination of sizing and weight. To obtain the needed factors, each module contains some routines that access the library and perform the required calculations. It is these routines which will be reviewed in this section; a summary list is given in Table 4.

INPUT PROCEDURE

The material properties input decks are part of the permanent data. These data form the second file on the program tape. During the loading process, the permanent data are transferred to a file called TAPE7, from which they are read in ordered sequence into various records in storage by program READ. These records can be accessed by any routine and can be reinitialized by READ for succeeding cases if the user so requests.

The material properties are records 41 through 60 in storage.

TABLE 4. ROUTINES USING MATERIAL LIBRARY

Routine	Module	Function Related to Library
READ	Input data processing	Initialize and reinitialize all material records.
WHVMAT	Flutter-temperature	Read records for wing, horizontal and vertical.
FTGCTL	Fatigue	Read records for wing, fuselage cover, and fuselage minor frames. Calculate KF_{TU}'s for those read. Rewrite records read.
MCNTL1	Air induction systems	Read records for ducts, ramps, and nacelles.
MATLF1	Air induction systems	Calculate required parameters.
MATLP2	Air induction systems	Print.
MTLCW	Wing and empennage	Read for wing (and pivot) or horizontal or vertical, whichever in work.
MTLFW	Wing and empennage	Calculate required parameters.
MTLPW	Wing and empennage	Print.
MFCNTL	Fuselage	Read for cover, longeron, major frames, and minor frames.
MATLF	Fuselage	Calculate.
MATLP1	Fuselage	Print.

FLUTTER AND TEMPERATURE MODULE

In this module, the routine WINMAT reads the material records for the wing, horizontal tail, and vertical tail and composes a table of ultimate tensile stress and shear modulus versus temperature. From each material record, the parameters used are as follows:

MATERIAL PROPERTIES USED

Description	Relative Location
Temperature	110, 135, 160, ...235
μ, Poisson's Ratio	111, 136, 161, ...236
ϵ_{CPL}, compression strain at proportional limits	112, 137, 162, ...237
σ_{CPL}, compression stress at proportional limit	114, 139, 164, ...239
F_{cy}, compression yield stress	118, 143, 168, ...243

FATIGUE MODULE

The fatigue control subroutine, FTGCTL, reads and writes those material records for which the calculation of fatigue factor, KF_{TU}, has been requested. This is the only place where material library data is changed from its input values. Fatigue calculations can be performed for two stations on the wing and for the fuselage cover and minor frames.

MATERIAL PROPERTIES USED

Description	Relative location
RA, reduction in area, fatigue parameter	5

$$RA = \frac{A_i - A_f}{A_i}$$

where

A_i = initial specimen cross-section area

A_f = final fracture cross-section area

ϵ_{CPL}, compression strain at proportional limit	112
σ_{CPL}, compression stress at proportional limit	114
F_{tu}, ultimate tension stress	126

MATERIAL PROPERTIES CALCULATED

Description	Relative location
KF_{IJ}, for fuselage endurance limit	130, 155, 180 ...255
KF_{IJ}, for fuselage pressure cycles	132, 157, 182 ...257
KF_{IJ}, for wing at side of fuselage	133, 158, 183 ...258
KF_{IJ}, for wing at outboard station	134, 159, 184 ...259

If any of the possible calculations are not requested, or if the calculation fails, the location in the library for that one is left unchanged. The material identification numbers and the before-and-after values of KF_{IJ} are printed at the end of the calculation.

MATERIAL SYSTEM MODULE

This module includes three routines which handle material library data. MATRIL is the control routine which reads library records for duct, ramp, and nacelle materials, as applicable for the vehicle in work. In MATLF1, the desired properties are obtained for temperatures corresponding to select points on the speed profile. The third routine MATLP2 is called only if a printout of the interpolated material properties is requested.

WING SYNTHESIS MODULE

The material control routine for this module is MTLCW. It reads the library record for the wing (or horizontal or vertical) material and calls MATLF. There the interpolation to design temperature and the stress-strain curve fits are performed. On return to MTLCW, the required material properties are saved in common for use by the synthesis routines. The subroutine MTLPW is called only if a printout of the developed properties is requested. If the wing data specifies a pivot, the procedure is repeated for the pivot material.

FUSELAGE MODULE

In control routine MFCNTL, library records are read sequentially for four material numbers designating major frame, minor frame, longeron, and cover materials. For each one, the material properties, interpolated to the temperature for a specific load condition, are determined in MATLF. The interpolated values for the four are saved in a record by MFCNTL for later use by the structural routines. The routine MATLP1 is called if a printout of the calculated material properties is requested.

PART 2

FLUTTER AND TEMPERATURE MODULE

Section I

INTRODUCTION AND SUMMARY

PROGRAM OBJECTIVES

The objectives of the flutter and temperature module are to set up the following data:

1. Structural temperatures corresponding to loading conditions. These are used by the synthesis modules in sizing wing, tail, body, and air induction system structures.

2. Data used by the wing and empennage modules in performing flutter analyses. These include the following:

   a. Definition of the critical lifting surface flutter design points (mach number and altitude), and the corresponding structural temperatures and shear moduli

   b. Definition of the dynamic pressures which are used in the manner of equivalent incompressible subsonic dynamic pressure for torsional divergence. These are for use in the wing and empennage module flutter routines.

The flutter and temperature module does not size or synthesize any of the structure. It does not perform the flutter analysis, which is a function of the wing and empennage modules.

MODULE STRUCTURE AND OPERATION

The program is written in FORTRAN IV extended program language for operation on the CDC 6600 computer, and is structured as a single overlay within 50,000 octal core locations.

The module is executed as part of the integrated structural weight estimation program (SWEEP). The module is automatically executed as part of the data management and design criteria generation sequence.

MODULE INPUT AND OUTPUT

Input data are initially set up by the data management module and transferred to the flutter and temperature module via mass storage and labeled common.

Output, consisting of speed-altitude profile data, structural temperatures, materials properties data, dynamic pressures, and inertia data, are transferred to the airloads and the wing and empennage modules via mass storage and labeled common.

APPROACH TO TEMPERATURE EVALUATION

THE NATURE OF THERMAL PREDICTIONS IN PRELIMINARY DESIGN

The prediction of temperature for a new design of aircraft is an iterative process. The general characteristics and performance levels permit first approximations from which designers can make initial selections of materials, arrangements, and structural concepts. These selections give the thermal analyst enough information to furnish the designer and structural analyst with improved and extended predictions. This interchange of information is repeated as the design progresses. It is applied to successively smaller details as detailed information becomes available, until finally an airplane evolves that is compatible with its natural and induced environments.

As a tool for preliminary design, this program will be used early in this iterative process when highly detailed estimates of temperature are not needed, and when available information is insufficient for such estimates. A sophisticated thermal analyzer program would be undesirable, as it would add unneeded complexity and increased core storage. The thermal routine is of sufficient depth for this phase of design.

THE USE OF SKIN TEMPERATURES

Normally, most aircraft structure is in close proximity to the skin both physically and thermally. The thermal resistance across structural joints is small; for instance, the temperatures of a skin and its supporting frame are close. Metals have high thermal conductivity, and the various frames and stiffeners provide good paths for heat flow to the interior. Heat to or from structural elements must enter or leave the airplane through the skin. Thus, the temperature of the substructure follows the temperature of the skin and approaches it under steady-state flight. The usual practice in preliminary design is to use skin temperature for structural temperature, and this practice is followed in this program. However, this generality must be treated with discretion, as there are many exceptions. What is acceptable for preliminary sizing, material selection, and weight estimates is not acceptable for detailed design.

LIMITATIONS AND ACCURACY

This thermal routine is a so-called"steady-state program;" that is, it gives the temperature which would exist after equilibrium has been established or, conversely, it gives the temperatures which would exist instantaneously in transient flight if the structure had zero heat capacity. Most structural skins approach their equilibrium temperatures rapidly, as their heat capacities are small compared to aerodynamic heating. Exceptions are skins over sources or sinks of heat such as hot turbojet engines or cold integral fuel tanks. The use of the steady-state format eliminates an incompatibility of structural and thermal analyses; the structural analysis is concerned with what is happening to the airplane at a particular instant; the thermal analysis is concerned with what has happened during the immediately prior history.

The shortcoming of a steady-state analysis is that actual temperatures lag behind those computed with zero heat capacity. This shortcoming may be appreciable when the critical airloads are applied immediately after transient maneuvers. It is of little concern when critical airloads are applied after several minutes of flight at the same altitude and mach number. The latter applies to much of preliminary design.

Figure 3 compares temperatures from a transient analysis (considering the heat capacity) with those from a so-called steady-state analysis where the heat capacity is ignored. Here, a heavy skin (0.190-inch thick) has been cold soaked during prolonged subsonic flight at medium altitude. At time zero, the airplane starts a rapid acceleration and climb to supersonic speed at high altitude. It maintains the speed and altitude for three-tenths of an hour. Then it descends and decelerates to medium altitude and loiter speed. Notice that:

1. The maximum temperatures are almost the same.

2. The general trends are the same

3. Error can result at any one instant of time by using the dashed curve.

4. For lighter skin thickness, the two curves would be closer to coincidence.

The limitations of this method lie in applications as previously discussed. Where structure is in close proximity to the skin and when the flight conditions are not transient, it is quite accurate. This is illustrated by Figure 4 which compares computed and measured temperatures on the XB-70 after 32 minutes of flight at mach 3.0.

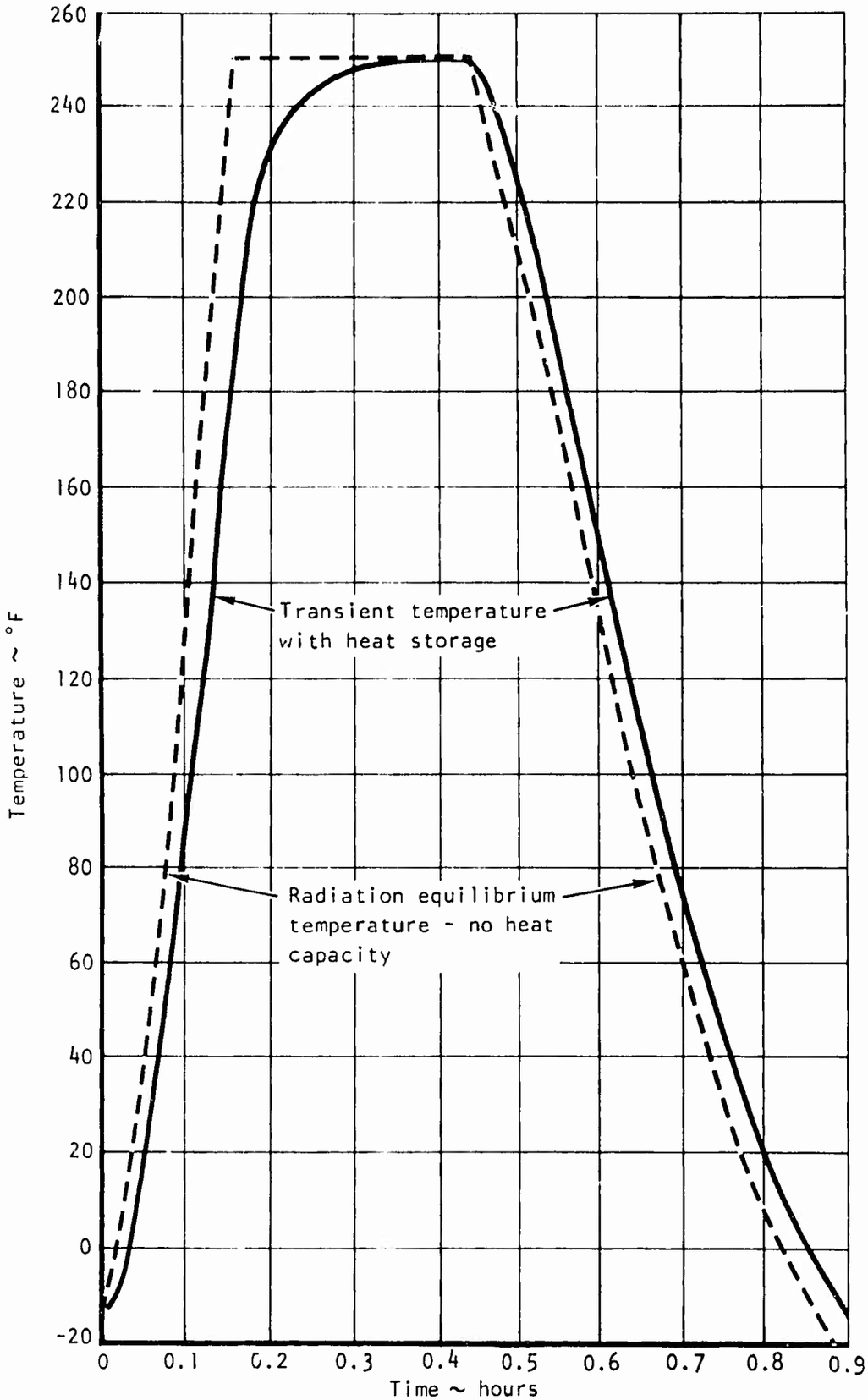


Figure 3. Effect of ignoring heat capacity.

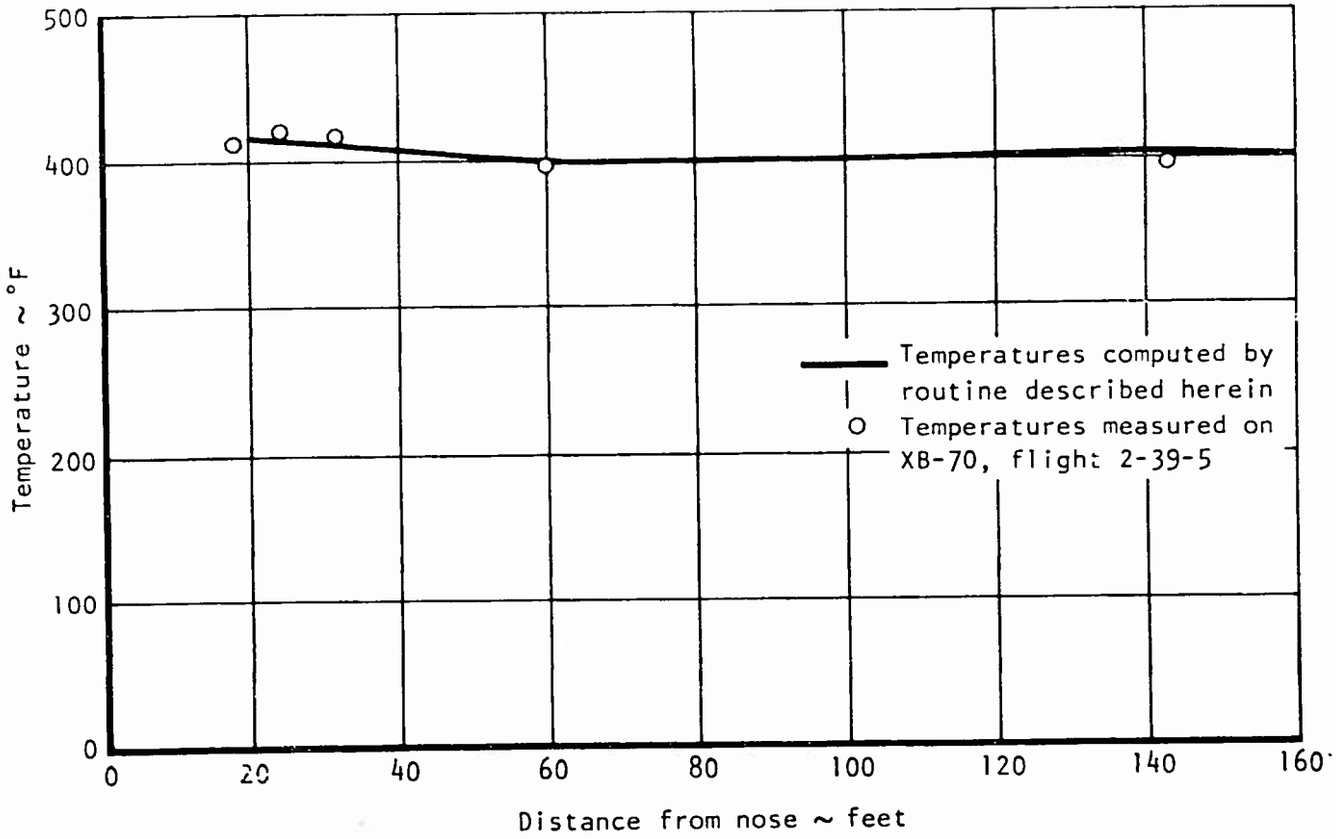


Figure 4. Comparison of computed and measured fuselage temperatures.

The most dominating heating or cooling effect in this program is the aerodynamic convection. The aerodynamic heating coefficient is computed by the well-recognized Blassius equation for laminar flow and the Van Driest method for turbulent flow. The latter will apply in most situations. Spalding and Chi[1] found it to be the best of 20 methods they checked with all available data. It checked almost as well as Spalding's own method based on these same data. Hopkins and Inouye[2] recommended it, based on a comparison of several leading methods. They suggest its application into the hypersonic regime.

The forcing potential for aerodynamic heating is based on the total temperature which, in turn, depends on specific heat. The specific heat as used here varies as a function of temperature in recognition of real gas effects, but it does not include effects of dissociation. Hence, it is quite accurate at subsonic and supersonic speeds, but it becomes progressively less accurate as one enters the hypersonic regime. For instance, at 2,240° F (1,500° K), this method gives 4.5° F error compared with the data of Reference 3, but at 3,140° F (2,000° K), the error has increased to 43.1° F. These temperatures correspond to flight at mach numbers 5.60 and 6.77, respectively.

APPROACH TO FLUTTER ESTIMATION

BACKGROUND

With the advent of higher flight speeds, the magnitude of flutter problems has become a major design consideration.

The requirements or design features necessary to prevent flutter often conflict with other design requirements. For instance, a thin, high-aspect-ratio wing may be desired for aerodynamic reasons. However, the weight increment over that resulting from strength requirements increases with increasing aspect ratio or decreasing thickness. The optimum wing then would probably be somewhat thicker and of lower aspect ratio than it would be if designed by strength and aerodynamic considerations only.

Unfortunately, it is impossible to formulate a true flutter analysis in which the required flutter speed is used as input to compute the optimum distribution of stiffness required. In fact, it is impossible to write an equation or set of equations for practical aircraft structures which can be solved directly for the flutter speed, even if all mass and stiffness properties are known. The reasons for this and methods for circumventing it are discussed in References 17 and 18. Briefly stated, the difficulty lies in the fact that the equations of motion are non-self-adjoint. The oscillatory aerodynamic forces are frequency and velocity-dependent, so that the speed and frequency at which flutter occurs must be known before the aerodynamic forces at flutter can be calculated.

The equations of motion are determined by the integration of many parameters over the entire structure. Thus, the distribution of quantities such as mass and stiffness are as important as the overall level, or the value at any particular point. In preliminary design stages, the level and distribution of these quantities are hardly ever known with sufficient accuracy to conduct a detailed flutter analysis. Therefore, it is evident that conducting an actual flutter analysis with detailed mass and stiffness distributions is not practical for preliminary design evaluations. Furthermore, sufficient time for such detailed analyses is usually not available.

SCOPE

Semiempirical methods have been developed for use in the preliminary design phase of vehicle synthesis. These methods are techniques of approximation that replace detailed flutter analyses. Techniques which have been incorporated in this program evaluate the prevention of:

1. Local panel flutter

2. Lifting surface flutter

3. T-tail flutter

Local panel flutter is generally associated with thin-skinned structures. This design consideration is evaluated for fuselage and nacelle structures. Discussion of the programmed methods are presented in Volumes V and VII of this document.

The development of the method used to evaluate surface flutter is based on the observation of some degree of correlation between the flutter speed and the static aeroelastic torsional divergence speed of an equivalent straight wing. The correlation is expressed by means of a parameter, e_e, which is a function of aspect ratio, sweep angle, and taper ratio. The expression for the parameter was derived from an envelope curve around a large number of points corresponding to theoretical and experimental evaluations of flutter speeds of a large variety of lifting surface types. The use of this "torsional divergence criteria" greatly simplifies the problem. The aerodynamic forces are not frequency-dependent, and inertia forces are eliminated from the problem. Naturally, some accuracy is lost, but since the correlation parameter is determined from actual flutter data, it may be thought of a "taking an average" of inertia and other effects to which torsional divergence considerations alone cannot relate.

The method determines the optimum stiffness distribution by calculating the stiffness distribution which will result in a constant shear stress over the span of the wing, in the torsional divergence mode.

The technique was originally developed to evaluate flutter at subsonic speeds. However, an extension has been developed for modifying the results to obtain stiffness predictions for flutter at transonic and supersonic speeds.

Derivation of the equations for calculating optimum stiffness distribution required to prevent flutter are described in Section II.

T-tails very often require considerably higher levels of stiffness to prevent flutter than do conventional tails. The stiffness increase above the levels required for strength is commonly higher in the vertical stabilizer, or fin, than in the horizontal stabilizer. Consequently, in preliminary design studies of T-tail aircraft it is necessary to make some estimate of the requirements for flutter prevention in order to have confidence that the tail design is realistic. It may be impossible to achieve a design which is actually optimum if flutter is not considered. In fact, it is conceivable that the stiffness requirements for a T-tail on a high-speed aircraft could be so high that the T-tail configuration would not represent an optimum design for the particular aircraft performance requirements. This fact may not be realized early enough in the design cycle to allow alternates to the T-tail to be selected, if preliminary estimates of the flutter prevention requirements are not made.

The programmed method is based on scaling from results of Reference 19 to establish required stiffness level. The correlation parameter, e_e, is used to account for differences in planform geometry.

Section II

METHODS AND FORMULATIONS

TEMPERATURE METHODOLOGY

HEAT BALANCE

The skin temperatures are solved from a heat balance in which the sum of five terms is equated to zero. The heat balance is merely a statement of the law of conservation of energy as applied to an element of skin. (See Figure 5.) In words, this balance is:

$$\begin{aligned} \text{Zero} = {} & \text{aerodynamic heat} \\ & + \text{solar heat} \\ & + \text{radiation between skin and ambient} \\ & + \text{heat from sundry sources} \\ & + \text{heat conducted or convected from interior} \end{aligned} \tag{1}$$

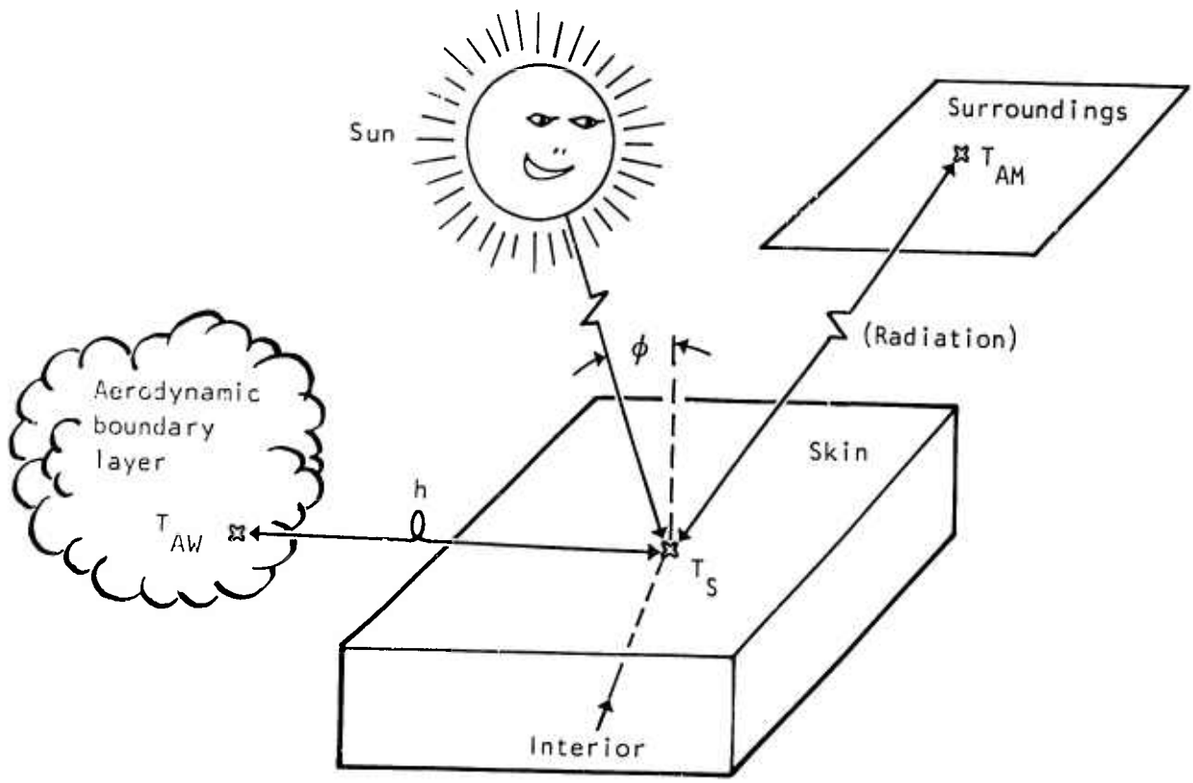


Figure 5. Heat balance diagram

This equation follows the convention of considering all terms as positive; i.e., all terms are written to express heat flowing into the skin. Under this convention, a term will become negative automatically when the skin's temperature exceeds the temperature of the connected node.

Presently, this program computes what is known as the "radiation equilibrium temperature" by setting the last two terms to zero. They are terms which express heat from within the airplane, and frequently they are not applicable. Large sections of an airplane closely approach the radiation equilibrium temperature. Examples are wing and tail surfaces which are externally heated from both sides or the cabin's structure where insulation prevents heat from flowing from the interior.

Flux Equation

All these heat transfer terms are based on the same area and time interval. These are divided out to change the equation, as it appears in the program, from an energy balance to a flux balance. Each term is now in BTU per hour per square foot. Equation 2, the flux equation, is shown for the aerodynamic heat, solar heat, and radiation between skin and ambient heat transfer terms.

$$0 = h\,(T_{AW} - T_S) + \alpha G \cos\phi + \sigma \epsilon\,(T_{AM}^4 - T_S^4) \qquad (2)$$

where

h = aerodynamic heat transfer coefficient, BTU/hr/°R/ft^2

T_{AW} = adiabatic wall temperature, °R

T_S = skin temperature, °R

α = absorptivity of surface to solar irradiation, (no units)

G = solar flux through a plane perpendicular to sun beams, BTU/hr/ft^2

ϕ = solar angle of incidence measured from normal to surface, degrees (ϕ is assumed to be zero in this program)

σ = Steffan-Boltzman constant, 1714 x 10^{-12} BTU/hr/°R^4/ft^2

ϵ = emittance of skin at skin temperature (no units)

T_{AM} = mean ambient temperature, °R

Derivation of each of these three heat transfer terms is discussed in the order that they are determined in this program.

SOLAR HEAT FLUX

The solar heating flux term in equation 2 is:

$$\alpha G \cos\phi = \text{solar heat flux, BTU/hr/ft}^2 \qquad (3)$$

Solar Flux

Sunshine is highly variant as evidenced by the spread of lines in figure 6. It varies with cloud cover, time of day, and solar activity. A rigorous standard for values to be used for aircraft design does not exist except for sea level. Reference 14, which has semihandbook status, recommends the curve shown in Figure 6. The zero altitude value corresponds to the value specified for military equipment on the ground by Reference 12. The asymptote of 435 BTU/hr/ft^2 is a frequently used value for the flux in the upper air above almost all of the water vapor, carbon dioxide, and dust that filter sunlight in the lower reaches of the atmosphere.

A curve fit of this heavy line is contained in a small function subprogram SOLARG. The program calls this function using altitude as a parameter.

Absorptivity and Emissivity

The solar absorptivity, α, and the emissivity, ϵ, which appears in the radiation between skin and ambient heat flux term, should not be confused. These terms are independent of each other. Both depend upon the paint, plating, anodizing, or other surface treatment that the airplane may receive. This independence evolves from the different source temperatures in these two radiation terms. The sun is about 10,000° F, and its radiation is in the short-wave portion of the spectrum. The radiation between the skin and the ambient is in the far infrared portion of the spectrum, as the sources are relatively cool. Between these two portions, there is ample room for changes in radiative properties. For example, a reduction of 70° F in skin temperature was obtained on the B-70 by using a finish which was both highly reflective in the solar portion of the spectrum and highly emissive in the far infrared portion. Absorptivity of 0.85 is used in this program. This value is representative of many painted surfaces. Should actual absorptivity be available, the user may input the value for this term.

The angle of incidence, ϕ, is presently taken as zero; i.e., the sunbeams strike perpendicularly. This maximizes the solar heat flux entering the skin, a permissible simplification in preliminary design. Angle of incidence may also be varied by the user.

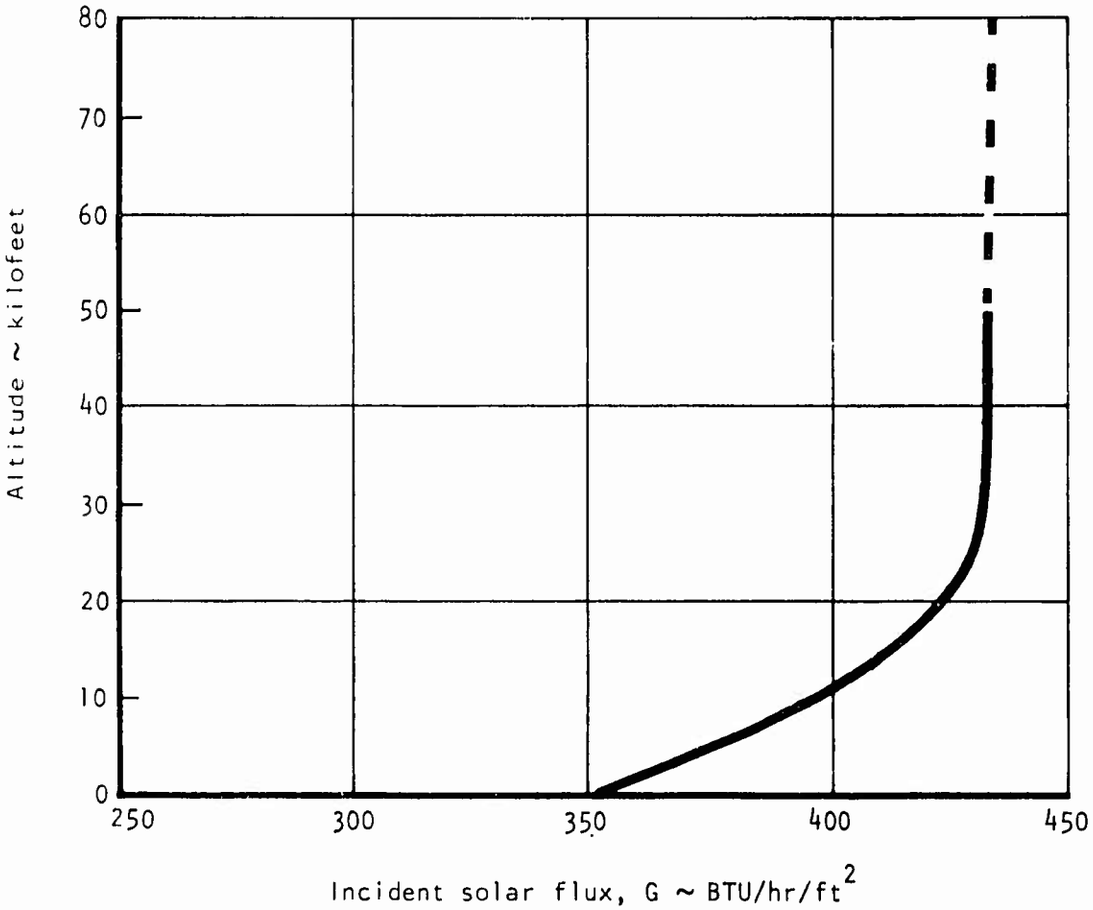


Figure 6. Recommended curve of maximum solar irradiation.

RADIATION FLUX BETWEEN SKIN AND AMBIENT

Radiation between skin and ambient can be regarded as the radiant cooling term, for the net radiation is usually away from the skin. It is written as a positive term in accordance with the convention of signs, and it automatically becomes negative when the skin's temperature exceeds the ambient temperature. The term is written as

$$\sigma \epsilon \left(T_{AM}^{4} - T_{S}^{4} \right) \tag{4}$$

where

σ = Steffan-Boltzman constant

= 1.714×10^{-12} BTU/ft^2/hr/°R^4

ϵ = emittance of skin at skin's temperature (no units)

T_{AM} = mean ambient temperature, °R

T_S = skin temperature, °R

Emissivity of 0.85 is used in this program. Should actual structure emissivity be known, the user may input the value for this term.

Nocturnal Radiation

The mean ambient temperature in equation 4, T_{AM}, is the fourth root of the sum of the products of the fourth powers of all surrounding temperatures (i.e., clouds, ground, atmosphere, etc) and their associated view factors from the skin. Its corresponding radiation is referred to as "nocturnal radiation."

Nocturnal radiation, the radiation from earth and sky, is usually a small term, and it is ignored; i.e., T_{AM} is set arbitrarily to zero. This partially balances the assumption that the sun shines perpendicular to the skin, a possible but not a probable occurrence. In the upper reaches of the atmosphere, nocturnal radiation approaches zero and, at low altitude, it is usually small compared with the aerodynamic heating term. Table 5, containing data extrapolated from Reference 15, shows the magnitudes. The data shown for the warm condition are the average of two sets of data - one for a clear, hot, moist night at Phoenix, Arizona, and the other for a clear, mild night at Dallas, Texas. Data shown for the cool condition are for a clear, cold, and dry night at Barrow, Alaska. The temperatures shown are those of a black-body that would produce the same radiant flux on the surface.

TABLE 5. NOCTURNAL RADIATIONS AND EQUIVALENT BLACK-BODY TEMPERATURES

Altitude (feet)	Warm Condition				Cool Condition			
	From Above		From Below		From Above		From Below	
	Flux (*)	Temp (°R)	Flux (*)	Temp (°R)	Flux (*)	Temp (°R)	Flux (*)	Temp (°R)
0	101	493	139	533	37	383	67	445
1,000	97	487	137	531	37	383	68	447
5,000	76	460	127	522	34	375	65	442
10,000	57	427	113	506	27	355	56	427
20,000	35	386	91	481	18	320	39	389
30,000	23	339	78	462	14	298	29	361
40,000	16	310	68	446	10	275	23	338
50,000	11	285	60	432	8	257	18	320
60,000	8	263	53	419	6	244	15	307
70,000	6	243	47	408	5	230	12	292
80,000	4	225	42	397	4	218	10	280
90,000	3	207	38	386	3	204	9	268
100,000	2	191	34	375	2	185	7	255

*BTU/hr/sq ft

AERODYNAMIC HEAT FLUX

The aerodynamic heat flux term in equation 2 is:

$$h(T_{AW} - T_s) = \text{aerodynamic heat flux, BTU/hr/ft}^2 \quad (5)$$

Atmospheric Properties

Aerodynamic heat transfer coefficient, h, and adiabatic wall temperature, T_{AW}, are dependent on vehicle speed and atmospheric properties at the specific flight condition. Function routines PRESH, TEMALT, and TTO develop this atmospheric data.

Local Static Pressure

The local static pressure is assumed equal to the free-stream static pressure; i.e., the pressure coefficients are assumed zero. This assumption

generally valid for large flat sections alined with the flow. At particular locations such as leading edges, canopies, windshields, etc, it causes error. Figure 7 illustrates the relative error for a delta wing at mach 3.00 and [illegible] feet. Here the differences of local pressure are holding the airplane aloft. The two solid curves were computed using the correct local static pressures and the local static temperatures. The dotted curve was computed from the free-stream values.

The free-stream static pressure is computed by the function subprogram PRESH, for "pressure height." This function is entered with the pressure altitude. It uses the hydrostatic equations and temperature distribution of the standard atmosphere (11).

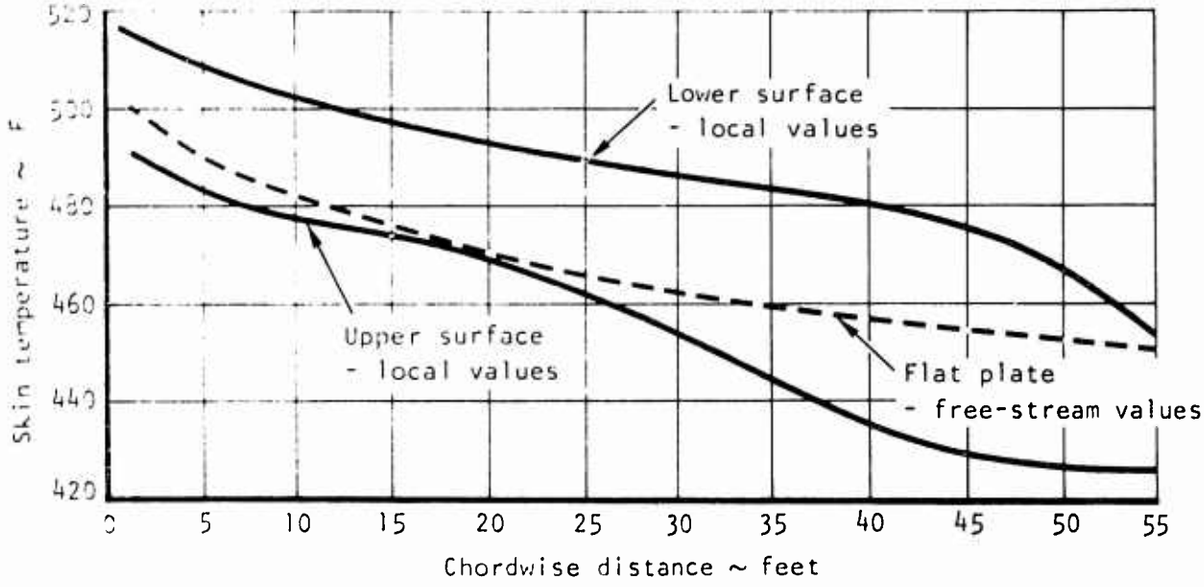


Figure 7. Comparison of using local and free-stream properties for a large wing at 3.00 mach and 65,000 feet.

Local static temperature

The local static temperature is used in the three aerodynamic heating subprograms: HBL, TBL, and TTO. It is assumed equal to the free-stream static temperature. Local static temperatures vary less percentagewise from free-stream static temperatures than the local pressure does from the free-stream pressure, as previously discussed. Hence, this assumption is justified for preliminary design.

The free-stream static temperature is computed from the pressure altitude by the function subprogram TEMALT, for "temperature versus altitude." This function consists of a series of usually linear equations which represent the segments of lines of Figure 8. The function contains six model atmospheres,

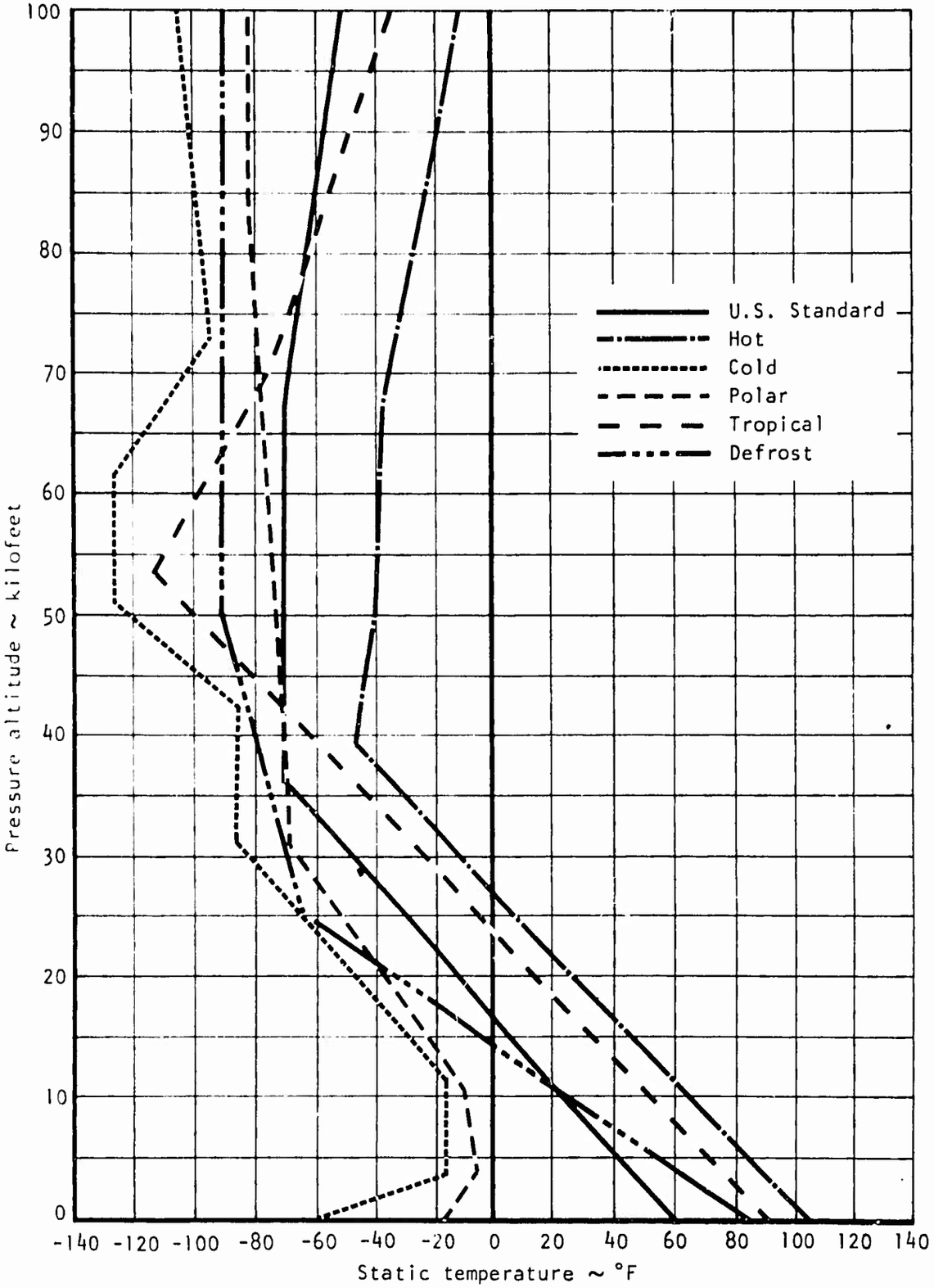


Figure 8. Static temperatures of model atmospheres.

of which only the standard atmosphere is currently used. These atmospheres and the indexing numbers for calling them are listed in Table 6.

TABLE 6. CALLING NUMBERS FOR MODEL ATMOSPHERES

Call	Model Atmosphere	Source Ref
1	U.S. Standard Atmosphere, 1962	11
2	Cold Atmosphere (MIL-STD-210A)	12
3	Hot Atmosphere (MIL-STD-210A)	12
4	Polar Atmosphere (MIL-STD-210A)	12
5	Tropical Atmosphere (MIL-STD-210A)	12
6	Defrost Atmosphere	13

Total Temperature

Both the function for the aerodynamic heating coefficient and the function for the adiabatic wall temperature require the total temperature internally.

The total temperature is defined as the temperature reached by bringing air to rest adiabatically and with no addition or subtraction of work. This definition is used to compute the total temperature by the method of constant total enthalpy where total enthalpy is defined as the sum of the static enthalpy and the kinetic energy.

$$H_T = H_1 + KE_1 = H_2 + KE_2 \tag{6}$$

where H = enthalpy

KE = kinetic energy

Subscripts T, 1, and 2 = total, initial, and final, respectively

By definition, the final kinetic energy is zero. Then:

$$KE_1 = H_2 - H_1 = \int_{T_1}^{T_2} wc_p \, dT = \frac{w V_1^2}{2gJ} \tag{7}$$

where

w = weight of air, lb

c_p = specific heat of air, BTU/lb/°R

g = gravitational acceleration, ft/sec^2

J = 778 ft-lb/BTU = Joule's constant

V_1 = initial local velocity, ft/sec

Specific heat varies as a function of temperature according to an equation by Donaldson (8).

$$c_p = \frac{R}{J}\left[\frac{7}{2} + \left(\frac{\theta/T}{e^{\theta/T}-1,000}\right)^2 \quad e^{\theta/T}\right] \tag{8}$$

where

c_p = specific heat of air, BTU/lb/°R

R = gas constant of air = 53.35 ft/°R

θ = 5,526° R = characteristic temperature of molecular vibration

T = varying static temperature of air as it is brought to rest, °R

The variable specific heat, equation 8, is substituted into equation 7, the weight cancelled from both terms, and the integration made between the limits of the static temperature, T_L, and the total temperature T_T.

$$\frac{V^2}{2gJ} = \frac{R}{J}\left[\frac{7}{2}\left(T_T - T_L\right) + \frac{\theta}{e^{\theta/T_T} - 1.000} - \frac{\theta}{e^{\theta/T_L} - 1.000}\right] \tag{9}$$

Equation 9 is solved by a trial and error process to return the total temperature, T_T.

Adiabatic Wall Temperature

The adiabatic wall temperature is the forcing potential, a mean effective temperature for heat transfer through the aerodynamic boundary layer. The adiabatic wall temperature, T_{AW}, is computed in the function subprogram, TBL. The equation for adiabatic wall temperature is:

$$T_{AW} = T_L + r \left(T_T - T_L\right) \tag{10}$$

where

T_{AW} = adiabatic wall temperature, °R

T_L = local static temperature, °R

r = recovery factor

T_T = total temperature, °R

The recovery factor is the square root of the Prandtl number for laminar flow and the cube root for turbulent flow. The free-stream Reynolds number is compared with the criterion for transition, and the square root or the cube root is selected accordingly. The Prandtl number varies with the reference temperature.

Reference Temperature

The thermal properties of air in both the HBL and TBL function subprograms are evaluated at the reference temperature as defined by Eckert[5].

$$T_{ref} = 0.280\ T_L + 0.500\ T_S + 0.220\ T_{AW} \tag{11}$$

where

T_{ref} = reference temperature, °R

T_L = local static temperature, °R

T_S = skin temperature, °R

T_{AW} = adiabatic wall temperature, °R

This reference temperature may be regarded as a weighted average of the temperatures that exist at various locations through the boundary layer.

Conductivity, Viscosity, Prandtl Number, and Reynolds Number

Thermal conductivity, viscosity, Prandtl number, and Reynolds number are used in the function subprograms for aerodynamic heating coefficient, h, and adiabatic wall temperature, T_{AW}. These properties vary according to the reference temperature which depends on the adiabatic wall temperature. These functions have trial and error solutions to converge iteratively on their answers.

Variations of conductivity and viscosity are calculated as recommended in References 10 and 11.

$$k = \frac{0.0011404\ T_{ref}^{1/2}}{1 + \frac{441.72}{T_{ref}}\ (10.00)^{21.6/T_{ref}}} \tag{12}$$

$$g\mu = 0.002627\ \frac{T_{ref}^{1.5}}{T_{ref} + 198.7} \tag{13}$$

where

k = thermal conductivity, BTU ft/hr/°F/ft^2

$g\mu$ = viscosity times gravitational acceleration, lb/hr/ft

T_{ref} = reference temperature, °R

N_{PR} = Prandtl number, $\frac{c_p \mu g}{k}$ (14)

N_{RE} = Reynolds number, $\frac{\rho V L}{\mu}$ (15)

where

V = Local flow-velocity, ft/sec

L = Characteristics-Length, taken as half the surface mean geometric chord

c_p = specific heat, BTU/lb/°R (equation 7)

Aerodynamic Heating Coefficient

The aerodynamic heating coefficient, h, is computed by a function subprogram, HBL. This subprogram was written to calculate h at one specific point on any of the following categories of surfaces:

1. Flat plates at zero angle of attack (parallel flow). Parameter h is calculated at the specified distance aft of the leading edge.

2. Flow over conical surfaces with body centerline at zero angle of attack. Parameter h is calculated at the specified distance aft of the leading edge.

3. Swept cylindrical leading edges. Parameter h is calculated at the leading edge.

4. Spherical bodies. Parameter h is calculated at the stagnation point.

Only method 1, specified in the calling program TEMPER, is used by SWEEP, since temperatures chosen for the structural design of all surfaces are those occurring at a distance 10 feet aft of the leading edge of a flat plate.

Subprogram HBL was written to account for either laminar or turbulent flow, depending upon whether the point at which the structural temperature is to be calculated lies forward or aft of the flow transition point. When the input value at transition Reynolds number is zero, as currently programmed, subprogram HBL automatically selects 1 million for that value. With the combination of 1 million for transition Reynolds number and 10.0 feet for the point of temperature calculation, the program will, in virtually all cases, determine h based upon turbulent flow properties.

Transition

The flow in the parallel and conical orientations varies automatically from laminar to turbulent and vice versa according to the preset criterion for change. The program compares the actual Reynolds number with this criterion and uses the appropriate mode of flow. Entering a very high Reynolds number of transition will cause only laminar flow to be considered. The default for this criterion is one million, a frequently used but not necessarily accurate value. Truitt[4] says, "The present state of the art unfortunately does not allow one to predict accurately the transition on a given body. Many factors must be taken into account and properly weighed. Except for the stagnation region problem, it is probably better for a preliminary analysis to assume that turbulent flow exists above local Reynolds number of one million." The precise value of the transitional criterion is not usually important, as transition generally occurs near the leading edge causing most of the airplane to be in the turbulent regime.

Laminar Coefficient

The laminar heat transfer coefficient is computed from the familiar Blassius equation

$$C_f = 0.664\, N_{RE}^{-0.500} \tag{16}$$

where

C_f = skin friction coefficient

N_{RE} = Reynolds number

This skin friction coefficient is transposed to a heat transfer coefficient by Reynolds analogy modified as recommended by Eckert[5].

$$h = \frac{C_f}{2}\, N_{PR}^{-2/3}\, g\rho c_p\, V \tag{17}$$

where

h = heat transfer coefficient, BTU/hr/°R/ft^2

C_f = skin friction coefficient, no units

N_{PR} = Prandtl number

$g\rho$ = specific weight, lb/ft^3

c_p = specific heat, BTU/lb/°K

V = local velocity, ft/sec

Turbulent Coefficient

For turbulent flow, the program calculates heat transfer coefficient by the Van Driest method. Actual detail and derivation of the equations used by Van Driest are found in References 6 and 7. Truitt [4] presents the equations in a workable form for engineering calculations.

SOLUTION FOR SKIN TEMPERATURE

The heat flux equation, based on the assumption that noctural radiation is negligible, can be written as shown in equation 18.

$$0 = h \left(T_{AW} - T_S\right) + \alpha G \cos\phi - \sigma \epsilon T_S^4 \tag{18}$$

Equation 18 can be rearranged as shown in equation 19.

$$T_S = A - B T_S^4 \tag{19}$$

where

$$A = \frac{h T_{AW} + \alpha G \cos\phi}{h}$$

$$B = \frac{\sigma \epsilon}{h}$$

Equation 19 is an inverted fourth-power parabola which is solved by a trial and error method that returns the only real and positive root. The method is a modified chord or reguli falsi method. The solution is performed by the function TSKIN, for "temperature of skin." It is described in detail by Reference 16.

Since both adiabatic wall temperature, T_{AW}, and aerodynamic heat transfer coefficient, h, are dependent on the equilibrium skin temperature, an iteration procedure is used. Subroutine TEMPER controls this iteration. The search loop is outlined as follows:

1. Estimate skin temperature.

2. Use TBL to determine adiabatic wall temperature based on the estimated skin temperature, equation 10.

3. Use HBL to determine aerodynamic heat transfer coefficient based on the estimated skin temperature.

4. Use TSKIN to calculate skin temperature, equation 19.

5. Test on estimated versus calculated temperature (Step 1 versus Step 4).

6. If calculated temperature has not converged sufficiently, enter loop at Step 2 and repeat using calculated for estimated skin temperature.

The program contains a criterion of convergency to which the difference of answers from successive passes are compared. One-tenth of a degree Fahrenheit (0.1° F) is used in the present version of the program. If the criterion is not met within 90 passes, the convergence criterion is raised to 1 degree. Then, up to 19 additional passes are allowed to attempt to converge, but in any case the final values are used.

MATERIALS PROPERTIES METHODOLOGY

For a discussion of the methodolgy used in determining materials properties, refer to Part 1 of this volume.

PANEL FLUTTER METHODOLOGY

Since panel flutter is evaluated only for fuselage and nacelle structures, discussion of this methodology is presented in the appropriate sections of Volumes V and VII.

LIFTING SURFACE FLUTTER METHODOLOGY

In a detailed flutter analysis, aerodynamic coefficients are determined for several values of the dimensionless parameter $b\omega/V$ (characteristic length times frequency of oscillation, divided by velocity). The equations of motion may then be written in the form of complex eigenvalue problem and solved at each value of $b\omega/V$ for frequency, velocity, and structural damping required to sustain harmonic oscillations. The damping required for harmonic oscillation is plotted versus velocity. The point on the curve at which damping required is equal to the damping which exists in the structure is the neutral stability point.

A truly optimum stiffness distribution would be one which resulted in a constant stress over the entire structure if it were deformed in the flutter mode. The flutter mode is determined by the combination of the aerodynamic and the inertia loading. The maximum loading is determined by the vectorial sum of the aerodynamic and inertia loads, since phase angles exist between the two types of load. However, according to Reference 18, examination of several flutter cases has shown that, for the planforms considered, the two types of loads are distributed very nearly in the same manner. Hence, a consideration of the aerodynamic loading alone provides a good approximation of the loading. Furthermore, it has been noted that the aerodynamic loading at the flutter point very closely resembles the loading at static aeroelastic, torsional divergence of an equivalent straight wing. This provides a very powerful tool for development of the technique for predicting stiffness required to prevent flutter. An important implication is that only the torsion stiffness need be considered. Naturally, this dictates that cases in which the ratio of bending frequency to torsion frequency is too close to unity are, in general, beyond the scope of the technique. These cases, however, are sufficiently rare that the majority of cases may be evaluated.

DERIVATION OF EQUATIONS

The dynamic pressure at torsional divergence of an unswept wing is given by the equation

$$q = \frac{\int GJ\theta'^2 dx}{C_{\ell_\alpha} e \int C^2 \theta^2 dx} \tag{20}$$

From this, a stiffness criterion has been defined in Reference 20.

$$C_{\ell_\alpha eq} = \frac{\int GJ\theta'^2 dx}{\int C^2\theta^2 dx} \tag{21}$$

For convenience, the product $C_{\ell_\alpha} eq$ has been defined arbitrarily as

$$e_e = \left(\frac{V_a}{1000}\right)^2 \frac{C_{\ell_\alpha} e_1}{2\pi} \quad (e_1 \text{ in \% chord}) \tag{22}$$

or

$$e_e = C_{\ell_\alpha} e_1 q/1.116 \quad (q \text{ in psi})$$

The parameter e_e is called the "effective eccentricity" of the surface, and can be thought of as the chordwise eccentricity the structure can support at divergence at 1,000 mph if the lift curve slope is equal to 2π.

Examination of a large collection of experimental flutter model data has shown that the parameter e_e is primarily a function of aspect ratio and sweepback angle. An empirical expression has been developed which gives the proper value of e_e to correlate well with a large amount of available data. This expression is, for the foregoing definition of e_e,

$$e_e = \frac{K}{(1 + 0.8/AR)^2} \frac{q}{1480} [0.4 + 0.7 \cos (\Lambda_{c/4} - 10°)] \tag{23}$$

where

K = 24.75 for wings

and

K = 25.88 for empennage surfaces.

This expression has been used with considerable success for the speed ranges below those where appreciable compressibility effects are encountered. A modification to be used for transonic and supersonic design points has been proposed and will be discussed in a later paragraph.

A technique has been developed for computing the torsional stiffness distribution which will result in a constant stress over the span of the wing for the torsional divergence mode. This technique will be presented in the matrix form. The wing is divided into chordwise strips as shown in Figure 9. The strips of width, Δx_i, are used for the definition of the aerodynamic terms, while the strips of width, ΔX_K, are used for definition of structural properties. The torsional stiffness of the wing is defined by the torsional constant, J_K, at the outboard edge of the K_{th} strip. The relation between twist angle and torsional loading

$$\frac{d\theta}{dx} = \frac{T}{GJ} \tag{24}$$

may be written in matrix form for the wing of Figure 9 as

$$G\,[J_{kk}]\,\{\theta_i'\} = \{T_i\} \tag{25}$$

where θ_i is interpreted as the change in twist angle over the i^{th} strip and T_i is the total torque on the structure at the i^{th} strip. Since the total torque at any station is a summation of the individual torque acting on the strip and on each strip outboard of the strip considered,

$$\{T_i\} = [I_n]^T\,\{\Delta T_i\} \tag{26}$$

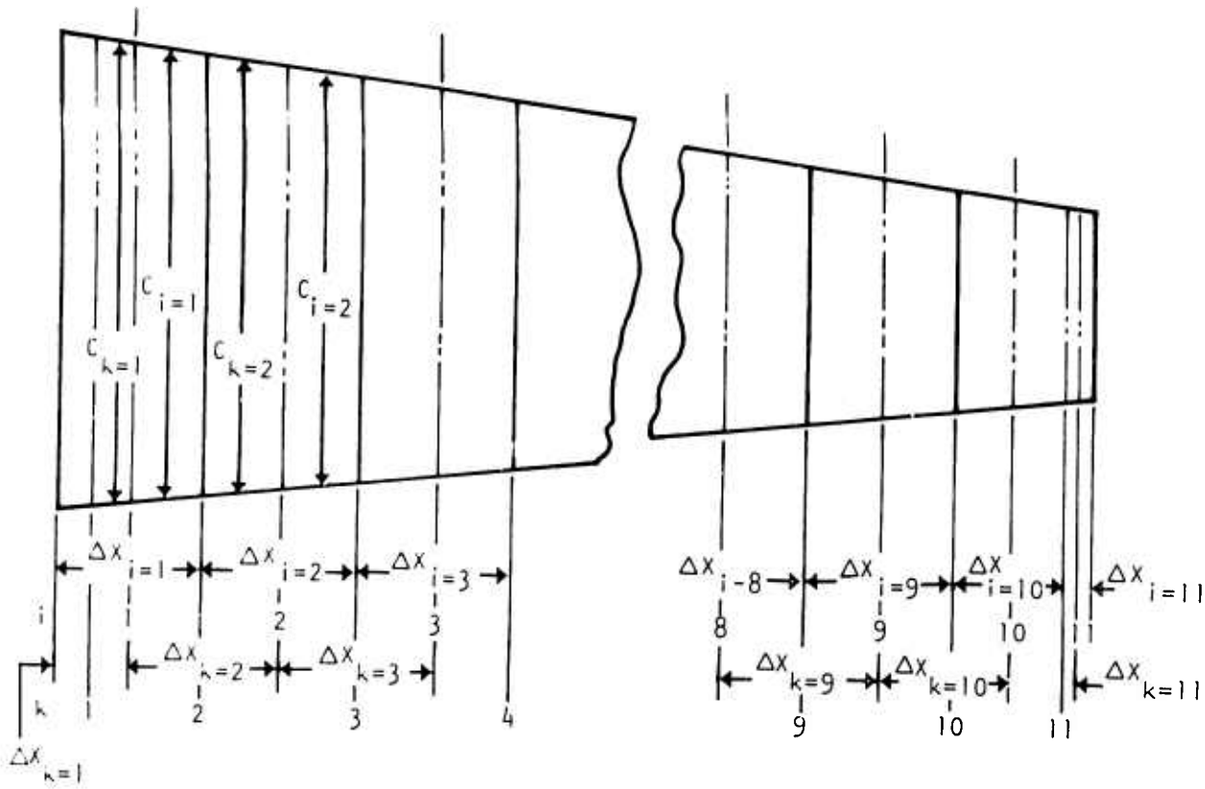


Figure 9. Wing geometry for derivation.

where

$$[I_n]^T = \begin{bmatrix} 1 & 1 & \cdot & \cdot & \cdot & 1 \\ 0 & 1 & 1 & \cdot & \cdot & 1 \\ \cdot & \cdot & 1 & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & 1 & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & 1 & \cdot \\ 0 & \cdot & \cdot & \cdot & 0 & 1 \end{bmatrix} \tag{27}$$

and $\{\Delta T_i\}$ can be expressed as

$$\{\Delta T_i\} = C_{\ell\alpha} q_e [C^2] [\Delta X_i] \{\theta_i\} \tag{28}$$

The term $C_{cut}qe$ has been defined in Reference 18 as 1.116 e_e. Using this notation,

$$G[J_{KK}]\{\theta'_i\} = 1.116\ e_e\ [I_n]^T\left[C_i^2\right][\Delta X_i]\{\theta_i\} \tag{29}$$

The condition that the torsional stress must be constant over the span requires that

$$\{T_i\} = 2\sigma_T[A_k]\{t_k\} \tag{30}$$

Also, the torsion constant J_k can be defined as

$$\{J_k\} = \left[4\ A_k^2\right][1/S_k]\{t_k\} \tag{31}$$

Equation 31 may be rearranged to express the skin thicknesses as

$$\{t_i\} = 1/2\left[1/A_k^2\right][S_k]\{J_k\} \tag{32}$$

Substituting equation 32 into equation 30 results in

$$\{T_i\} = 2\sigma_T/4[A_k/S_k]\{J_k\} \tag{33}$$

Substituting equation 33 for T_i in equation 25 and rearranging results in

$$\{\theta'_i\} = 2\sigma_T/4G\{S_k/A_k\} \tag{34}$$

The numerical integration of equation 34 may be expressed as

$$\{\theta_i\} = 2\sigma_T/4G[I_n][\Delta X_{kk}]\{S_k/A_k\} \tag{35}$$

Equations 34 and 35 may now be substituted into equation 10 to obtain the expression for the required optimum stiffness distribution

$$\{\omega\} = 1.110\, e_e \left[\frac{A_k}{S_k}\right] [I_n]^{-1} \left[C_i^2\right] [\Delta X_i] [I_n] [\Delta X_k] \left\{\frac{S_k}{A_k}\right\} \tag{36}$$

The values for A_k/S_k may not be known or it may not be desirable to spend time computing these quantities for preliminary design approximations. However, there is a substitution which can be made for A_k/S_k in most cases. If the width of the torque box is proportional to the wing chord and the thickness to-chord ratio is constant across the span, then A_k/S_k is proportional to the wing chord, for a rectangular torque box.

The advantage of this substitution is readily seen; the wing chord at the K_{tj} stations can be determined much more quickly than the value of A_k/S_k. The error due to this approximation is almost negligible, even in many practical cases where the preceding assumptions are not exactly true. This is primarily because the level of A_k/S_k has no effect on the torsion constants computed. The values for A_k/S_k are used once and the reciprocals are used once in the matrix equation. Thus, it is evident that if the column matrix A_k/S_k were multiplied by any arbitrary constant and the column $\{S_k/A_k\}$ by the reciprocal of the constant, the net result would be no change in the equation. It may be concluded that only the relative distribution of values of A_k/S_k across the span is important. Although most torque box cross sections are not exactly rectangular, their deviation from this shape does not in itself appreciably affect the manner in which the values of A_k/S_k are distributed over the span.

An integrated form of equation 36 is presented in Reference 21. This form of the equation has been programmed in subroutines GJCAL and GJSI of the wing and empennage weight estimation module.

APPLICATION TO SWEPTBACK WINGS

Although the previous derivation used a straight wing as the example planform, sweptback wings can also be handled. The relation for e_e, given by equation 24 contains an empirical expression to account for sweepback angle. The only additional consideration necessary is that of defining the length and position of the elastic axis. Although no definite theoretical method has been formulated for this, techniques have been developed which have consistently given good results.

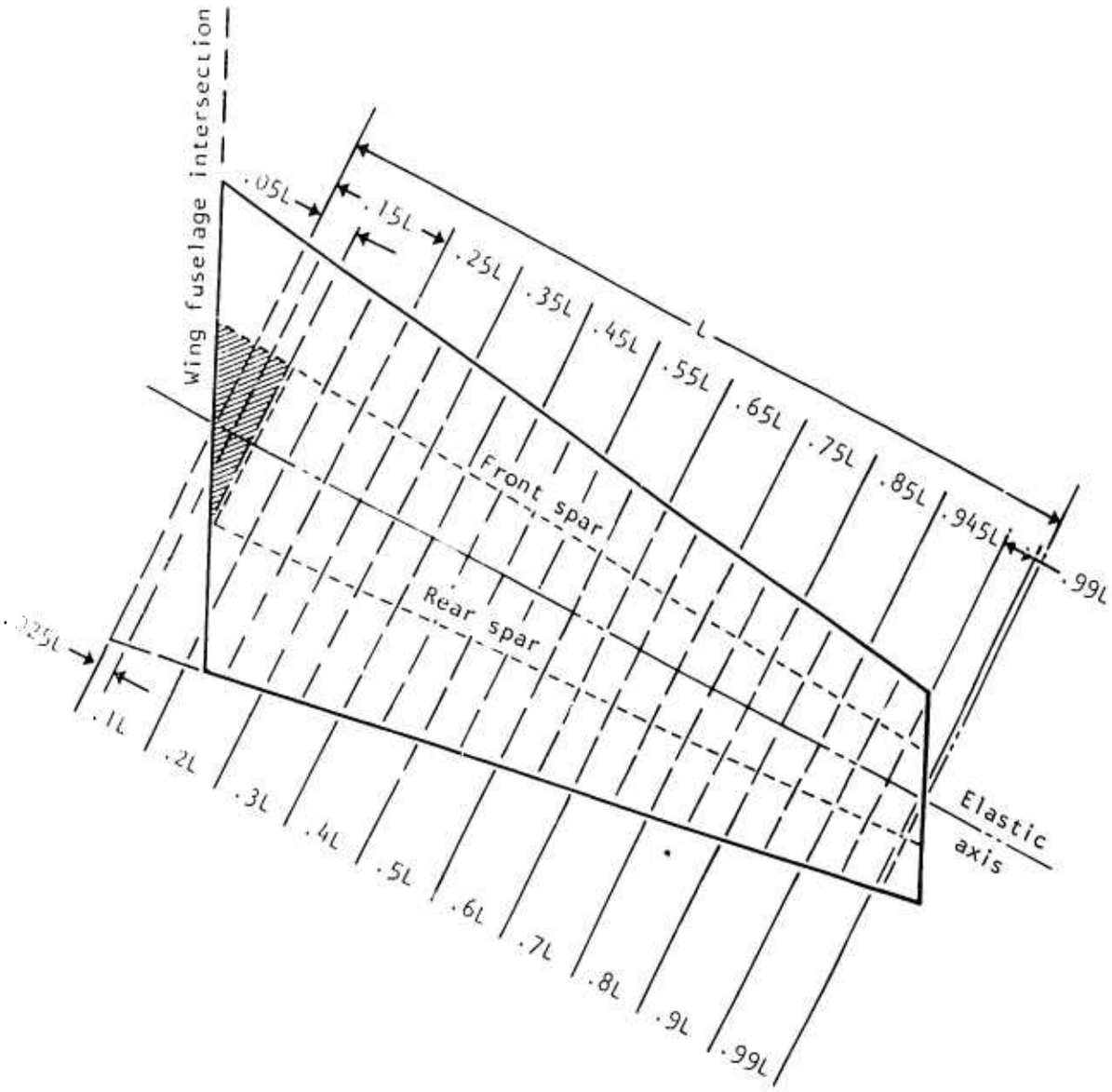
The geometry for a typical swept wing is shown in Figure 10. It has been found that best results are obtained if the chords perpendicular to the elastic axis are defined as shown in Figure 9. That is, the trailing edge is extended inboard of the wing-fuselage intersection and the chords in the wing root area are defined by the full distance between the leading edge and the extended trailing edge along the line normal to the elastic axis. The tip area, however, is not handled in a similar manner. The chords, measured along the normal to the elastic axis, from the trailing edge to the intersection of the normal with the tip are used in the equation.

The manner of dividing the wing into strips, which has given good results and has been adopted as a standard technique, is also shown in Figure 10. The ith stations are defined as lying at percent span stations .05, .15, .25, .35, .45, .55, .65, .75, .85, .945, and .99. The kth stations are at distances from the root equal to .025, .1, .2, .3, .4, .5, .6, .7, .8, .9, and .99 times the span. This strip definition has also been adopted as the standard for straight wings as well as sweptback planforms. When this division of the planform is used, the matrix defined by $[I_n]\ [\Delta X_k]$ may be written as

$$[I_n]\ [\Delta X_k] = l \begin{bmatrix} .05 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .05 & .1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .05 & .1 & .1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .05 & .1 & .1 & .1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ .05 & .1 & .1 & .1 & .1 & 0 & 0 & 0 & 0 & 0 & 0 \\ .05 & .1 & .1 & .1 & .1 & .1 & 0 & 0 & 0 & 0 & 0 \\ .05 & .1 & .1 & .1 & .1 & .1 & .1 & 0 & 0 & 0 & 0 \\ .05 & .1 & .1 & .1 & .1 & .1 & .1 & .1 & 0 & 0 & 0 \\ .05 & .1 & .1 & .1 & .1 & .1 & .1 & .1 & .1 & 0 & 0 \\ .05 & .1 & .1 & .1 & .1 & .1 & .1 & .1 & .1 & .095 & 0 \\ .05 & .1 & .1 & .1 & .1 & .1 & .1 & .1 & .1 & .095 & .045 \end{bmatrix}$$

where l = total structural span along the elastic axis.

The length of the elastic axis is assumed to be defined by the distance from the wing-fuselage intersection to the tip, provided the wing-fuselage intersection is not extremely flexible. For wings of moderate sweep, the chordwise location of the elastic axis is not extremely critical, and it has been the practice to assume the 50-percent chord line as the elastic axis, if the true location is not known. For more sharply swept wings, the chordwise location is slightly more critical, since chordwise changes in elastic axis location can cause a more appreciable change in length of the elastic axis. However, it has been found that the location of the elastic axis can usually be estimated accurately enough with only the simplest of calculations.



Figue 10. Geometry for swept wing.

$[U_n]^T[C_j^2][\Delta x_j]$ is equivalent to

$$\frac{L}{10}\begin{bmatrix}
C^2_{.05L} & C^2_{.15L} & C^2_{.25L} & C^2_{.35L} & C^2_{.45L} & C^2_{.55L} & C^2_{.65L} & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & C^2_{.15L} & C^2_{.25L} & C^2_{.35L} & C^2_{.45L} & C^2_{.55L} & C^2_{.65L} & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & C^2_{.25L} & C^2_{.35L} & C^2_{.45L} & C^2_{.55L} & C^2_{.65L} & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & C^2_{.35L} & C^2_{.45L} & C^2_{.55L} & C^2_{.65L} & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & 0 & C^2_{.45L} & C^2_{.55L} & C^2_{.65L} & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & 0 & 0 & C^2_{.55L} & C^2_{.65L} & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & 0 & 0 & 0 & C^2_{.65L} & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & C^2_{.75L} & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & C^2_{.85L} & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & .8C^2_{.945L} & .2C^2_{.99L} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & .2C^2_{.99L}
\end{bmatrix}$$

Low aspect ratio, highly swept planforms are common for empennage surfaces and present a special case in the treatment of the computed GJ in the area of the root of the surface. This case is different because the actual cross section of the torque box becomes narrower in the area inboard of the elastic axis station where the trailing edge of the torque box intersects the root rib, or fuselage, side. In this area, the trailing edge of the torque box

section which is normal to the elastic axis is actually formed by the root rib. This is a triangular area, shown as a shaded area in Figure 10. The most rigorous application of the method would require that the true values for the ratio of torque box area to perimeter be used in the equations. However, it has been found that an approximation can be made which simplifies the input data and still allows sufficient accuracy to be obtained. This approximate procedure consists of merely assuming that the ratio of torque box area to perimeter continues to follow the same variation in this root area as it follows over the outer span. The GJ is computed under this assumption; then, the GJ computed is not used for design of the sections inboard of the elastic axis station at which the rear spar intersects the fuselage or root rib. Instead, the required GJ is assumed to be that which results from a constant skin gage over the triangular area under consideration. This gage is required to be the same as that determined by the required GJ at the elastic axis station which forms the outboard edge of the triangular area. This results in decreased stiffness requirements in the inboard area, as compared to the actual value. However, experience has shown that the use of the full chord of the surface for the inboard area results in an adequate level of stiffness over the remainder of the span to compensate for the loss in stiffness in the inboard area.

EXTENSION TO TRANSONIC AND SUPERSONIC SPEEDS

The previous technique is based on incompressible aerodynamic theory and, therefore, is not directly applicable for transonic and supersonic design. The technique used for extending the method to higher speeds is based on observed characteristics of plots of the dimensionless flutter parameter $b\omega_\alpha \sqrt{\mu}/a$ versus mach number. Plots of this parameter for several different planforms are shown in Figures 11 through 13. The area below such a curve represents the region of instability, while the area above the curve is the stable or no-flutter region. It is usually found that aspect ratio, taper ratio, and sweep angle are the primary factors which affect the level and shape of these curves, except in cases where frequency ratios are close to unity, or mass ratios are very low. Therefore, for design purposes, it is assumed that wings having the same aspect ratio, taper ratio, and sweep angle will have approximately the same flutter boundary or plot of $b\omega_\alpha \sqrt{\mu}/a$ vesus mach number.

Straight lines through the origin of such a plot are lines of constant dynamic pressure, or q, for a given wing, and the slope of the line is inversely proportional to the square root of q. Horizontal lines are lines of constant altitude or lines of constant density, with speed of sound times square root of density inversely proportional to $b\omega_\alpha \sqrt{\mu}/a$. As shown by Figures 11 through 13, the curves are always straight lines for mach numbers below the speed range at which compressibility effects begin. This is in line with the known fact that flutter usually occurs at a constant dynamic pressure in the subsonic speed range.

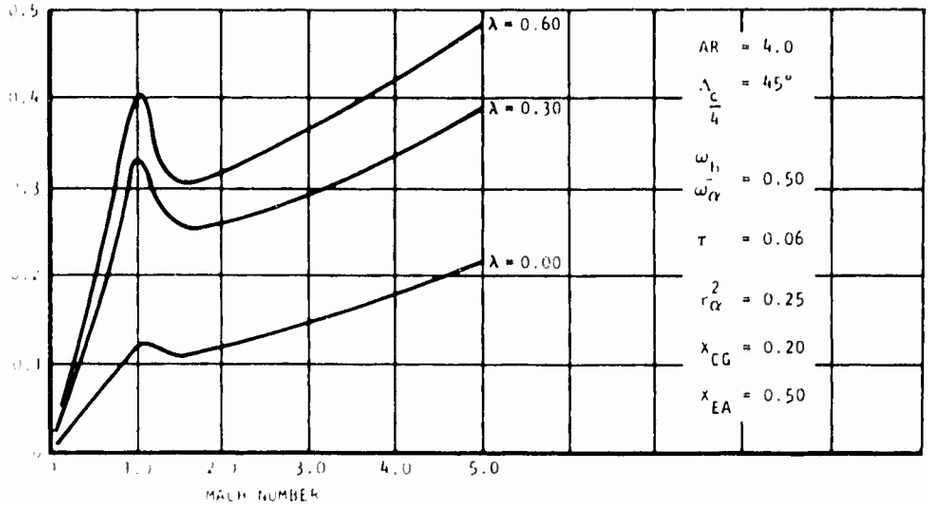


Figure 11. Effect of taper ratio, λ .

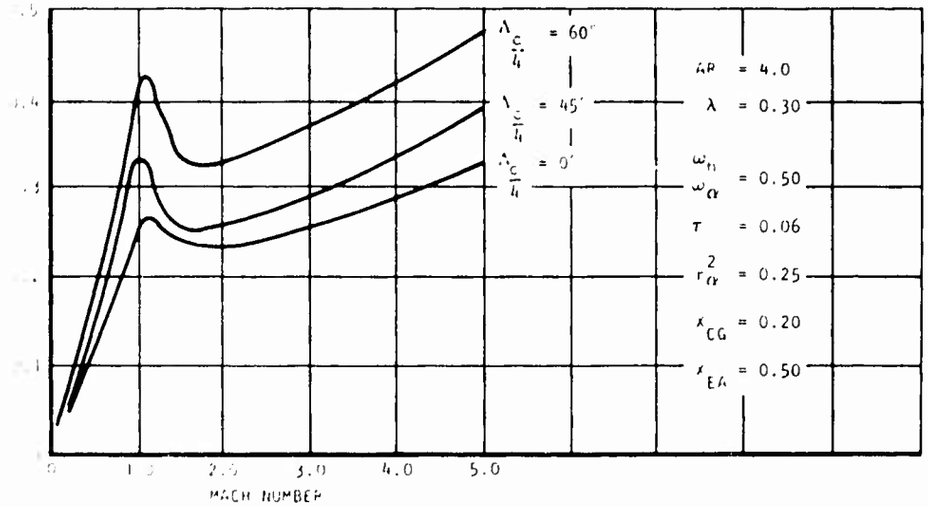


Figure 12. Effect of quarter-chord sweep angle, $\Lambda_{\frac{c}{4}}$.

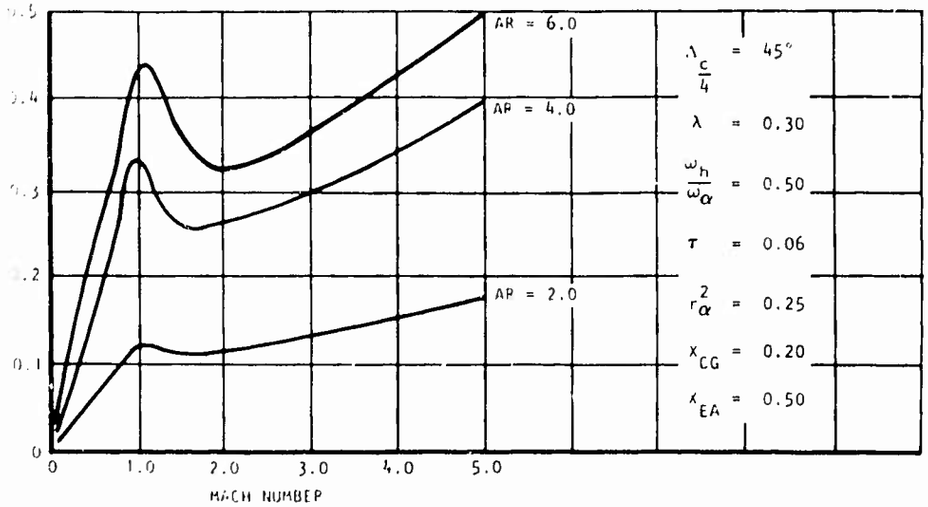


Figure 13. Effect of aspect ratio, AR.

It will now be shown how these characteristics of plots of the dimensionless flutter parameter suggest a technique whereby such plots were used to modify the stiffness criteria developed in the preceding paragraphs. The required stiffness computed by the aforementioned method is directly proportional to dynamic pressure. Therefore, the modification will be effected by computing the proper dynamic pressure to be inserted in the preceding equations so that the stiffness computed will insure flutter stability at the required speeds. This dynamic pressure is determined from the plot of $b\omega_\alpha \sqrt{\mu}/a$ versus mach number for the planform, and from the required speed-altitude curve by the following procedure: An altitude or density scale to be superimposed on the plot of $b\omega_\alpha \sqrt{\mu}/a$ versus mach number may be chosen so that when the required speed-altitude curve is plotted, no points on the flutter boundary lie above the speed-altitude curve, but so that the flutter boundary is tangent to the speed-altitude curve at one or more points. This, of course, assumes that the required speed-altitude curve or speed-density curve is defined by speeds sufficiently above the maximum operating speed of the air vehicle to provide the required margin of safety in flutter stability. The validity of arbitrarily placing the altitude, or density scale, on the flutter boundary plot stems from the fact that $b\omega_\alpha \sqrt{\mu}/a$ is nondimensional. Locating the altitude scale for a given wing merely defines the relative level of ω which the wing must have in order for the values of $b\omega_\alpha \sqrt{\mu}/a$ to be compatible with the altitude scale. The frequency, ω_α, is directly proportional to the square root of the wing stiffness level so that the choice of the altitude scale may be thought of as defining the required relative stiffness level of the wing.

The altitude scale chosen then defines the dynamic pressure which corresponds to the constant q-line of the flutter bondary. This dynamic pressure is the value to be used in the calculation of the required stiffness for the wing.

ILLUSTRATIVE EXAMPLE

An example of the procedure to determine the proper dynamic pressure to be used in equation 23 illustrates the technique. This approach has been programmed in subroutine QSUB in the flutter and temperature module.

It will be assumed that it is desired to compute the stiffness requirements for a surface with aspect ratio = 4.0, taper ratio = 0.3, and a sweepback of the quarter chord line of 45 degrees. The flight operational requirements will be assumed to be those described by the altitude mach number curve in Figure 14.

It will be further assumed that a 20-percent margin in speed and a 44-percent margin in dynamic pressure must be added to the operational requirement to obtain the flutter design requirement. The general flutter boundary for the planform is taken from Figure 15. The requirement for 20-percent margin in speed determines that a sea-level altitude line must intersect the flutter boundary at M = 0.96.

This is shown in Figure 15 as line AB. A line drawn through the origin and the point of intersection of the sea-level line and the flutter boundary represents the required flutter design q of 1,370 psf. This is shown as line BD in Figure 15. It may be seen that all points on the flutter boundary for mach numbers greater than 0.96 lie below their required design q-line. However, at mach numbers below 0.96, a portion of the boundary lies above the required q-line. Hence, this relative location of the design q-line on the plot will not result in satisfaction of the requirement for margin of safety in dynamic pressure. Therefore, a new line must be drawn on the plot to represent the design q-line. This is line CE in Figure 15 and is drawn so that it is just tangent to the flutter boundary. This line now represents the design dynamic pressure, q = 1,370 psf. The corresponding new sea-level line may be defined by drawing a horizontal line, FG in Figure 15, so that it intersects the design q-line at M = 0.96. The proper relation between the altitude scale and the general flutter boundary has now been established, and lines IK and KE represent the design requirements obtained by adding the necessary margin of safety in speed and dynamic pressure to the operational curve. The final step is to determine what value of dynamic pressure is represented by the straight-line portion of the flutter boundary, designated by line CH in Figure 15. Since the slopes of straight lines through the origin are inversely proportional to the square root of dynamic pressure, the dynamic pressure which corresponds to line CH is given by the dynamic pressure of line CG multiplied by the square of the ratio of the slope of line CG to the slope of line CH. For the subject example, this ratio of the slopes is 0.357/0.307 = 1.16, and the square of the ratio is 1.35. Therefore, the dynamic pressure corresponding to line CH is 1.35 x 1,370 = 1,850 psf. If this value of dynamic pressure is used in equation 36, the resulting stiffness will be the optimum distribution which will provide the required margin of safety for the operational curve of Figure 14. For limitations inherent in the programmed selection of these critical dynamic pressure, refer to note on page 141.

This example shows that compressibility effects can greatly increase the stiffness required to prevent flutter. In this example, the method indicates that a 35-percent increase in stiffness is necessitated by compressibility effects. Clearly, when increments of this magnitude are involved, optimum design cannot be achieved if the unmodified stiffness criterion for the incompressible speed range is used.

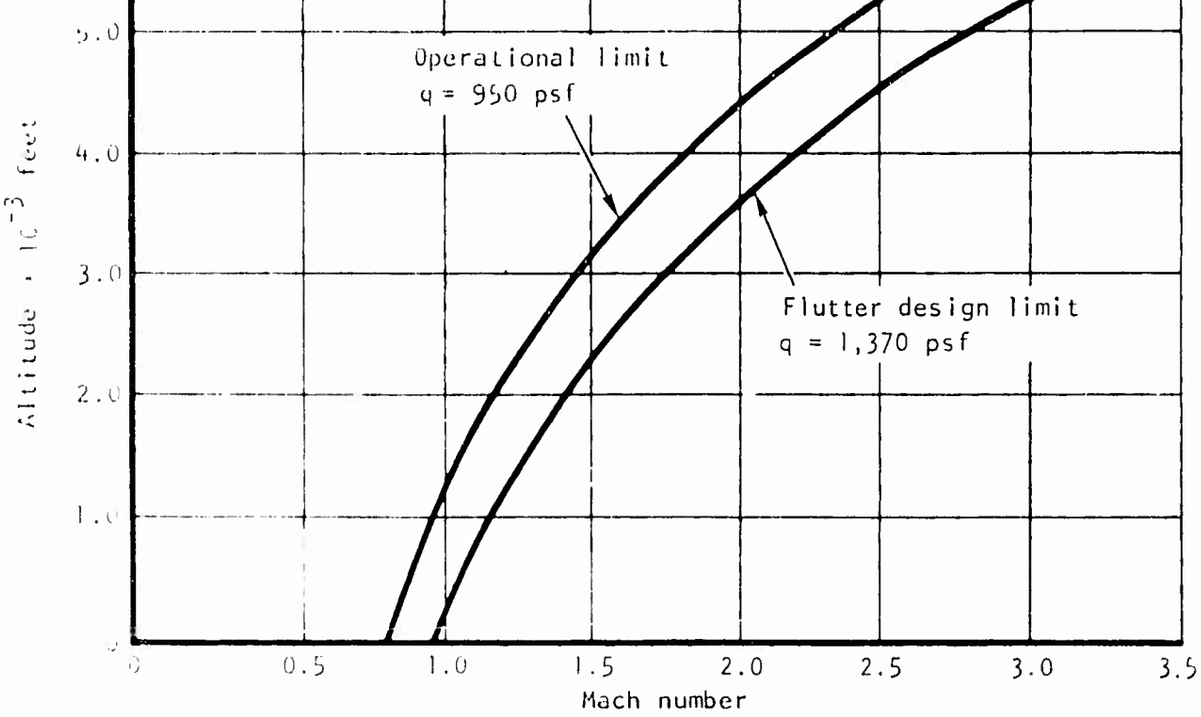


Figure 14. Altitude and mach number curves for example No. 1.

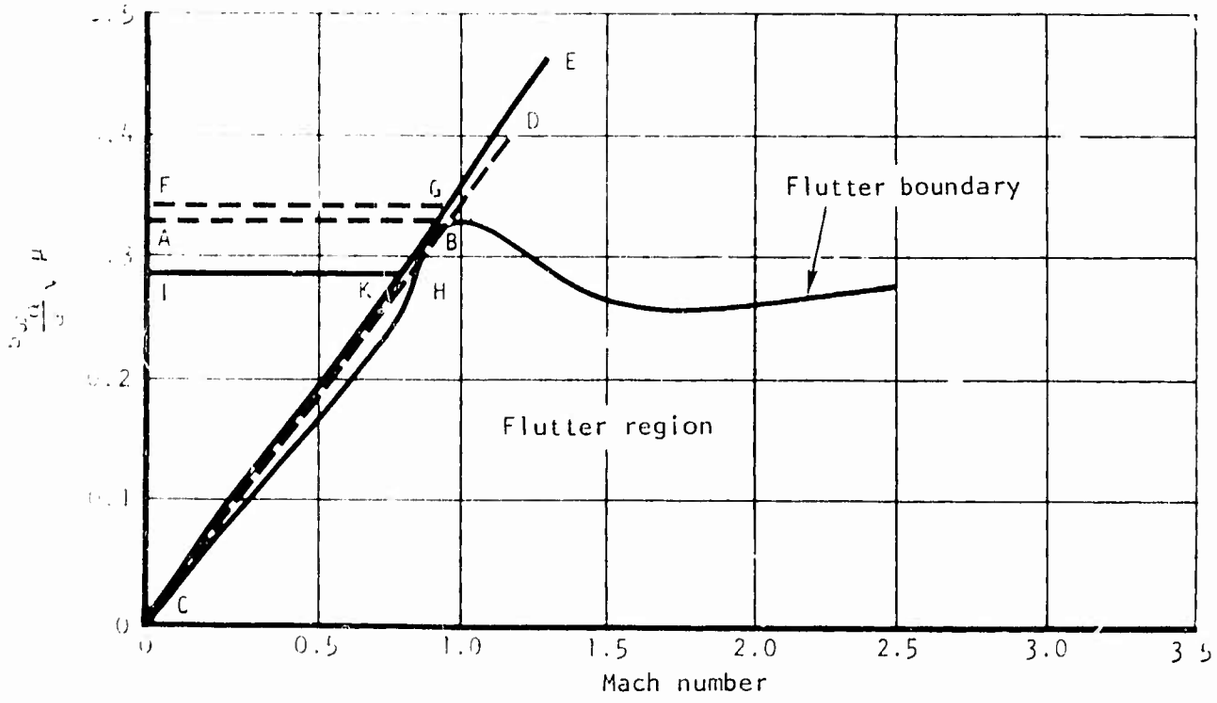


Figure 15. Flutter boundary and design requirements for example No. 1.

INTERPOLATION FOR FLUTTER BOUNDARIES

It is often necessary to compute stiffness requirements for planforms having combinations of aspect ratio, taper ratio, and sweep angle which are not identical to any of the combinations represented by Figures 11 through 13. However, these parameters for most practical surfaces do fall within the ranges of aspect ratio, taper ratio, and sweep which correspond to the figures. For these cases, the flutter boundary for the planforms were approximated by interpolation between the curves in Figures 11 through 13. Tabulated values of the flutter parameter versus mach number are shown in Table 7.

To illustrate the interpolation technique, the example planform has an aspect ratio of 5.0, a taper ratio of 0.25, and a sweep angle of 30 degrees. The value for the altitude stiffness parameter at a particular mach number is given by the figurative formula:

$$\begin{pmatrix} AR = 5 \\ \lambda = .25 \\ \Lambda_{c/4} = 30^\circ \end{pmatrix} = \frac{\begin{pmatrix} AR = 5 \\ \lambda = .3 \\ \Lambda_{c/4} = 45^\circ \end{pmatrix}\begin{pmatrix} AR = 4 \\ \lambda = .25 \\ \Lambda_{c/4} = 45^\circ \end{pmatrix}\begin{pmatrix} AR = 4 \\ \lambda = .3 \\ \Lambda_{c/4} = 30^\circ \end{pmatrix}}{\begin{pmatrix} AR = 4 \\ \lambda = .3 \\ \Lambda_{c/4} = 45^\circ \end{pmatrix}}$$

This procedure is used in subroutine SVFTAB to obtain the flutter parameter curve for the given wing, horizontal tail, and vertical tail planform geometries.

T-TAIL FLUTTER METHODOLOGY

Although some interaction in stiffness requirements of the horizontal and vertical tail surfaces may occur, the stiffness level of the vertical tail is usually the most important for T-tail flutter, provided, of course, that the horizontal tail has adequate stiffness to prevent flutter when it is treated as an independent surface. It is therefore assumed that the preliminary stiffness requirements for the horizontal tail are adequately determined by the method described for the prevention of surface flutter.

TABLE 7. DATA FOR FLUTTER PARAMETER VERSUS MACH NUMBER CURVES

Curve	1		2	3	4	5	6	7
AR	4.0		2.0	6.0	4.0	4.0	4.0	4.0
λ	0.3		0.3	0.3	0.3	0.3	0.0	0.6
$\Lambda_{c/4}$	45°		45°	45°	0°	60°	45°	45°
Point	Mach No.	TaP	TAR2	TAR6	TSB0	TSB60	TTR0	TTR60
1	0.200	0.060	0.024	0.082	0.052	0.073	0.025	0.077
2	0.400	0.120	0.048	0.164	0.104	0.146	0.050	0.154
3	0.600	0.180	0.072	0.246	0.156	0.219	0.075	0.231
4	0.800	0.240	0.096	0.328	0.208	0.292	0.100	0.308
5	0.825	0.255	0.099	0.342	0.214	0.307	0.103	0.322
6	0.850	0.275	0.102	0.360	0.220	0.325	0.106	0.340
7	0.875	0.295	0.105	0.385	0.226	0.343	0.109	0.360
8	0.900	0.310	0.108	0.400	0.232	0.360	0.112	0.375
9	0.925	0.322	0.111	0.410	0.238	0.376	0.115	0.387
10	0.950	0.327	0.113	0.418	0.244	0.390	0.118	0.395
11	0.975	0.330	0.115	0.425	0.250	0.401	0.121	0.400
12	1.000	0.332	0.117	0.430	0.255	0.410	0.123	0.403
13	1.025	0.333	0.119	0.433	0.259	0.417	0.125	0.404
14	1.050	0.332	0.120	0.435	0.263	0.422	0.126	0.405
15	1.075	0.329	0.121	0.437	0.266	0.424	0.127	0.404
16	1.100	0.325	0.122	0.436	0.268	0.425	0.128	0.402
17	1.125	0.320	0.123	0.437	0.269	0.423	0.127	0.395
18	1.150	0.314	0.122	0.435	0.268	0.420	0.126	0.385
19	1.175	0.307	0.121	0.433	0.266	0.416	0.125	0.370
20	1.200	0.300	0.120	0.430	0.263	0.410	0.124	0.358
21	1.300	0.278	0.117	0.413	0.252	0.382	0.115	0.330
22	1.400	0.267	0.114	0.390	0.245	0.354	0.111	0.310
23	1.500	0.262	0.112	0.365	0.240	0.337	0.110	0.306
24	1.600	0.259	0.111	0.350	0.237	0.330	0.111	0.305
25	1.700	0.257	0.110	0.337	0.235	0.327	0.112	0.307
26	1.800	0.257	0.110	0.330	0.234	0.325	0.114	0.310
27	1.900	0.258	0.111	0.323	0.235	0.327	0.116	0.313
28	2.000	0.260	0.112	0.320	0.236	0.330	0.118	0.316
29	2.100	0.262	0.114	0.320	0.237	0.333	0.121	0.320
30	2.200	0.264	0.116	0.322	0.238	0.337	0.124	0.324
31	2.300	0.266	0.118	0.325	0.239	0.341	0.127	0.328
32	2.400	0.269	0.120	0.328	0.241	0.345	0.130	0.333
33	2.500	0.272	0.122	0.333	0.243	0.349	0.133	0.338
34	3.000	0.292	0.130	0.360	0.256	0.372	0.148	0.364
35	3.500	0.315	0.139	0.392	0.273	0.397	0.164	0.392
36	4.000	0.339	0.149	0.425	0.291	0.423	0.181	0.422
37	4.500	0.364	0.160	0.460	0.310	0.451	0.199	0.454
38	5.000	0.390	0.172	0.498	0.330	0.480	0.217	0.486

The important problem remaining then is to develop a method for determining preliminary stiffness requirements for the vertical tail. Experimental flutter data from wind tunnel flutter models of a typical T-tail are given in Reference 19. These data are used as the basis of a stiffness criteria for the vertical tail in T-tail configurations. In order to develop the criteria, dynamic similarity relations were used to allow scaling the flutter model results to the desired full-scale tail. This establishes the required stiffness level. The optimum distribution of the stiffness is then determined by methods described for the prevention of surface flutter.

SCALING FROM TEST RESULTS

In order to use the results of Reference 19 for different size horizontal tails relative to the vertical tail, and different aspect ratio vertical tails, some assumptions must be made. Scaling the entire model uniformly is considered as included in the general scaling relations developed. The assumptions are:

1. Flutter of the full scale occurs at the same reduced velocity as the model, or

$$\left(\frac{V}{b\omega}\right)_{MOD} = \left(\frac{V}{b\omega}\right)_{FS} \tag{37}$$

$$\omega_{FS} = \omega_{MOD} \frac{b_{MOD}}{b_{FS}} \frac{V_{FS}}{V_{MOD}} \tag{38}$$

where

V = flutter velocity

b = reference length, average chord

ω = flutter frequency

subscripts

FS = refers to full scale

MOD = refers to model

2. Assume mass ratio effects are negligible, so it can be assumed that

$$\left(\frac{V_{FS}}{V_{MOD}}\right)^2 = \frac{q_{FS}}{q_{MOD}} \tag{39}$$

where

q = flutter dynamic pressure

3. Assume that scaling the cantilevered torsion frequency of the vertical tail, with horizontal tail attached, gives the proper flutter frequency

4. The cantilevered torsion frequency of the vertical tail is determined entirely by the GJ of the vertical tail and the yawing moment of inertia of the horizontal tail

From assumptions 1 and 2,

$$\omega_{FS}^2 = \omega_{MOD}^2 \left(\frac{b_{MOD}}{b_{FS}}\right)^2 \left(\frac{q_{FS}}{q_{MOD}}\right) \tag{40}$$

In order to determine the optimum GJ distribution to provide the required frequency, assume an inertia torque at the tip, T, of the vertical tail elastic axis:

$$T = \omega^2 I_\psi \theta_T \tag{41}$$

where

I_ψ = inertia of the horizontal tail

θ_T = change in twist angle

Also, assume that an optimum GJ will result if skin thickness is distributed such that the torsion stress is constant over the span of the vertical tail.

$$\{T_K\} = 2\left[A_K\right]\left[\sigma_K\right]\{t_K\} \tag{42}$$

$$\{t_K\} = \frac{1}{2}\left[\frac{1}{A_K}\right]\left[\frac{1}{\sigma_K}\right]\{t_K\} \tag{43}$$

where

t_K = skin thickness

If T_K is only due to torque at the tip, then T_K is a constant over the span such that

$$\{t_K\} = \frac{T}{2\sigma} \left\{\frac{1}{A_K}\right\} \tag{44}$$

from the definition of GJ,

$$GJ = 4 \left[\frac{A_K^2}{S_K}\right] \{t_K\} \tag{45}$$

Equation 46 is then obtained by inserting equation 44 in equation 25

$$GJ = \frac{2T}{\sigma} \left\{\frac{A_K}{S_K}\right\} \tag{46}$$

From equation 35,

$$\theta_T = \frac{\sigma}{2G} \left[\Delta X_K\right] \left\{\frac{S_K}{A_K}\right\} \tag{47}$$

From equations 41 and 47,

$$T = \omega^2 I_\psi \frac{\sigma}{2G} \left[\Delta X_K\right] \left\{\frac{S_K}{A_K}\right\} \tag{48}$$

Then, from equations 46 and 48,

$$G(GJ) = \omega^2 I_\psi \left(\left[\Delta X_K\right] \left\{\frac{S_K}{A_K}\right\}\right) \left\{\frac{A_K}{S_K}\right\} \tag{49}$$

From equations 40 and 49,

$$\{GJ\} = \omega_{MOD}^2 \left(\frac{b_{MOD}}{b_{FS}}\right)^2 \left(\frac{q_{FS}}{q_{MOD}}\right) I_\psi \left(\left[\Delta X_K\right] \left\{\frac{S_K}{A_K}\right\}\right) \left\{\frac{A_K}{S_K}\right\} \tag{50}$$

In order to include some of the effects of the change in aerodynamic forces on the vertical tail due to change in vertical tail aspect ratio, e_{eT}, the modified stiffness parameter can be used. The right-hand side of equation 50 would be multiplied by e_{eT}/e_{eTMOD} to introduce the effects of vertical planform. The planform geometry parameter, e_{eT}, is defined by equation 51.

$$e_{eT} = \frac{25.88}{(1+0.8/AR)^2}\left[0.4 + 0.7 \cos\left(\Lambda c/4 - 10°\right)\right] \tag{51}$$

Model parameters are combined into a single constant C_{TT}.

$$C_{TT} = \frac{(\omega_{MOD}\ b_{MOD})^2}{q_{MOD}\ e_{eT_{MOD}}} \tag{52}$$

The solution for torsional stiffness can then be written in terms of the constant, C_{TT}, and the full-scale parameters. Equation 53 is the form used in subroutine GJTT of the wing and empennage weight estimation module.

$$\{GJ\} = \frac{C_{TT}\ e_{eT}\ q\ I_{\psi}}{b^2}\left(\left[\Delta X_K\right]\ \left\{\frac{S_K}{\Lambda_K}\right\}\right)\left\{\frac{\Lambda_K}{S_K}\right\} \tag{53}$$

where

GJ = torsional stiffness, lb-in.^{2}

C_{TT} = model scaling parameter, in.^{6}/lb^2/sec^2

e_{eT} = planform geometry parameter, psi

q = dynamic pressure at flutter, lb/in.^{2}, this is the flutter design pressure which includes safety factor on flutter speed

I_{ψ} = horizontal tail yaw inertia, lb-in.-sec^2

b = average chord of vertical tail, in.

The flutter model parameters in equation 52 are obtained from Reference 19. Data from model numbers 1 through 7 were used for the case for 15-degree horizontal tail dihedral. Data from model numbers 8 and 9 were used for 0-degree dihedral. The values of C_{TT} versus mach number are shown in Figure 16.

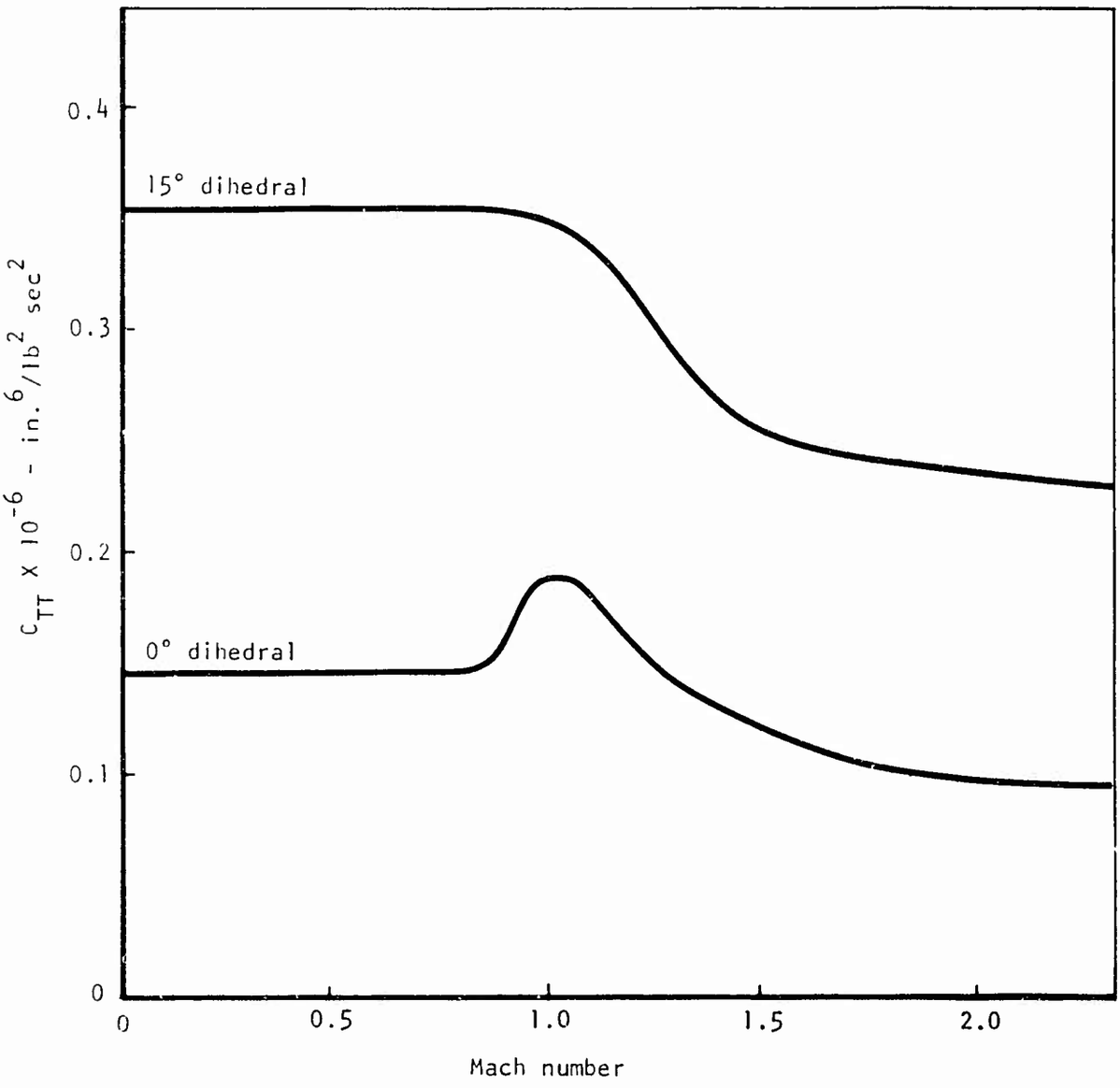


Figure 16. Model scaling parameter, C_{TT}, versus mach number for T-tails.

No data are given in Reference 19 for mach numbers above 1.3 or below 0.7. The straight line extrapolation below M = 0.7 is considered reliable, since subsonic flutter occurs at approximately a constant dynamic pressure for most surfaces. The extrapolation above M = 1.3, however, is only based on intuition and observation of supersonic flutter trends for other types of surfaces. This is not expected to be a significant problem, since critical flutter conditions almost always occur at high subsonic or transonic mach numbers.

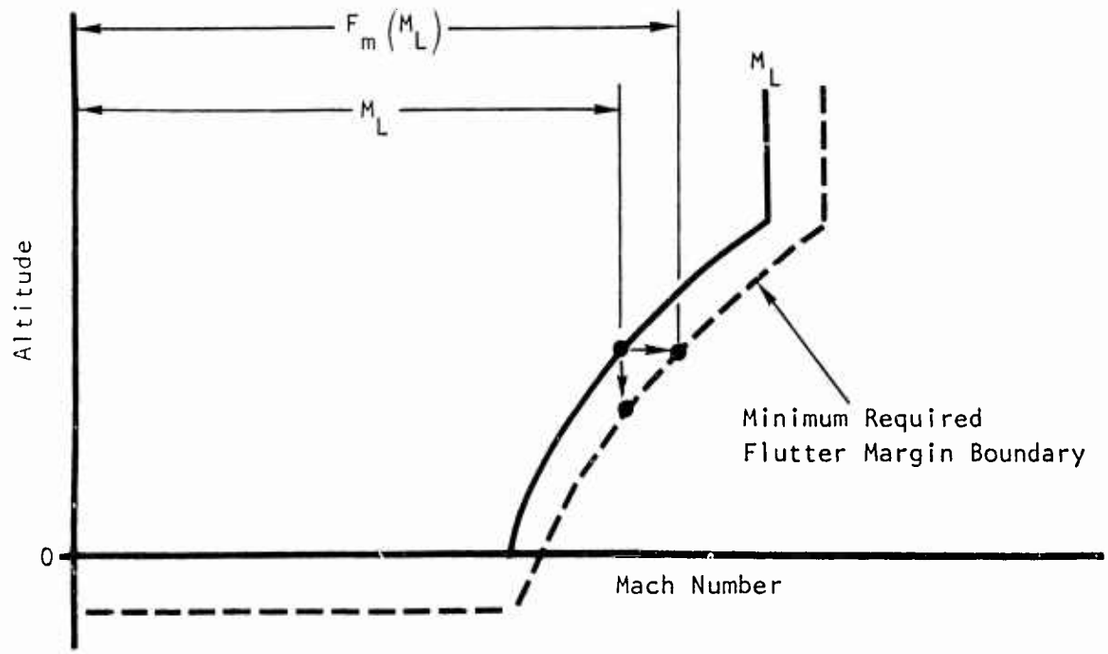
In using the values of C_{TT} for preliminary design, it must be noted that the minimum allowable torsion stiffness level will be determined by the largest product of C_{TT} and q for cases where q varies with mach numbers.

FLUTTER MARGIN

To insure safety, there are two distinct definitons of flutter margin for evaluating vehicle limit speed-altitude profile. The flutter margin, F_m, for a given profile point is defined as follows:

1. $M_{Design} = (F_m)\ (M_L)$, constant altitude
2. $q_{Design} = (F_m)^2\ (q_L)$, constant mach number

A graphical significance of this definition is shown in the following sketch.



For constant dynamic pressure profiles, there is no difference between these two definitions for points above sea level. For increasing dynamic pressure profiles and along the sea level line, the second definition establishes the flutter margin boundary.

SYMBOLS USED IN FLUTTER METHODOLOGY EQUATIONS

A	Torque box cross-sectional area, in.
AR	Aspect ratio
a	Speed of sound, ft/sec
b	Reference chord, in.
C	Chord, in.
$C_{\ell\alpha}$	Lift curve slope
C_{TT}	Model parameter, $in.^6/lb^2/sec^2$
e	Chordwise eccentricity - measure of distance between elastic axis and chenter of pressure
e_e	Flutter-stiffness index, $lb/in.^2$ (refer to equation 22)
e_{eT}	Flutter-stiffness index, $lb/in.^2$ (refer to equation 51)
G	Material shear modulus, $lb/in.^2$
I_ψ	Horizontal tail yaw inertia, lb-in.-sec^2
J	Torsion constant of torque box, $in.^4$ (refer to equations 32 and 45)
K	Constants, $lb/in.^2$
L	Structural length of elastic axis, in.
M	Mach number
q	Dynamic pressure, $lb/in.^2$ or lb/ft^2
S	Perimeter of torque box, in.
T	Total torque acting on a section, in.-lb
t	Structure material thickness, in.
V_a	Velocity of airstream, miles/hr

X	Spanwise coordinate measured along elastic axis, in.
θ	Wing twist angle, radians
θ'	Section increment in twist angle, radians/in.
Λ	Sweepback angle, deg
λ	Taper ratio
μ	Mass ratio, ratio of surface weight to weight of air enclosed by a circumscribed cylinder
ω	Frequency, radians/sec

General Subscripts

FS	Denotes full scale
i	Index of surface section used to define aerodynamic terms
K	Index of surface section used to define structure terms
MOD	Denotes model

Matrix Symbols

$[\ ]$	Row matrix
$[\ ]$	Square or rectangular matrix
$[\ ]$	Diagnonal matrix
$\{\ \}$	Column matrix
$[I_n]$	Integrating matrix made up of unit elements on and below the principal diagonal, and zero elements above the principal diagonal
$[I_n]^T$	Integrating matrix made up of unit elements on and above the principal diagonal, and zero elements below the principal diagonal

Section III

PROGRAM DESCRIPTION

GENERAL DISCUSSION

The main functions of the flutter and temperature program module are:

1. To determine design data at the critical flutter point for the wing, horizontal tail, and vertical tail

2. To determine structure temperature at the vehicle speeds and altitudes where either loads or flutter are evaluated

Specific calculating functions are divided into separate subsets of routines which are called by the module control routine OLAY3.

THERMAL PROGRAM FUNCTIONS

Seven function subroutines called by subroutine TEMPER are used to calculate equilibrium skin temperatures at the design loading conditions and at the critical flutter speeds.

These routines include the following:

- PRESH Calculates local pressure at a given geopotential altitude
- TEMALT Calculates local temperature for a standard atmosphere at a given geopotential altitude
- TTO Calculates total temperature at a given vehicle speed and altitude
- SOLARG Calculates solar flux at a given geopotential altitude
- TBL Calculates adiabatic wall temperature based on an assumed skin temperature
- HBL Calculates aerodynamic heat transfer coefficient based on assumed adiabatic wall and skin temperatures
- TSKIN Calculates skin temperature by solving the heat equation

FLUTTER PROGRAM FUNCTIONS

Routines called by subroutine WHVQQ are used to determine the design dynamic pressure, corrected for compressibility effects, and the corresponding material shear modulus at the design point.

The following three routines called by WHVQQ are used for determining temperatures and atmospheric properties:

- PRESH Calculates local pressure at a given geopotential altitude; returns pressure in lb/ft^2 to the using statement.

- TEMALT Calculates local temperature for a standard atmosphere at a given geopotential altitude; returns temperature in degrees Rankine to the using statements.
- TEMPER Calculates skin temperature for a given mach number and altitude; returns skin temperature in degrees Fahrenheit as part of the argument list. Arguments, in the order of the calling statement, are shown in the following list; the letter "I" is used to designate input argument, and "C" to denote calculated variable.

Argument	Type	Description
XM	I	Vehicle mach number
AL	I	Local altitude, ft
PRE	C	Local static pressure, $lb/in.^2$
TLOC	C	Local static temperature, ^{o} R
TTOT	C	Total temperature, ^{o} R
SFX	C	Solar flux, $BTU/hr/ft^2$
TSKR	C	Equilibrium skin temperature, ^{o} R
TSF	C	Equilibrium skin temperature, ^{o} F
IRE	C	Error indicator

In addition to the three aforementioned routines, WHVQQ uses the following routines to set up materials data and flutter parameters:

- WHVMAT Enters the material library files and sets up tables of compression yield stress and shear modulus versus temperature for the wing, horizontal tail, and vertical tail structural materials.

- SVFTAB Interpolates the flutter parameter tables to obtain flutter parameter versus mach number for each of the surfaces.

- QINC Calculates incompressible dynamic pressure for a given mach number, local pressure, and local temperature.

- QSUB Calculates design dynamic pressure, corrected for compressibility effects, at each of the speed-altitude profile points.

LOGIC FLOW

The calling-called matrix for the program showing interdependence of routines is shown in Figure 17.

Calling \ Called	TEMPER	WHVQQ	PRESH	TEMALT	TTO	SOLARG	TBL	HBL	TSKIN	WHVMAT	SVFTAB	QINC	QSUB
OLAY 3	X	X											
TEMPER			X	X	X	X	X	X	X				
WHVQQ	X		X	X						X	X	X	X

Figure 17. Calling-called matrix for flutter and temperature module.

Usage of the flutter and temperature routines within the flutter and temperature module is depicted in Figure 18. Logic flow within the temperature program is shown in Figure 19. Logic flow within the flutter program is shown in Figure 20.

Temperature data calculated by the flutter and temperature module are used both by the module itself in establishing materials properties for subsequent flutter evaluations and by other modules in setting up materials properties for structural synthesis.

MODULE INTERFACES, INPUT, AND OUTPUT

The flow of data to this module and the usage of data calculated by this module are shown in Figure 21.

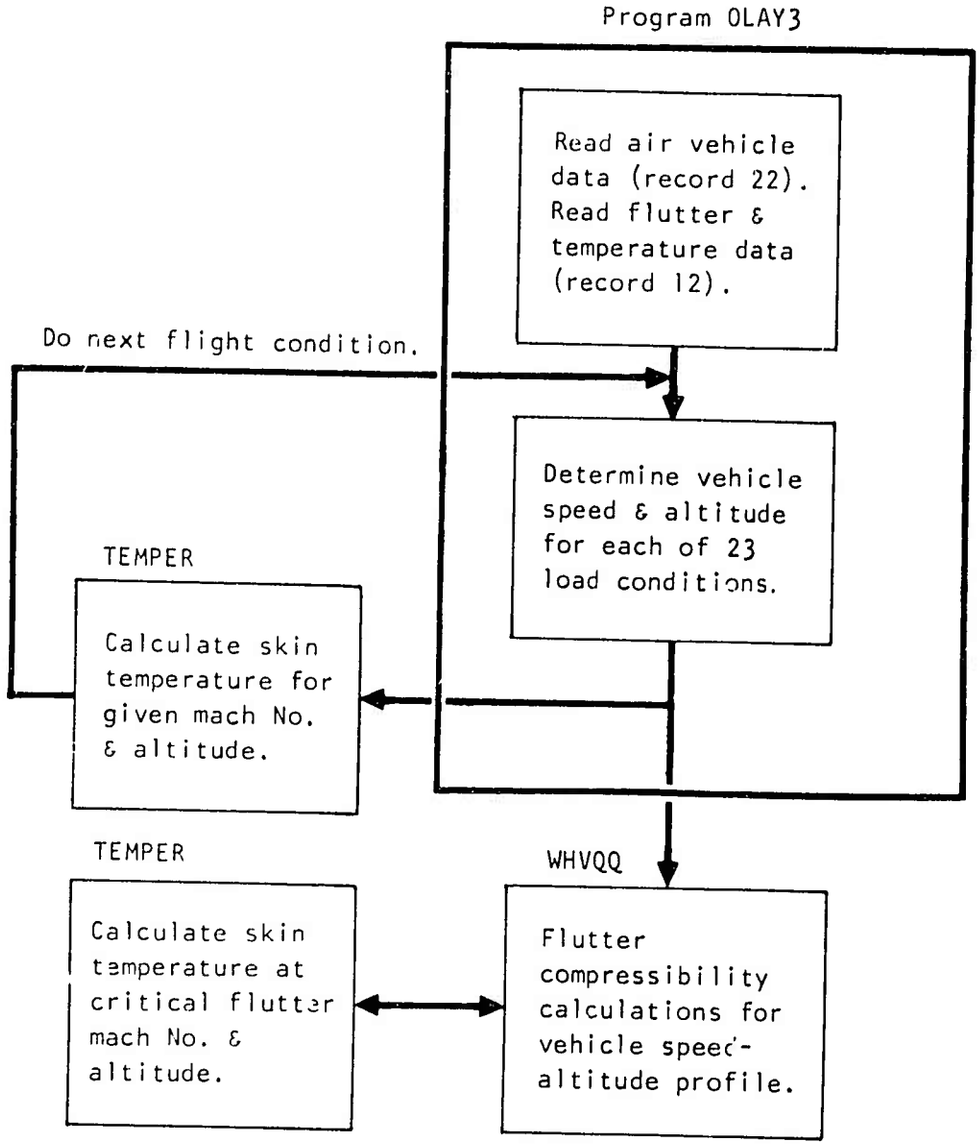


Figure 18. Temperature and flutter routine usage in flutter and temperature module.

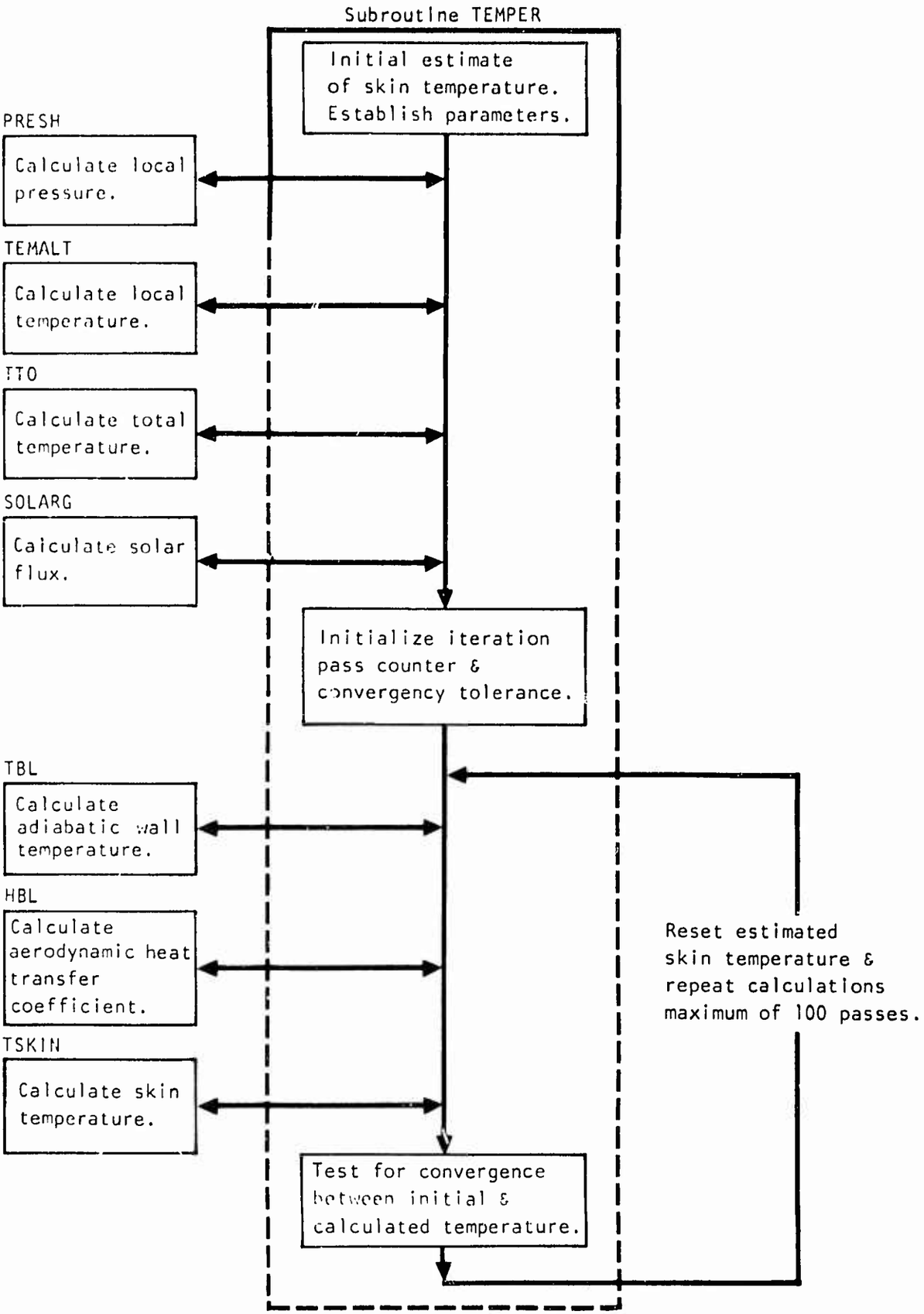


Figure 19. Logic flow diagram for temperature routines.

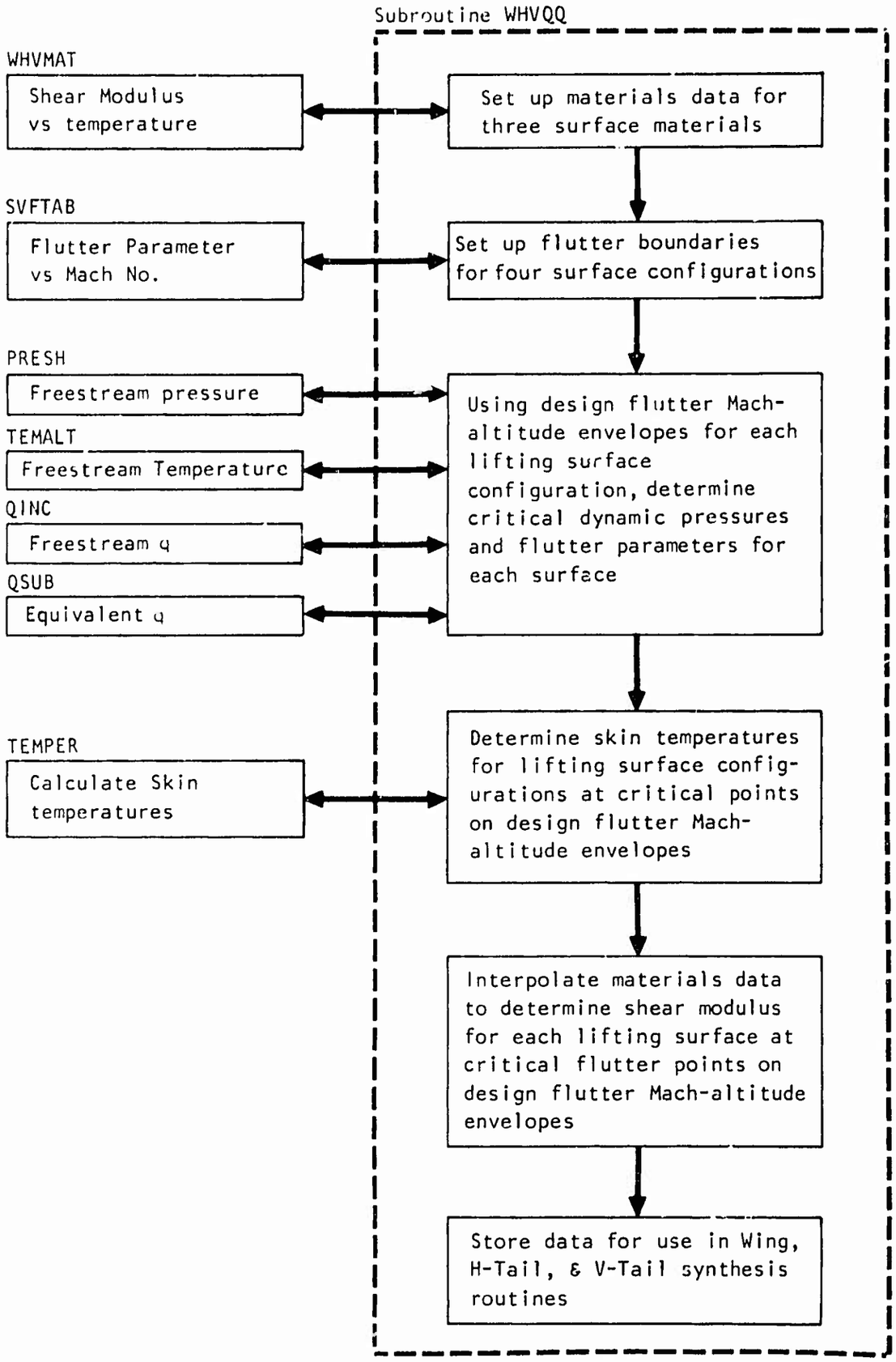


Figure 20. Logic Flow Diagram for Flutter Routines.

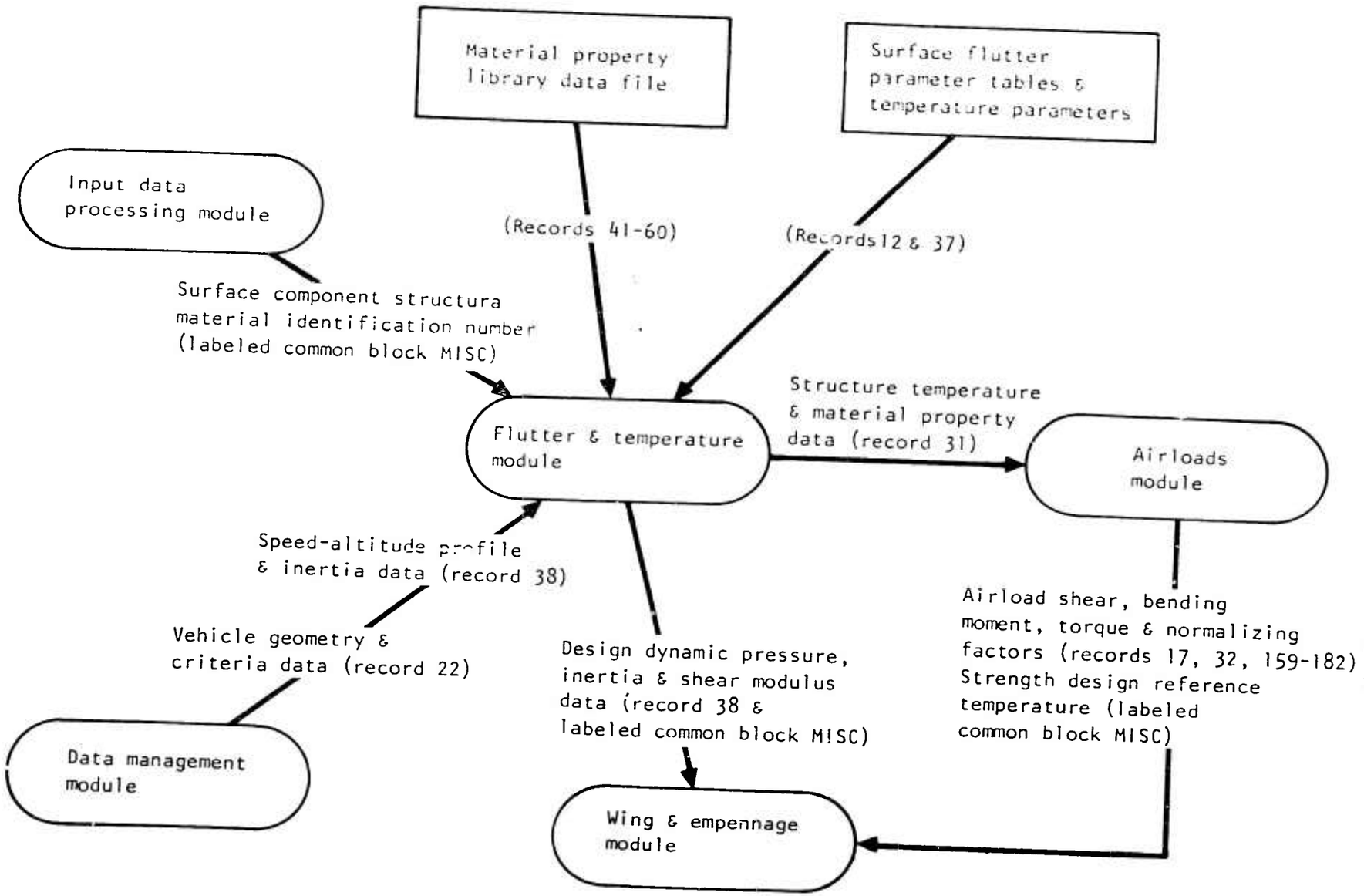


Figure 21. Flow of flutter and temperature module related data.

Figure 22 depicts the flow of flutter-related data to and from the module. Speed altitude profile data input by the user is expanded in the data management module. Figure 23 shows the relationship between input points, loads evaluation points, and flutter evaluation points.

Routines which evaluate flutter considerations are integrated into different modules of SWEEP. A cross-reference list of flutter evaluation and data processing routines within these modules is shown in Table 8.

GENERAL MAPS

Data storage and transmittal are accomplished through the use of common, labeled common, mass storage files, and argument lists. Mass storage records are read into and written from regions in common or from program regions.

Common consists of 762 cell which are divided into the major regions shown in Table 9. Table 10 presents an alphabetical listing of arrays and variables within the common region. Type designates whether variable is input (I) or calculated (C). When the variables in this table are subsets of larger arrays, the higher order array is referenced in brackets. Tables 11 and 12 are expanded explanations of arrays which are not explained in the alphabetical listing.

Labeled common blocks IPRINT and MISC are used to transmit print controls and design data, respectively. IP(41) in the IPRINT block is used to designate output print of design data generated in this module. Variables in the MISC block pertinent to this module are shown in Table 14.

Mass storage file records used in this module are shown in Table 15. The SPAL and IM arrays are read into and written from program regions. The SPAL array is described in Table 17. The IM array is described under the description of subroutine WHMAT.

Arguments used to transmit data to the temperature calculating routines are shown in the following list in the order of the calling statement. The letter I is used to designate input argument, and C to denote calculated variable.

Argument	Type	Description
XMACH	I	Vehicle mach number
ALT	I	Local altitude, ft
PRESSI	C	Local static pressure, psi
TLOC	C	Local static temperature, deg R
TTOT	C	Total temperature, deg R

Argument	Type	Description
SUN	C	Solar flux, BTU/hr/ft^2
XSKIN	C	Equilibrium skin temperature, deg R
XSKINF	C	Equilibrium skin temperature, deg F
IER	C	Error indicator

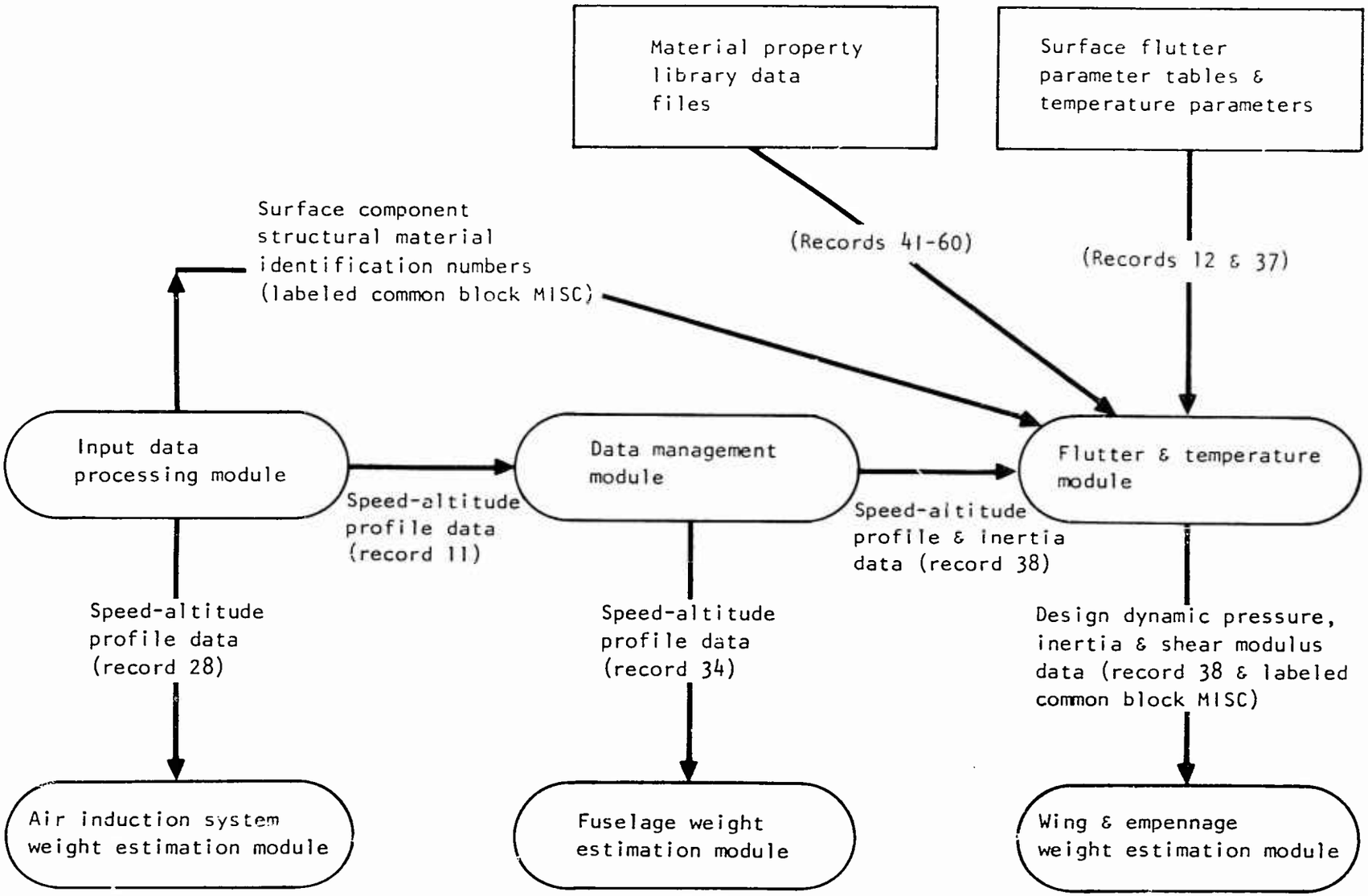


Figure 22. Flow of flutter-related data.

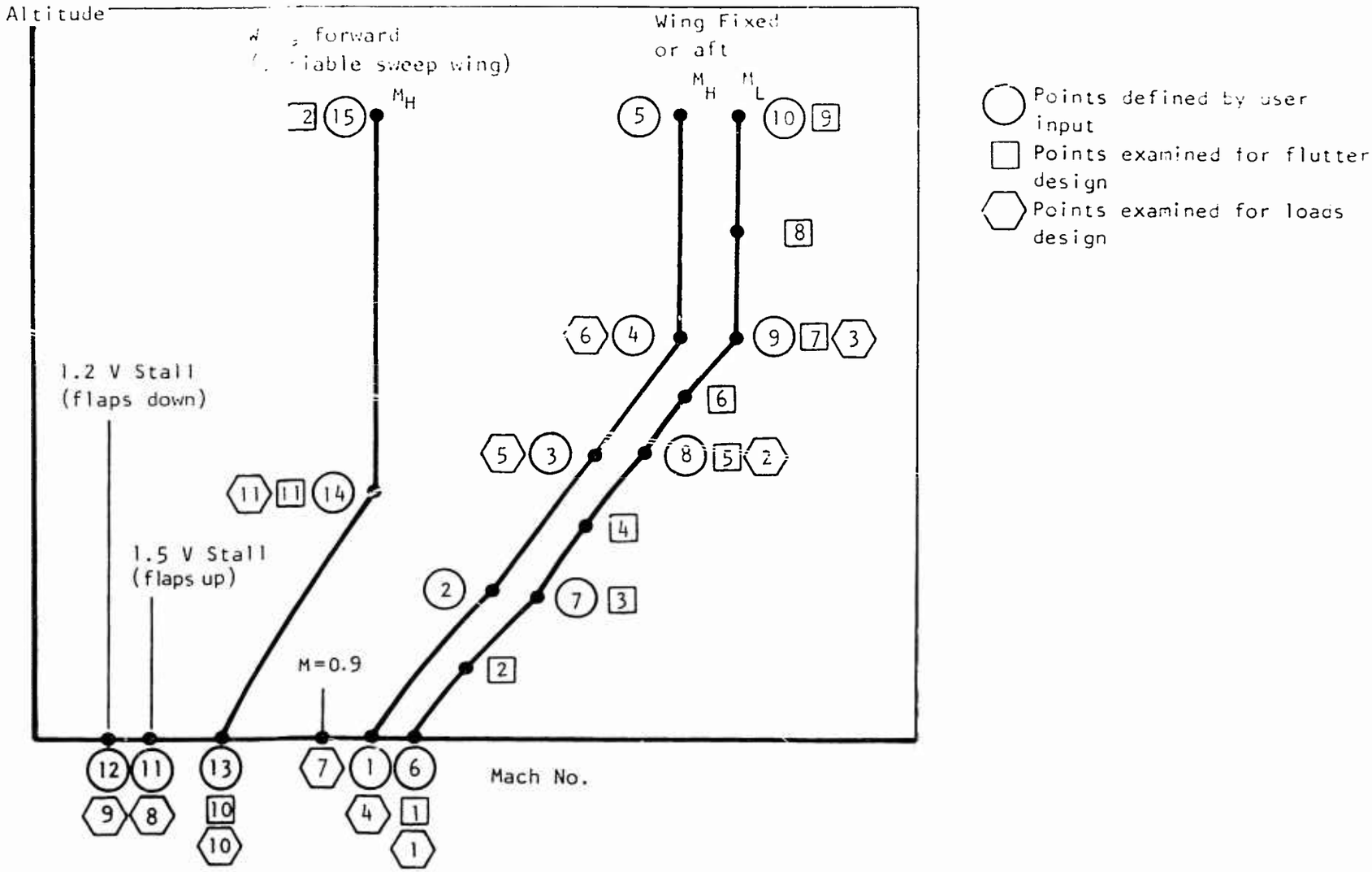


Figure 23. Speed-altitude profile points.

TABLE 8. FLUTTER EVALUATION AND DATA PROCESSING ROUTINES

Module	Routine Name	Description	Reference Volume
Input data processing	READ	Write speed-altitude profile data in record 28 for use by air induction system weight estimation module Store wing, horizontal tail, and vertical tail structural material identification numbers in labeled common block MISC for use in flutter and temperature module.	II
Data management	SPDALT	Expand input speed-altitude profile data by interpolating for intermediate points, and calculate dynamic pressure	II
	AVDATA	Write expanded limit speed-altitude profile data for use by fuselage weight estimation module in record 34 Write expanded limit speed-altitude profile data and horizontal tail inertial data in record 38 for use by flutter and temperature module and wing and empennage weight estimation module	II
Flutter and temperature	WHVCQ	Calculate design dynamic pressure and shear modulus data, and store in record 38 for use by wing and empennage weight estimation module	IV
Air induction system weight estimation	SPAL	Expand input speed-altitude profile data by interpolating for intermediate points, and calculate dynamic pressure	V
	NACELE	Determine critical flutter point, and calculate nacelle panel thickness to prevent local panel flutter	V

TABLE 8. FLUTTER EVALUATION AND DATA PROCESSING ROUTINES (CONCL)

Module	Routine Name	Description	Reference Volume
Wing and empennage weight estimation	CCNTL	Transfer flutter design parameters from record 38 and labeled common block MISC into working data region	VI
	WODATA	Transfer revised horizontal tail inertia data into record 38 for use in T-tail flutter evaluation	VI
	GJCAL	Evaluation control and calculations for surface and T-tail flutter	VI
	GJSI	Calculation of torsional stiffness to prevent surface flutter	VI
	GJTT	Calculation of torsional stiffness to prevent T-tail flutter	VI
	VFCAL	Calculation of structure thickness (metal) to satisfy required torsional stiffness.	VI
	ACWMS	Calculation of structure thickness (multispar composite) to satisfy required torsional stiffness	VI
	ACWSTR	Calculation of structure thickness (stringer composite) to satisfy required torsional stiffness.	VI
Fuselage weight estimation	QCRIT	Scan speed-altitude profile for critical flutter point	VII
	FCOVER	Calculate cover thickness to prevent local panel flutter	VII

TABLE 9. BLANK COMMON

Variable Name	Size	Common Location	Description
SVF	180	1	Refer to Table 12
DATA	312	181	Refer to Table 11
TFW	38	493	Composite flutter paramter for wing in fixed or aft position
TFH	38	531	Composite flutter parameter for horizontal tail
TFV	38	569	Composite flutter parameter for vertical tail
TFWF	38	607	Composite flutter parameter for wing in forward position
TF	38	645	Composite flutter parameter, working location
XMNI	20	665	Design mach number
Q	20	685	Incompressible dynamic pressure at design mach numbers
QQ	20	705	Dynamic pressure corrected for compressibility effect
XMATOP	20	725	Mach number associated with QQ
GW	6	745	Shear modulus at library temperature for wing material
GH	6	751	Shear modulus at library temperatures for horizontal tail material
GV	6	757	Shear modulus at library temperatures for vertical tail material

TABLE 10. COMMON VARIABLES

Variable Name	Size	Common Location	Type	Description	Subroutine Reference
ABSORP	1	487	I	0.85, absorptivity of structure surface (DATA)	TEMPER
ATMOS	1	489	I	1.0, model atmosphere indicator (DATA)	TEMPER
COSPHI	1	488	I	1.0, cosine of angle from normal of (DATA) sun rays	TEMPER
DATA	312	181	I	Permanent data array	OLAY3, SVFTAB
EMISS	1	485	I	0.85, emissivity of structure surface (DATA)	TEMPER
GH	6	751	C	Shear modulus at library temperatures for horizontal tail material (SVF)	OLAY3, WHVMAT, WHVQQ
GV	6	757	C	Shear modulus at library temperature for vertical tail material	OLAY3, WHVMAT, WHVQQ
GW	6	745	C	Shear modulus at library temperature for wing material	OLAY3, WHVMAT, WHVQQ
NHOR	1	165	C	Number of values in horizontal tail stress-G-temperature table (SVF)	WHVMAT, WHVQQ
NVER	1	179	C	Number of values in vertical tail stress-G-temperature table (SVF)	WHVMAT, WHVQQ
NWING	1	151	C	Number of values in wing stress-G-temperature table (SVF)	WHVMAT, WHVQQ
PSI	23	1	C	Ambient pressure at each load condition (SVF)	OLAY3
Q	20	685	C	Incompressible dynamic pressure at design mach numbers	QSUB, WHVQQ
QQ	20	705	C	Dynamic pressure corrected for compressibility effects	QSUB, WHVQQ

TABLE 10. COMMON VARIABLES (CONT)

Variable Name	Size	Common Location	Type	Description	Subroutine Reference
SFLUX	23	70	C	Sun flux at each load condition (SVF)	OLAY3
STH	6	153	C	Compression yield stress for horizontal tail material at library temperatures (SVF)	WHVMAT
STV	6	167	C	Compression yield stress for vertical tail material at library temperatures (SVF)	WHVMAT
STW	6	70	C	Compression yield stress for wing material at library temperatures (SVF)	WHVMAT
SVF	180	1	C	Major surface material properties and structure temperature data for use in airloads module	OLAY3, WHVMAT
SWEEP	1	492	I	0.0, sweep of leading edge of surface (DATA)	TEMPER
S80H	1	166	C	Compression yield stress of horizontal tail material at 80° F (SVF)	WHVMAT
S80V	1	180	C	Compression yield stress of vertical tail material at 80° F (SVF)	WHVMAT
S80W	1	152	C	Compression yield stress of wing material at 80° F (SVF)	WHVMAT
TABLE	38	181	I	Mach numbers for flutter parameter tables (DATA)	QSUB
TAR2	38	257	I	Flutter parameter table for aspect ratio of 2.0, quarter chord sweep of 45 degrees and taper ratio of 0.3 (DATA)	SVFTAB
TAR6	38	295	I	Flutter parameter table for aspect ratio of 6.0, quarter chord sweep of 45 degrees and taper ratio of 0.3 (DATA)	SVFTAB

TABLE 10. COMMON VARIABLES (CONT)

Variable Name	Size	Common Location	Type	Description	Subroutine Reference
TBP	38	219	I	Flutter parameter table for aspect ratio of 4.0, quarter chord sweep of 45 degrees and taper ratio of 0.3 (DATA)	SVFTAB
TEMPH	6	159	C	Horizontal tail material library temperatures (SVF)	WINMAT, WINQQ
TEMPV	6	173	C	Vertical tail material library temperatures (SVF)	WINMAT, WINQQ
TEMPW	6	145	C	Wing material library temperatures (SVF)	WINMAT, WINQQ
TF	38	645	C	Composite flutter parameter, working location	QSUB, WINQQ
TFH	38	531	C	Composite flutter parameter for horizontal tail	SVFTAB
TFV	38	569	C	Composite flutter parameter for vertical tail	SVFTAB
TFW	38	493	C	Composite flutter parameter for wing-fixed or aft	SVFTAB
TFWF	38	607	C	Composite flutter parameter for wing-forward	SVFTAB
TLOCAL	23	47	C	Ambient temperature for each load condition (SVF)	OLAY3
TREY	1	491	I	0.0, transition Reynolds number (DATA)	TEMPER
TSB0	38	333	I	Flutter parameter for aspect ratio of 4.0, quarter chord sweep of 0 degrees and taper ratio of 0.3 (DATA)	SVFTAB
TSB60	38	371	I	Flutter parameter for aspect ratio of 4.0, quarter chord sweep of 60 degrees and taper ratio of 0.3 (DATA)	SVFTAB
TSKINF	23	116	C	Equilibrium skin temperature at each load condition, ° F (SVF)	OLAY3

TABLE 10. COMMON VARIABLES (CONCL)

Variable Name	Size	Common Location	Type	Description	Subroutine Reference
TSKINR	23	93	C	Equilibrium skin temperature at each load condition, °R (SVF)	OLAY3
TTOTAL	23	47	C	Total temperature at each load condition, °R (SVF)	OLAY3
TTR0	38	409	I	Flutter parameter for aspect ratio of 4.0, quarter chord sweep of 45 degrees and taper ratio of 0.0 (DATA)	SVFTAB
TTR60	38	447	I	Flutter parameter for aspect ratio of 4.0, quarter chord sweep of 45 degrees and taper ratio of 0.6 (DATA)	SVFTAB
VFF	1	485	I	1.15, flutter margin (DATA)	WHVQQ
XLNGTH	1	490	I	10.0, distance from front of body to temperature point (DATA)	TEMPER
XMATOP	20	725	C	Mach numbers associated with QQ	QSUB, WHVQQ
XMNI	2	665	C	Design mach numbers	QSUB, WHVQQ

TABLE 11. DATA ARRAY VARIABLES

Loc	Variable Name	Description	Subroutine Reference
1 · 38	TABLE (1) · TABLE (38)	* Mach numbers for flutter parameter curves	SVFTAB
39 · 76	TBP (1) · TBP (38)	* Flutter parameter for aspect ratio of 4.0, sweep of the quarter chord of 45°, and taper ratio of 0.3	SVFTAB
77 · 114	TAR2 (1) · TAR2 (38)	* Flutter parameter for aspect ratio of 2.0, sweep of the quarter chord of 45°, and taper ratio of 0.3	SVFTAB
115 · 152	TAR6 (1) · TAR6 (38)	* Flutter parameter for aspect ratio of 6.0, sweep of the quarter chord of 45°, and taper ratio of 0.3	SVFTAB
153 · 190	TSB0 (1) · TSB0 (38)	* Flutter parameter for aspect ratio of 4.0, sweep of the quarter chord of 0°, and taper ratio of 0.3	SVFTAB
191 · 228	TSB60 (1) · TSB60 (38)	* Flutter parameter for aspect ratio of 4.0, sweep of the quarter chord of 60°, and taper ratio of 0.3	SVFTAB
229 · 266	TTR0 (1) · TTR0 (38)	* Flutter parameter for aspect ratio of 4.0, sweep of the quarter chord of 45°, and taper ratio of 0	SVFTAB
267 · 304	TTR60 (1) · TTR60 (38)	* Flutter parameter for aspect ratio of 4.0, sweep of the quarter chord of 45°, and taper ratio of 0.6	SVFTAB
305	VFF	1.15, Flutter margin	WHVQQ
306	EMISS	0.85, emissivity of structure surface	TEMPER
307	ABSORP	0.85, absorptivity of structure surface	TEMPER
308	COSPHI	1.0, cosine of angle from normal of suns rays	TEMPER
309	ATMOS	1.0, model atmosphere indicator, 1.0 = 1962 U.S. standard	TEMPER
310	XLNGTH	10.0, distance from front of surface to temperature calculation point	TEMPER
311	TREY	0.0, transition Reynolds number	TEMPER
312	SWEEP	0.0, sweep of leading edge of surface	TEMPER

*Values for this array can be found in Table 7 in the flutter methodology section.

TABLE 12. SVF ARRAY VARIABLES

Loc	Variable Name	Description
1	PSI (1)	Ambient pressure at load condition 1, psi
.	.	to
23	PSI (23)	Ambient pressure at load condition 23, psi
24	TLOCAL (1)	Ambient temperature at load condition 1, °R
.	.	to
46	TLOCAL (23)	Ambient temperature at load condition 23, °R
47	TTOTAL (1)	Total temperature at load condition 1, °R
.	.	to
69	TTOTAL (23)	Total temperature at load condition 23, °R
70	SFLUX (1)	Sun flux at load condition 1, BTU/hr/ft^2
.	.	to
92	SFLUX (23)	Sun flux at load condition 23, BTU/hr/ft^2
93	TSKINR (1)	Equilibrium skin temperature at load condition 1, °R
.	.	to
115	TSKINR (23)	Equilibrium skin temperature at load condition 23, °R
116	TSKINF (1)	Equilibrium skin temperature at load condition 1, °F
.	.	to
138	TSKINF (23)	Equilibrium skin temperature at load condition 23, °F
139	STW (1)	Wing material compression yield stress at library temperature 1, psi
.	.	to
144	STW (6)	Wing material compression yield stress at library temperature 6, psi
145	TEMPW (1)	Wing material library temperature 1, °F
.	.	to
150	TEMPW (6)	Wing material library temperature 6, °F
151	NWING	Number of values in wing stress-G-temperature table
152	S80W	Wing material compression yield stress at 80° F
153	STH (1)	Horizontal tail material compression yield stress
.	.	at library temperature 1, psi

TABLE 12. SVF ARRAY VARIABLES (CONCL)

Loc	Variable Name	Description
158	STH (6)	Horizontal tail material compression yield stress at library temperature 6, psi
159	TEMPH (1)	Horizontal tail material library temperature 1, °F
•	•	to
164	TEMPH (6)	Horizontal tail material library temperature 6, °F
165	NHOR	Number of values in horizontal tail stress-G-temperature table
166	S80H	Horizontal tail material compression yield stress at 80° F
167	STV (1)	Vertical tail material compression yield stress at library temperature 1, psi
•	•	to
172	STV (6)	Vertical tail material compression yield stress at library temperature 6, psi
173	TEMPV (1)	Vertical tail material library temperature 1, °F
•	•	to
178	TEMPV (6)	Vertical tail material library temperature 6, °F
179	NVER	Number of values in vertical tail stress-G-temperature table
180	S80V	Vertical tail material compression yield stress at 80° F

TABLE 13. ITEMS USED FROM BC ARRAY

BC Loc	Description
19	Altitude at point 1 on speed profile with wings fixed or aft, ft
20	Altitude at point 2 on speed profile with wings fixed or aft, ft
21	Altitude at point 3 on speed profile with wings fixed or aft
22	Level-flight maximum speed at altitude 1 with wings fixed or aft, mach No.
23	Level-flight maximum speed at altitude 2 with wings fixed or aft, mach No.
25	Altitude at point 1 on speed profile with wings forward (variable sweep only), ft
26	Altitude at point 2 on speed profile with wings forward (variable sweep only), ft
28	Level-flight maximum speed at altitude 1 with wings forward, mach No.
29	Level-flight maximum speed at altitude 2 with wings forward, mach No.
31	Minimum speed with flaps up at maximum design weight, knots
32	Minimum speed with flaps down at landing desing weight, knots
166	Limit speed at altitude 1 with wings fixed or aft, mach No.
167	Limit speed at altitude 2 with wings fixed or aft, mach No.
168	Limit speed at altitude 3 with wings fixed or aft, mach No.

TABLE 14. XMISC ARRAY VARIABLES (MISC BLOCK)

Loc	Description	Subroutine Reference
1 · 4	Controls and design data used by other program modules	
5	Dynamic pressure for wing design, lb/ft^2 (wing fixed or aft)	WHVQQ
6	Dynamic pressure for horizontal tail design, lb/ft^2	WVHQQ
7	Dynamic pressure for vertical tail design, lb/ft^2	WHVQQ
8 · 11	Design temperature data used in airloads module	
12	Aspect ratio of wing (fixed or aft)	SVFTAB
13	Quarter chord sweep of wing (fixed or aft), deg	SVFTAB
14	Taper ratio of wing (fixed or aft)	SVFTAB
15	Wing structural material identification number	WHVMAT, WHVQQ
16	Aspect ratio of horizontal tail	SVFTAB
17	Quarter chord sweep of horizontal tail, deg	SVFTAB
18	Taper ratio of horizontal tail	SVFTAB
19	Horizontal tail structural material identification number	WHVMAT, WHVQQ
20	Aspect ratio of vertical tail	SVFTAB
21	Quarter chord sweep of vertical tail, deg	SVFTAB
22	Taper ratio of vertical tail	SVFTAB
23	Vertical tail structural material identification number	WHVMAT, WHVQQ

TABLE 14. XMISC ARRAY VARIABLES (MISC BLOCK) (CONCL)

Loc	Description	Subroutine Reference
24	Weight data used by other program modules	
25	Aspect ratio of wing (forward)	SVFTAB
26	Quarter chord sweep of wing (forward), deg	SVFTAB
27	Taper ratio of wing (forward)	SVFTAB
28	Wing structural material shear modulus at design flutter point, lb/in.^{2}	WHVQQ
29	Horizontal tail structural material shear modulus at design flutter point, lb/in.^{2}	WHVQQ
30	Vertical tail structural material shear modulus at design flutter point, lb/in.^{2}	WHVQQ
31 . 52	Controls and design data used by other program modules	
53	Vertical tail-type indicator -1 = single tail 0 = dual tail 1 = T-tail	WHVQQ
54 . 100	Controls and design data used by other program modules	

TABLE 15. MASS STORAGE FILE RECORDS

Record No.	Variable & Length	Write Routine	Read Routine	Description
12	DATA (312)	Input data processing module	OLAY3	Flutter parameter tables and temperature parameters (refer to Table 11)
22	EC (195)	Data management module	OLAY3	Vehicle design data (refer to Table 13)
31	SVF (180)	OLAY3	Airloads module	Wing, horizontal tail, and vertical tail material property and structure temperature data (refer to Table 12)
37	GJDAT (100)	Input data processing module	WHVQQ	T-tail flutter parameter tables (refer to Table 18)
38	SPAL (50)	Data management module, WHVQQ	WHVQQ	Speed-altitude profile and T-tail inertia data (refer to Table 17)
41 60	EM (300)	Input data processing module	WHVMAT	Material property library data (refer to subroutine description, WHVMAT)

SUBROUTINE DESCRIPTIONS

PROGRAM OLAY3

General Description

Deck name: OLAY3
Entry name: CALL OVERLAY (5HALPHA, 3, 0)
Called by: OLAY00
Subroutines called: TEMPER, WHVQQ

This is the control program for the flutter and temperature module, and it preforms the basic initialization tasks. Arrays to be used for output are cleared. Required input is read from the following files:

- File 12, the DATA array, containing permanent data for both flutter and temperature (refer to Table 11)
- File 22, the BC array, providing the altitude and mach number data for the load conditions (refer to Table 13)

For each load condition, the program sets up altitude and mach number as shown in Table 16 and Figure 23. Subroutine TEMPER is called to determine the pressure and temperature data required by the airloads module, for each load condition. These arrays are saved in SVF and are described in Table 12.

After the load condition loop is completed, subroutine WHVQQ is called to determine material related and flutter design items.

The SVF array is saved in file 31.

Arrays and Variables Used

BC array items are shown in Table 13.

Arrays and Variables Calculated

PSI, SFLUX, TLOCAL, TSKINF, TSKINR, and TTOTAL are subarrays of SVF and are described in Table 12.

TABLE 16. ALTITUDE AND MACH NUMBER FOR EACH FLIGHT LOAD CONDITION

Load Condition No.	Speed-Altitude Profile Point (Figure 23)	Altitude, ft (ALT Array)	Mach No. (XMACH Array)
1	1	BC(19)	BC(166)
2	2	BC(20)	BC(167)
3	3	BC(21)	BC(168)
4	7	0.0	0.90
5	10	BC(25)	BC(28)
6	4	BC(19)	BC(22)
7	10	BC(25)	BC(28)
8	8	0.0	(1.5/661.3) BC(31)
9	9	0.0	(1.2/661.3) BC(32)
10	4	BC(19)	BC(22)
11	5	BC(20)	BC(23)
12	10	BC(25)	BC(28)
13	11	BC(26)	BC(29)
14	4	BC(19)	BC(22)
15	5	BC(20)	BC(23)
16	10	BC(25)	BC(28)
17	11	BC(26)	BC(29)
18	4	BC(19)	BC(22)
19	5	BC(20)	BC(23)
20	1	BC(19)	BC(166)
21	3	BC(21)	BC(168)
22	1	BC(19)	BC(166)
23	3	BC(21)	BC(168)

Refer to Table 13 for description of BC array variables.

Scratch Arrays and Variables

- ALT, XMACH described in Table 16
- BB (9), BB (10) intermediate storage for altitude and mach number
- IER error indicator returned by TEMPER

Labeled Common Arrays

None

Mass Storage Records Used

- Reads: record 12, DATA, Table 11
  record 22, PC, Table 13
- Write: record 31, SVF, Table 12

Error Messages

This one-line message is printed if IER is greater than 15, which indicates that the skin temperature calculation failed to converge.

LOAD CONDITION XX - THE TEMPERATURE LOOP DID NOT CLOSE IN 100 ITERATIONS. THE SKIN TEMPERATURE YYY.YYY IS FROM THE LAST ITERATION.

FUNCTION HBL

General Description

Deck name:	HBL
Entry name:	HBL (XMACH, PO, TO, TSK, DIST, XLAMDA, REY, METHOD, IER, TOTI, TAWI)
Called by:	TEMPER
Subroutines called:	None

This routine calculates boundary layer heat transfer coefficient. Although the routine has several calculation choices, it is used here only for flat plate (wedges or cylinders) alined with the flow. This choice is with METHOD equal to 1, which is set in TEMPER.

Arrays and Variables Used

The input arguments are:

DIST	Characteristic length - METHOD = 1 uses distance aft of leading edge, XLNGTH, which is set to 10.0.
METHOD	Calculation choice - TEMPER sets to 1.
PO	Local static pressure - TEMPER sets to PRESS, which is the result of function PRESH.
REY	Transition Reynolds number - TEMPER sets to TREY, which was set to 1,000,000.0 by TBL.
TAW	Adiabatic wall temperature - set to BLT, the result of function TBL.
TOT	Total temperature - set to TOTT, the result of function TTO.
TSK	Skin temperature - set to XSKIN, the estimated skin temperature in the iteration loop in TEMPER.
TO	Local static temperature - set to TLOC, the result of function TEMALT.
XLAMDA	Angle of sweep - set to SWEEP, which is set to zero.
XMACH	Mach number.

Arrays and Variables Calculated

HBL	The boundary layer heat transfer coefficient is returned to the expression using the function.
IER	The error indicator is set to zero when conditions are met, to values from 1 through 8 for various errors, but is not tested on return.

Scratch Variables

ANAL	Prandtl number raised to -2/3, factor in laminar heat transfer coefficient equation
ANUM	Factor in turbulent heat transfer coefficient equation
ASQ	Factor in turbulent heat transfer coefficient
B	Partial term in turbulent flow equations
COND	Conductivity at reference temperature, TSTR
CSFT	Counter in iteration loop for turbulent skin friction - maximum number trials is 101, then the last value is used.
CSFN	Skin friction coefficient
CSFN1	Initial and previous skin friction coefficient for turbulent flow
EXPO	Partial term in values for static temperature
EXP1	Partial term in values for reference temperature

GAMMAO	Ratio of specific heats at static temperature
GRHO	$g\rho$ - density at reference temperature
GRHOO	$g\rho$ - density at static temperature
GVIS	g_{μ} - viscosity at reference temperature
GVISO	$g\mu$ - viscosity at static temperature
PRN	Prandtl number
PSI	Term in turbulent flow equation for skin friction
REN	Reynolds number based on reference temperature
RENO	Reynolds number based on static temperature
SPHT	Specific heat at constant pressure at reference temperature
SPHTO	Specific heat at constant pressure at static temperature
SPSDO	Speed of sound at static temperature
TAW	Adiabatic wall temperature
THETA	Term in turbulent flow equation for skin friction
TOT	Total temperature set from TOTI
TSTR	Reference temperature - weighted average through the boundary layer
VELO	Vehicle speed

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

FUNCTION PRESH

General Description

Deck name: PRESH
Entry name: PRESH (ALT)
Called by: TEMPER, WHVQQ
Subroutine called: None

This routine returns pressure for the input geopotential altitude using the relation defined by the U.S. standard atmosphere, 1962.

Arrays and Variables Used

The input argument ALT is th geopotential altitude.

Arrays and Variables Calculated

PRESH The resulting pressure is returned directly to the expression where the function is used

Scratch Variables

ALOFT Altitude divided by 1,000.0, a factor in the pressure equations
EXPO Exponential term for altitudes between 36,089.239 and 65,616.80

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

This message is printed for ALT greater than 154,199.48:

WARNING - ALTITUDE IS BEYOND VALID RANGE OF PRESH.

The pressure returned is calculated by the equation for the highest altitude range.

SUBROUTINE QINC

General Description

Deck name: QINC
Entry name: QINC (XM, PO, TO, Q)
Called by: WHVQQ
Subroutines called: None

This routine calculates incompressible dynamic pressure for a given mach number, local pressure, and local temperature.

Arrays and Variables Used

PO	Input argument, ambient pressure, lb/ft^2
TO	Input argument, ambient temperature, ^{o} R
XM	Mach number

Arrays and Variables Calculated

Q	Output argument, incompressible dynamic pressure

Scratch Arrays and Variables

EXP1	e^{TOT}, intermediate term
G	32.17405, acceleration of gravity, ft/sec^2
GAMMA	Ratio of specific heats
R	53.35045, gas constant, $ft/^{o}$ R
RHO	Density of air, $slug/ft^3$
SPHT	Specific heat at constant pressure, ft-lb/lb/^{o} R
SPSD	Speed of sound, ft/sec
TOT	5526.0/TO, intermediate term

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

SUBROUTINE QSUB

General Description

Deck name: QSUB
Entry name: QSUB (LIM)
Called by: MHVQQ
Subroutines called: None

This routine calculates the design dynamic pressure corrected for compressibility effects at each point on the speed-altitude profile. The argument, LIM, is the number of points to be used. The other required data and the results are transmitted via blank common.

Arrays and Variables Used

LIM	Input argument, number of mach number-dynamic pressure points
Q	Incompressible dynamic pressure at design mach numbers
TABLE	Mach numbers for flutter parameter arrays
TF	Flutter parameter array for the surface being evaluated
XMN	Design mach numbers

Arrays and Variables Calculated

QQ	Dynamic pressure corrected for compressibility effects
XMATOP	Mach numbers associated with QQ

Scratch Arrays and Variables

I	General index, range from 1 to LIM
N	Index for search of TABLE
NS	Index of highest TF from 1 to NSAVE inclusive
NSAVE	Index of TABLE mach no, just below or equal to XMN
TFAMS	Set to larger of TFP or TOP
TFP	Composite flutter parameter at XMN
TOP	Highest TF from 1 to NSAVE inclusive
XMN	Mach number from XMN1 in work

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

FUNCTION SOLARG

General Discussion

Deck name:	SOLARG
Entry name:	SOLARG (ALT)
Called by:	TEMPER
Subroutines called:	None

This routine gives solar flux, as a function of altitude, in British thermal units per hour per square foot through a plane perpendicular to the sun's rays.

For altitudes less than 30,000.0 feet:

$$SOLARG = 435.0 - 0.141 \left(\frac{30{,}000.0-ALT}{1{,}000.0}\right)^{1.85}$$

For altitudes of 30,000.0 feet and over:

SOLARG = 435.0

Arrays and Variables Used

ALT Input geopotential altitude

Arrays and Variables Calculated

SOLARG Resultant solar flux is returned to the using expression

Scratch Variables

ALOFT Altitude divided by 1,000.0

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

SUBROUTINE SVFTAB

General Description

Deck name: SVFTAB
Entry name: SVFTAB
Called by: WHVQQ
Subroutines called: None

This routine calculates the composite flutter parameters. These tables are set up for those surfaces for which a nonzero value of aspect ratio is given. Calculations can be made for the wing fixed or aft, wing forward, horizontal tail, and/or vertical tail. The calculated arrays will be printed if IP(41) is zero. (See Figure 24.)

Arrays and Variables Used

TABLE Mach numbers for the flutter parameter curves
TAR2 Flutter parameter curve for aspect ratio of 2.0, sweep of the quarter chord of 45°, and taper ratio of 0.3.
TAR6 Flutter parameter array for aspect ratio of 6.0, sweep of the quarter chord of 45°, and taper ratio of 0.3
TBP Flutter parameter array for aspect ratio of 4.0, sweep of the quarter chord of 45°, and taper ratio of 0.3

*** WING (FIXED OR AFT) *** ** SVFTAB - IP(41) **

FLUTTER PARAMETER VS MACH NUMBER

MACH NO.	AR = 1.68	SWEEP(C/4) = 70.1 DEG	TAPER = .300	COMPOSITE
0.200	.0201	.0817	.0600	.0274
0.400	.0402	.1634	.1200	.0548
0.600	.0604	.2452	.1800	.0822
0.800	.0805	.3269	.2400	.1096
0.825	.0830	.3419	.2550	.1113
0.850	.0855	.3585	.2750	.1115
0.875	.0880	.3752	.2950	.1120
0.900	.0906	.3935	.3100	.1149
0.925	.0931	.4122	.3220	.1191
0.950	.0947	.4323	.3270	.1252
0.975	.0964	.4486	.3300	.1311
1.000	.0981	.4623	.3320	.1366
1.025	.0998	.4733	.3330	.1418
1.050	.1006	.4824	.3320	.1462
1.075	.1014	.4877	.3290	.1504
1.100	.1023	.4921	.3250	.1549
1.125	.1031	.4921	.3200	.1586
1.150	.1023	.4911	.3140	.1600
1.175	.1014	.4891	.3070	.1616
1.200	.1006	.4838	.3000	.1622
1.300	.0981	.4518	.2780	.1594
1.400	.0956	.4124	.2670	.1476
1.500	.0939	.3873	.2620	.1388
1.600	.0931	.3776	.2590	.1357
1.700	.0922	.3740	.2570	.1342
1.800	.0922	.3706	.2570	.1330
1.900	.0931	.3733	.2580	.1346
2.000	.0939	.3770	.2600	.1361
2.100	.0956	.3806	.2620	.1388
2.200	.0973	.3860	.2640	.1422
2.300	.0989	.3913	.2660	.1455
2.400	.1006	.3960	.2690	.1481
2.500	.1023	.4006	.2720	.1507
3.000	.1090	.4257	.2920	.1589
3.500	.1165	.4520	.3150	.1672
4.000	.1249	.4793	.3390	.1766
4.500	.1341	.5094	.3640	.1877
5.000	.1442	.5404	.3900	.1998

Figure 24. Sample output - flutter parameter versus mach number.

TSB0	Flutter parameter array for aspect ratio of 4.0, sweep of the quarter chord of 0°, and taper ratio of 0.3
TSB60	Flutter parameter array for aspect ratio of 4.0, sweep of the quarter chord of 60°, and taper ratio of 0.3
TTR0	Flutter parameter array for aspect ratio of 4.0, sweep of the quarter chord of 45°, and taper ratio of 0.0
TTR60	Flutter parameter array for aspect ratio of 4.0, sweep of the quarter chord of 45°, and taper ratio of 0.6

Arrays and Variables Calculated

TFH	Flutter parameter array for horizontal tail
TFV	Flutter parameter array for vertical tail
TFW	Flutter parameter array for wing (fixed or aft)
TFWF	Flutter parameter array for wing (forward)

Scratch Arrays and Variables

Geometry items relocated from XMISC:

Name	XMISC Location	Description
ARH	16	Aspect ratio of horizontal tail
ARV	20	Aspect ratio of vertical tail
ARW	12	Aspect ratio of wing (fixed or aft)
ARWF	25	Aspect ratio of wing (forward)
SPH	17	Quarter chord sweep of horizontal tail
SPV	21	Quarter chord sweep of vertical tail
SPW	13	Quarter chord sweep of wing (fixed or aft)
SPWF	26	Quarter chord sweep of wing (forward)
TRH	18	Taper ratio of horizontal tail
TRV	22	Taper ratio of vertical tail
TRW	14	Taper ratio of wing (fixed or aft)
TRWF	27	Taper ratio of wing (forward)

Other scratch items:

Name	Size	Description
AR	1	Aspect ratio, working location
I	1	Scratch counter, indicates which surface in work
N	1	Scratch counter
PCNT	1	Factor to modify input flutter parameter array for the required geometry

Name	Size	Description
SB	1	Quarter chord sweep, working location
TAR	38	Flutter parameter interpolated to the aspect ratio in work
TF	38	Composite flutter parameter, working location
TR	1	Taper ratio, working location
TSB	38	Flutter parameter interpolated to the quarter chord sweep in work
TTR	38	Flutter parameter interpolated to the taper ratio in work

Labeled Common Arrays

IP(41) from block IPRINT is the print/no-print indicator. If IP(41) is zero, the tables of mach number versus flutter parameter are printed.

The XMISC items used from block MISC are itemized under geometry items in the foregoing description of scratch.

Mass Storage File Records Used

None

Error Messages

None

FUNCTION TBL

General Description

Deck name:	TBL
Entry name:	TBL (XMACH, PO, TO, TSK, DIST, XLAMDA, REY, METHOD, IER, TOT1)
Called by:	TEMPER
Subroutines called:	None

This routine calculates adiabatic wall temperature. In the calculation, variation of specific heat, viscosity, conductivity, and density are taken into account. Since these variables are interrelated, an iterative solution is used.

Arrays and Variables Used

The input arguments are:

DIST	Distance aft of the leading edge for which XLNGTH is used. Its value is 10.0.
METHOD	Calculated choice 0 or 1 returns skin temperature; 2 returns stagnation temperature. In TEMPER, use METHO, which is 1.
PO	Local static pressure - use PRESS, which is the result of function PRESH.
REY	Transition Reynolds number - use TREY, which is set to zero, indicating that the routine uses 1,000,000.0
	Note REY is reset to 1,000,000.0.
TOTT	Total temperature - use TOTT, the result of function TTO.
TSK	Skin temperature - use XSKIN, the estimated skin temperature in the iteration loop in TEMPER.
TO	Local static temperature - use TLOC, the result of function TEMALT.
XLAMDA	Angle of sweep - use SWEEP, which is set to zero.
XMACH	Local mach number.

Arrays and Variables Calculated

TEL	Adiabatic wall temperature is returned to the using expression.
IER	The error indicator - if two, the solution failed to converge, and the value returned is based on a recovery factor of 0.875.
REY	If input as zero, is reset to 1,000,000.0.

Scratch Variables

COND	Thermal conductivity of boundary layer
EXP1	Term in specific heat equations
GAMMA	Ratio of specific heats
GRHO	Specific weight, g_r, lb/ft^3
GVIS	Viscosity times gravitational acceleration
IND	Counter in iteration loop
PRN	Prandtl number
RECOV	Recovery factor
REN	Freestream Reynolds number
SPHT	Specific heat at constant pressure
SPHTV	Specific heat at constant volume

SPSD	Speed of sound
TBLI	Initial and prior boundary layer temperature
TSTR	Reference temperature
TOT	Total temperature, set to TOTI
VLL	Velocity of air vehicle

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

FUNCTION TEMALT

General Description

Deck name: TEMALT
Entry name: TEMALT (ALT, TI)
Called by: TEMPER, WHVQQ
Subroutines called: None

This routine returns air temperature for an input pressure altitude and model atmosphere number. The altitude is assumed to be in terms of the 1962 U.S. standard atmosphere geopotential altitude. There are five model atmospheres plus the defrost day of MIL-T-5842 in this routine.

TI	Atmosphere
1.0	U.S. Standard atmosphere, 1962
2.0	Cold atmosphere as given in Table II of MIL-STD-210A
3.0	Hot atmosphere as given in Table III of MIL-STD-210A
4.0	Polar atmosphere as given in Table IV of MIL-STD-210A
5.0	Tropical atmosphere as given in Table V of MIL-STD-210A
6.0	Defrost day of MIL-T-5842

Model atmosphere number one is specified in permanent data, but the coding for the other atmospheres is complete and intact.

Arrays and Variables Used

The input arguments are:

ALT	Geopotential altitude
II	ATMOS, DATA(309)

Arrays and Variables Calculated

TEMALT The resulting temperature, is returned directly to the expression using the function

Scratch Variables

ALOFT	Altitude divided by 1,000.0
II	Model atmosphere number
SLOPE	Intermediate calculation term

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

WARNING - ALTITUDE IS BEYOND VALID RANGE OF TEMALT.

This message is printed if the altitude is above the highest altitude for the model atmosphere in use. For the No. 1.0 atmosphere, the altitude is 154,200.0 feet and the temperature returned is calculated by the equation for altitude range 104,987.0 to 154,200.0.

SUBROUTINE TEMPER

General Description

Deck name:	TEMPER
Entry name:	TEMPER (XMACH, ALT, PRESSI, TLOC, TTOT, SUN, XSKIN, XSKINF, IER)
Called by:	OLAY3, WHVQQ
Function routines used:	PRESH, TEMALT, TTO, SOLARG, TBL, HBL, TSKIN

This routine determines the pressure, local temperature, total temperature, solar flux, and skin temperature for a given altitude and mach number. In the iteration for skin temperature, if the loop does not close to 0.1 degree in 90 iterations, the tolerance is loosened to 1 degree. If the calculation does not converge in 10 more iterations, the error indicator is set and the last temperature is returned.

Arrays and Variables Used

ABSORP	Structure surface absorptivity
ALT	Input argument altitude
ATMOS	Model atmosphere identification number
COSPHI	Cosine of solar angle of incidence
EMISS	Structure surface emissivity
SWEEP	Sweep of surface
TREY	Transition Reynolds number
XLNGTH	Distance from front of body to point of temperature calculation
XMACH	Input argument mach number

Arrays and Variables Calculated

The output arguments are:

IER	Error indicator set to 16 if skin temperature calculation does not converge
PRESSI	Pressure at altitude, $lb/in.^2$
SUN	Solar flux in BTU/hr/sq ft
TLOC	Temperature at altitude, ^{o} R
TTOT	Temperature of moving vehicle's immediate surroundings, ^{o} R
XSKIN	Skin temperature (assumed value during iteration) ^{o} R
XSKINF	Skin temperature, ^{o} F

Scratch Variables

A	Term in temperature equation
B	Coefficient in temperature equation
BLHTC	Boundary layer heat transfer coefficient
BLT	Boundary layer temperature
CRIT	Tolerance in skin temperature calculation set to 0.1 for first 90 passes, and 1.0 for last 10.
IPASS	Pass counter in iteration loop
IPTEN	IPASS/10 used in testing
METHO	1, used for TBL for flow parallel to the surface
METHOD	1, used for HBL for parallel plane flow
PRESS	Pressure at altitude, lb/ft^2
XSKIN2	Second skin temperature in iteration, the new temperature which is placed in XSKIN each time to use as the estimate for the next pass
XY	Absolute value of (XSKIN2-XSKIN), for testing against CRIT

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

FUNCTION TSKIN

General Description

Deck name: TSKIN
Entry name: TSKIN (A, B, C, IER)
Called by: TEMPER
Subroutines called: None

This routine solves the flux equation for the positive real root of skin temperature by an iterative process. The process used is to find the intersection in the first quadrant of the lines $Y = X$ and $Y = A - B X^4$.

Arrays and Variables Used

Input arguments A and B are calculated in TEMPER. Argument C, the iteration tolerance, is set to CRIT and is 0.1 or 1.0, depending on how many passes have been made in the overall loop which uses this function.

Arrays and Variables Calculated

TSKIN, the resulting temperature, is returned to the expression using the function.

IER is set to 16 if this function does not converge in 51 calculation passes.

Scratch Variables

DENOM	Denominator of new X (i.e., XS) in iteration loop
ICOUNT	Counter in iteration loop maximum is 51
XP	Starting value is $\left(\frac{A}{B}\right)^{1/4}$, and then set from XR
XR	X where the secant of the curve $Y = A - B X^4$, across the first quadrant, crosses the line $Y = X$
XS	New X, based on points XP, YP and XR, YR, where chord crosses $Y = X$
YP	Starts as zero (i.e., $Y = A - B X^4$ evaluated for $X = \left(\frac{A}{B}\right)^4$) then set from YR
YS	Evaluation of $Y = A - B X^4$ for $X = XS$
XNUM	Numerator of new X (i.e., XS) in iteration loop

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

The error messages that are provided for negative values A and/or B cannot occur with the simplified form used in SWEEP.

FUNCTION TIO

General Description

Deck name:	TIO
Entry name:	TIO (XMACH, TO, IER)
Called by:	TEMPER
Subroutines called:	None

This routine determines the temperature of the air in the vicinity of the moving air vehicle. The basic derivation relates the change in enthalphy of air to the change in kinetic energy. The variation of specific heat with temperature is taken into account.

Arrays and Variable Used

The input arguments are:

XMACH	Free-stream mach number
TO	Free-stream temperature - the temperature obtained from function TEMACH

Arrays and Variables Calculated

TIO	The resulting temperature is returned directly to the using expression
IER	Output argument, if zero calculation criteria were met; if one, the solution did not converge, and the temperature returned is based on constant GAMMA.

Scratch Variable

DELTAT	Incremental temperature
EXP1	Term in specific heat equation
EXP2	Term in specific heat equation
GAMMA	Ratio of specific heats, SPHT/SPHTV
IND	Iteration counter

SPHT	Specific heat at constant pressure, at TO
SPHTA	Adjusted, or new, specific heat
SPHTI	Initial, or prior, specific heat
SPHTV	Specific heat at constant volume at TO
SPSD	Speed of sound
VEL	Velocity

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

SUBROUTINE WHVMAT

General Discussion

Deck name:	WHVMAT
Entry name:	WHVMAT
Called by:	WHVQQ
Subroutines called:	None

Using the material records specified for the major surfaces, this routine sets up tables of compression yielded stress and shear modulus versus temperature. The stress at 80° F is determined by interpolation in the stress table. Figure 25 is a sample of the output from this routine which is printed when IP(41) is zero.

Arrays and Variables Used

Each material record used is read into the TM array; five items are used from each temperature block in the record. Locations are given for the first temperature. For each succeeding temperature, add 25 to the locations.

*** WING ***
7175-T6 AL BARE PLTE 0.25 TO 0.50 IN. MIL-HDBK-5 H DATA PSI.
REF TABLE 3.2.7.0(H) PAGE 334 4-00-72

TEMPERATURE	STRESS (PSI)	G (PSI)
80.	71000.	3947368.
0.	0.	0.
0.	0.	0.
0.	0.	0.
0.	0.	0.
0.	0.	0.

STRESS AT 80 DEGREES 71000.

*** HORIZONTAL TAIL ***
2024-TH51 AL BARE PLATE 0.5 TO 1.0 IN. REF-AFL 90/1.10
120 HRS AT 290 DEG MIL-HDBK-5 S DATA 10-24-60

TEMPERATURE	STRESS (PSI)	G (PSI)
80.	58500.	4022551.
200.	55500.	3903346.
300.	49500.	3755523.
0.	0.	0.
0.	0.	0.
0.	0.	0.

STRESS AT 80 DEGREES 58500.

*** VERTICAL TAIL ***
2024-TH51 AL BARE PLATE 0.5 TO 1.0 IN. REF-AFL 90/1.10
120 HRS AT 290 DEG MIL-HDBK-5 S DATA 10-24-60

TEMPERATURE	STRESS (PSI)	G (PSI)
80.	58500.	4022551.
200.	55500.	3903346.
300.	49500.	3755523.
0.	0.	0.
0.	0.	0.
0.	0.	0.

STRESS AT 80 DEGREES 58500.

Figure 25. Sample output - stress and shear modulus versus temperature.

IM Location	Variable Name	Description
110	TEMP	Temperature (^{o} F) for the following data:
111		Mu, Poisson's ratio
112		ϵ_{cPL}, compression strain at the proportional limit
114		σ_{cPL}, compression stress at the proportional limit
118	ST	F_{cy}, compression stress at yield point

Locations IM(261) through IM(300) containing the material title are also used if the printout is requested.

Arrays and Variables Calculated

GH	Shear modulus at library temperature for horizontal tail material
GV	Shear modulus at library temperature for vertical tail material
GW	Shear modulus at library temperature for wing material
NHOR	Number of values in horizontal tail stress-G-temperature table
NVER	Number of values in vertical tail stress-G-temperature table
NWING	Number of values in wing stress-G-temperature table
STH	Compression yield stress for horizontal tail material at library temperatures
STV	Compression yield stress for vertical tail material at library temperatures
STW	Compression yield stress for wing material at library temperatures
S80H	Compression yield stress for horizontal tail material at 80^{o} F
S80V	Compression yield stress for vertical tail material at 80^{o} F
S80W	Compression yield stress for wing material at 80^{o} F
TEMPH	Horizontal tail material library temperatures
TEMPV	Vertical tail material library temperatures
TEMPW	Wing material library temperatures

Scratch Arrays and Variables

DMNOH	From XMISC(19) material number for horizontal
DMNOV	From XMISC(23) material number for vertical
DMNOW	From XMISC(15) material number for wing
G	Shear modulus, working array
I	Counter for which surface in work
IEL	Material record number

L1	First point subscript in interpolation for 80 degrees
L2	Second point subscript in interpolation for 80 degrees
N	Scratch counter
NN	Scratch counter
NTEMP	Number of temperature blocks in material record being used
ST	Compression stresses, working array
S80	Stress at 80 degrees, working location
TEMP	Temperatures from material record, working array

Labeled Common Arrays

IP(41) from block IPRINT is the print/no-print indicator. When IP(41) is zero, the stress and G versus temperature tables are printed.

XMISC values, from block MISC, used are the material numbers itemized under Scratch.

Mass Storage File Records Used

Those material records between 41 and 60 whose numbers are specified by material identification number plus 40 are read.

Error Messages

None

SUBROUTINE WHVQQ

General Description

Deck name: WHVQQ
Entry name: WHVQQ
Called by: OLAY3
Subroutines called: WHVMAT, SVFTAB, QINC, QSUB, TEMPER
Function routines used: PRESH, TEMALT

This subroutine controls the search for wing, horizontal tail, and vertical tail, design dynamic pressure, corrected for compressibility effects, and the corresponding material shear modulus. For variable sweep wing vehicles, this routine determines the design dynamic pressure and shear

modulus for the wing in both the forward and aft positions. This routine also scans the limit speed profile for the maximum dynamic pressure for T-tail flutter evaluation. In order to develop these data, the following procedure is used:

1. Call MIVMAT, which enters the material library files and sets up tables of compression yield stress and shear modulus for the wing, horizontal tail, and vertical tail structural materials. These data are stored in the blank common array SVF.

2. Read record 38, speed-altitude profile data and flutter margin.

3. Call SVFIAB, which interpolates the flutter parameter tables from record 12 to obtain flutter parameter versus mach number for each of the surfaces.

4. Use function routines PRESH and TEMALT and call QINC to calculate dynamic pressure at the limit speed-altitude profile (wings fixed or aft) points.

5. Set up a table of mach numbers and dynamic pressures representing the design flutter margin boundary at constant altitude.

6. Call QSUB to calculate the equivalent dynamic pressure for incompressible torsional divergence corresponding to each point on the flutter mach-altitude profile.

7. Scan the data from QSUB for the maximum design dynamic pressure and the corresponding mach number for the wing.

NOTE: PROGRAM LIMITATION

This pressure is a maximum, though not in general the critical, value for lifting surface flutter evaluations. Correct values should be determined through an evaluation of the ratio of dynamic pressure to shear modulus. Such an approach would account for the influence of temperature upon the critical flutter condition. However, the values of shear modulus for most aircraft structural materials does not change significantly in the transonic mach number ranges where flutter is usually critical. Cases in which the value of shear modulus, G, does vary significantly in the mach number range where flutter is critical could be

conveniently handled by first computing the variation of G along the V_L profile (defined as G_M) and then multiplying the flutter boundary determined by step 3 by $\sqrt{G_{ref}/G_M}$; where G_{ref} is the shear modulus at room temperature. The procedure of step 7 could then use this modified flutter boundary, and the maximum design dynamic pressure obtained would be the true flutter critical value

8. Repeat steps 6 and 7 for the horizontal and vertical tails.

9. Set up a table of mach numbers and dynamic pressures representing the design flutter margin boundary at constant mach number.

10. Repeat steps 6 through 8 for constant mach number flutter margin.

11. If aircraft has a variable-sweep wing, do steps 4, 5, 6, 7, and 9 for limit speed-altitude profile with wing in forward position.

12. Calculate T-tail flutter parameter at each speed-altitude profile point for flutter margin at constant altitude and constant mach number.

13. Scan T-tail flutter parameter and dynamic pressure data for design dynamic pressure.

14. Call TEMPER to calculate structure temperature at design flutter point for:

    a. Wing fixed or aft
    b. Horizontal tail
    c. Vertical tail
    d. Wing forward (variable sweep only)
    e. T-tail flutter

15. Interpolate material property data for shear modulus at structure temperature associated with design flutter points.

16. Write flutter design data in record 38 and labeled common block MISC for use in the wing and empennage weight estimation module.

Arrays and Variable Used

Common region variables:

GH	Shear modulus at library temperatures for horizontal tail material
GV	Shear modulus at library temperatures for vertical tail material
GW	Shear modulus at library temperatures for wing material
NHOR	Number of values in horizontal tail stress-G-temperature tables
NVER	Number of values in vertical tail stress-G-temperature tables
NWING	Number of values in wing stress-G-temperature tables
QQ	Dynamic pressure corrected for compressibility effect at speed profile altitude
TEMPH	Horizontal tail material library temperatures; NHOR values
TEMPV	Vertical tail material library temperatures; NVER values
TEMPW	Wing material library temperatures; NWING values
TFH	Flutter parameter array at table mach numbers for horizontal tail
TFV	Flutter parameter array at table mach numbers for vertical tail
TFW	Flutter parameter array at table mach numbers for wing fixed or aft
TFWF	Flutter parameter array at table mach numbers for wing forward
VFF	Flutter speed margin
XMATOP	Mach number associated with QQ

Program region variables (refer to Table 17):

ALTA, ALTF, FM, XMA, XMF

Program region variables (refer to Table 18):

CTTD1, CTTD2, CTT1, CTT2, PC

Arrays and Variables Calculated

Common region variables:

Q	Incompressible dynamic pressure at design mach numbers
TF	Flutter parameter array for the surface being evaluated
XMN1	Design mach numbers

TABLE 17. SPAL ARRAY VARIABLES

Loc	Name Variable	Description
1		Weight of horizontal tail per side
2		Y_{cg}, butt plane of horizontal tail cg, per side
3		X_{cg}, fuselage station of horizontal tail cg, per side
4		Z_{cg}, water plane of horizontal tail cg, per side
5		I_{pitch}, pitch inertia about X_{cg} per vehicle
6		I_{roll}
7		I_{yaw}, yaw inertia about X_{cg} per vehicle
8	XMTD	M_{TT}, design mach number for T-tail
9	QTT	Q_{TT}, design dynamic pressure for T-tail
10		G_{TT}, shear modulus for T-tail
11	CTT	K_{TT}, K-factor for T-tail
12		Γ_H, dihedral angle of horizontal tail
13		Not used
14		Not used
15		Not used
16	MF	Flutter speed margin
17	ALTA(1)	Altitude 1 of M_L diagram
.	.	to
25	ALTA(9)	Altitude 9 of M_L diagram
26	XMA(1)	Mach number 1 of M_L diagram
.	.	to
34	XMA(9)	Mach number 9 of M_L diagram
35	ALTF(1)	Altitude 1 of M_L diagram for wing in forward position
.	.	to
37	ALTF(3)	Altitude 3 of M_L diagram for wing in forward position
38	XMF(1)	Mach number 1 of M_L diagram for wing in forward position
.	.	to
40	XMF(3)	Mach number 3 of M_L diagram for wing in forward position
41	AWF	Critical flutter altitude for wing in forward position
42	XMWF	Mach number corresponding to AWF
43	TWF	Temperature of skin at AWF, XMWF
44	QQWF	Dynamic pressure corrected for compressibility at AWF, XMWF
45	GWF	Shear modulus at TWF
46	TSF(1)	Wing temperature for flutter design for wing fixed or - aft - ° F
47	TSF(2)	Horizontal tail temperature for flutter design - ° F
48	TSF(3)	Vertical tail temperature for flutter design - ° F
49	TFTT	Vertical tail temperature for T-tail flutter design - ° F
50		Not used

TABLE 18. GJDAT ARRAY VARIABLES

Loc	Value	Variable Name	Description
1			Not used
.			
17			Not used
18	20.0	PC	Number of flutter parameter points
19	0.0	CTTD1	Dihedral angle for flutter parameter values in CTT1 array, deg
20	15.0	CTTD2	Dihedral angle for flutter parameter values in CTT2 array, deg
21	0.0	CTTM(1)	Mach number at point 1
22	0.82		
23	0.85		
24	0.88		
25	0.92		
26	0.95		
27	0.97		
28	1.0		
29	1.04	to	
30	1.07		
31	1.12		
32	1.2		
33	1.3		
34	1.4		
35	1.5		
36	1.6		
37	1.7		
38	1.8		
39	1.9		
40	2.0	CTTM(20)	Mach number at point 20
41	146000.0	CTT1(1)	T-tail flutter parameter for CTTD1 at CTTM(1)
42	146000.0		
43	146000.0		
44	149000.0		
45	154000.0		
46	178000.0		
47	186000.0		
48	190000.0		
50	188000.0		
49	191000.0		
50	188000.0		

TABLE 18. GJDAT ARRAY VARIABLES (CONCL)

Loc	Value	Variable Name	Description
51	184000.0		
52	172000.0		
53	158000.0		
54	142000.0		
55	130000.0		
56	121000.0		
57	113000.0		
58	108000.0		
59	105000.0		
60	102000.0	CTT1(20)	T-tail flutter parameter for CTTD1 at CTTM(20)
61	344000.0	CTT2(1)	T-tail flutter parameter for CTTD2 at CTTM(1)
62	355000.0		
63	355000.0		
64	355000.0		
65	355000.0		
66	353000.0		
67	351000.0		
68	350000.0		
69	345000.0		
70	340000.0		
71	340000.0		
71	331000.0		
72	310000.0		
73	284000.0		
74	264000.0		
75	253000.0		
76	249000.0		
77	244000.0		
78	240000.0		
79	238000.0		
80	235000.0	CTT2(20)	T-tail flutter parameter for CTTD2 at CTTM(20)
81			Not used
.			
100			Not used

Program region variables (refer to Table 17):

AWF, CTT, GWF, QQWF, QTT, TFTT, TSF, TWF, XMAF, SMTD, and SPAL(10)
N Number of speed-altitude profile points

Scratch Arrays and Variables

AL Altitude at design flutter for wing fixed or aft, horizontal tail, and vertical tail
DTT Absolute value of horizontal tail dihedral
FACT T-tail flutter parameter times dynamic pressure at speed-altitude profile points
FACT1 Maximum of values in FACT array
FMM Flutter speed margin squared; margin on dynamic pressure
G Shear modulus, working array
GG Shear modulus at structure temperature
GHT Horizontal tail structural material shear modulus at design flutter point
GTEMP Structure temperature, working array
GVT Vertical tail structural material shear modulus at design flutter point
GWING Wing structural material shear modulus at design flutter point with wings fixed or aft
I Scratch counter
IC Curve interpolation point counter
ITT Speed-altitude profile point at design T-tail flutter
IFEXT Indicator to designate extrapolation of T-tail flutter parameter data
IER Error indicator
IT Index of point on mach-altitude envelope corresponding to maximum design flutter dynamic pressure for wing fixed or aft, horizontal tail, and vertical tail
ITW Speed-altitude profile point at design flutter for wings forward
J Counter for search
1 = test on flutter speed margin
2 = test of flutter dynamic pressure margin
K Scratch counter
L1 Interpolation lower limit point indicator
L2 Interpolation upper limit point indicator
NP Number of T-tail flutter parameter points
NTEMP Number of values in stress-G-temperature tables, working array
PO Local static pressure, lb/ft^2
PRE Local static pressure, $lb/in.^2$
QA Incompressible dynamic pressure at limit speed-altitude profile points

SFX	Sun flux, BTU/hr/ft^2
TEMP	Structure temperature, working array
TLOC	Local static temperature, ^{o} R
TO	Local static temperature, ^{o} R
TSKR	Equilibrium skin temperature, ^{o} R
TT	T-tail flutter parameter at speed-altitude profile points
TTOT	Total temperature, ^{o} R
XM	Mach number at design flutter for wing fixed or aft, horizontal tail, and vertical tail.
XMTT	Mach number at limit speed-altitude profile T-tail flutter design point

Labeled Common Arrays

IP(41)	Print/no-print indicator 0 = print dynamic pressure and design shear modulus data (figures 26 through 29) 1 = no print
XMISC(5)	Dynamic pressure for wing design, lb/ft^2
XMISC(6)	Dynamic pressure for horizontal tail design, lb/ft^2
XMISC(7)	Dynamic pressure for vertical tail design, lb/ft^2
XMISC(15)	Wing structural material identification number; established in input data processing module
XMISC(19)	Horizontal tail structural material identification number; established in input data processing module
XMISC(23)	Vertical tail structural material identification number; established in input data processing module
XMISC(28)	Wing structural material shear modulus at design flutter point, lb/in.^{2}
XMISC(29)	Horizontal tail structural material shear modulus at design flutter point, lb/in.^{2}
XMISC(30)	Vertical tail structural material shear modulus at design flutter point, lb/in.^{2}
XMISC(53)	Vertical tail-type indicator -1 = single tail 0 = dual tail 1 = T-tail

Mass Storage File Records Used

Record 37	GJDAT array, T-tail flutter parameter tables
Record 38	SPAL array, speed-altitude profile and T-tail inertia data, is read and written

FLUTTER SPEED MARGIN = 1.20 ** WHVJJ - IP(41) **

WING FIXED UP AFT

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	1.2800	2426.3	1.5360	3493.9	1657.9
5000.	1.4419	2562.1	1.7303	3689.5	1379.6
10000.	1.6275	2697.9	1.9530	3885.0	1140.3
15000.	1.7984	2703.6	2.1581	3893.1	935.8
20000.	1.9950	2709.2	2.3940	3901.2	762.1
27500.	2.1946	2371.0	2.6335	3414.3	551.2
35000.	2.4150	2032.9	2.8980	2927.3	390.2
37500.	2.5185	1961.1	3.0222	2823.9	346.1
40000.	2.6250	1889.2	3.1500	2720.5	312.7

HORIZONTAL TAIL

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	1.2800	2426.3	1.5360	3493.9	1589.4
5000.	1.4419	2562.1	1.7303	3689.5	1322.6
10000.	1.6275	2697.9	1.9530	3885.0	1093.2
15000.	1.7984	2703.6	2.1581	3893.1	897.1
20000.	1.9950	2709.2	2.3940	3901.2	730.6
27500.	2.1946	2371.0	2.6335	3414.3	528.4
35000.	2.4150	2032.9	2.8980	2927.3	398.2
37500.	2.5185	1961.1	3.0222	2823.9	367.1
40000.	2.6250	1889.2	3.1500	2720.5	339.7

VERTICAL TAIL

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	1.2800	2426.3	1.5360	3493.9	1551.7
5000.	1.4419	2562.1	1.7303	3689.5	1291.2
10000.	1.6275	2697.9	1.9530	3885.0	1067.3
15000.	1.7984	2703.6	2.1581	3893.1	875.8
20000.	1.9950	2709.2	2.3940	3901.2	713.2
27500.	2.1946	2371.0	2.6335	3414.3	528.0
35000.	2.4150	2032.9	2.8980	2927.3	399.4
37500.	2.5185	1961.1	3.0222	2823.9	365.4
40000.	2.6250	1889.2	3.1500	2720.5	335.5

Figure 26. Sample output - dynamic pressure to satisfy flutter speed margin.

FLUTTER C MARGIN = 1.4400 ** ARVO1 - IP(41) **

WING FIXED OR AFT

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	1.2800	2426.3	1.2800	3493.5	2387.4
5000.	1.4419	2562.1	1.4419	3689.5	1586.6
10000.	1.6275	2697.9	1.6275	3885.0	1642.1
15000.	1.7984	2703.6	1.7984	3893.1	1347.6
20000.	1.9950	2709.2	1.9950	3901.2	1097.4
27500.	2.1946	2371.0	2.1946	3414.3	793.7
35000.	2.4150	2032.9	2.4150	2927.3	561.9
37500.	2.5185	1961.1	2.5185	2823.9	498.4
40000.	2.6250	1889.2	2.6250	2720.5	442.0

HORIZONTAL TAIL

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	1.2800	2426.3	1.2800	3493.5	2286.7
5000.	1.4419	2562.1	1.4419	3689.5	1504.5
10000.	1.6275	2697.9	1.6275	3885.0	1574.2
15000.	1.7984	2703.6	1.7984	3893.1	1291.5
20000.	1.9950	2709.2	1.9950	3901.2	1052.0
27500.	2.1946	2371.0	2.1946	3414.3	760.9
35000.	2.4150	2032.9	2.4150	2927.3	538.7
37500.	2.5185	1961.1	2.5185	2823.9	477.8
40000.	2.6250	1889.2	2.6250	2720.5	423.7

VERTICAL TAIL

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	1.2800	2426.3	1.2800	3493.5	2234.4
5000.	1.4419	2562.1	1.4419	3689.5	1859.3
10000.	1.6275	2697.9	1.6275	3885.0	1536.8
15000.	1.7984	2703.6	1.7984	3893.1	1261.2
20000.	1.9950	2709.2	1.9950	3901.2	1027.0
27500.	2.1946	2371.0	2.1946	3414.3	742.8
35000.	2.4150	2032.9	2.4150	2927.3	525.9
37500.	2.5185	1961.1	2.5185	2823.9	466.5
40000.	2.6250	1889.2	2.6250	2720.5	422.5

Figure 27. Sample output - dynamic pressure to satisfy flutter dynamic pressure margin.

** WHVOQ - IP(4) **

T-TAIL FLUTTER DIHEDRAL = 0.0

FLUTTER SPEED MARGIN = 1.15

SPEED-ALTITUDE PROFILE POINTS ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	FLUTTER DESIGN MACH NUMBER	DYNAMIC PRESSURE	CIT	Q*CIT
0.	.6000	533.1	.6900	705.1	.146000E+06	.102938E+09
5000.	.6499	520.4	.7473	688.2	.146000E+06	.100484E+09
10000.	.7060	507.7	.8119	671.4	.146000E+06	.980275E+08
15000.	.7688	494.0	.8841	653.3	.156439E+06	.102204E+09
20000.	.8400	480.3	.9660	635.2	.189200E+06	.120178E+09
21250.	.8548	471.9	.9830	624.1	.190435E+06	.118847E+09
22500.	.8700	463.5	1.0005	613.0	.190962E+06	.117055E+09
36250.	.8700	248.5	1.0005	328.7	.190962E+06	.627603E+08
50000.	.8700	128.3	1.0005	169.7	.190962E+06	.324092E+08

FLUTTER Q MARGIN = 1.3225

SPEED-ALTITUDE PROFILE POINTS ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	FLUTTER DESIGN MACH NUMBER	DYNAMIC PRESSURE	CIT	Q*CIT
0.	.6000	533.1	.6000	705.1	.146000E+06	.102938E+09
5000.	.6499	520.4	.6499	688.2	.146000E+06	.100484E+09
10000.	.7060	507.7	.7060	671.4	.146000E+06	.980275E+08
15000.	.7688	494.0	.7688	653.3	.146000E+06	.953834E+08
20000.	.8400	480.3	.8400	635.2	.148000E+06	.940084E+08
21250.	.8548	471.9	.8548	624.1	.149804E+06	.934898E+08
22500.	.8700	463.5	.8700	613.0	.152333E+06	.933760E+08
36250.	.8700	248.5	.8700	328.7	.152333E+06	.500647E+08
50000.	.8700	128.3	.8700	169.7	.152333E+06	.258532E+08

DESIGN POINT

SPEED-ALTITUDE PROFILE POINTS ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	FLUTTER DESIGN MACH NUMBER	DYNAMIC PRESSURE	CIT	Q*CIT
20000.	.8400	480.3	.9660	635.2	.189200E+06	.120178E+09

Figure 28. Flutter parameter and dynamic pressure to satisfy T-Tail flutter.

** ... - IP(41) **

WING

FLUTTER SPEED MARGIN = 1.20

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	0.8000	947.8	0.8000	1364.8	1363.8
10000.	0.9000	825.0	1.0000	1188.1	1078.5
30000.	1.0000	439.9	1.2000	633.4	472.9

FLUTTER Q MARGIN = 1.4400

SPEED-ALTITUDE PROFILE POINTS			FLUTTER DESIGN		
ALTITUDE FEET	MACH NUMBER	DYNAMIC PRESSURE	MACH NUMBER	DYNAMIC PRESSURE	COMPRESSIBLE DYNAMIC PRESSURE
0.	0.8000	947.8	0.8000	1364.8	1364.8
10000.	0.9000	825.0	0.9000	1188.1	1201.6
30000.	1.0000	439.9	1.0000	633.4	621.4

*** DESIGN TEMPERATURE, PRESSURE AND G ***

	PROFILE POINT	ALTITUDE	MACH NO.	TEMPERATURE	PRESSURE	G (PSI)
WING	1	0.	1.0500	161.3	2387.4	3947369.
HORIZONTAL	1	0.	1.1000	170.9	2268.7	3932267.
VERTICAL	1	0.	1.1250	175.9	2234.4	3927333.

Figure 29. Sample output - dynamic pressure data for wings forward and surface flutter design data.

Error Messages

*****EXTRAPOLATED ON T-TAIL STIFFNESS COEFF. FOR MACH NO. x.x, CTT = y.y when x.x is mach number and y.y is value of coefficient to be used.

Section IV

MODULE FLOW CHARTS AND FORTRAN LISTS

FLOW CHART USAGE

The automatically generated computer program flow charts (AUTOFLOW) presented in this document include a table of contents, flow charts, and FORTRAN lists of all routines in the module. The 80-column card lists are sequenced and grouped by routine.

Because the AUTOFLOW system used is IBM-oriented, the functions of the BUFFERIN and BUFFEROUT statements are not recognized, but these statements appear in proper order in note boxes. Also, the PROGRAM name does not appear on the main program, and library routines READMS and WRITMS are listed as undefined external references.

CROSS-REFERENCE LIST

The AUTOFLOW table of contents which precedes the flow charts and FORTRAN lists serves to cross reference the latter two. This table lists the following from left to right:

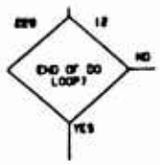
- The card identification from columns 73 through 80 of this card, or card sequence number. When sequence number is used in place of card identification, it is enclosed in parentheses.
- The page and box number where this card is displayed in a flow chart.
- The FORTRAN statement number from columns 1 through 5 of this card.
- The card identification(s) or sequence number(s) of the card(s) referring to this card (repeated as required).
- The pages and box numbers where the cards referring to this card are displayed in a flow chart (repeated as required).

FLOW CHARTS

The flow charts produced by AUTOFLOW use USASI conventional symbols. Since the flow charts are mechanically drawn from the program source deck, there are no omissions or vague generalizations about the processing within the boxes.

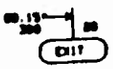
Every box on each page is uniquely numbered and may be referred to from elsewhere in the program. The source of a reference to a box will be indicated by showing the page and box number. If the number is followed by an asterisk, there are multiple references to this point, and the others may be found by using the cross-reference list.

The most-often-used symbol is the decision box. Like all boxes, its box number is above and to the right of the box. Its FORTRAN statement number is above and to the left of the box. The decision choices for the paths are printed.

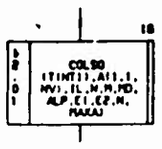


The unconditional transfer connecter has its page number destination printed above or to the left of the box number destination within the connecter. If there is a FORTRAN statement number at the destination, it is printed below the connecter.

The exit box example shows a connecter from page 9, box 15.

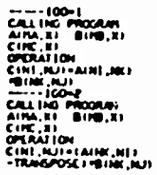


The subroutine call box includes the calling sequence. The page and box numbers of the flow chart of the called subroutine are shown on the left-hand side of the box. The page number is above the box number.

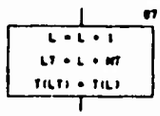


The note box encloses comments of a functional nature,

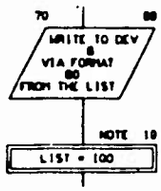
as differentiated from the 21 column comments, which are left justified without a box, that show the comment cards included in the FORTRAN deck.



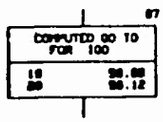
The process box is used to enclose FORTRAN arithmetic statements.



Input and output are shown as communicating with a device. The list used follows, if appropriate:



The computed GØ TØ becomes a branch table showing the page and box number of each of the ordered branches.



The column connecters and initial connecters are the only boxes without external box numbers. The function of the initial connecter is always clear,

but the label given is the symbol in the next FORTRAN card, which is often blank.

The column connecter identifies the page and box number to which it connects.

TABLE OF CONTENTS

FOR

AUTOFLOW CHART SET

CARD ID PAGE/BOX NAME REFERENCES (SOURCE SEQUENCE NO. AND PAGE/BOX)

FORTRAN MODULE FLUTTER AND TEMPERATURE

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - PROCEDURES

(000017) 2.02 10
(000017) 2.02 (000017) 2.03
(000020) 2.05 (000022) 2.07
(000022) 2.06 11
(000030) 2.11 (000091) 3.05
(000035) 2.13 72 (000032) 2.12 (000032) 2.12 (000032) 2.12
(000039) 2.14 73 (000032) 2.12
(000043) 2.15 74 (000032) 2.12 (000032) 2.12 (000032) 2.12
(000047) 2.16 75 (000032) 2.12
(000051) 2.17 76 (000032) 2.12 (000032) 2.12 (000032) 2.12 (000032) 2.12
(000055) 2.18 77 (000032) 2.12 (000032) 2.12 (000032) 2.12 (000032) 2.12
(000059) 2.19 78 (000032) 2.12
(000060) 2.20 81 (000084) 2.21
(000063) 2.21 84 (000032) 2.12
(000066) 2.22 85 (000032) 2.12 (000032) 2.12 (000032) 2.12
(000070) 2.23 86 (000032) 2.12 (000032) 2.12
(000073) 2.24 87 (000037) 2.13 (000041) 2.14 (000045) 2.15 (000049) 2.16 (000053) 2.17
(000057) 2.18 (000061) 2.20 (000068) 2.22
(000081) 3.01 98 (000076) 2.25
(000085) 3.03 101 (000084) 3.02
(000091) 3.05 123 (000076) 2.25 (000084) 3.02

CHART TITLE - NON-PROCEDURAL STATEMEN S

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION HBL(XMACH,PO,TO,TSK,DIST,XLAMDA,REY,METHOD,IER,TOTI,TAH)

(000171) 7.02 10
(000172) 7.03 11
(000176) 7.04 13 (000170) 7.01
(000177) 7.05 14
(000178) 7.06 15 (000173) 7.03 (000175) 7.07 (000182) 7.09
(000174) 7.07 12 (000171) 7.02
(000180) 7.08 20 (000176) 7.04
(000181) 7.09 21
(000183) 8.01 22 (000180) 7.08
(000184) 8.02 23
(000186) 8.03 24 (000183) 8.01
(000189) 8.05 25
(000190) 8.06 26 (000188) 8.04
(000206) 8.13 100 (000205) 8.12 (000205) 8.12
(000207) 8.14 30
(000208) 8.15 35 (000208) 8.13
(000210) 8.17 40
(000215) 8.20 50
(000217) 8.21 60 (000209) 8.16
(000225) 8.25 65
(000226) 8.26 70 (000224) 8.24 (000231) 8.29
(000229) 8.28 80
(000232) 8.30 90
(000233) 8.31 110 (000228) 8.27
(000235) 9.01 300 (000205) 8.12 (000205) 8.12
(000239) 9.03 130
(000241) 9.05 140
(000242) 9.06 150 (000238) 9.02 (000240) 9.04
(000244) 9.08 180
(000245) 9.09 170 (000243) 9.07
(000252) 9.13 180
(000255) 9.15 190
(000258) 9.16 210 (000254) 9.14
(000258) 9.17 220 (000251) 9.12
(000268) 9.22 229
(000269) 9.23 230 (000257) 9.16

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(000274) 9 26 1000 (000179) 7.08 (000214) 8.19 (000218) 8.20 (000234) 8.31

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION PRESH(ALT)

(000287) 11 03 10
(000289) 11 04 20 (000286) 11.02
(000290) 11.05 30 (000286) 11.02
(000293) 11 06 40 (000289) 11 04
(000294) 11 07 50
(000297) 11 08 60 (000293) 11.06
(000299) 11.10 65
(000301) 11 11 100 (000288) 11.03 (000292) 11.05 (000296) 11.07 (000298) 11.09

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - SUBROUTINE QINC(XM,PO,TO,Q)

(000310) 14 01 QINC (001331) 59.17-X (001415) 61.10-X

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - SUBROUTINE QSUB(LIM)

(000351) 16 01 QSUB (001349) 59.26-X (001424) 61.18-X
(000353) 16 02 (000389) 17.15
(000357) 16 04 47 (000355) 16.03
(000361) 17.01 48 (000355) 16.03
(000362) 17 02 (000368) 17.05
(000363) 17 03 49
(000364) 17.04 52 (000362) 17.02
(000368) 17 05 50 (000363) 17.03
(000370) 17 06 54 (000367) 17.04
(000373) 17.08 (000376) 17.10
(000374) 17 09 62
(000378) 17 10 60 (000373) 17.08
(000380) 17.12 71 (000378) 17.11
(000384) 17 13 72 (000378) 17.11
(000387) 17.14 69 (000359) 16.04 (000382) 17.12
(000389) 17 15 100

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION SOLARG(ALT)

(000405) 20 03 10
(000407) 20.04 20 (000404) 20.02
(000408) 20.05 30 (000406) 20.03

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - SUBROUTINE SVFTAB

(000417) 22.01 SVFTAB (001305) 59.03-X
(000444) 22.02 (000447) 22.04
(000447) 22.03 699
(000465) 22.09 (000581) 25.04
(000467) 22.11 301 (000465) 22.09
(000469) 22.12 305 (000467) 22.11
(000475) 22.13 302 (000465) 22.09
(000478) 22.14 332
(000481) 22.15 303 (000465) 22.09
(000483) 22.16 306 (000481) 22.15
(000500) 23.01 204 (000495) 23.08
(000502) 23.03 205
(000502) 23.03 (000502) 23.04

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(0000488)	23.05 304	(0000485) 22.09	
(0000490)	23.06 307	(0000488) 23.05	
(0000494)	23.07 308	(0000472) 22.12	(0000478) 22.14 (0000486) 22.18
(0000495)	23.08 200		
(0000496)	23.09 201		
(0000498)	23.11 202		
(0000498)	23.11	(0000498) 23.12	
(0000504)	23.13 210	(0000494) 23.07	
(0000506)	23.15 215		
(0000506)	23.15	(0000506) 23.16	
(0000508)	23.17 220	(0000503) 23.04	(0000499) 23.12
(0000509)	23.18 230		
(0000511)	23.20 235		
(0000511)	23.20	(0000511) 23.21	
(0000513)	23.22 240	(0000508) 23.17	
(0000515)	23.24 245		
(0000515)	23.24	(0000515) 23.25	
(0000517)	23.26 250	(0000512) 23.21	
(0000518)	23.27 260		
(0000520)	23.29 265		
(0000520)	23.29	(0000520) 23.30	
(0000522)	24.01 270	(0000517) 23.26	
(0000524)	24.03 275		
(0000524)	24.03	(0000524) 24.04	
(0000526)	24.05 280	(0000521) 23.30	
(0000527)	24.06 290		
(0000527)	24.06	(0000527) 24.07	
(0000530)	24.09 5003		
(0000534)	24.11 291	(0000532) 24.10	
(0000539)	24.12 292	(0000532) 24.10	
(0000544)	24.13 293	(0000532) 24.10	
(0000549)	24.14 294	(0000532) 24.10	
(0000553)	24.15 298	(0000537) 24.11	(0000542) 24.12 (0000547) 24.13
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(0000562)	24.21 5004	(0000529) 24.08	
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(0000567)	24.24 325		
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(0000571)	24.27 336		
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(0000574)	24.29 323	(0000564) 24.22	
(0000575)	24.30 326		
(0000575)	24.30	(0000575) 24.31	
(0000578)	25.01 324	(0000564) 24.22	
(0000579)	25.02 327		
(0000579)	25.02	(0000579) 25.03	
(0000581)	25.04 300	(0000487) 22.11 (0000572) 24.28	(0000475) 22.13 (0000481) 22.15 (0000488) 23.05 (0000568) 24.25 (0000576) 24.31

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION TBL(XMACH,PO,TO,TSK,DIST,XLAMDA,REY,METHOD,IER,TOTI)

(0000637)	28.02 10		
(0000639)	28.01 20	(0000636) 28.01	
(0000640)	28.02 30		
(0000641)	28.03 40	(0000639) 28.01	
(0000653)	28.07 50	(0000673) 28.19	
(0000660)	28.11 52		
(0000661)	28.12 54		
(0000665)	28.13 58	(0000659) 28.10	
(0000667)	28.15 60		
(0000668)	28.16 70	(0000668) 28.14	(0000694) 28.20
(0000671)	28.18 80		
(0000672)	28.19 85		
(0000683)	28.20 56	(0000660) 28.11	
(0000674)	28.21 90	(0000671) 28.18	
(0000676)	28.22 100	(0000638) 28.02	(0000662) 28.12 (0000670) 28.17

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CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION TEMALT(ALT,TI)

(0000718)	31 01	200	(0000700)	31 07									
(0000719)	31.02	210											
(0000762)	31 03	400	(0000701)	31 08									
(0006783)	31 04	410											
(0000698)	31 06	10											
(0000700)	31 07	20											
(0000701)	31.08	30											
(0000702)	31 09	40											
(0000705)	31 10	100	(0000700)	31.07									
(0000706)	31 11	110											
(0000759)	31 12	300	(0000701)	31.08									
(0000760)	31 13	310											
(0000708)	31 14	120	(0000705)	31 10									
(0000709)	31 15	125	(0000705)	31 10									
(0000763)	31 16	320	(0000759)	31.12									
(0000764)	31.17	325	(0000759)	31 12									
(0000711)	32 01	140	(0000708)	31.14									
(0000712)	32 02	145											
(0000714)	32 03	160	(0000711)	32 01									
(0000721)	33 01	220	(0000718)	31 01									
(0000722)	33 02	225	(0000718)	31.01									
(0000724)	33 03	230	(0000721)	33.01									
(0000725)	33 04	235											
(0000726)	33 05	236											
(0000732)	33 06	240	(0000724)	33.03									
(0000733)	33 07	245	(0000724)	33.03									
(0000729)	33 08	237	(0000725)	33 04									
(0000735)	33.09	250	(0000732)	33 06									
(0000738)	33.10	251											
(0000739)	34.01	252	(0000735)	33.09									
(0000740)	34 02	253											
(0000742)	34 03	260	(0000739)	34 01									
(0000743)	34.04	265	(0000739)	34.01									
(0000745)	34 05	270	(0000742)	34.03									
(0000746)	34 06	275											
(0000750)	34.08	280	(0000745)	34 05									
(0000751)	34.09	285											
(0000754)	35 01	290	(0000750)	34.08									
(0000762)	35 02	330	(0000763)	31.16									
(0000768)	35 03	335	(0000763)	31.16									
(0000770)	35 04	340	(0000767)	35.02									
(0000771)	35 05	345	(0000767)	35.02									
(0000773)	35 06	350	(0000770)	35.04									
(0000774)	35 07	360											
(0000777)	35 08	370	(0000773)	35.06									
(0000785)	36 01	420	(0000782)	31.03									
(0000788)	36.02	425	(0000782)	31.03									
(0000789)	36 03	430	(0000785)	35.01									
(0000795)	36 04	435	(0000785)	36.01									
(0000792	36.05	440	(0000788)	36 03									
(0000794	36 06	445	(0000788)	36.03									
(0000795	36.07	450	(0000792)	36 05									
(0000799)	37 01	500	(0000702)	31.09									
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(0000801)	37.03	502											
(0000806)	37.04	520	(0000799)	37.01									
(0000807)	37.05	525	(0000799)	37.01									
(0000808)	37.06	526											
(0000803)	37.07	503	(0000800)	37.02									
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(0000811)	37.09	527	(0000807)	37.05									
(0000819)	38 01	539	(0000702)	31.09									
(0000821)	38.03	540											
(0000822)	38.04	542											
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(0000769) 35.03 (0000772) 35.05 (0000776) 35.07 (0000779) 35.08 (0000787) 36.02
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(0000005) 37.07 (0000816) 37.08 (0000813) 37.09 (0000823) 38.04 (0000825) 38.09

(0000629) 38.07 810 (0000715) 32.04

(0000831) 38.08 830 (0000710) 31.15 (0000713) 32.02 (0000715) 32.04 (0000828) 38.06

(0000824) 38.09 543 (0000821) 38.03

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - SUBROUTINE TEMPER(XMACH,ALT,PRESSI,TLOC,TTOT,SUN,XSKIN,XSKINF,IER

(0000840) 41.01 TEMPER (0000811) 3.01-X (0001547) 84.14-X (0001554) 84.18-X (0001563) 84.21-X

(0000890) 42.02 59 (0000952) 42.12

(0000952) 42.12 103 (0000941) 42 . (0000944) 43.01

(0000956) 42.13 105 (0000952) 42.12 (0000947) 43.02

(0000943) 43.01 101 (0000941) 42.11

(0000946) 43.02 102 (0000941) 42.11

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION TSKIN(A,B,C,IER)

(0000978) 46.02 2

(0000979) 46.03 3

(0000987) 46.05 7 (0000977) 46.01

(0000988) 46.06 8

(0000983) 46.08 5 (0000978) 46.02

(0000994) 46.10 15 (0000987) 46.05

(0001001) 46.12 21 (0001017) 46.18

(0001004) 46.13 25

(0001005) 46.14 30

(0001007) 46.15 47 (0001004) 46.13

(0001012) 46.16 45

(0001013) 46.17 50

(0001018. 46.19 55

(0001.9) 46.20 60 (0001012) 46.16

(0001020) 46.21 70 (0000902) 46.04 (0000991) 46.07 (0000981) 46.09 (0001006) 46.14 (0000993) 47.01

(0000952) 47.01 10 (0000987) 46.05

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION TTO(XMACH,TO,IER)

(0001055) 50.02 3

(0001057) 50.03 5 (0001054) 50.01

(0001068) 50.06 10 (0001075) 50.10

(0001073) 50.09 20

(0001074) 50.10 30

(0001076) 50.11 40 (0001073) 50.09

(0001078) 50.12 50 (0001058) 50.02 (0001072) 50.08

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - SUBROUTINE WHYMAT

(0001086) 52.01 WHYMAT (0001297) 59.01-X

(0001.3) 52.04 (0001247) 56.27

(0001113) 52.05 601 (0001111) 52.04

(0001115) 52.06 605 (0001113) 52.05

(0001118) 52.07 602 (0001111) 52.04

(0001120) 52.08 615 (0001118) 52.07

(0001121) 52.09 618

(0001124) 52.10 603 (0001111) 52.04

(0001125) 53.01 625 (0001124) 52.10

(0001171) 53.02 626

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(0011291) 53 05 810 (0011181) 52 08 (0011221) 52 09
(0011301) 53 04 811
(0011301) 53 04 (0011301) 53 05
(0011351) 53 08 (0011431) 53 12
(0011401) 53 10 838
(0011421) 53 11 839 (0011391) 53 09
(0011431) 53 12 840 (0011411) 53 10
(0011511) 53 14 801 (0011491) 53 13
(0011551) 54 01 805 (0011491) 53 13
(0011581) 54 03 (0011611) 54.05
(0011591) 54 04 807
(0011611) 54 05 810 (0011581) 54 03
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(0011651) 54 07 820 (0011631) 54 06
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(0011751) 55 02 835 (0011691) 55 01
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(0011771) 55 04 836
(0011801) 55 05 840 (0011761) 55 03
(0011811) 55 06 845 (0011671) 54 07 (0011791) 55 04 (0011731) 55 16
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(0011871) 55 08 852 (0011201) 52 08 (0011261) 53 01
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(0011901) 55 11 669
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(0012141) 56 05 (0012141) 56 07
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(0012331) 56 18 (0012351) 56 20
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(0012401) 56 22 683 (0012221) 56 11
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(0012431) 56 24 693
(0012471) 56 27 600 (0011131) 52 05 (0011181) 52 07 (0011241) 52.10 (0012301) 56.16 (0012381) 56.21

CHART TITLE - NEW PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - SUBROUTINE ARYOO

(0012571) 54 01 ARYOO (0000091) 3 06-X
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(0013141) 59 09 14 (0013121) 59 07
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(0013221) 59 13 33 (0013181) 59 10
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(0013431) 59 21 (0013841) 60.17
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(0013461) 59 23 102
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(001388)	60.19 510		
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(001488)	62.15		(001508) 63.15
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(0016731)	68 06 941		
(0016761)	68 07 997	(0016721) 68 05	
(0016791)	68 08 1005	(0016751) 68 06	
(0016821)	68 11 1000	(0016701) 68 04	

CHART TITLE - NON-PROCEDURAL STATEMENTS

LOCATION		DIAGNOSTIC
CARD ID	PAGE/BOX	
(0000241	2.08	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(0000251	2.09	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(0000981	3.07	UNDEFINED - 'WRITMS' EXTERNAL REFERENCE
(0011321	53.06	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(0013021	54.02	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(0014491	62.06	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(0016891	68.11	UNDEFINED - 'WRITMS' EXTERNAL REFERENCE

PROGRAM FLOW CHARTS

OF

FLUTTER AND TEMPERATURE MODULE

CHART TITLE - PROCEDURES

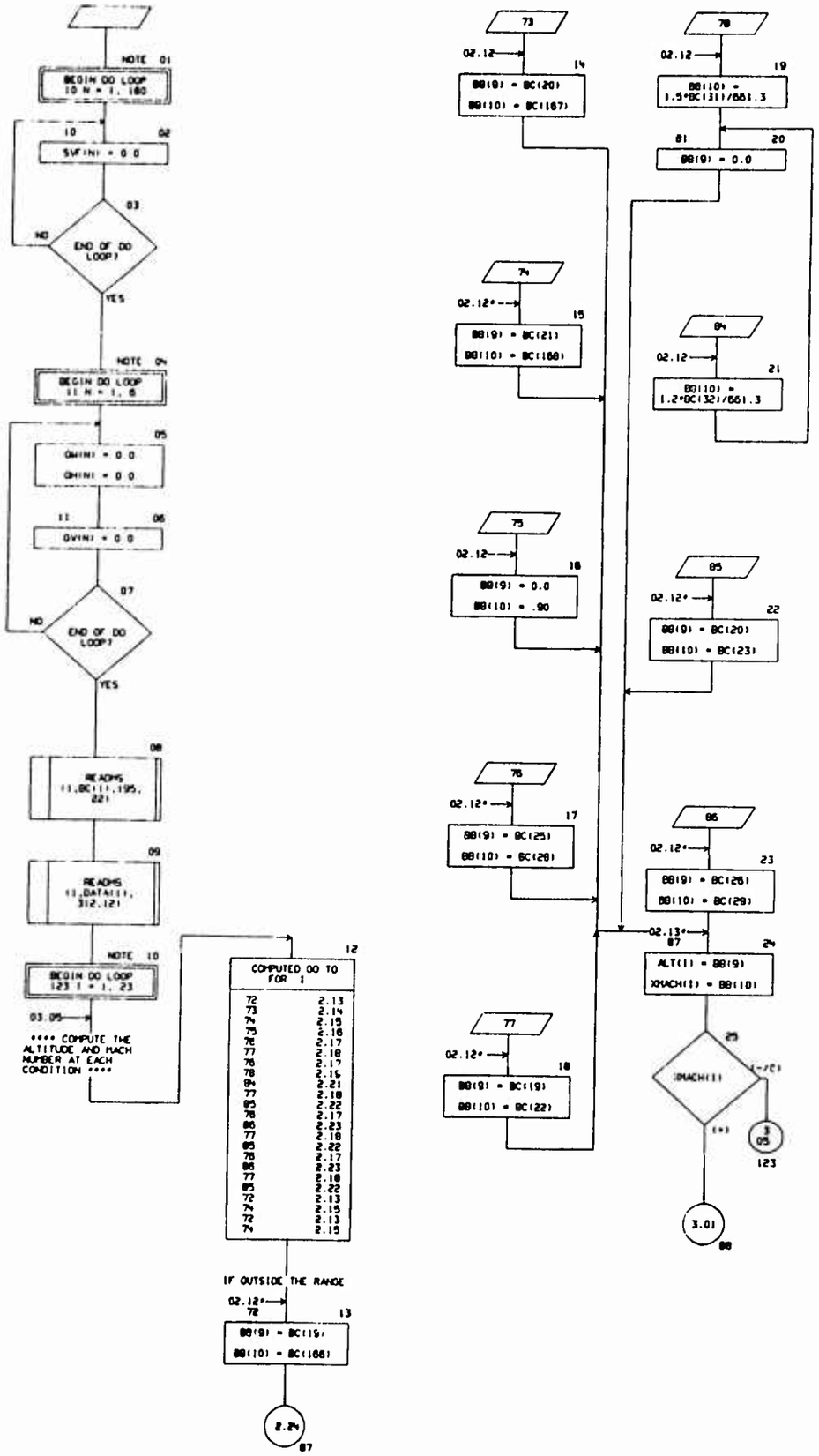


CHART TITLE - PROCEDURES

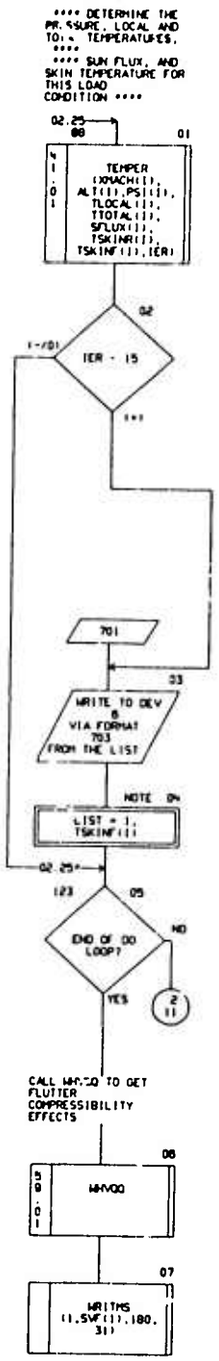


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      PROGRAM OLAY3
      COMMON    $VF(180),DATA(312),TFW(38),TFH(38),TFV(38),TFWF(38),
                TF(38),XMN(20),Q(20),QQ(20),XMATOP(20),
                OW(8),OH(8),OV(8)
      DIMENSION PS(23),TLOCAL(23),TTOTAL(23),SFLUX(23),TSKINR(23),
                TSKINF(23)
      DIMENSION BC(195),ALT(23),XMACH(23),BB(10)
      EQUIVALENCE          ($VF( 1),PS    ()),($VF( 24),TLOCAL()),
     ($VF( 47),TTOTAL()),($VF( 70),SFLUX ()),($VF( 93),TSKINR()),
     ($VF(116),TSKINF())
  703 FORMAT(15HOLOAD CONDITION,I3,77H - THE TEMPERATURE LOOP DID NOT CL
     OSE IN 100 ITERATIONS. THE SKIN TEMPERATURE,F8 3,27H IS FROM THE L
     AST ITERATION/)
```

CHART TITLE - INTRODUCTORY COMMENTS

```
C                              FUNCTION HBL
C
C     NOTE-  THIS FUNCTION SUBPROGRAM COMPUTES AERODYNAMIC HEATING
C     COEFFICIENTS BY THE METHOD OF E R. VAN DRIEST.  IT IS DESCRIBED IN
C     REPORT NA-63-1473.  THIS VERSION IS IN FORTRAN IV.
C
C
C     PROGRAM TO COMPUTE BOUNDARY LAYER HEAT TRANSFER COEFFICIENTS
C
C     C.J. MAC MILLER                              28 MARCH,1964
C
C     THE EQUATION IS PROGRAMMED AS FOLLOWS....
C
C       BOUNDARY LAYER HEAT TRANSFER COEFFICIENT  =
C
C            HBL(XMACH,PO,TO,TSK,DIST,XLAMDA,REY,METHOD,IER)
C
C       WHERE - XMACH = LOCAL MACH NUMBER, DIMENSIONLESS
C                  PO = LOCAL PRESSURE, PSF
C                  TO = LOCAL TEMPERATURE, DEG RANKINE
C                 TSK = SKIN TEMPERATURE, DEG RANKINE
C                DIST = CHARACTERISTIC LENGTH, FEET
C                       WITH METHOD 1-2, = LENGTH AFT OF LEADING EDGE
C                       WITH METHOD 3-4, = DIAMETER OF LEADING EDGE
C              XLAMDA = ANGLE OF SWEEP, DEGREES
C                 REY = TRANSITION REYNOLDS NUMBER, DIMENSIONLESS. IF
C                       NO VALUE OF REY IS SUBMITTED, THE FUNCTION
C                       WILL SUPPLY A VALUE OF ONE MILLION
C              METHOD = SURFACE ORIENTATION
C                       METHOD = 1 FOR FLAT PLATE, WEDGES, CYLINDERS
C                                  ALIGNED WITH FLOW
C                              = 2 FOR CONES OR OTHER SURFACES OF REV-
C                                  OLUTION
C                              = 3 FOR STAGNATION HEAT TRANSFER OF TWO
C                                  DIMENSIONAL SHAPES AS CYLINDERS
C                              = 4 FOR STAGNATION HEAT TRANSFER OF
C                                  THREE DIMENSIONAL SHAPES AS SPHERES
C                 IER = ERROR INDICATOR
C                  IF IER = 0, NO ERROR, SOLUTION CRITERIA WERE MET.
C                     IER = 1, SOLUTION FOR TOTAL TEMPERATURE DID NOT
C                              CONVERGE IN 100 PASSES, VALUE RETURNED
C                              IS BASED ON CONSTANT GAMMA.
C                     IER = 2, SOLUTION FOR BOUNDARY LAYER TEMPERATURE
C                              DID NOT CONVERGE IN 100 PASSES, VALUE
C                              RETURNED IS BASED ON RECOVERY OF .875
C                  IF IER = 3, SOLUTION FOR SKIN FRICTION COEFFICIENT
C                              DID NOT CONVERGE IN 100 PASSES, SOLU-
C                              TION FOR BOUNDARY LAYER COEF. WAS CON-
C                              TINUED WITH CURRENT VALUE OF C(F).
C                     IER = 4, ARGUMENT XMACH IS ZERO, DIST IS ZERO,
C                              HBL = 0.00
C                     IER = 5, ARGUMENT XMACH IS ZERO, DIST IS
C                              POSITIVE, HBL = 0.00
C                     IER = 6, ARGUMENT XMACH IS POSITIVE, DIST IS
C                              MINUS OR ZERO, HBL = 0.00
C                    IER = 7, ARGUMENT TO IS BELOW 160 DEGREES RANKINE
C                    A VALUE OF HBL =0.0 IS RETURNED.
C                    IER = 8, ARGUMENT TSK IS BELOW 160 RANKINE.
C                    SOLUTION CONTINUES USING TO FOR TSK.
```

CHART TITLE - INTRODUCTORY COMMENTS

THE VALUE OF BOUNDARY LAYER HEAT TRANSFER COEFFICIENT IS RETURNED
IN BTU/HR-FT**2-DEG F TO THE CALLING PROGRAM

**** *** ****

CHART TITLE - FUNCTION HBL(XMACH,PO,TO,TSK,DIST,XLAMDA,REY,METHOD,IER,TOTL,TAH)

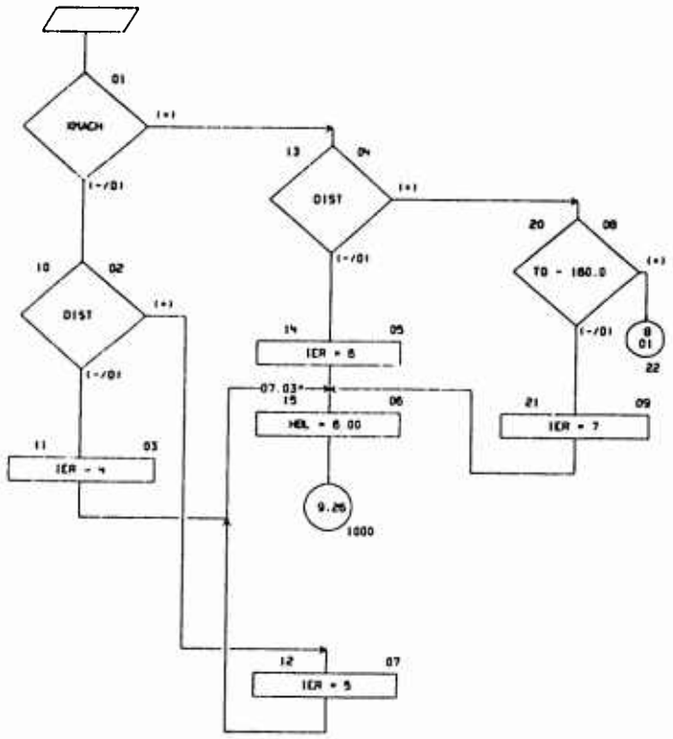


CHART TITLE - FUNCTION HBL(XMACH,P0,T0,TSK,DIST,XLAMDA,REY,METHOD,IER,TOTI,TAHI

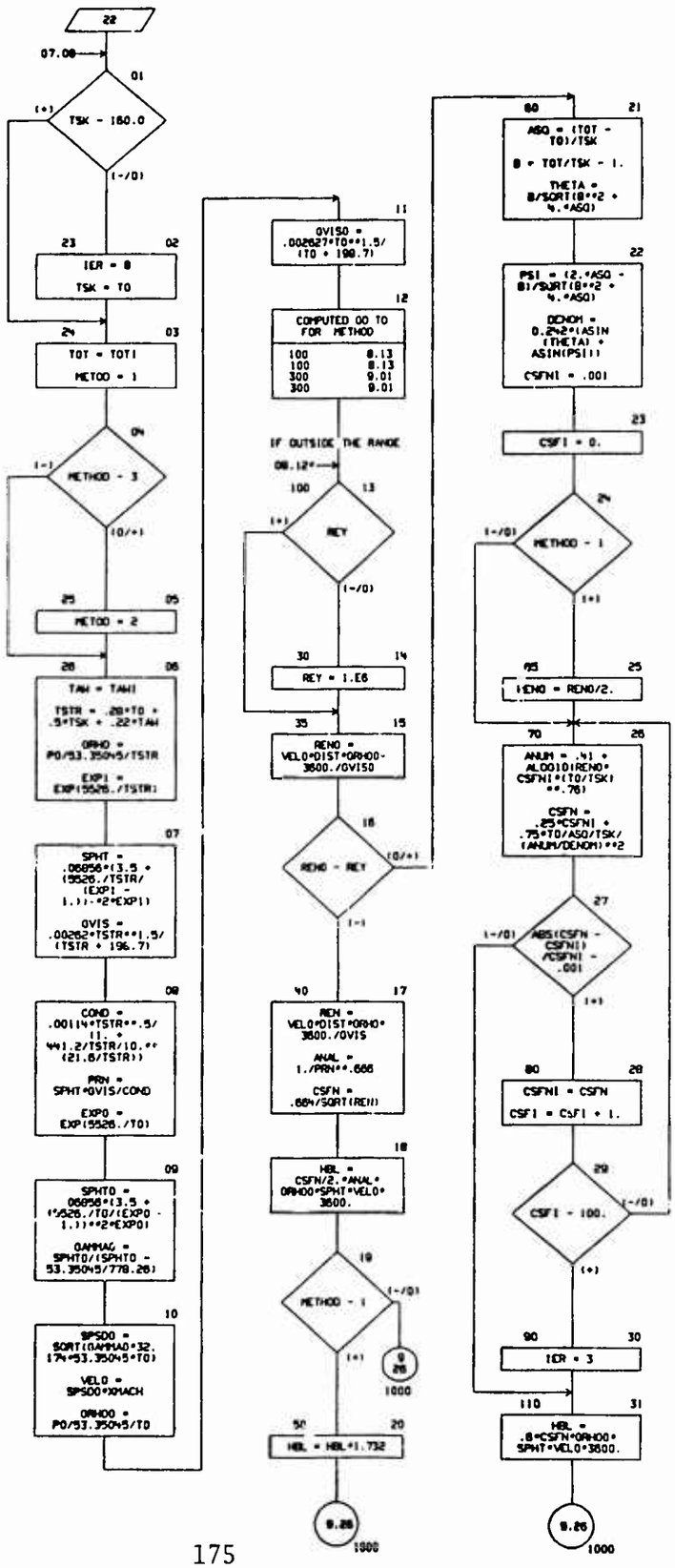


CHART TITLE - FUNCTION HBL(XMACH,PO,TO,TSK,DIST,XLAMDA,REY,METHOD,IER,TOTI,TAH)

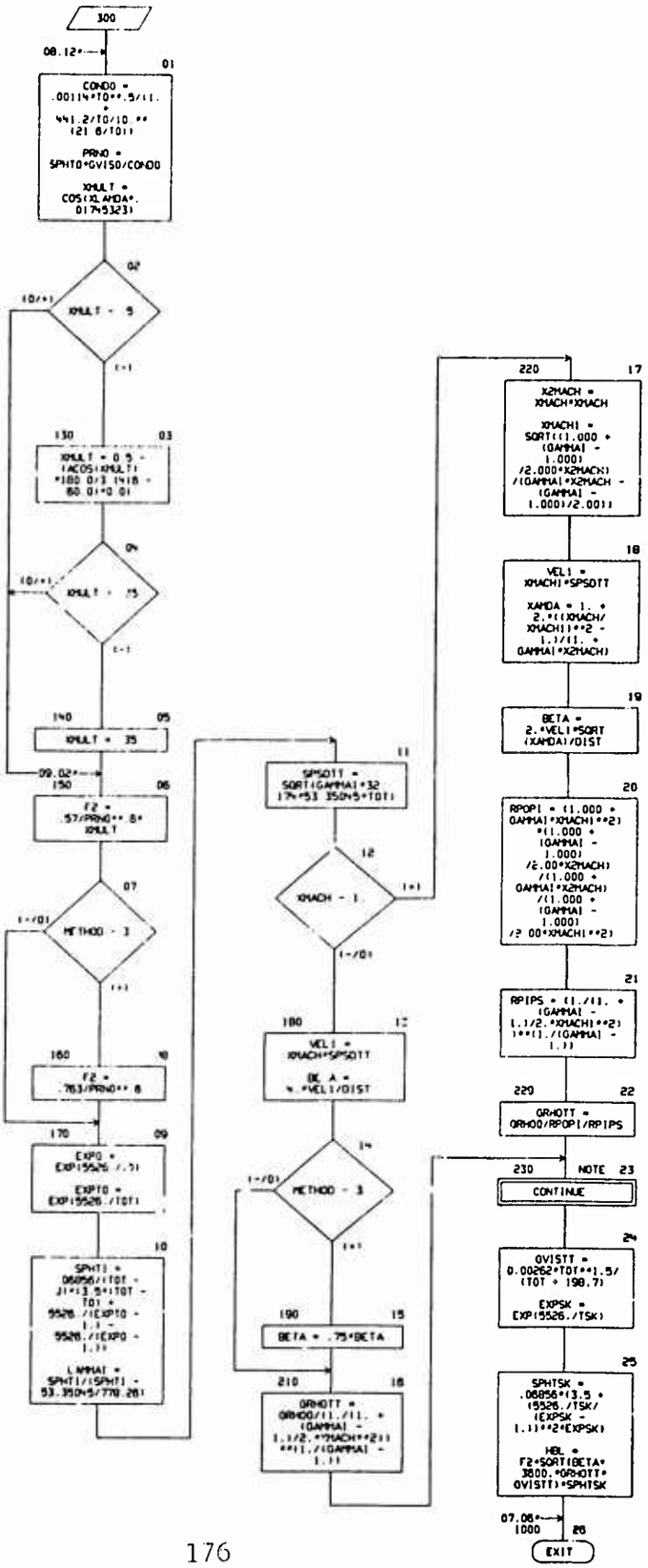


CHART TITLE - INTRODUCTORY COMMENTS

FUNCTION FRESH

CHART TITLE - FUNCTION PRESH(ALT)

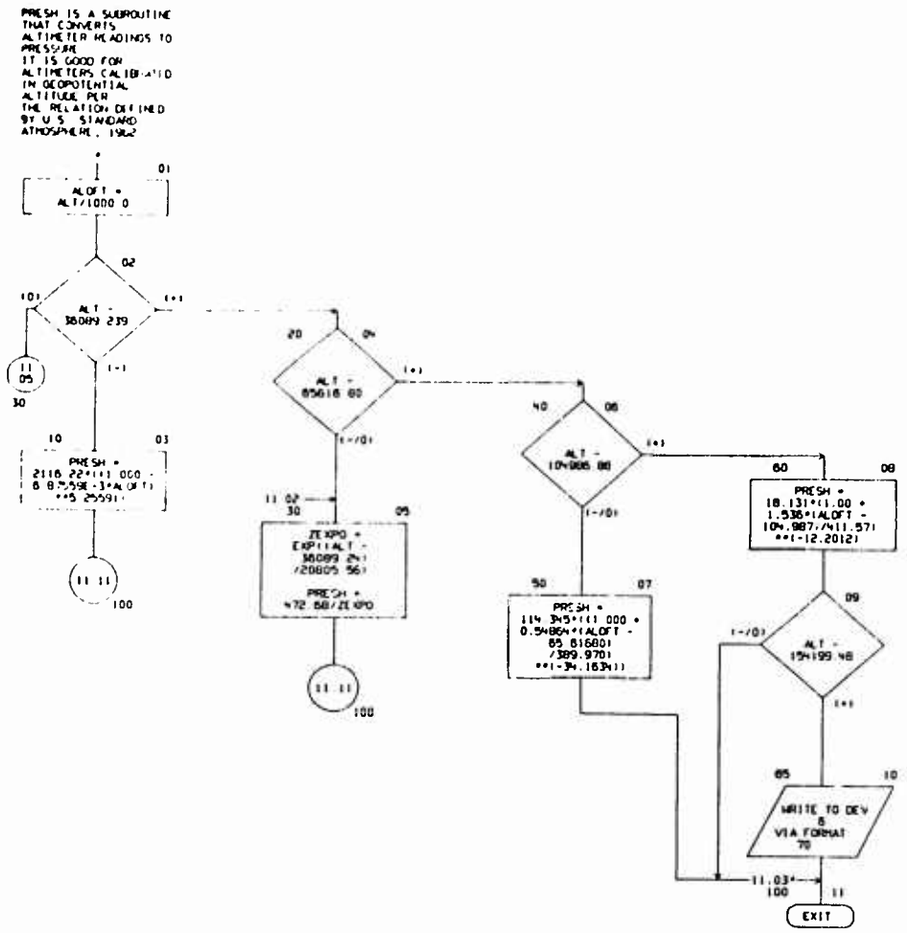


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
70      FORMAT(1H @X'@HWARNING- ALTITUDE IS BEYOND VALID RANGE OF PRESH.)
```

CHART TITLE - INTRODUCTORY COMMENTS

SUBROUTINE QINC

CHART TITLE - SUBROUTINE QINC(XM,PO,TO,Q)

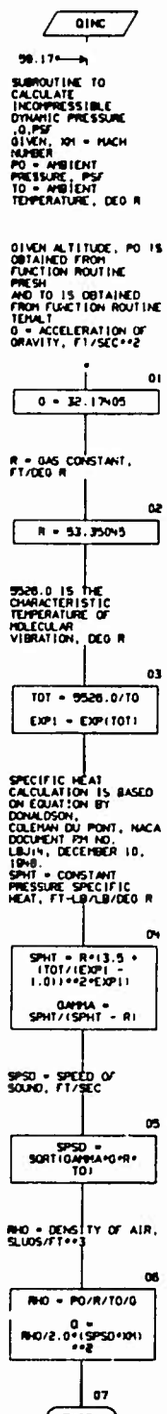


CHART TITLE - INTRODUCTORY COMMENTS

SUBROUTINE OSUB

CHART TITLE - SUBROUTINE OSUB(LIM)

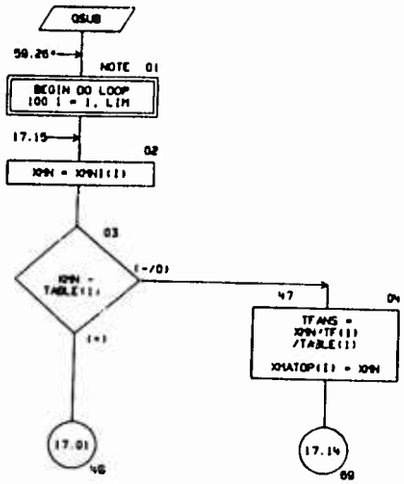


CHART TITLE - SUBROUTINE OSUBIL(IN)

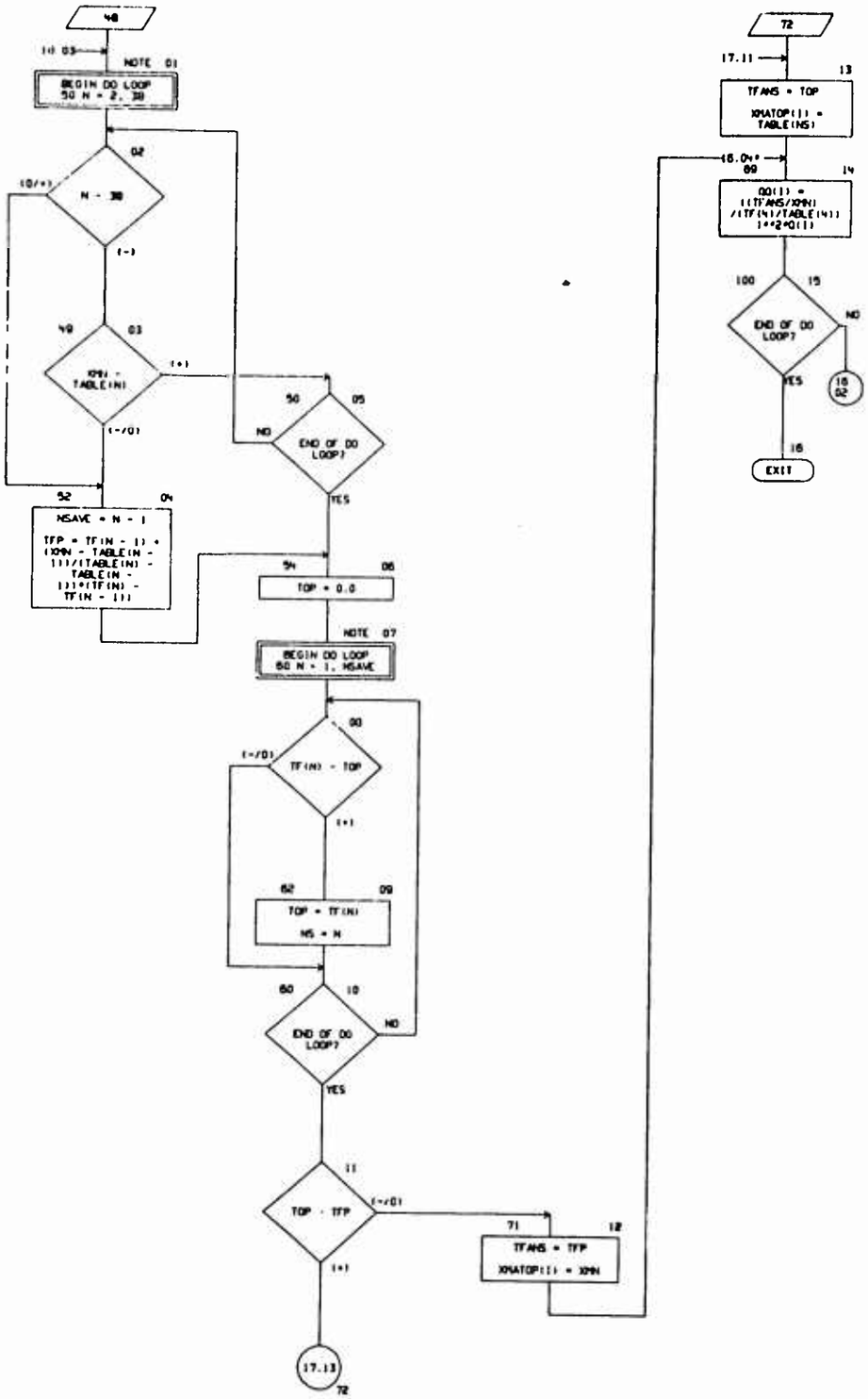


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON    $WF(180),DATA(312),TFH(38),TFH(38),TFV(38),TFWF(38),
                TF(38),XHN(20),Q(20),QQ(20),XHATOP(20)
      DIMENSION TABLE(38)
      EQUIVALENCE (TABLE(1),DATA(1))
```

CHART TITLE - INTRODUCTORY COMMENTS

FUNCTION SOLARO

CHART TITLE - FUNCTION SOLARQ(ALT)

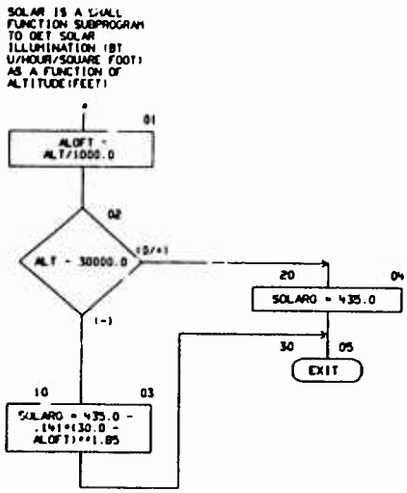


CHART TITLE - INTRODUCTORY COMMENTS

```
))))))
```

CHART TITLE - SUBROUTINE SWTAB

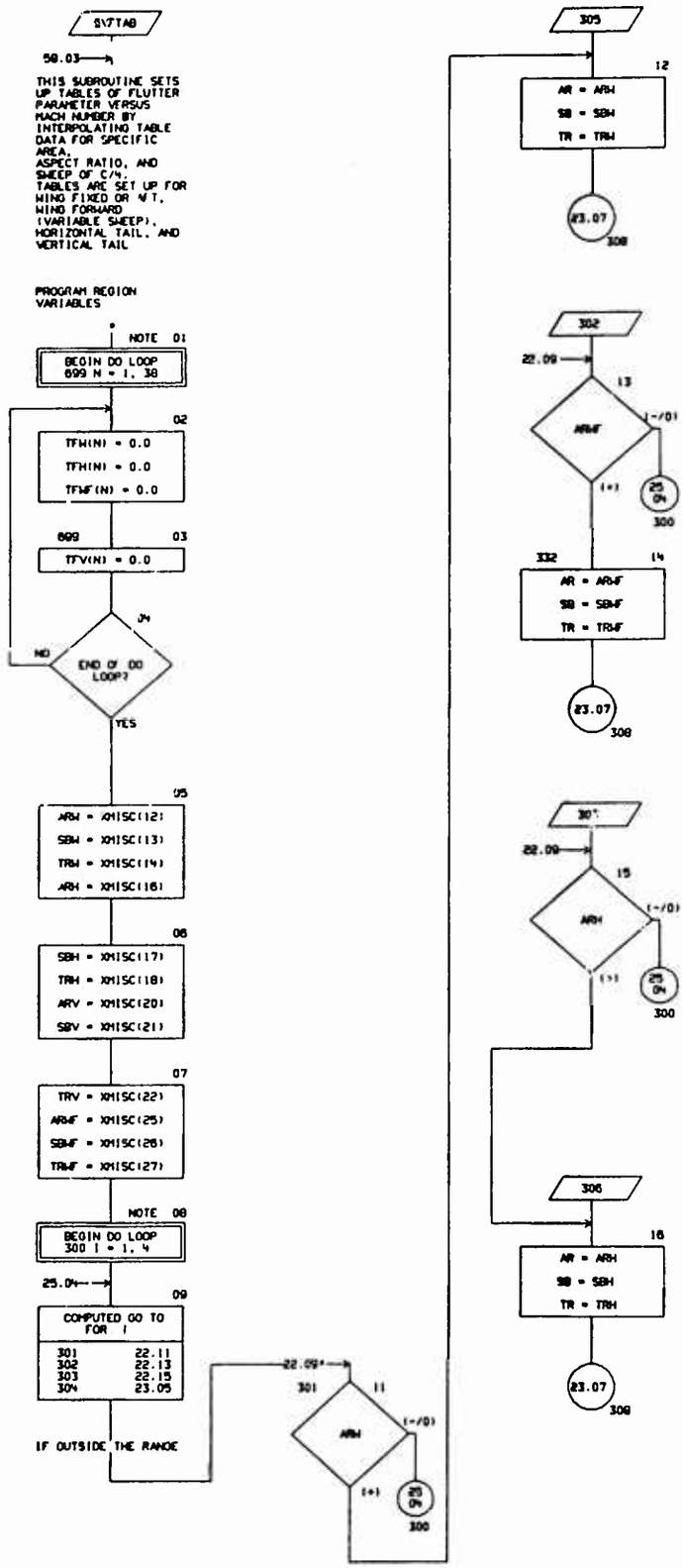


CHART TITLE - SUBROUTINE SWTAB

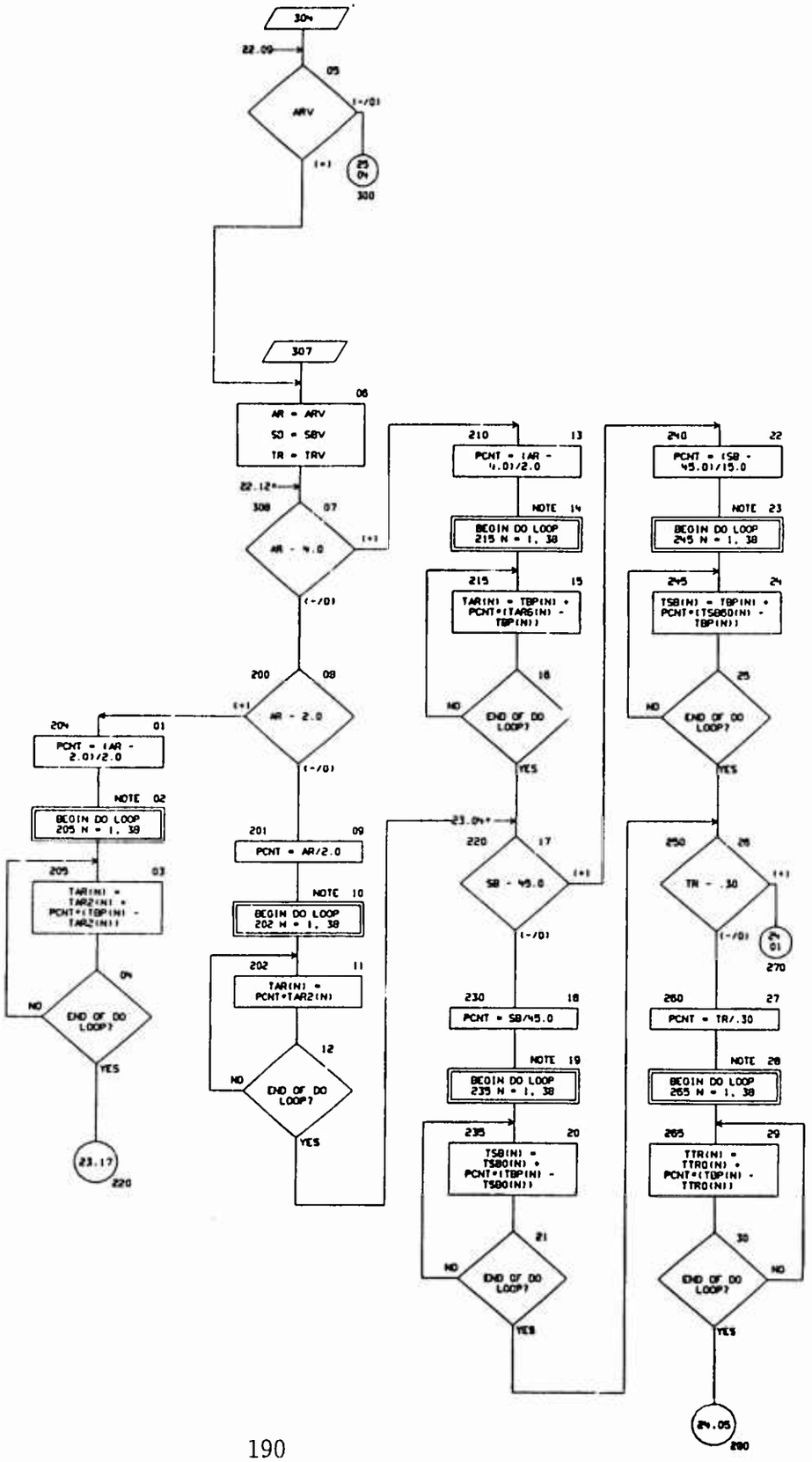


CHART TITLE - SUBROUTINE SWTAB

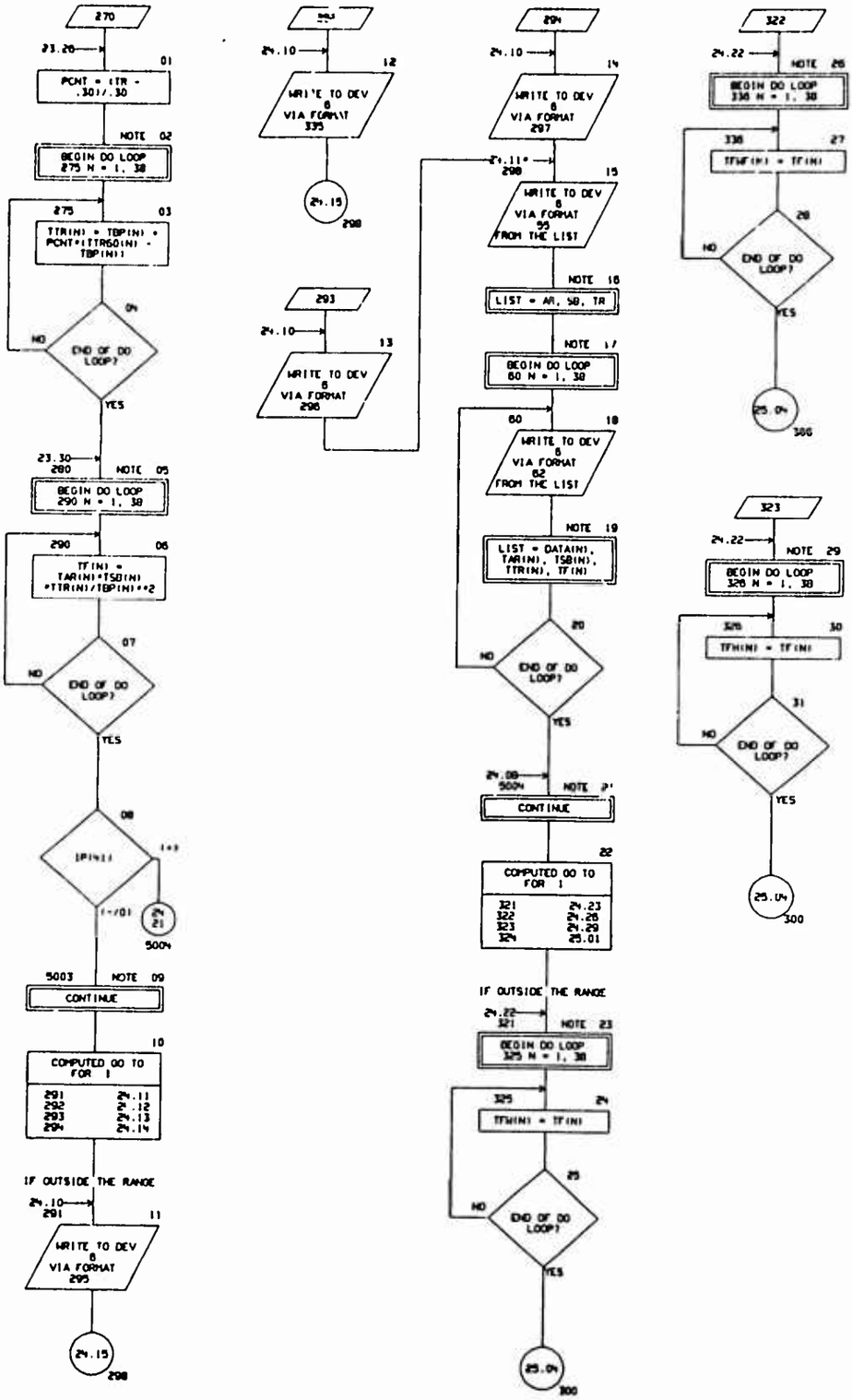


CHART TITLE - SUBROUTINE SWTAB

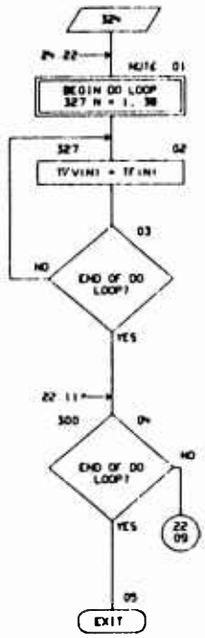


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON    $WF(180),DATA(312),TFW(30),TFH(30),TFV(30),TFWF(30)
      COMMON /IPRINT/IP(80)
      COMMON /MI$C/ XMI$C(100)
      DIMENSION TABLE(30),TBP(30),TAR2(30),TAR8(30),
     1 TS80(30),TS860(30),TTR0(30),TTR60(30)
      DIMENSION TAR(30),TS8(30),TTR(30),TF(30)
      EQUIVALENCE (TABLE(1),DATA( 1)),( TBP(1),DATA( 39)),
     1           ( TAR2(1),DATA( 77)),( TAR8(1),DATA(115)),
     2           ( TS80(1),DATA(153)),(TS860(1),DATA(191)),
     3           ( TTR0(1),DATA(229)),(TTR60(1),DATA(267))
  295 FORMAT(1HI,40X,27H*** WING (FIXED OR AFT) ***,
     1 21X,21H** SWFTAB - IP(41) **//)
  135 FORMAT(1HI,40X,22H*** WING (FORWARD) ***,
     1 26X,21H** SWFTAB - IP(41) **//)
  296 FORMAT(1HI,35X,23H*** HORIZONTAL TAIL ***,
     1 30X,21H** SWFTAB - IP(41) **//)
  297 FORMAT(1HI,35X,21H*** VERTICAL TAIL ***,
     1 32X,21H** SWFTAB - IP(41) **//)
   55 FORMAT(1H ,35X,32HFLUTTER PARAMETER VS MACH NUMBER//
     1          18X,8HMACH NO.,12X,5HAR = ,F5.2,4X,13HSWEEP(C/4) = ,
     2 F4.1,4H DEG,3X,8HTAPER = ,F4.3,10X,8HCOMPOSITE//)
   62 FORMAT(17X,F5.3,18X,F5.4,15X,F5.4,15X,F5.4,15X,F5.4)
```

CHART TITLE - INTRODUCTORY COMMENTS

```
''''''
```

CHART TITLE - FUNCTION TBL(XMACH,PO,TO,TSK,DIST,XLAMDA,REY,METHOD,IER,TOTI)

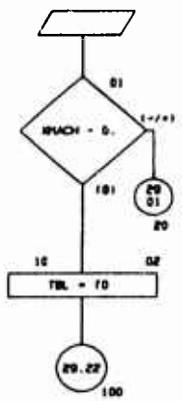


CHART TITLE - FUNCTION TBL(XMACH,P0,T0,TSK,DIST,XLAMDA,REY,METHOD,IER,TOT)

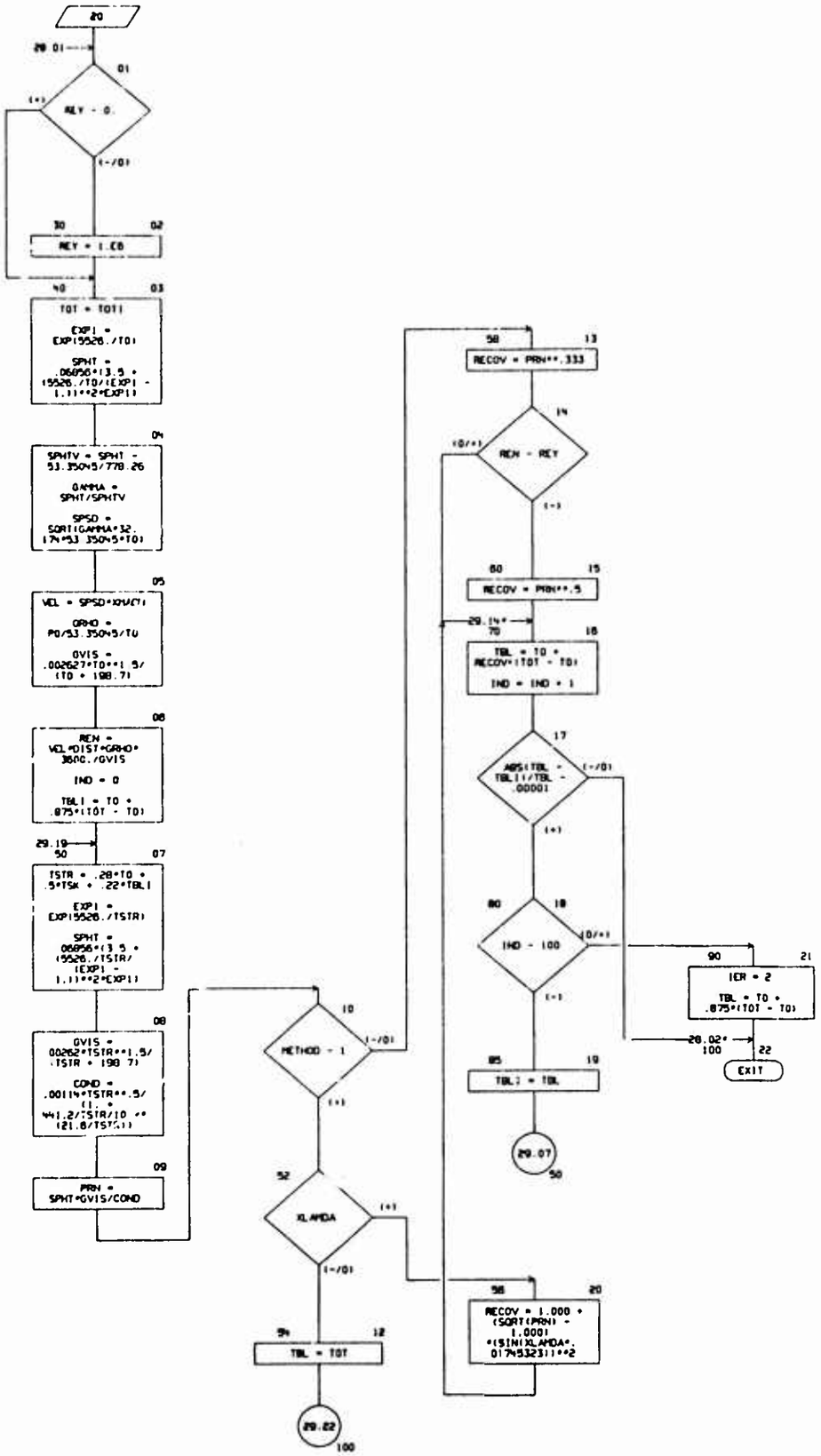


CHART TITLE - INTRODUCTORY COMMENTS

FUNCTION TEMALT

CHART TITLE - FUNCTION TEMALT(ALT,IT)

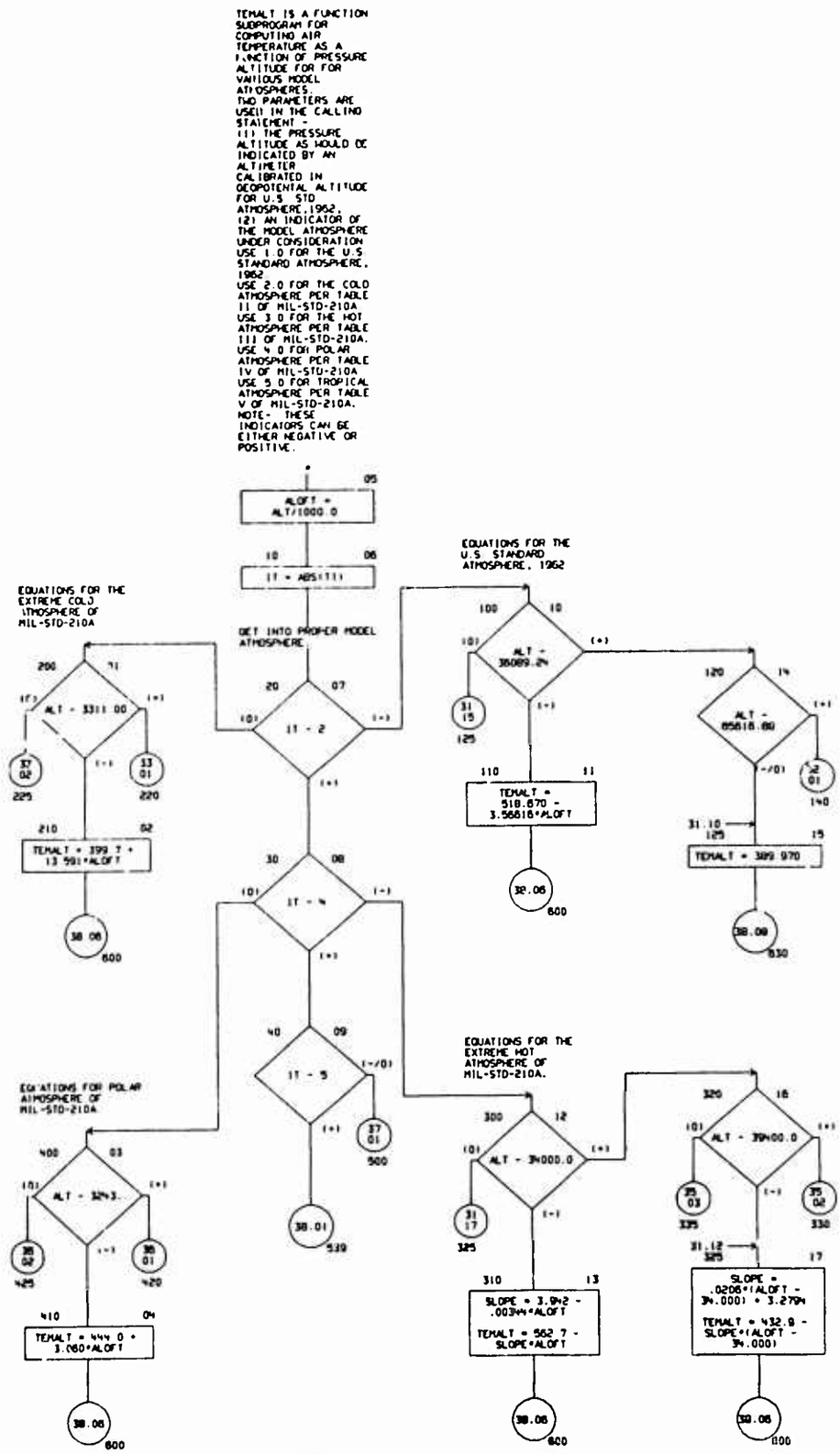


CHART TITLE - FUNCTION TEMALT(ALT,TI)

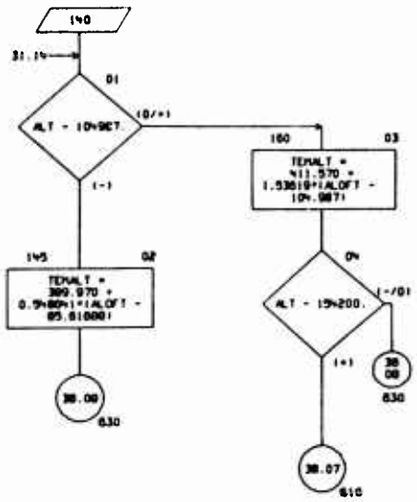


CHART TITLE - FUNCTION TEMALT(ALT,TI)

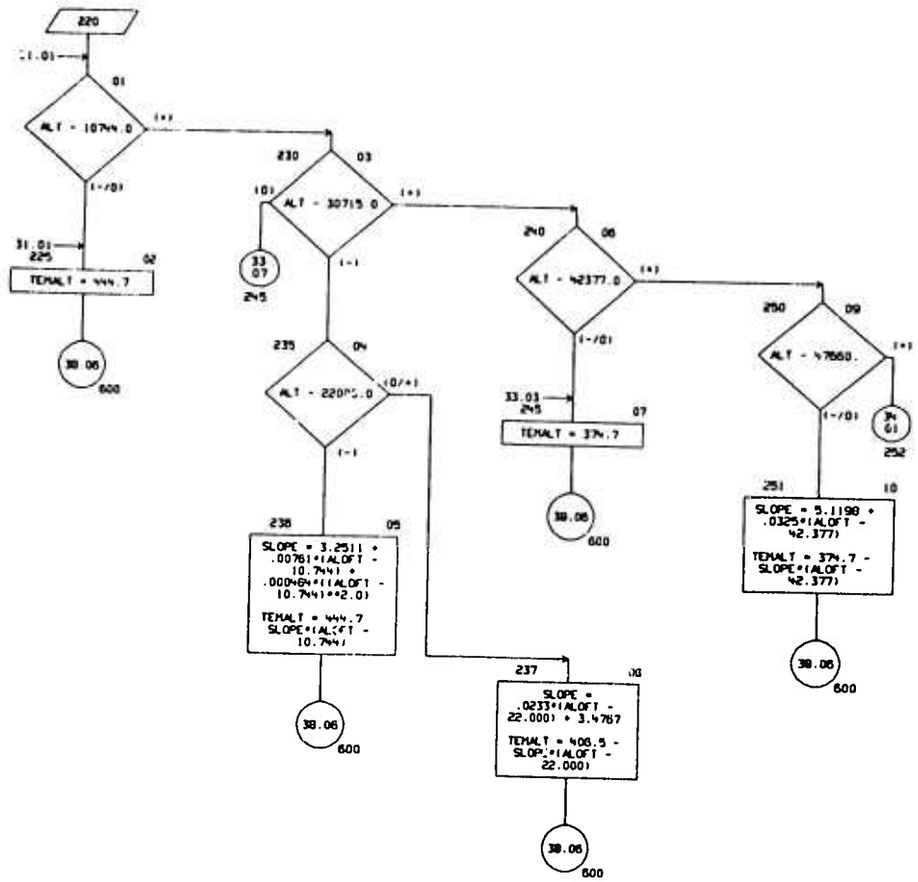


CHART TITLE - FUNCTION TEMALT(ALT,TI)

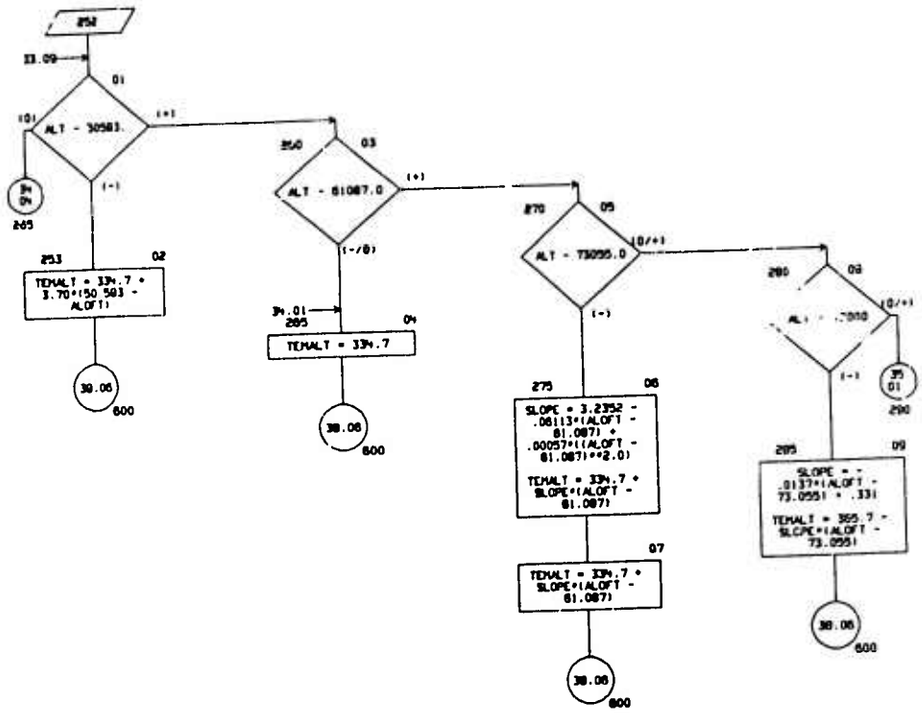


CHART TITLE - FUNCTION TEMALT(ALT,TI)

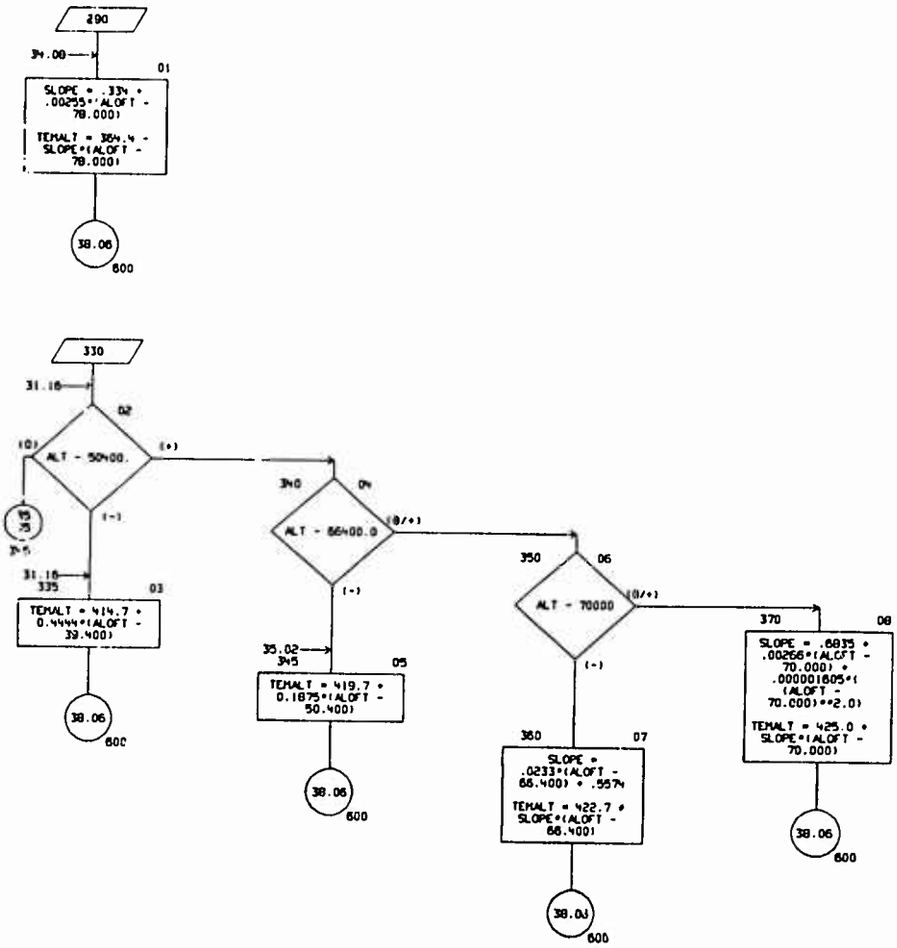


CHART TITLE - FUNCTION TEMALT(ALT,TI)

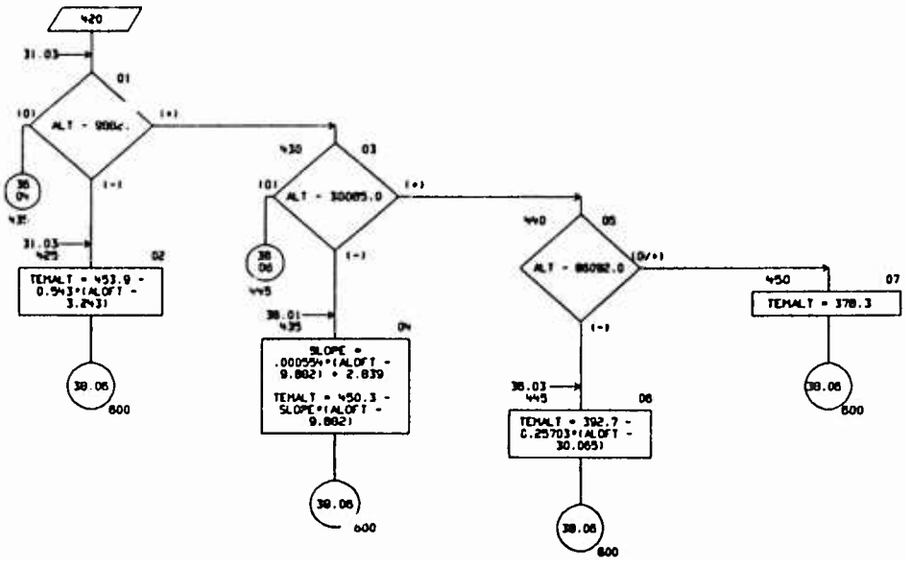


CHART TITLE - FUNCTION TEMALT(ALT,TI)

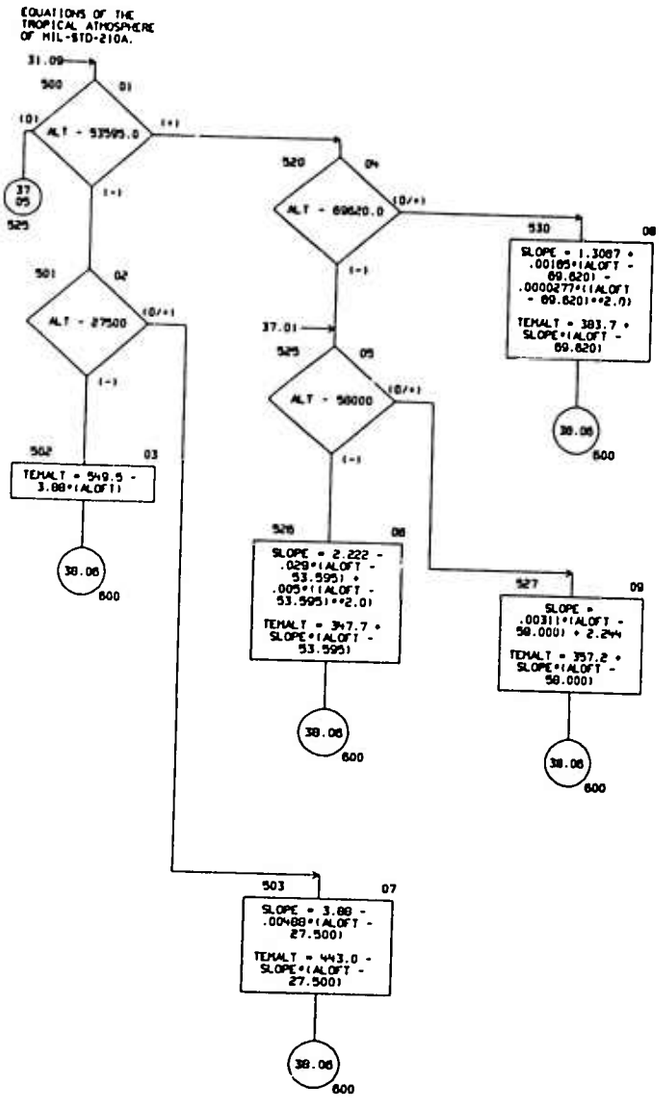


CHART TITLE - FUNCTION TEMALT(ALT,TI)

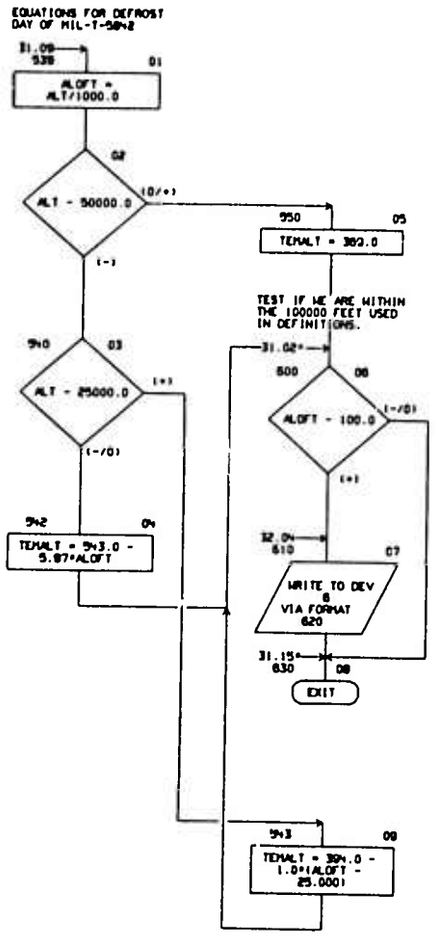


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      620   FORMAT(1H 6X30HWARNING- ALTITUDE IS BEYOND VALID RANGE OF TEMP,I
```

CHART TITLE - INTRODUCTORY COMMENTS

SUBROUTINE TEMPER

CHART TITLE - SUBROUTINE TEMPER(XMACH,ALT,PRESSI,TLOC,TTOT,SUN,XSKIN,XSKINF,IER

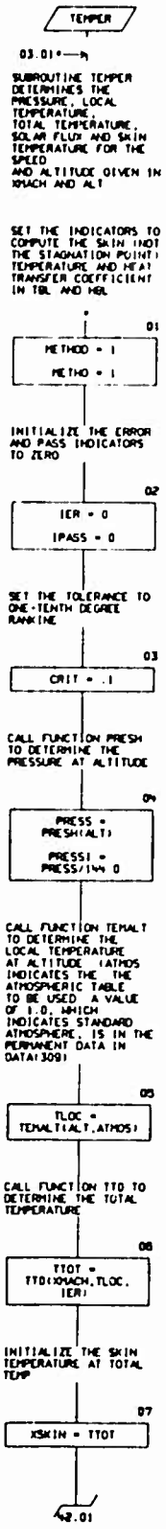


CHART TITLE - SUBROUTINE TEMPER(XMACH,ALT,PRESSI,TLOC,TTOT,SUN,XSKIN,XSKINF,IER

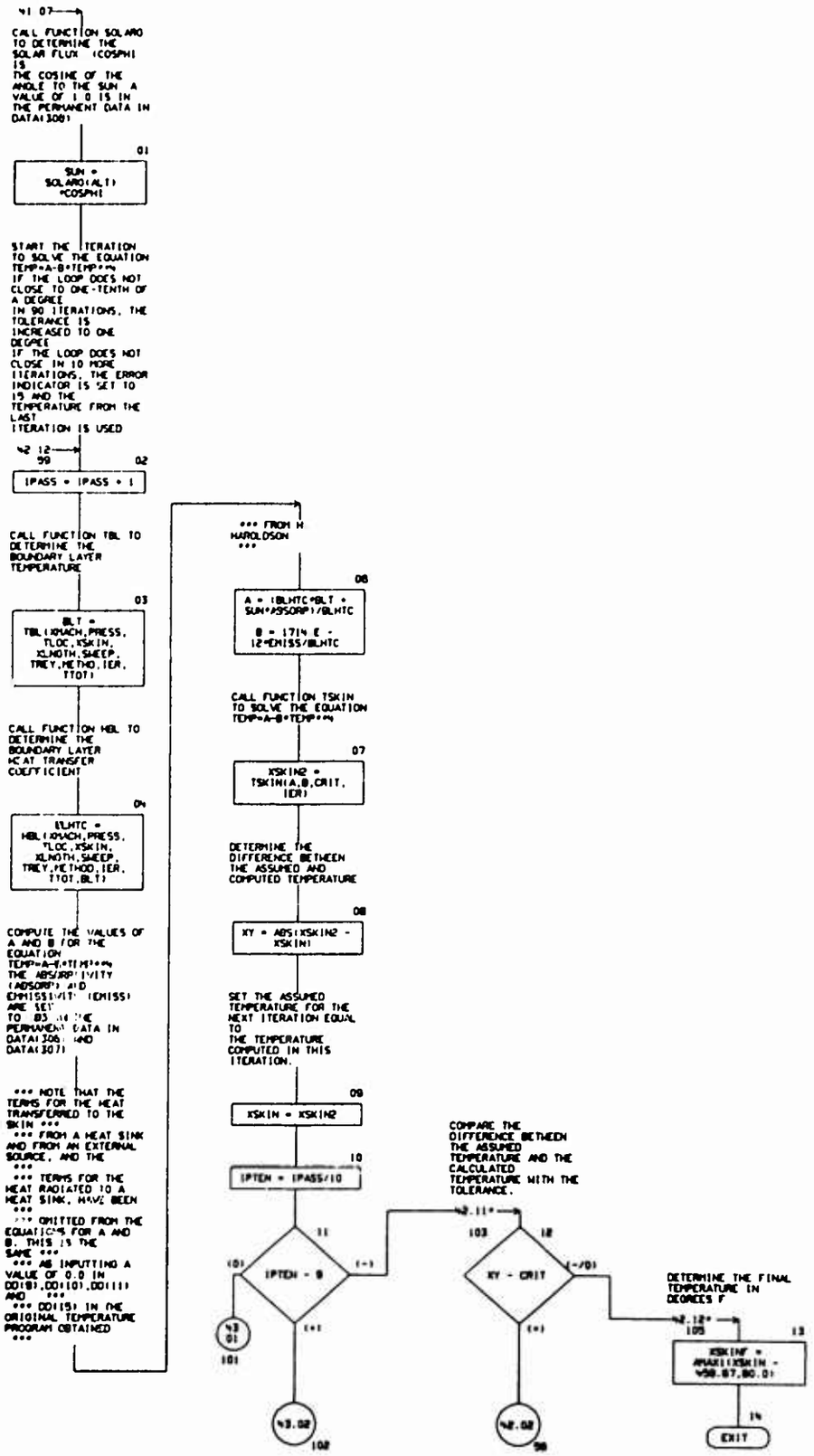


CHART TITLE - SUBROUTINE TEMPER(XMACH,ALT,PRESSI,TLOC,TTOT,SUM,XSKIN,XSKINF,IER

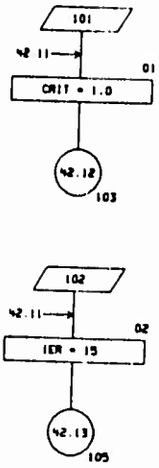


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON    SWF(100),DATA(312),TFW(30),TFH(30),TFV(30),TFWF(30)
      EQUIVALENCE          (EMISS ,DATA(306)),(ABSORP,DATA(307)),
     (COSPHI,DATA(308)),(ATMOS ,DATA(309)),(XL_NOTH,DATA(310)),
     (TREY  ,DATA(311)),(SHEEP ,DATA(312))
```

CHART TITLE - INTRODUCTORY COMMENTS

```
C*************************************************************
C                      FUNCTION TSKIN
C*************************************************************
C
C     TSKIN IS A FUNCTION SUBPROGRAM FOR SOLVING TEMPERATURES FROM
C  AN EQUATION OF FIRST AND FOURTH POWERS IN THE FORM
C     T = A+B* T**4
C  ALL TEMPERATURES ARE IN DEGREES RANKINE. THE ROOT IS REAL AND
C  POSITIVE
C       THE FUNCTION IS CALLED BY THE STATEMENT
C       TEMP = TSKIN(A,B,C,IER)
C  WHEN A AND B ARE CONSTANTS, C IS A CRITERIAN FOR SATISFACTORY
C  CONVERGENCE, AND IER IS AN ERROR INDICATOR
```

CHART TITLE - FUNCTION TSKINIA,B,C,IER)

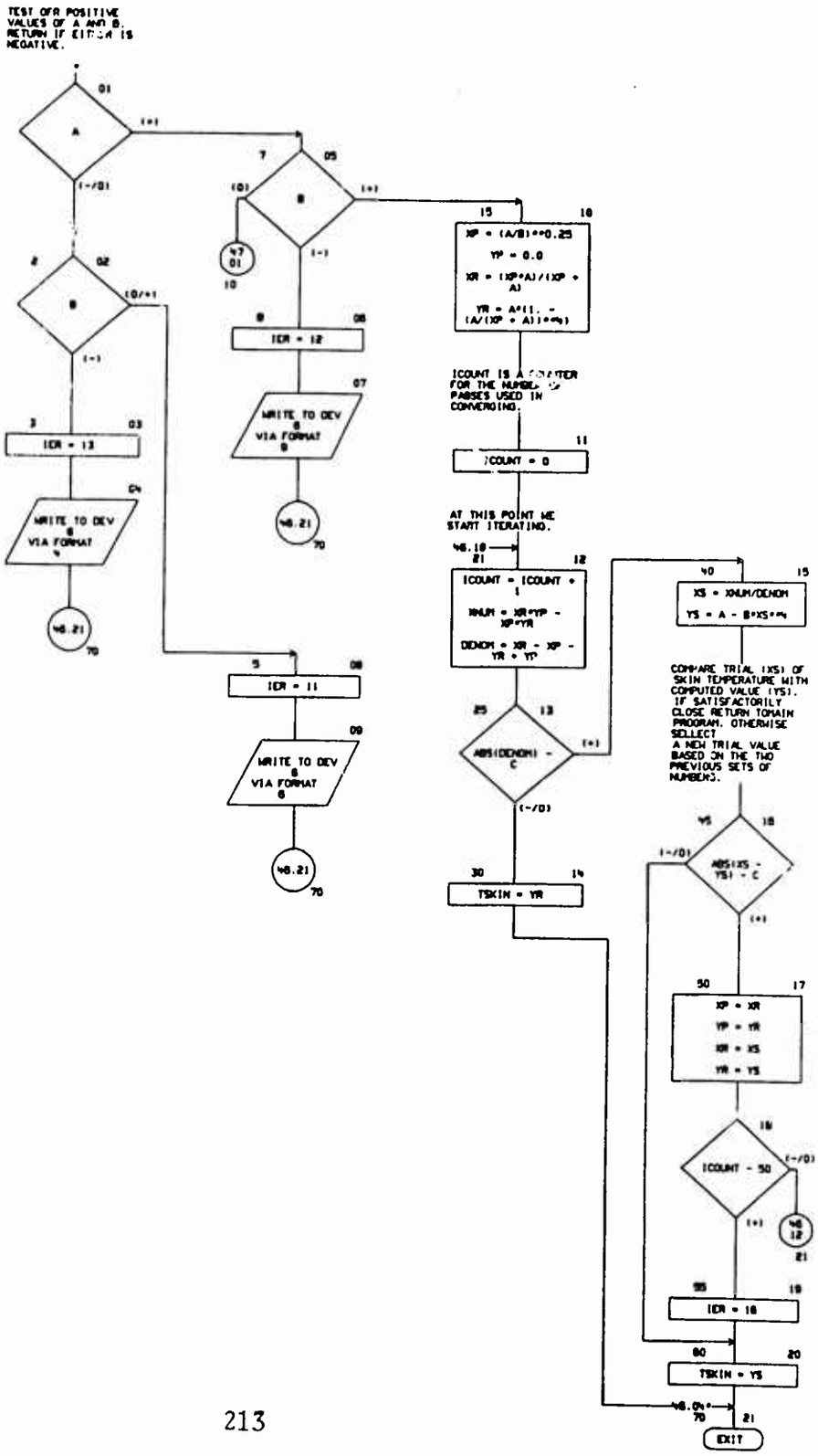


CHART TITLE - FUNCTION TSKIN(A,B,C,IER)

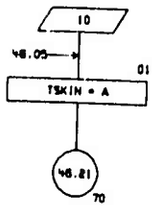


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
4     FORMAT(1HO 10X,'BOTH A AND B ARE NEGATIVE. TSKIN IS DISCONTINUED')
6     FORMAT(1HO 10X,'A IS NEGATIVE OR ZERO. TSKIN IS DISCONTINUED.')
8     FORMAT(1HO 10X,'B IS NEGATIVE. TSKIN IS DISCONTINUED')
```

CHART TITLE - INTRODUCTORY COMMENTS

```
)))))))
```

CHART TITLE - FUNCTION TTO(XMACH,TO,IER)

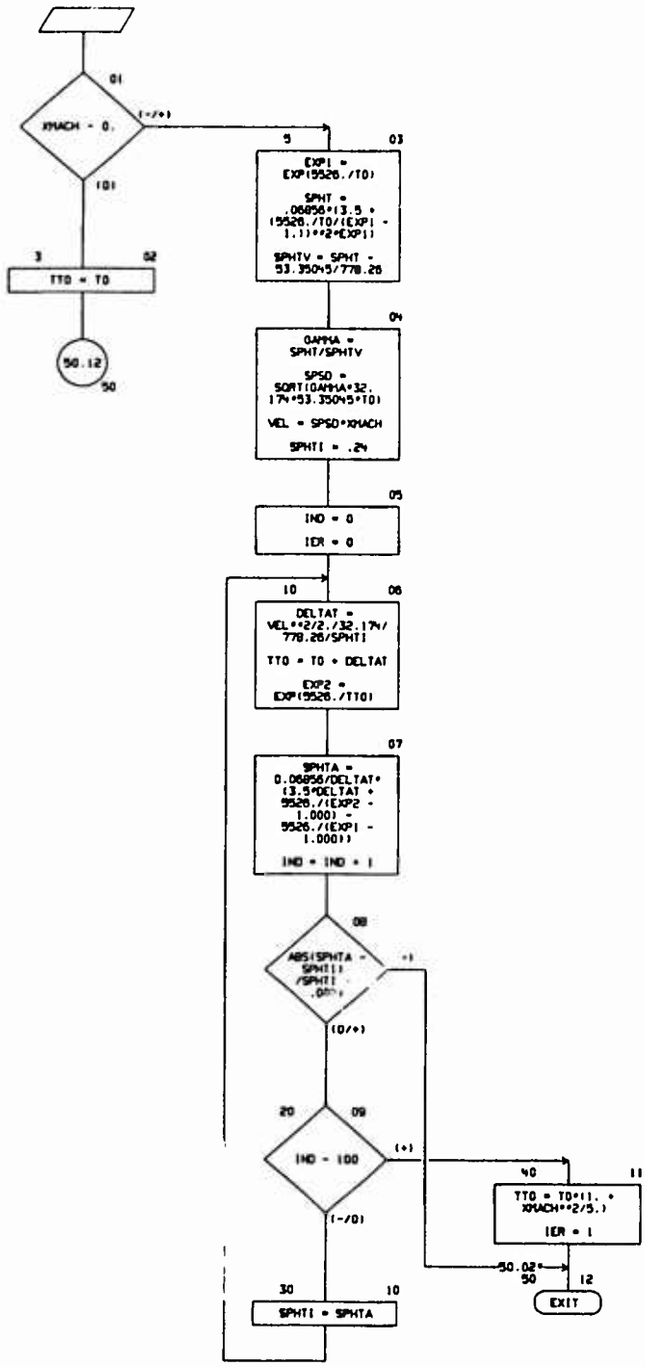


CHART TITLE - INTRODUCTORY COMMENTS

SUBROUTINE HAYMAT

CHART TITLE - SUBROUTINE MMMAT

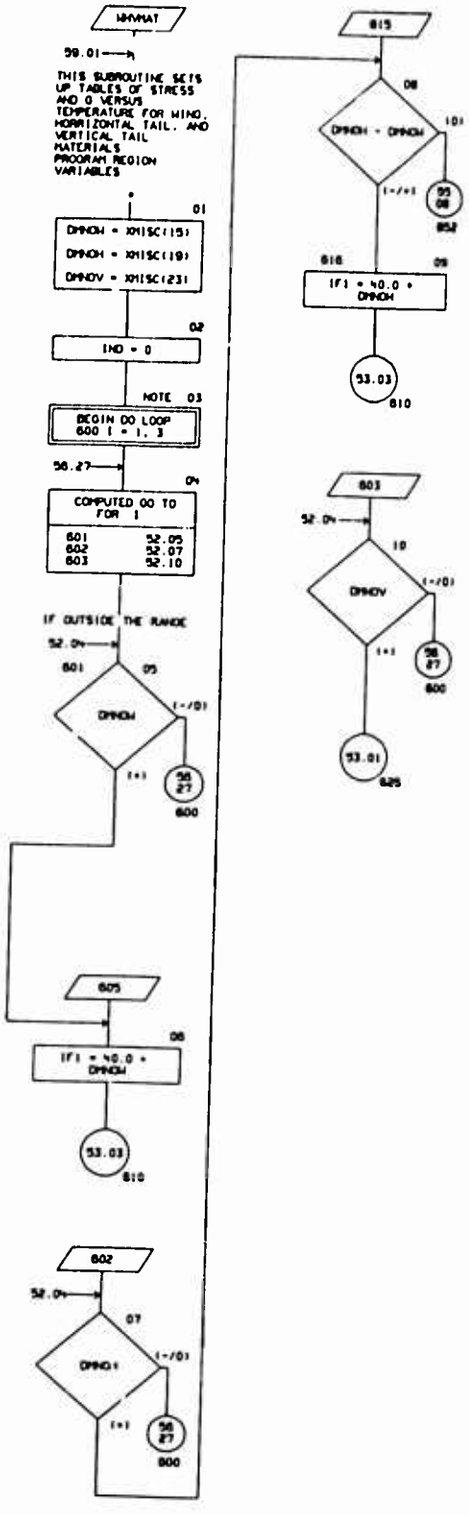


CHART TITLE - SUBROUTINE MMMAT

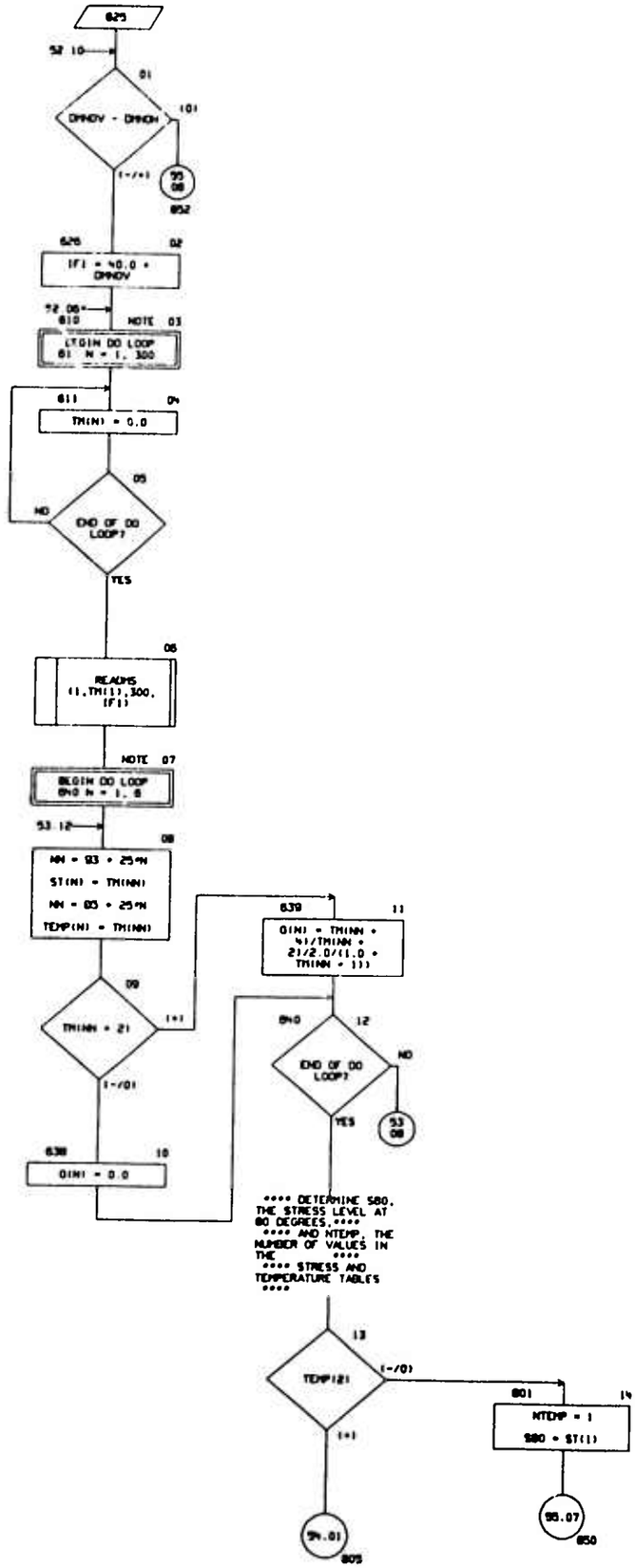


CHART TITLE - SUBROUTINE HYMAT

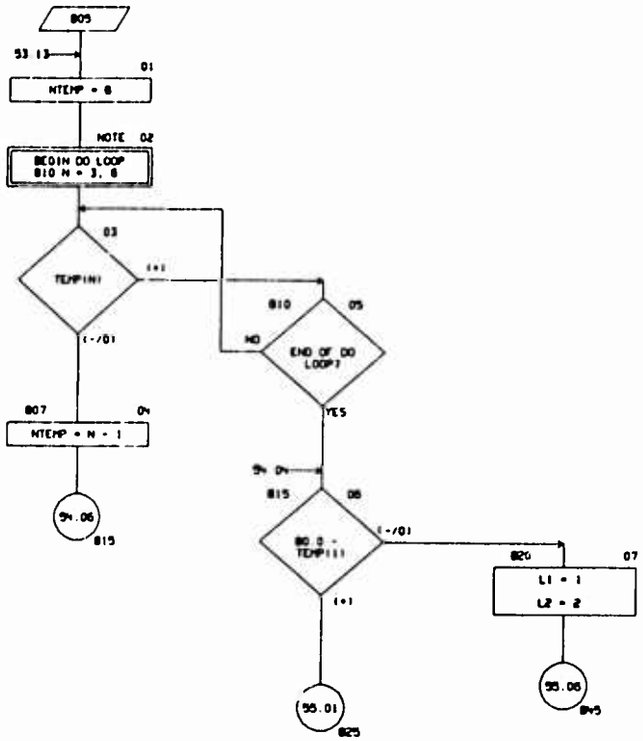


CHART TITLE - SUBROUTINE MMVMAT

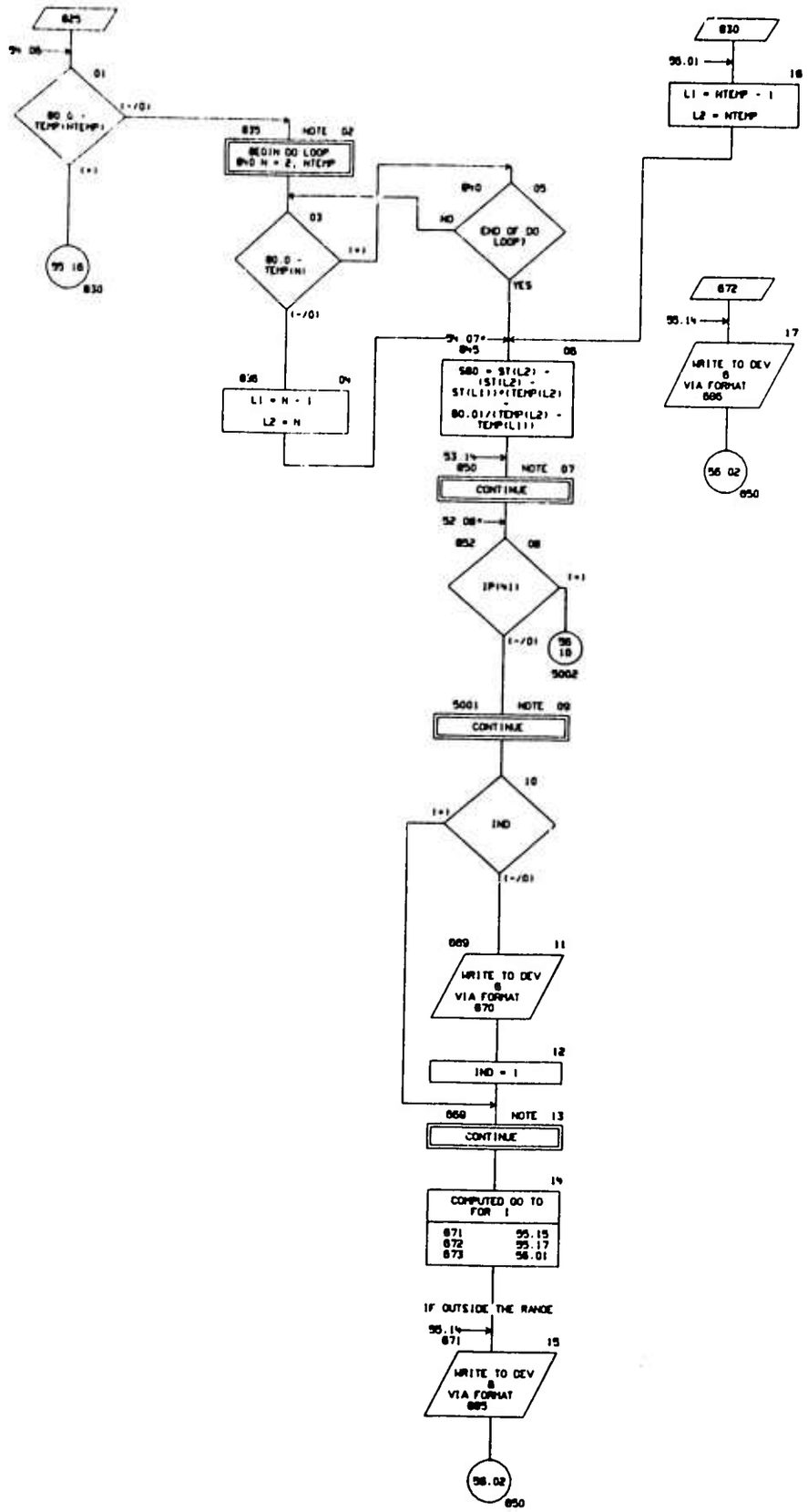
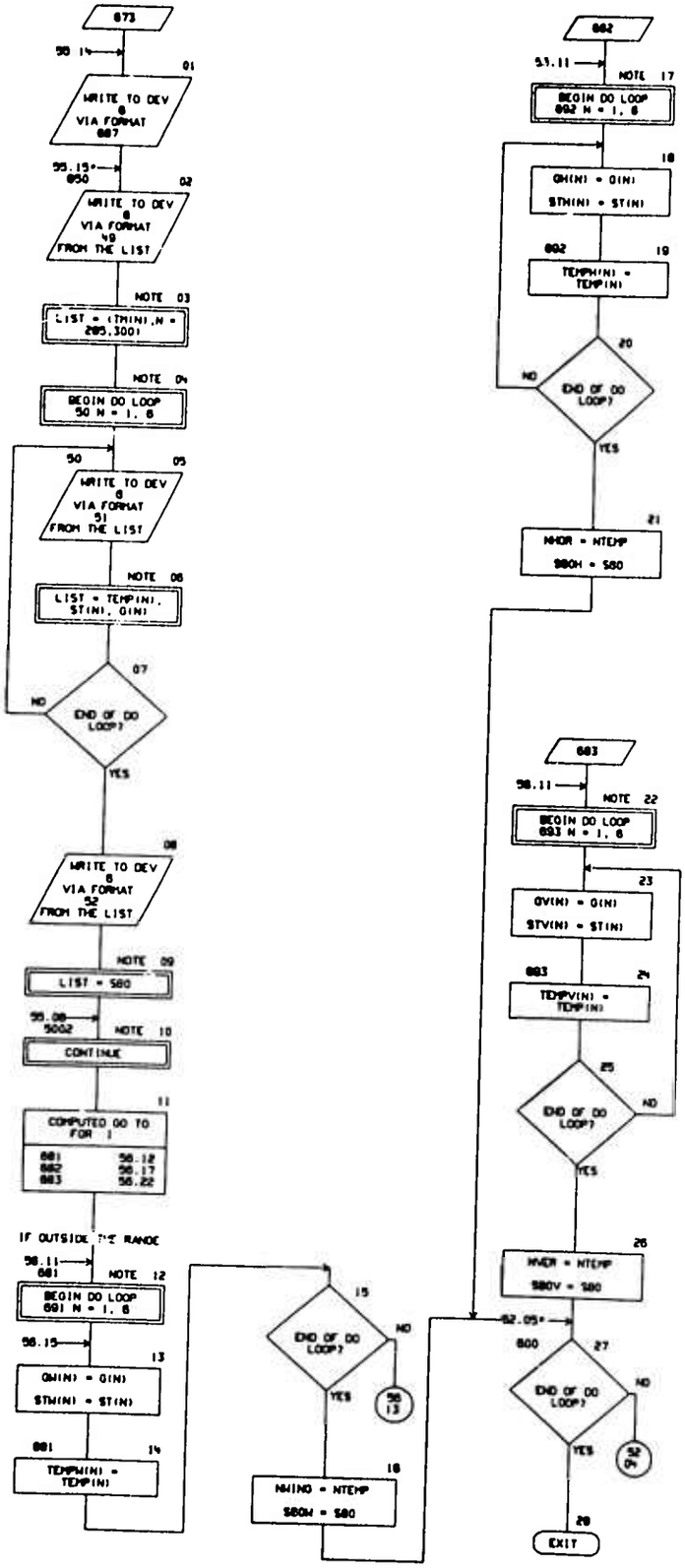


CHART TITLE - SUBROUTINE WWMAT



O-RT TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON    $WF(180),D(1:3)(2),TFW(30),TFH(30),TFV(30),TFWF(30),
                TF(30),XMN(20),Q(20),QQ(20),XMATOP(20),
                QW(6),QH(6),QV(6)
      COMMON /IPRINT/IP(80)
      COMMON /MISC/XMISC(100)
      DIMENSION  $TW(6),$TH(6),$TV(6),TEMPW(6),TEMPH(6),TEMPV(6)
      DIMENSION TM(300),ST(6),TEMP(6),Q(6)
      EQUIVALENCE                                ($WF(139),$TW   (1)),
     ($WF(145),TEMPW (1)),($WF(153),$TH   (1)),($WF(159),TEMPH (1)),
     ($WF(167),$TV   (1)),($WF(173),TEMPV (1)),($WF(151),NWIND    ),
     ($WF(165),NHOR    ),($WF(179),NVER    ),($WF(152),S80W    ),
     ($WF(166),S80H    ),($WF(180),S80V    )
870   FORMAT(1H1,88X,21H*** WHYMAT - IP(4)= **)
885   FORMAT(  45X,12H*** WING *** )
886   FORMAT( /40X,23H*** HORIZONTAL TAIL *** )
887   FORMAT( /40X,21H*** VERTICAL TAIL *** )
49    FORMAT(10X,8A10/10X,8A10//30X,11HTEMPERATURE,5X,12HSTRESS (PSI),
       10X,7HQ (PSI)/)
51    FORMAT(33X,F6.0,9X,F8.0,9X,F11.0)
52    FORMAT(/30X,20HSTRESS AT 80 DEGREES,F10.0)
```

CHART TITLE - INTRODUCTORY COMMENTS

SUBROUTINE HHVQQ

CHART TITLE - SUBROUTINE HHVQD

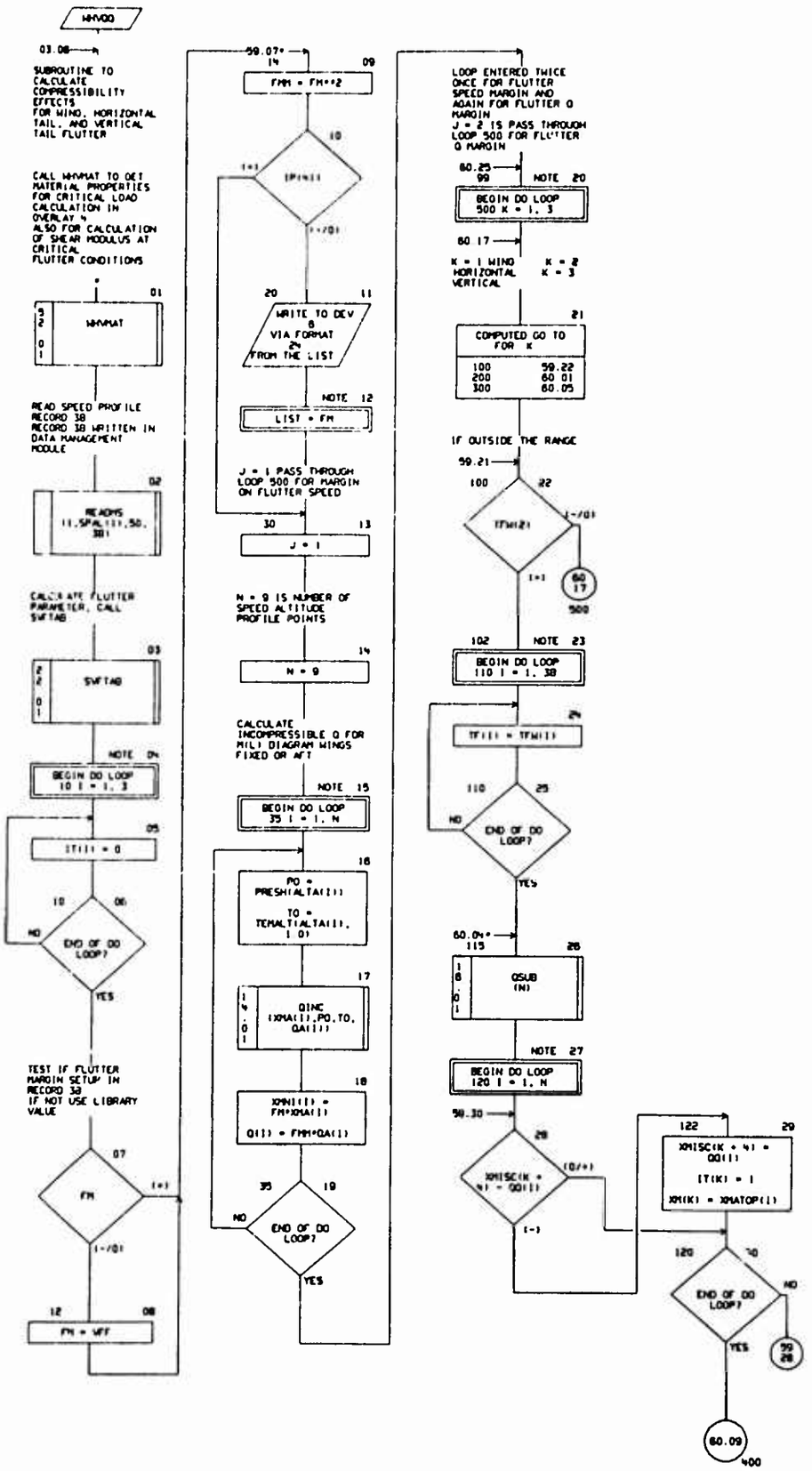


CHART TITLE - SUBROUTINE MMOD

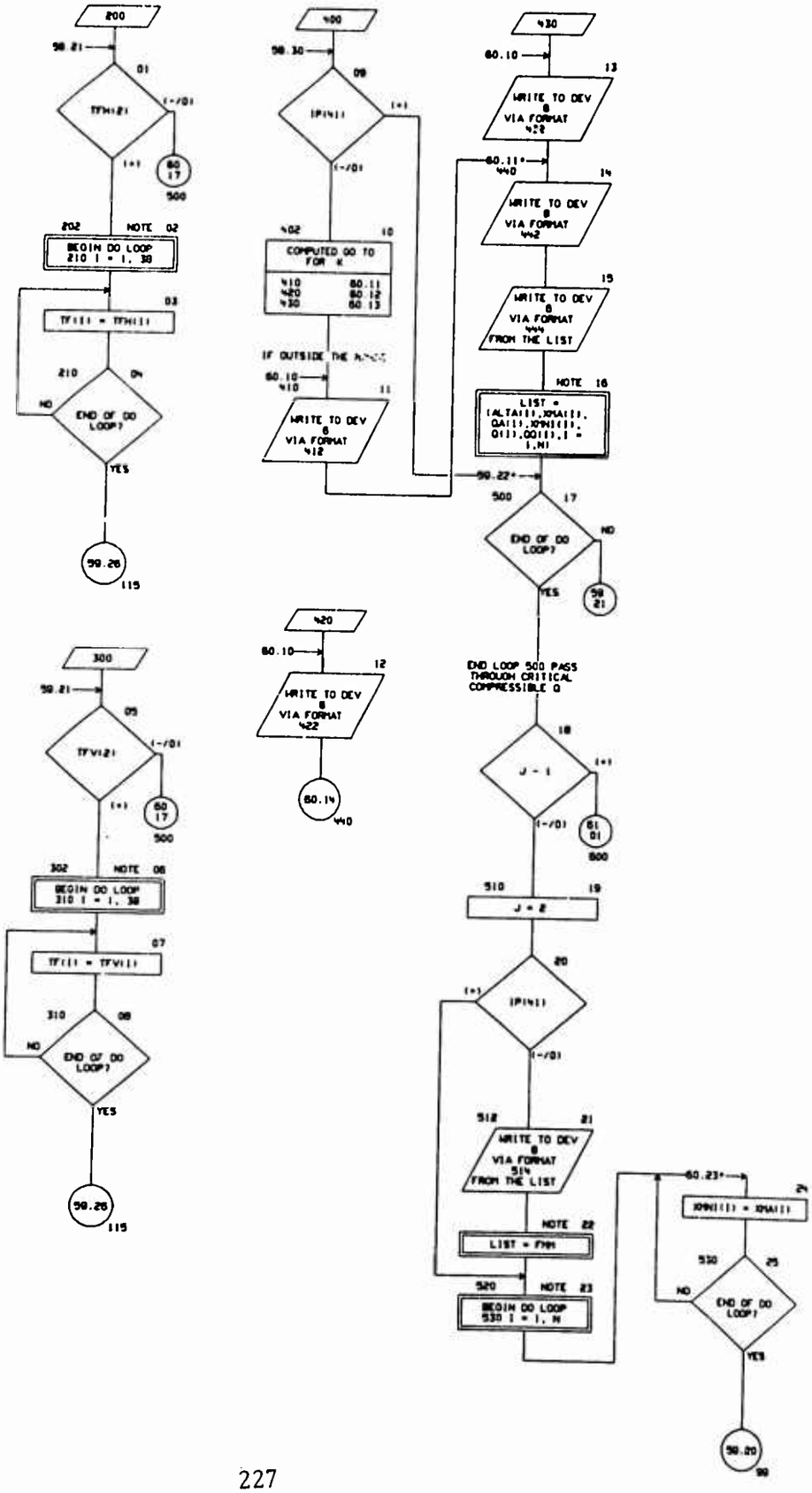


CHART TITLE - SUBROUTINE MHVOO

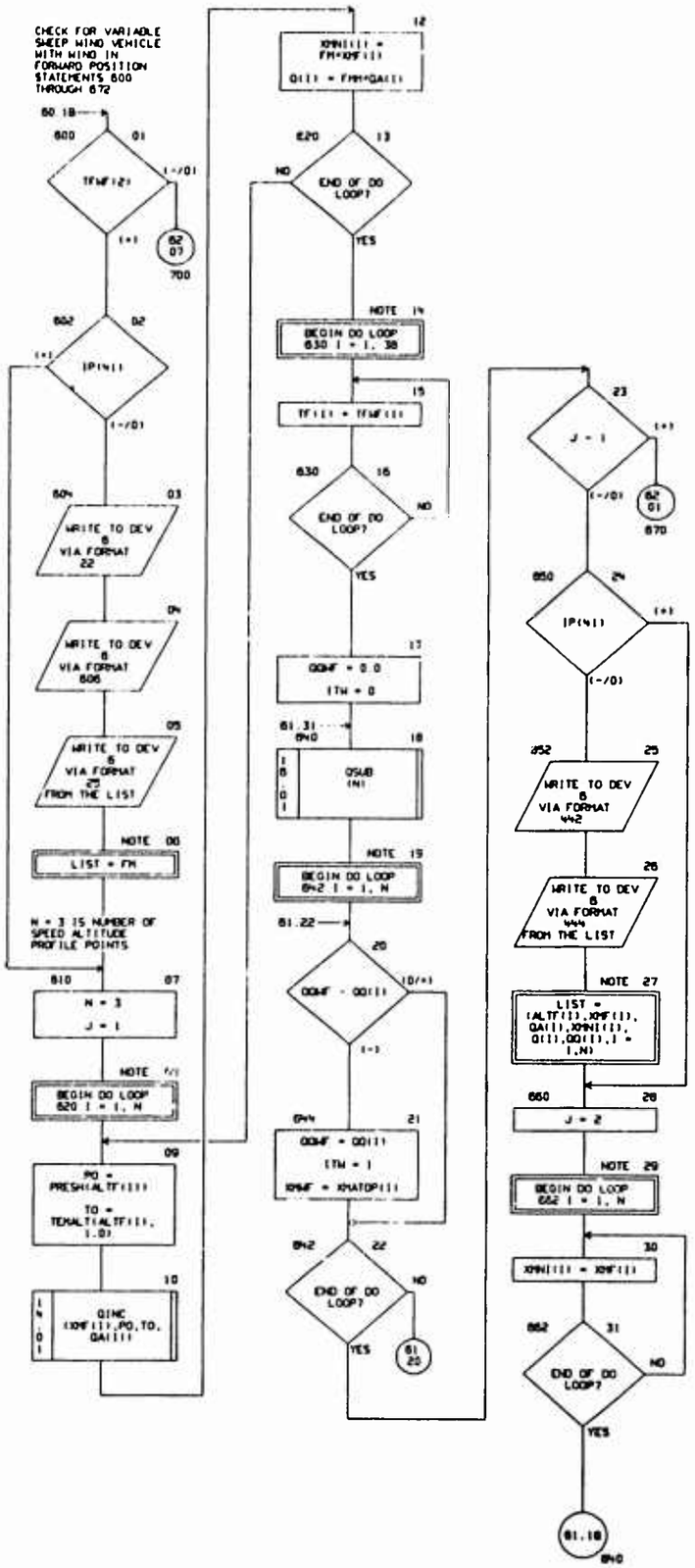


CHART TITLE - SUBROUTINE MMVOO

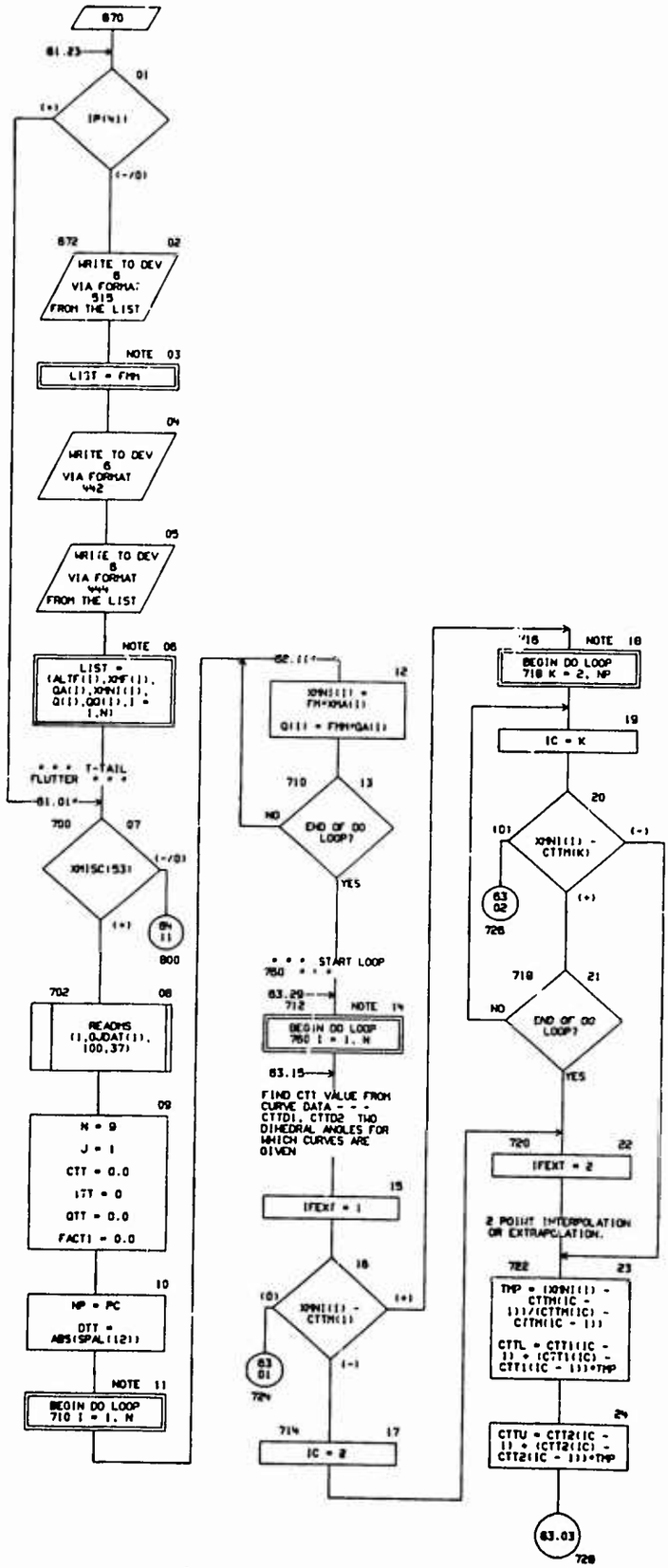


CHART TITLE - SUBROUTINE HHVOO

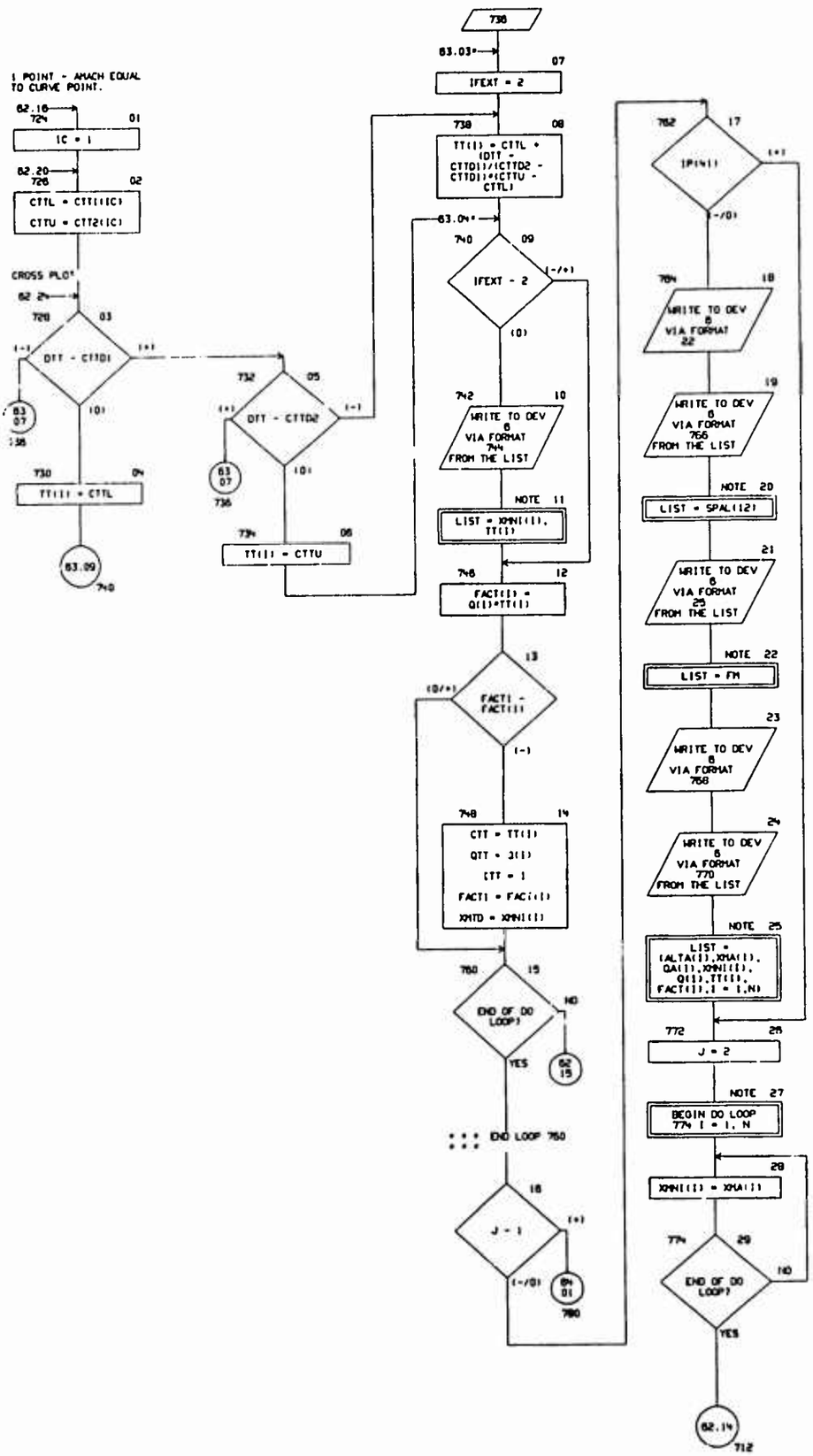


CHART TITLE - SUBROUTINE HHVOO

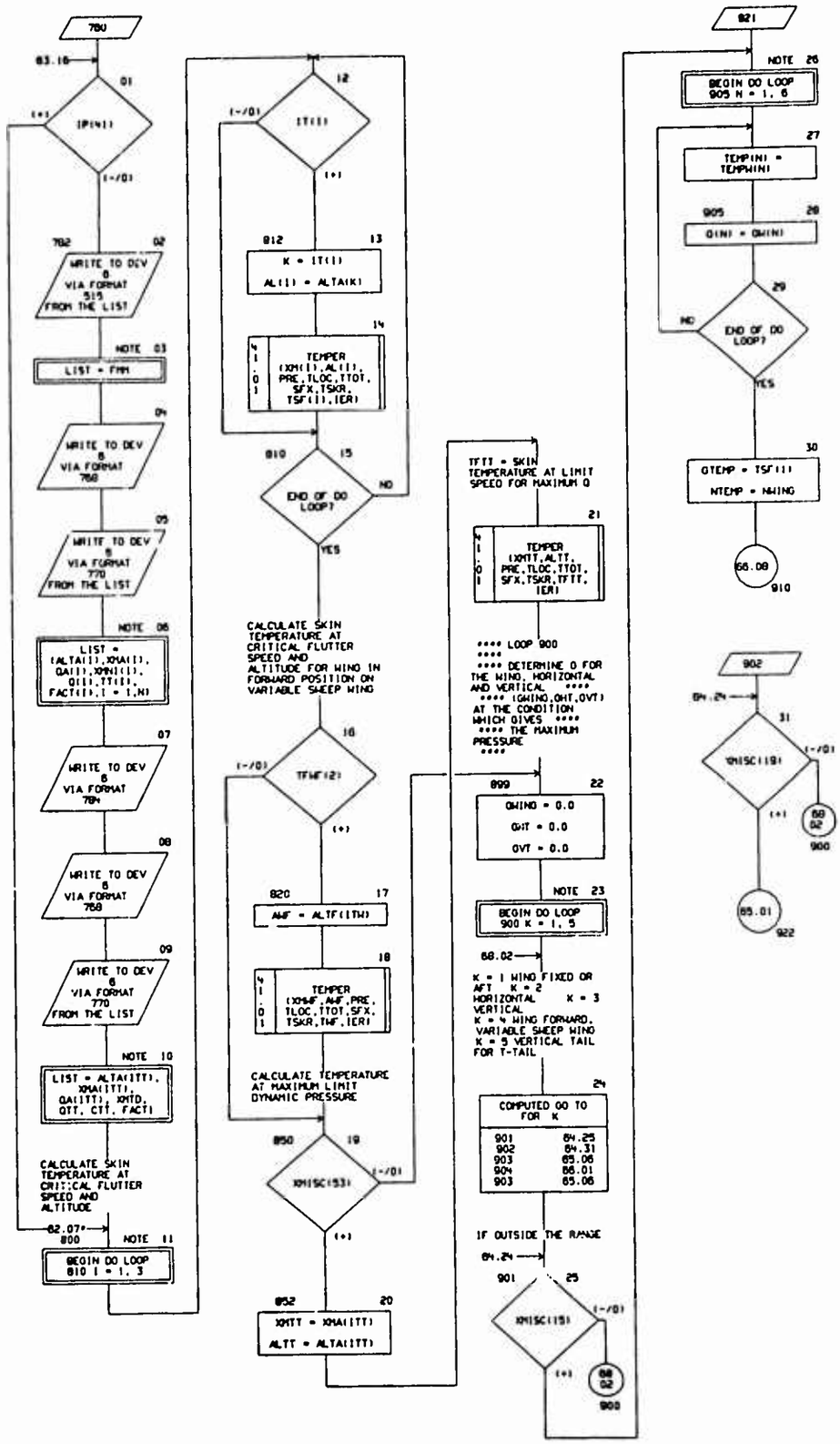


CHART TITLE - SUBROUTINE HHVOO

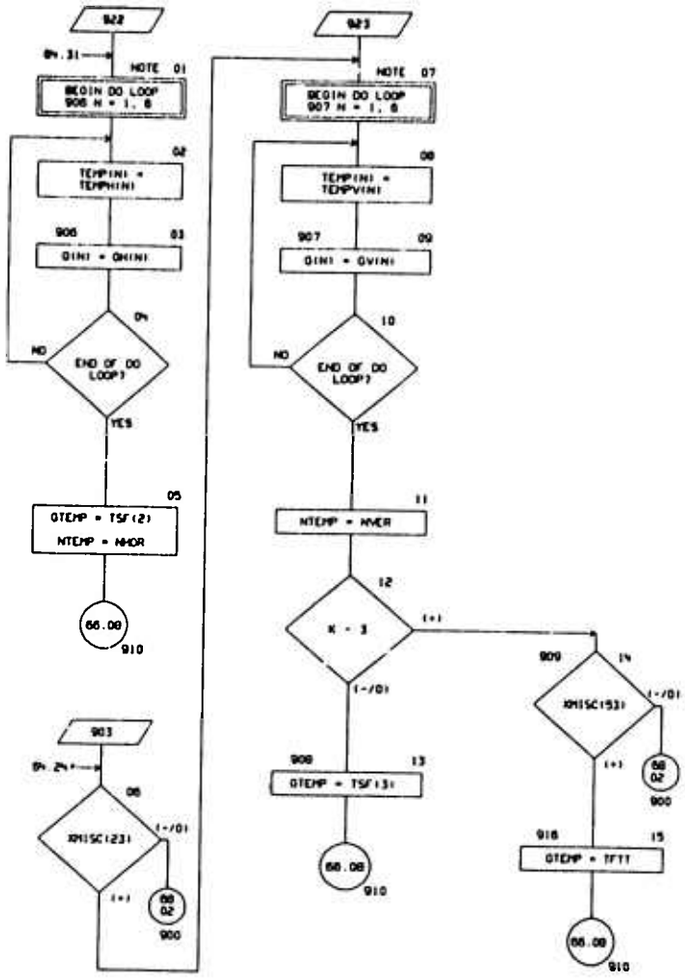
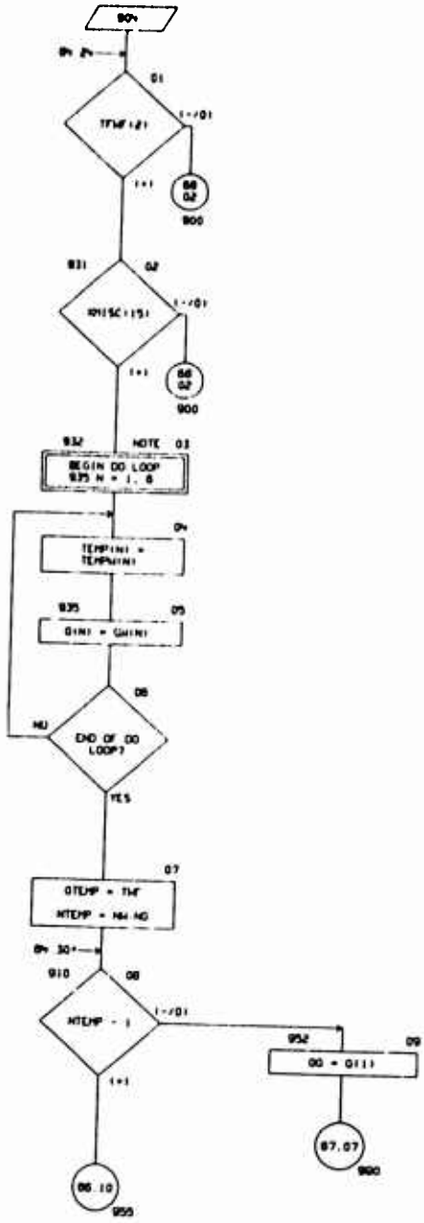


CHART TITLE - SUBROUTINE HHVOO



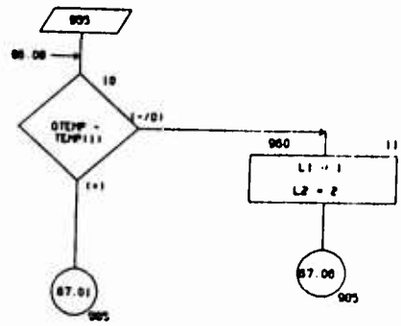


CHART TITLE - SUBROUTINE HHVOO

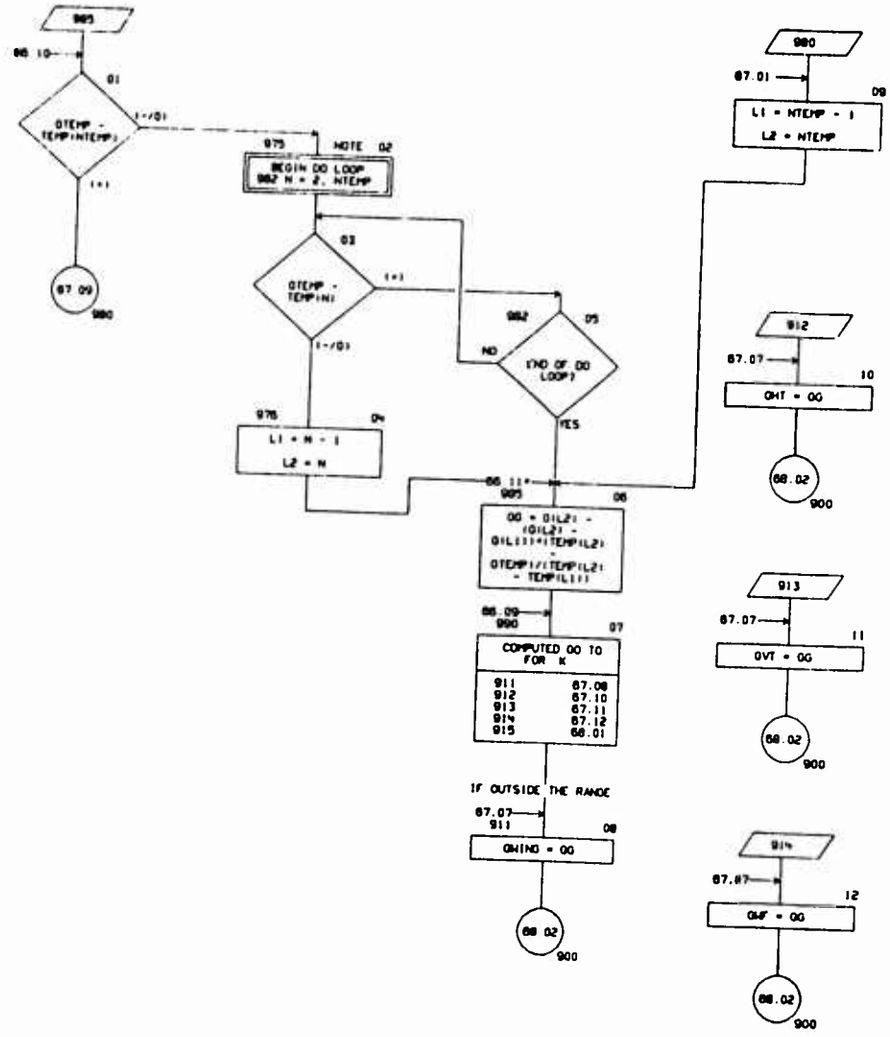


CHART TITLE - SUBROUTINE HMOO

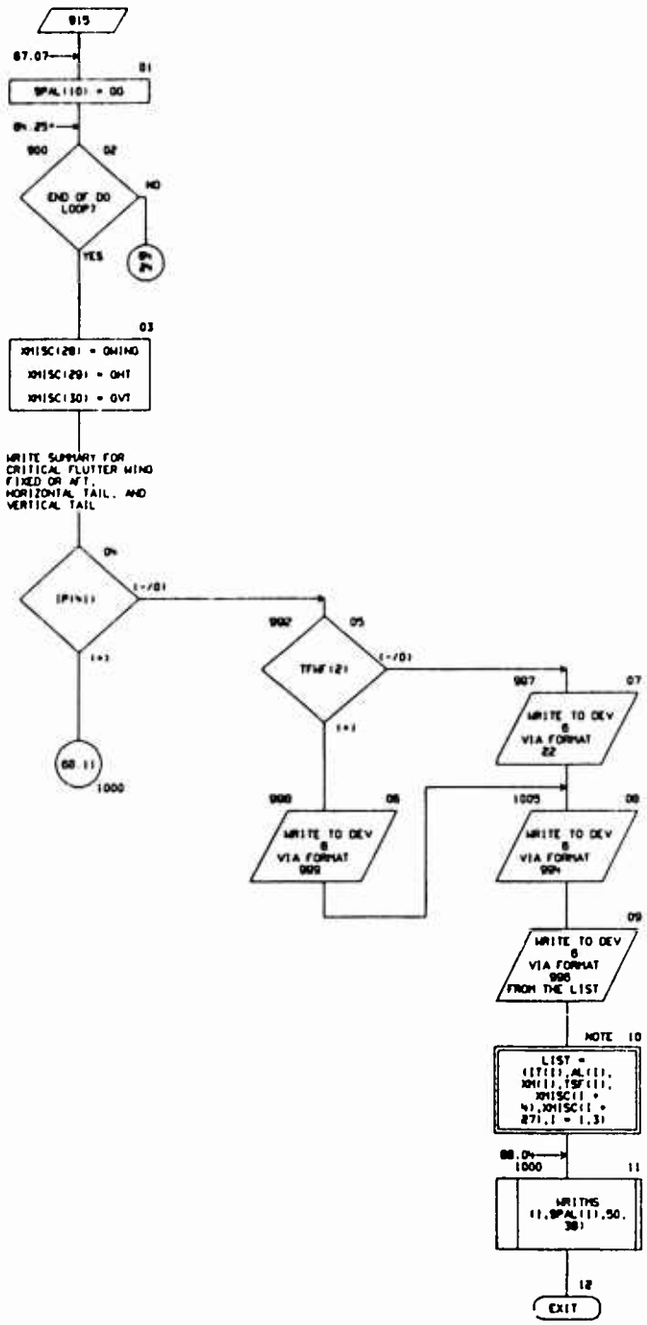


CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON    SWF(180),DATA(312),TFW(38),TFH(38),TFV(38),TFWF(38),
     1          TF(38),XMN(20),Q(20),QQ(20),XMATOP(20),
     2          QW(8),QH(8),QV(8)
      COMMON /IPRINT/IP(80)
      COMMON /MISC/XMISC(100)
      DIMENSION TEMPW(8),TEMPH(8),TEMPV(8)
      DIMENSION SPAL(50)
      DIMENSION ALTA(9),XMA(9),ALTF(3),XMF(3)
      DIMENSION GJDAT(100),CTTH(20),CTT1(20),CTT2(20)
      DIMENSION TT(20),FACT(20)
      DIMENSION QA(20)
      DIMENSION AL(3),XM(3),IT(3),TSF(3)
      DIMENSION TEMP(8),Q(8)
      EQUIVALENCE (DATA(305),WF)
      EQUIVALENCE (SWF(145),TEMPW(1)),(SWF(159),TEMPH(1))
     1 ,(SWF(173),TEMPV(1)),(SWF(151),NWING),(SWF(165),NHOR)
     2 ,(SWF(179),NVER)
      EQUIVALENCE (SPAL(16),FM),(SPAL(17),ALTA(1))
     1 ,(SPAL(26),XMA(1)),(SPAL(35),ALTF(1)),(SPAL(38),XMF(1))
     2 ,(SPAL(41),AMF),(SPAL(42),XMAF),(SPAL(43),THF)
     3 ,(SPAL(44),QQMF),(SPAL(45),QMF)
      EQUIVALENCE (QTT,SPAL(9)),(CTT,SPAL(11)),(XMTO,SPAL(8))
     1 ,(TSF(1),SPAL(46)),(TFTT,SPAL(49))
      EQUIVALENCE (PC,GJDAT(18)),(CTTDI,GJDAT(19)),(CTTD2,GJDAT(20))
     1 ,(CTTH(1),GJDAT(21)),(CTT1(1),GJDAT(41)),(CTT2(1),GJDAT(61))
  24  FORMAT(1HI,40X,22HFLUTTER SPEED MARGIN =,F5 2,22X,
     1  20H** WHVQQ - IP(4)) **)
 412  FORMAT(1HO,45X,17HWING FIXED OR AFT)
 422  FORMAT(1HO,46X,15HHORIZONTAL TAIL)
 432  FORMAT(1HO,47X,13HVERTICAL TAIL)
 442  FORMAT(19X,29HSPEED-ALTITUDE PROFILE POINTS,12X,/,4HFLUTTER DESIGN/
     1 82X,12HCOMPRESSIBLE/19X,8HALTITUDE,6X,4HMACH,5X,7HDYNAMIC,11X,
     2 4HMACH,5X,7HDYNAMIC,9X,7HDYNAMIC / 21X,4HFEET,7X,8HNUMBER,3X,
     3 8HPRESSURE,10X,8HNUMBER,3X,8HPRESSURE,8X,8HPRESSURE)
 444  FORMAT(16X,F11 0,F11 4,F11 1,5X,F11 4,F11 1,5X,F11.1)
 514  FORMAT(1HI,42X,18HFLUTTER Q MARGIN =,F7.4,22X,
     1    20H** WHVQQ - IP(4)) **)
  22  FORMAT(1HI,88X,20H** WHVQQ - IP(4)) **)
 606  FORMAT(1HO,48X,12HWING FORWARD)
  25  FORMAT(1HO,40X,22HFLUTTER SPEED MARGIN =,F5 2)
 515  FORMAT(1HO,42X,18HFLUTTER Q MARGIN =,F7 4)
 744    FORMAT( 60HO***** EXTRAPOLATED ON T-TAIL STIFFNESS COEFF  FOR M
     1ACH NO .   1F6 2,   8H, CTT = , 1E9.3 )
 766  FORMAT(1HO,37X,14HT-TAIL FLUTTER,5X,10HDIHEDRAL =,F5 1)
 768  FORMAT(11X,29HSPEED-ALTITUDE PROFILE POINTS,12X,14HFLUTTER DESIGN/
     1 11X,8HALTITUDE,6X,4HMACH,5X,7HDYNAMIC,11X,4HMACH,5X,7HDYNAMIC,
     2  9X,3HCTT,12X,5HQ=CTT/13X,4HFEET,7X,8HNUMBER,3X,8HPRESSURE,
     3 10X,8HNUMBER,3X,8HPRESSURE)
 770  FORMAT(8X,F11 0,F11.4,F11.1,5X,F11 4,F11 1,2E16.6)
 784  FORMAT(1HO,48X,12HDESIGN POINT)
 999  FORMAT(///////)
 994  FORMAT(33X,42H*** DESIGN TEMPERATURE, PRESSURE AND Q *** //18X,
     1 13HPROFILE POINT,4X,8HALTITUDE,3X,8HMACH NO ,3X,11HTEMPERATURE,
     2 3X,8HPRESSURE,4X,7HQ (PSI) )
 996  FORMAT(8X,4HWING,8X,17,6X,F11 0,F11 4,F14.1,F11.1,F11 0/
     1 8X,10HHORIZONTAL,2X,17,6X,F11 0,F11.4,F14.1,F11.1,F11 0/
     2 8X,8HVERTICAL,4X,17,6X,F11.0,F11 4,F14 1,F11.1,F11 0)
```

FORTRAN LISTING

OF

FLUTTER AND TEMPERATURE MODULE

```
11/07/73      INPUT LISTING                                  AUTOFLOW CHART SET - SWEEP   FLUTTER AND TEMPERATURE
FORTRAN MODULE      (LIST,AUTOSEQ)
CARD NO       ****                          CONTENTS                                    ****
    1              PROGRAM OLAY3
    2        C
    3              COMMON     $VF(180),DATA(312),TFW(38),TFH(38),TFV(38),TFWF(38),
    4             *           TF(38),XMN(20),Q(20),QQ(20),XMATOP(20),
    5             *           OW(6),OH(6),OV(6)
    6        C
    7              DIMENSION  PSI(23),TLOCAL(23),TTOTAL(23),SFLUX(23),TSKINR(23),
    8             *           TSKINF(23)
    9        C
   10              DIMENSION  BC(195),ALT(23),XMACH(23),BB(10)
   11        C
   12              EQUIVALENCE           (SVF(  1),PSI   (1)),(SVF( 24),TLOCAL(1)),
   13             * (SVF( 47),TTOTAL(1)),(SVF( 70) SFLUX (1)),(SVF( 93),TSKINR(1)),
   14             * (SVF(116),TSKINF(1))
   15        C
   16              DO 10 N=1,180
   17           10 SVF(N) = 0.0
   18        C
   19              DO 11 N=1,6
   20              OW(N) = 0.0
   21              OH(N) = 0.0
   22           11 OV(N) = 0.0
   23        C
   24              CALL READMS(1,BC(1),195,22)
   25              CALL READMS(1,DATA(1),312,12)
   26        C
   27        C
   28              DO 123 I=1,23
   29        C
   30        C     **** COMPUTE THE ALTITUDE AND MACH NUMBER AT EACH CONDITION ****
   31        C
   32              GO TO (72,73,74,75,76,77,76,78,84,77,85,76,86,77,85,76,86,77,85,72
   33             1,74,72,74),I
   34        C
   35           72 BB(9)=BC(19)
   36              BB(10)=BC(166)
   37              GO TO 87
   38        C
   39           73 BB(9)=BC(20)
   40              BB(10)=BC(167)
   41              GO TO 87
   42        C
   43           74 BB(9)=BC(21)
   44              BB(10)=BC(168)
   45              GO TO 87
   46        C
   47           75 BB(9)=0.0
   48              BB(10)= 90
   49              GO TO 87
   50        C
   51           76 BB(9)=BC(25)
   52              BB(10)=BC(28)
   53              GO TO 87
   54        C
   55           77 BB(9)=BC(19)
   56              BB(10)=BC(22)
   57              GO TO 87
   58        C
   59           78 BB(10)=1.5*BC(31)/661.3
   60           81 BB(9)=0.0
   61              GO TO 87
   62        C
   63           84 BB(10)=1.2*BC(32)/661.3
   64              GO TO 81
   65        C
   66           85 BB(9)=BC(20)
   67              BB(10)=BC(23)
   68              GO TO 87
   69        C
   70           86 BB(9)=BC(26)
```

```
CARD NO  ****                          CONTENTS                          ****
   71          BB(10)=BC(29)
   72    C
   73       87 ALT(I) = BB(9)
   74          XMACH(I) = BB(10)
   75    C
   76          IF(XMACH(I))123,123,88
   77    C
   78    C     **** DETERMINE THE PRESSURE, LOCAL AND TOTAL TEMPERATURES,  ****
   79    C     **** SUN FLUX, AND SKIN TEMPERATURE FOR THIS LOAD CONDITION ****
   80    C
   81       88 CALL TEMPER(XMACH(I),ALT(I),PS(I),TLOCAL(I),TTOTAL(I),SFLUX(I),
   82         *            TSKMAX(I),TSKINF(I),IER)
   83    C
   84          IF(IER -15)123,123,701
   85    C
   86       701 WRITE(6,703)I,TSKINF(I)
   87       703 FORMAT(15HOLOAD CONDITION,I3,77H - THE TEMPERATURE LOOP DID NOT CL
   88         *OSE IN 100 ITERATIONS. THE SKIN TEMPERATURE,F8 3,27H IS FROM THE L
   89         *AST ITERATION/)
   90    C
   91       123 CONTINUE
   92    C
   93    C
   94    C        CALL HHVQQ TO GET FLUTTER COMPRESSIBILITY EFFECTS
   95          CALL HHVQQ
   96    C
   97    C
   98          CALL WRITHS(I,SVF(1),180,3I)
   99    C
  100          END
  101    C
  102    C )))))))
```

```
CARD NO ****                          CONTENTS                          ****
  142   C                     IF IER = 0, NO ERROR, SOLUTION CRITERIA WERE MET.  HANN0195
  143   C                       IER = 1, SOLUTION FOR TOTAL TEMPERATURE DID NOT HANN0200
  144   C                                CONVERGE IN 100 PASSES, VALUE RETURNED HANN0205
  145   C                                IS BASED ON CONSTANT GAMMA.            HANN0210
  146   C                       IER = 2, SOLUTION FOR BOUNDARY LAYER TEMPERATUREHANN0215
  147   C                                DID NOT CONVERGE IN 100 PASSES, VALUE  HANN0220
  148   C                                RETURNED IS BASED ON RECOVERY OF  875  HANN0225
  149   C                     IF IER = 3, SOLUTION FOR SKIN FRICTION COEFFICIENT HANN0230
  150   C                                DID NOT CONVERGE IN 100 PASSES, SOLU-  HANN0235
  151   C                                TION FOR BOUNDARY LAYER COEF  WAS CON- HANN0240
  152   C                                TINUED WITH CURRENT VALUE OF C(F)      HANN0245
  153   C                       IER = 4, AROUMENT XMACH IS ZERO, DIST IS ZERO,  HANN0250
  154   C                                REL = 6.00                             HANN0255
  155   C                       IER = 5, ARGUMENT XMACH IS ZERO, DIST IS       HANN0258
  156   C                                POSITIVE, REL = 6.00                   HANN0257
  157   C                       IER = 6, ARGUMENT XMACH IS POSITIVE, DIST IS   HANN0258
  158   C                                MINUS OR ZERO, REL = 6.00              HANN0259
  159   C                     IER = 7, ARGUMENT TO IS BELOW 180 DEGREES RANKINEHANN0261
  160   C                     A VALUE OF REL =6.0 IS RETURNED                  HANN0262
  161   C                     IER = 8, ARGUMENT TSK IS BELOW 180 RANKINE.      HANN0263
  162   C                     SOLUTION CONTINUES USING TO FOR TSK              HANN0264
  163   C                                                                      HANN0265
  164   C     THE VALUE OF BOUNDARY LAYER HEAT TRANSFER COEFFICIENT IS RETURNED HANN0266
  165   C     IN  BTU/HR-FT**2-DEG F  TO THE CALLING PROGRAM                   HANN0270
  166   C                                                                      HANN0275
  167   C                                                                      HANN0280
  168   C     ****                          ***                        ****  HANN0310
  169         FUNCTION REL(XMACH,P0,T0,TSK,DIST,XLAMDA,REY,METHOD,IER,TOTI,TAWI)HANN0315
  170           IF ( XMACH )10,10,13                                         HANN0320
  171        10 IF ( DIST )11,11,12                                          HANN0322
  172        11 IER = 4                                                      HANN0324
  173           GO TO 15                                                     HANN0325
  174        12 IER = 5                                                      HANN0326
  175           GO TO 15                                                     HANN0327
  176        13 IF ( DIST )14,14,20                                          HANN0328
  177        14 IER = 6                                                      HANN0332
  178        15 REL = 6.00                                                   HANN0334
  179           GO TO 1000                                                   HANN0335
  180        20 IF ( T0 - 180.0 )21,21,22                                    HANN0336
  181        21 IER = 7                                                      HANN0337
  182           GO TO 15                                                     HANN0338
  183        22 IF ( TSK - 180.0 )23,23,24                                   HANN0339
  184        23 IER = 8                                                      HANN0340
  185           TSK = T0                                                     HANN0341
  186        24 TOT = TOTI                                                   HANN0343
  187           METOD = 1                                                    HANN0345
  188           IF(METHOD-3)26,25,25                                         HANN0350
  189        25 METOD = 2                                                    HANN0355
  190        26 TAW = TAWI                                                   HANN0360
  191           TSTR =  .28*T0 +  .5*TSK +  .22*TAW                          HANN0365
  192           GRHO = P0/53.3504/5/TSTR                                     HANN0370
  193           EXP1 =  EXP(5526./TSTR)                                      HANN0375
  194           SPHT = .06856*(3.5 + (5526./TSTR)/(EXP1-1.))**2 * EXP1)      HANN0380
  195           GVIS =  .00262*TSTR**1.5/(TSTR+198.7)                        HANN0385
  196           COND = .00114*TSTR** 1.5/(1.+441.2/TSTR/10.**(21.6/TSTR))    HANN0390
  197           PRN = SPHT*GVIS/COND                                         HANN0395
  198           EXP0 =  EXP(5526./T0)                                        HANN0400
  199           SPHT0 =  .06856*(3.5 + (5526./T0)/(EXP0-1.))**2 * EXP0)      HANN0405
  200           GAMMA0 = SPHT0/(SPHT0-53.3504/778.26)                        HANN0410
  201           SPSD0 =  SQRT(GAMMA0*32.174*53.3504*T0)                      HANN0415
  202           VEL0 = SPSD0*XMACH                                           HANN0420
  203           GRH00 = P0/53.3504/T0                                        HANN0425
  204           GVIS0 =  .002627*T0**1.5/(T0+198.7)                          HANN0430
  205           GO TO (100,100,300,300),METHOD                               HANN0435
  206       100 IF(REY)30,30,35                                              HANN0440
  207        30 REY = 1.E8                                                   HANN0445
  208        35 REN0 = VEL0*DIST*GRH00*3600./GVIS0                           HANN0450
  209           IF(REN0-REY)40,60,60                                         HANN0455
  210        40 REN = VEL0*DIST*GRH0*3600./GVIS                              HANN0460
  211           ANAL = 1./PRN**.666                                          HANN0465
  212           CSFN = .664/ SQRT(REN)                                       HANN0470
```

```
CARD NO  ****                          CONTENTS                                  ****
     213        HBL = CSFN/2.*ANAL*ORHOO*SPHT*VELO*3600.                          HANN0475
     214        IF(METHOD-1)1000,1000,50                                          HANN0480
     215     50 HBL = HBL*1.732                                                   HANN0485
     216        GO TO 1000                                                        HANN0490
     217     60 ASQ = (TOT-TO)/TSK                                                HANN0495
     218        B = TOT/TSK-1.                                                    HANN0500
     219        THETA = B/ SQRT(B**2+4.*ASQ)                                      HANN0505
     220        PSI = (2.*ASQ-B)/ SQRT(B**2+4.*ASQ)                               HANN0510
     221        DENOM = 0.5*( ASIN(THETA)+ ASIN(PSI))                             HANN0515
     222        CSFNI = .001                                                      HANN0520
     223        CSFI = 0.                                                         HANN0525
     224        IF(METHOD-1)70,70,65                                              HANN0530
     225     65 RENO = RENO/2.                                                    HANN0535
     226     70 ANUM = .41 + ALOG10(RENO*CSFNI*(TO/TSK)**.76)                     HANN0540
     227        CSFN = .25*CSFNI+.75*TO/ASQ/TSK/(ANUM/DENOM)**2                   HANN0545
     228        IF( ABS(CSFN-CSFNI)/CSFNI-.001)110,110,80                         HANN0550
     229     80 CSFNI = CSFN                                                      HANN0555
     230        CSFI = CSFI+1.                                                    HANN0560
     231        IF(CSFI-100.)70,70,90                                             HANN0565
     232     90 IER = 3                                                           HANN0570
     233    110 HBL = .8*CSFN*ORHOO*SPHT*VELO*3600.                               HANN0575
     234        GO TO 1000                                                        HANN0580
     235    300 COND0 = .00134*TO**.5/(1.+44.2/TO/10.**(21.6/TO))                 HANN0585
     238        PRNO = SPHTO*VISO/COND0                                           HANN0590
     237        XMULT = COS(XLAMDA * .0174533)                                    HANN0595
     238        IF(XMULT-.5)130,150,150                                           HANN0600
     239    130 XMULT = 0.5 - ( ACOS(XMULT)*180.0/3.1416 - 60.0)*0.01             HANN0605
     240        IF(XMULT-.35)140,150,150                                          HANN0610
     241    140 XMULT = .35                                                       HANN0615
     242    150 F2 = .57/PRNO**.6*XMULT                                           HANN0620
     243        IF(METHOD-3)170,170,160                                           HANN0625
     244    160 F2 = .783/PRNO**.6                                                HANN0630
     245    170 EXPO = EXP(5526./TO)                                              HANN0635
     246        EXPTO = EXP(5526./TOT)                                            HANN0640
     247        SPHTI = .06856/(TOT-TO)*(3.5*(TOT-TO)+5526./(EXPTO-1.)-5526./(EXPO HANN0645
     248       1-1.))                                                             HANN0650
     249        GAMMAI = SPHTI/(SPHTI-53.3505/778.26)                             HANN0655
     250        SPSDTT = SQRT(GAMMAI*32.174*53.3505*TOT)                          HANN0660
     251        IF(XMACH-1.)180,180,220                                           HANN0665
     252    180 VELI = XMACH*SPSDTT                                               HANN0670
     253        BETA = 4.*VELI/DIST                                               HANN0675
     254        IF(METHOD-3)210,210,190                                           HANN0680
     255    190 BETA = .75*BETA                                                   HANN0685
     256    210 ORHOTT = ORHOO/(1./(1.+(GAMMAI-1.)/2.*XMACH**2))**(1./(GAMMAI-1.))HANN0690
     257        GO TO 230                                                         HANN0695
     258    220 X2MACH = XMACH*XMACH                                              HANN0700
     259        XMACHI = SQRT( ( 1.000 +(GAMMAI -1.000 )/2.000*X2MACH )/( GAMMAI  HANN0705
     260       1   *X2MACH - ( GAMMAI - 1.000 )/2.00 ))                           HANN0710
     261        VELI = XMACHI*SPSDTT                                              HANN0715
     262        XAMDA = 1.+2.*((XMACH/XMACHI)**2-1.)/((1.+GAMMAI*X2MACH)          HANN0720
     263        BETA = 2.*VELI* SQRT(XAMDA)/DIST                                  HANN0725
     264        RPOPI = ( 1.000 + GAMMAI*XMACHI**2 )*( 1.000 + (GAMMAI-1.000)/2.00HANN0730
     265       1   *X2MACH)/( 1.000 + GAMMAI*X2MACH )/( 1.000 + ( GAMMAI - 1.000 )HANN0735
     266       2   /2.00*XMACHI**2 )                                             HANN0738
     267        RPIPS = (1./(1.+(GAMMAI-1.)/2.*XMACHI**2))**(1./(GAMMAI-1.))     HANN0740
     268    229 ORHOTT = ORHOO/RPOPI/RPIPS                                        HANN0741
     269    230 CONTINUE                                                          HANN0750
     270        OVISTT = 0.00262*TOT**1.5/(TOT+198.7)                             HANN0751
     271        EXPSK = EXP(5526./TSK)                                            HANN0755
     272        SPHTSK = .06856*(3.5+(5526./TSK/(EXPSK-1.))**2*EXPSK)             HANN0760
     273        HBL = F2* SQRT(BETA*3600.*ORHOTT*OVISTT)*SPHTSK                   HANN0765
     274   1000 RETURN                                                           HANN0770
     275        END                                                               HANN0775
     276  C
     277  C )))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))))
     278  C                          FUNCTION PRESH
     279  C (((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
     280  C
     281        FUNCTION PRESH(ALT)                                               00000040
     282  C     PRESH IS A SUBROUTINE THAT CONVERTS ALTIMETER READINGS TO PRESSURE00000010
     283  C     IT IS GOOD FOR ALTIMETERS CALIBRATED IN GEOPOTENTIAL ALTITUDE PER 00000020
```

```
CARD NO  ****                          CONTENTS                          ****
  284    C     THE RELATION DEFINED BY U.S  STANDARD ATMOSPHERE, 1962      00000030
  285          ALOFT = ALT/1000.0                                          00000050
  286          IF ( ALT  - 36089.239)10,30,20                              00000060
  287       10 PRESH = 2116.22*( ( 1.000 - 6.87559E-3*ALOFT )**5.2559) )   00000070
  288          GO TO 100                                                   00000080
  289       20 IF( ALT - 65616.80)30,30,40                                 00000090
  290       30 ZEXPO = EXP( ( ALT - 36089.24 )/20805.56 )                  00000100
  291          PRESH = 472.68/ZEXPO                                        00000110
  292          GO TO 100                                                   00000120
  293       40 IF( ALT - 104986.88 )50,50,60                               00000130
  294       50 PRESH = 114.345*(( 1.000 + 0.94864*( ALOFT - 65.61680)/389.970 )  00000140
  295         1   **(-34.1634))                                           00000145
  296          GO TO 100                                                   00000150
  297       60 PRESH = 18.131*(1.00+1.536*(ALOFT-104.987)/411.57)**(-12.2012)  00000151
  298          IF( ALT - 154199.48 )100,100,65                             00000152
  299       65 WRITE(6,70)                                                 00000155
  300       70 FORMAT(1H 6X9HWARNING- ALTITUDE IS BEYOND VALID RANGE OF PRESH.)  00000160
  301      100 RETURN                                                      00000170
  302          END                                                         00000180
  303    C
  304    C )))))))
```

```
CARD NO  ****                          CONTENTS                          ****
     355          IF(XMN - TABLE(1))47,47,48
     356      C
     357       47 TFANS = XMN * TF(1) / TABLE(1)
     358          XMATOP(1) = XMN
     359          GO TO 99
     360      C
     361       48 DO 50 N=2,38
     362          IF(N - 38)49,52,52
     363       49 IF(XMN - TABLE(N))52,52,50
     364       52 NSAVE = N - 1
     365          TFP = TF(N-1) + (XMN-TABLE(N-1)) / (TABLE(N)-TABLE(N-1))
     366         *   * (TF(N)-TF(N-1))
     367          GO TO 54
     368       50 CONTINUE
     369      C
     370       54 TOP = 0.0
     371      C
     372          DO 60 N=1,NSAVE
     373          IF(TF(N) - TOP)60,60,62
     374       62 TOP = TF(N)
     375          NS = N
     376       60 CONTINUE
     377      C
     378          IF(TOP - TFP)71,71,72
     379      C
     380       71 TFANS = TFP
     381          XMATOP(1) = XMN
     382          GO TO 99
     383      C
     384       72 TFANS = TOP
     385          XMATOP(1) = TABLE(NS)
     386      C
     387       99 QQ(1) = ((TFANS/XMN) / (TF(N)/TABLE(N)))**2 * Q(1)
     388      C
     389      100 CONTINUE
     390      C
     391          RETURN
     392      C
     393          END
     394      C
     395      C )))))))  (((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((((
     396      C                          FUNCTION SOLARG
     397      C {{{{
```

```
      COMMON /MISC/ XMISC(100)
C
      DIMENSION TABLE(38),TBP(38),TAR2(38),TAR6(38),
     * TSB0(38),TSB60(38),TTR0(38),TTR60(38)
C       PROGRAM REGION VARIABLES
      DIMENSION TAR(38),TSB(38),TTR(38),TF(38)
C
C
C
C
      EQUIVALENCE (TABLE(1),DATA( 1)),( TBP(1),DATA( 39)),
     *           ( TAR2(1),DATA( 77)),( TAR6(1),DATA(115)),
     *           ( TSB0(1),DATA(153)),(TSB60(1),DATA(191)),
     *           ( TTR0(1),DATA(229)),(TTR60(1),DATA(267))
C
C
C
      DO 699 N=1,38
      TFW(N) = 0.0
      TFH(N) = 0.0
      TFV(N) = 0.0
  699 TF(N) = 0.0
C
      ARH  = XMISC(12)
      SBH  = XMISC(13)
      TRH  = XMISC(14)
      ARH  = XMISC(16)
      SBH  = XMISC(17)
      TRH  = XMISC(18)
      ARV  = XMISC(20)
      SBV  = XMISC(21)
      TRV  = XMISC(22)
      ARWF = XMISC(25)
      SBWF = XMISC(26)
      TRWF = XMISC(27)
C
C
      DO 300 I=1,4
C
      GO TO (301,302,303,304),I
C
  301 IF(ARH)300,300,305
C
  305 AR = ARH
      SB = SBH
      TR = TRH
      GO TO 308
C
C
  302 IF(ARWF)300,300,332
  332 AR = ARWF
      SB = SBWF
      TR = TRWF
      GO TO 308
C
  303 IF(ARH)300,300,306
C
  306 AR = ARH
      SB = SBH
      TR = TRH
      GO TO 308
C
  304 IF(ARV)300,300,307
C
  307 AR = ARV
      SB = SBV
      TR = TRV
C
  308 IF(AR - 4.0)200,200,210
  200 IF(AR - 2.0)201,201,204
  201 PCNT = AR / 2.0
```

CARD NO **** CONTENTS ****

```
497            DO 202 N=1,38
498          202 TAR(N) = PCNT * TAR2(N)
499              GO TO 220
500          204 PCNT = (AR - 2.0) / 2.0
501              DO 205 N=1,38
502          205 TAR(N) = TAR2(N) + PCNT * (TBP(N) - TAR2(N))
503              GO TO 220
504          210 PCNT = (AR - 4.0) / 2.0
505              DO 215 N=1,38
506          215 TAR(N) = TBP(N) + PCNT * (TAR6(N) - TBP(N))
507          C
508          220 IF(SB - 45.0)230,230,240
509          230 PCNT = SB / 45.0
510              DO 235 N=1,38
511          235 TSB(N) = TSB0(N) + PCNT * (TBP(N) - TSB0(N))
512              GO TO 250
513          240 PCNT = (SB - 45.0) / 15.0
514              DO 245 N=1,38
515          245 TSB(N) = TBP(N) + PCNT * (TSB60(N) - TBP(N))
516          C
517          250 IF(TR - .30)260,260,270
518          260 PCNT = TR / .30
519              DO 265 N=1,38
520          265 TTR(N) = TTR0(N) + PCNT * (TBP(N) - TTR0(N))
521              GO TO 280
522          270 PCNT = (TR - .30) / .30
523              DO 275 N=1,38
524          275 TTR(N) = TBP(N) + PCNT * (TTR60(N) - TBP(N))
525          C
526          280 DO 290 N=1,38
527          290 TF(N) = TAR(N) * TSB(N) * TTR(N) / TBP(N)**2
528          C
529              IF(IP(4))5003,5003,5004
530           5003 CONTINUE
531          C
532              GO TO (291,292,293,294),I
533          C
534          291 WRITE(6,295)
535          295 FORMAT(1H1,40X,27H*** WING (FIXED OR AFT) ***,
536             1 21X,21H** SWFTAB - IP(4)) **//)
537              GO TO 298
538          C
539          292 WRITE(6,335)
540          335 FORMAT(1H1,40X,22H*** WING (FORWARD) ***,
541             1  26X,21H** SWFTAB - IP(4)) **//)
542              GO TO 298
543          C
544          293 WRITE(6,296)
545          296 FORMAT(1H1,35X,23H*** HORIZONTAL TAIL ***,
546             1  30X,21H** SWFTAB - IP(4)) **//)
547              GO TO 298
548          C
549          294 WRITE(6,297)
550          297 FORMAT(1H1,35X,21H*** VERTICAL TAIL ***,
551             1  32X,21H** SWFTAB - IP(4)) **//)
552          C
553          298 WRITE(6,55)AR,SB,TR
554           55 FORMAT(1H ,35X,32HFLUTTER PARAMETER VS MACH NUMBER//
555             *           16X,8HMACH NO.,12X,5HAR = ,F5.2,4X,13HSWEEP(C/4) = ,
556             * F4.1,4H DEG,3X,8HTAPER = ,F4.3,10X,9HCOMPOSITE//)
557          C
558              DO 60 N=1,38
559           60 WRITE(6,62)DATA(N),TAR(N),TSB(N),TTR(N),TF(N)
560           62 FORMAT(17X,F5.3,16X,F5.4,15X,F5.4,15X,F5.4,15X,F5.4)
561          C
562           5004 CONTINUE
563          C
564              GO TO (321,322,323,324),I
565          C
566          321 DO 325 N=1,38
567          325 TFW(N) = TF(N)
```

```
CARD NO  ****                          CONTENTS                          ****
     568         GO TO 300
     569    C
     570      322 DO 326 N=1,38
     571      326 TFWF(N) = TF(N)
     572         GO TO 300
     573    C
     574      323 DO 326 N=1,38
     575      326 TFH(N) = TF(N)
     576         GO TO 300
     577    C
     578      324 DO 327 N=1,38
     579      327 TFV(N) = TF(N)
     580    C
     581      300 CONTINUE
     582    C
     583         RETURN
     584         END
     585    C
     586    C !!!!
```

CARD NO	**** CONTENTS ****	
639	20 IF(REY-0)30,30,40	TAMA0275
640	30 REY = 1 E6	TAMA0280
641	40 TOT = TOT1	TAMA0285
642	EXP1 = EXP(5526 /T0)	TAMA0290
643	SPHT = 06856 * (3 5 + (5526./T0/(EXP1-1))**2* EXP1)	TAMA0295
644	SPHTV = SPHT - 53 35045/778.26	TAMA0300
645	GAMMA = SPHT/SPHTV	TAMA0305
646	SPSO = SQRT(GAMMA*32 174*53 35045*T0)	TAMA0310
647	VEL = SPSO*XMACH	TAMA0315
648	QRHO = P0/53 35045/T0	TAMA0320
649	QVIS = .002627 * T0**1.5/(T0+198 7)	TAMA0325
650	REN = VEL*DIST*QRHO*3600 /QVIS	TAMA0330
651	IND = 0	TAMA0335
652	TBL1 = T0 + .875*(TOT-T0)	TAMA0340
653	50 TSTR = .28*T0 + .5*TSK + .22*TBL1	TAMA0345
654	EXP1 = EXP(5526 /TSTR)	TAMA0350
655	SPHT = 06856 * (3 5 + (5526 /TSTR/(EXP1-1))**2*EXP1)	TAMA0355
656	QVIS = .00262*TSTR**1.5/(TSTR+198.7)	TAMA0360
657	COND = .00114*TSTR** 5/(1 +44) 2/TSTR/10 **(2) 6/TSTR))	TAMA0365
658	PRN = SPHT*QVIS/COND	TAMA0370
659	IF (METHOD-1)50,58,52	TAMA0375
660	52 IF(XLAMDA)54,54,56	TAMA0380
661	54 TBL = TOT	TAMA0385
662	GO TO 100	TAMA0390
663	56 RECOV = 1.000 + (SQRT(PRN) - 1 000)*(SIN(.5*XLAMDA*.0174532))**2	TAMA0395
664	GO TO 70	TAMA0400
665	58 RECOV = PRN**.333	TAMA0405
666	IF(REN-REY)60,70,70	TAMA0410
667	60 RECOV = PRN**.5	TAMA0415
668	70 TBL = T0 + RECOV*(TOT-T0)	TAMA0420
669	IND = IND+	TAMA0425
670	IF(ABS(TBL-TBL1)/TBL- 00001)100,100,80	TAMA0430
67.	80 IF(IND-100)85,90,90	TAMA0435
672	85 TBL1 = TBL	TAMA0440
673	GO TO 50	TAMA0445
674	90 IER = 2	TAMA0450
675	TBL = T0 + .875*(TOT-T0)	TAMA0455
676	100 RETURN	TAMA0460
677	END	TAMA0465
678	C	
679	C)))))))

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CARD NO  ****  CONTENTS                                                    ****
     GO TO 830                                                                00000320
   140 IF( ALT - 104987. )145,180,180                                         00000325
   145 TEMALT = 389 970 + 0 546641*( ALOFT - 65.61688 )                       00000330
     GO TO 830                                                                00000331
   160 TEMALT = 411.570 + 1 53618 * ( ALOFT - 104 987 )                       00000335
     IF( ALT - 154200 )830,830,810                                            00000340
C                                                                             00000345
C    EQUATIONS FOR THE EXTREME COLD ATMOSPHERE OF MIL-STD-210A                00000350
   200 IF( ALT - 3311 00 )210,225,220                                         00000360
   210 TEMALT = 399 7 + 13 591*ALOFT                                          00000370
     GO TO 600                                                                00000375
   220 IF( ALT - 10744 0 )225,225,230                                         00000380
   225 TEMALT = 444 7                                                         00000385
     GO TO 600                                                                00000386
   230 IF(ALT-30715.0)235,245,240                                             00000390
   235 IF(ALT-22000 0)236,237,237                                             00000391
   236 SLOPE=3 2511* 00761*(ALOFT-10 7441+ 000484*((ALOFT-10 7441**2 0)       00000392
     TEMALT=444 7-SLOPE*(ALOFT-10 7441                                        00000393
     GO TO 600                                                                00000394
   237 SLOPE= 0233*(ALOFT-22.000)+3.4787                                      00000395
     TEMALT=406 5-SLOPE*(ALOFT-22 000)                                        00000396
     GO TO 600                                                                00000410
   240 IF( ALT - 42377 0 )245,245,250                                         00000420
   245 TEMALT = 374.7                                                         00000430
     GO TO 600                                                                00000440
   250 IF(ALT - 47660 )251,251,252                                            00000451
   251 SLOPE=5 1198* 0325*(A  T-42.377)                                       00000452
     TEMALT=374.7-SLOPE*(A OFT 42.377)                                        00000453
     GO TO 600                                                                00000453
   252 IF( ALT - 50583 )253,265,260                                           00000454
   253 TEMALT = 334 7 + 3 70*( 50.583 - ALOFT )                               00000455
     GO TO 600                                                                00000470
   260 IF( ALT - 61087 0 )265,265,270                                         00000480
   265 TEMALT = 334 7                                                         00000490
     GO TO 600                                                                00000500
   270 IF( ALT - 73055 0 )275,280,280                                         00000510
   275 SLOPE=3 2352-.06113*(ALOFT-61.087)+ 00057*((ALOFT-61.087)**2 0)        00000520
     TEMALT=334.7+SLOPE*(ALOFT-61 087)                                        00000523
     TEMALT = 334 7 + SLOPE*( ALOFT - 61 087 )                                00000525
     GO TO 600                                                                00000530
   280 IF(ALT-78000)285,290,290                                               00000540
   285 SLOPE=- 0137*(ALOFT-73 055)+ 331                                       00000542
     TEMALT=365.7-SLOPE*(ALOFT-73 055)                                        00000544
     GO TO 600                                                                00000546
   290 SLOPE= 334+ 00255*(ALOFT-78 000)                                       00000548
     TEMALT=384.4-SLOPE*(ALOFT-78.000)                                        00000549
     GO TO 600                                                                00000550
C                                                                             00000555
C    EQUATIONS FOR THE EXTREME HOT ATMOSPHERE OF MIL-STD-210A                 00000560
   300 IF( ALT - 34000 0 )310,325,320                                         00000570
   310 SLOPE=3 942- 00344*ALOFT                                               00000580
     TEMALT=562.7-SLOPE*ALOFT                                                 00000585
     GO TO 600                                                                00000590
   320 IF( ALT - 39400.0 )325,335,330                                         00000600
   325 SLOPE=.0206*(ALOFT-34 000)+3.2794                                      00000610
     TEMALT=432 9-SLOPE*(ALOFT-34.000)                                        00000615
     GO TO 600                                                                00000620
   330 IF( ALT - 50400 )335,345,340                                           00000630
   335 TEMALT = 414.7 + 0 4444*( ALOFT - 39.400 )                             00000640
     GO TO 600                                                                00000650
   340 IF( ALT - 66400.0 )345,350,350                                         00000660
   345 TEMALT = 419.7 + 0.1875*( ALOFT - 50.400 )                             00000670
     GO TO 600                                                                00000675
   350 IF(ALT-70000)360,370,370                                               00000680
   360 SLOPE=.0233*(ALOFT-66.400)+ 5574                                       00000682
     TEMALT=422.7+SLOPE*(ALOFT-66.400)                                        00000684
     GO TO 600                                                                00000686
   370 SLOPE=.6835+.00268*(ALOFT-70.000)+.000001605*((ALOFT-70.000)**2.0)     00000687
     TEMALT=425.0+SLOPE*(ALOFT-70.000)                                        00000689
     GO TO 600                                                                00000690
C                                                                             00000695
```

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CARD NO  ****                          CONTENTS                          ****
  781    C     EQUATIONS FOR POLAR ATMOSPHERE OF MIL-STD-210A.                    00000700
  782      400 IF( ALT - 3243 )410,425,420                                       00000710
  783      410 TEMALT=444 0+3 060*ALOFT                                          00000720
  784          GO TO 600                                                         00000730
  785      420 IF( ALT - 9882 )425,435,430                                       00000740
  786      425 TEMALT = 451.9 - 0 543*(ALOFT - 3 243 )                           00000750
  787          GO TO 600                                                         00000760
  788      430 IF( ALT - 30065 0 )435,445,440                                    00000770
  789      435 SLOPE= 00055*(ALOFT-9 882)**2 839                                 00000780
  790          TEMALT=450 3-SLOPE*(ALOFT-9 882)                                  00000781
  791          GO TO 600                                                         00000790
  792      440 IF( ALT - 86092 0 )445,450,450                                    00000800
  793      445 TEMALT = 392 7 - 0 25703*( ALOFT - 30 065 )                       00000810
  794          GO TO 600                                                         00000820
  795      450 TEMALT = 378 3                                                    00000830
  796          GO TO 600                                                         00000840
  797    C                                                                       00000845
  798    C     EQUATIONS OF THE TROPICAL ATMOSPHERE OF MIL-STD-210A              00000850
  799      500 IF(ALT-53595 0)501,525,520                                        00000860
  800      501 IF(ALT-27500)502,503,503                                          00000861
  801      502 TEMALT=549 5-3 88*(ALOFT)                                         00000862
  802          GO TO 600                                                         00000863
  803      503 SLOPE=3 88  00488*(ALOFT-27 500)                                  00000864
  804          TEMALT=443 0-SLOPE*(ALOFT-27 500)                                 00000865
  805          GO TO 600                                                         00000866
  806      520 IF( ALT - 69620 0 )525,530,530                                    00000890
  807      525 IF(ALT-58000)526,527,527                                          00000900
  808      526 SLOPE=2 222- 029*(ALOFT-53 595)+ 005*((ALOFT-53 595)**2.0)        00000901
  809          TEMALT=347.7+SLOPE*(ALOFT-53 595)                                 00000902
  810          GO TO 600                                                         00000903
  811      527 SLOPE= 0031*(ALOFT-58 000)+2 244                                  00000904
  812          TEMALT=357 2+SLOPE*(ALOFT-58 000)                                 00000905
  813          GO TO 600                                                         00000910
  814      530 SLOPE=. 3087+ 0165*(ALOFT-69 620)-.0000277*((ALOFT-69 620)**2.0)  00000920
  815          TEMALT=381 7+SLOPE*(ALOFT-69 620)                                 00000923
  816          GO TO 600                                                         00000924
  817    C                                                                       00000925
  818    C     EQUATIONS FOR DEFROST DAY OF MIL-T-5842                           00000925
  819      539 ALOFT=ALT/1000 0                                                  00000926
  820          IF(ALT-50000 0)540,550,550                                        00000927
  821      540 IF(ALT-25000.0) 542,542,543                                       00000928
  822      542 TEMALT=543 0-5 97*ALOFT                                           00000929
  823          GO TO 600                                                         00000930
  824      543 TEMALT=394 0-1 0*(ALOFT-25.000)                                   00000931
  825          GO TO 600                                                         00000932
  826      550 TEMALT=369 0                                                      00000933
  827    C     TEST IF WE ARE WITHIN THE 100000 FEET USED IN DEFINITION          00000930
  828      600 IF(ALOFT - 100 0 )630,630,610                                     00000940
  829      610 WRITE(6,620)                                                      00000950
  830      620 FORMAT(1H 6X50HWARNING- ALTITUDE IS BEYOND VALID RANGE OF TEMALT.)00000960
  831      630 RETURN                                                            00000970
  832          END                                                               00000980
  833    C
  834    C !!!!
```

```
CARD NO  ****                    CONTENTS                    ****
  852    C
  853          METHOD = 1
  854          METHO = 1
  855    C
  856    C     INITIALIZE THE ERROR AND PASS INDICATORS TO ZERO
  857    C
  858          IER = 0
  859          IPASS = 0
  860    C
  86.    C     SET THE TOLERANCE TO ONE-TENTH DEGREE RANKINE
  862    C
  863          CRIT = .1
  864    C
  865    C     CALL FUNCTION PRESH TO DETERMINE THE PRESSURE AT ALTITUDE
  866    C
  867          PRESS = PRESH(ALT)
  868          PRESSI = PRESS/144.0
  869    C
  870    C     CALL FUNCTION TEMALT TO DETERMINE THE LOCAL TEMPERATURE
  871    C     AT ALTITUDE  (ATMOS INDICATES THE  THE ATMOSPHERIC TABLE
  872    C     TO BE USED. A VALUE OF 1.0, WHICH INDICATES STANDARD
  873    C     ATMOSPHERE, IS IN THE PERMANENT DATA IN DATA(309)
  874    C
  875          TLOC = TEMALT(ALT,ATMOS)
  876    C
  877    C     CALL FUNCTION TTO TO DETERMINE THE TOTAL TEMPERATURE
  878    C
  879          TTOT = TTO(XMACH,TLOC,IER)
  880    C
  881    C     INITIALIZE THE SKIN TEMPERATURE AT TOTAL TEMP
  882          XSKIN = TTOT
  883    C
  884    C     CALL FUNCTION SOLARG TO DETERMINE THE SOLAR FLUX  (COSPHI IS
  885    C     THE COSINE OF THE ANGLE TO THE SUN. A VALUE OF 1.0 IS IN
  886    C     THE PERMANENT DATA IN DATA(308)
  887    C
  888          SUN = SOLARG(ALT) * COSPHI
  889    C
  890    C     START THE ITERATION TO SOLVE THE EQUATION TEMP=A-B*TEMP**4
  891    C     IF THE LOOP DOES NOT CLOSE TO ONE-TENTH OF A DEGREE
  892    C     IN 90 ITERATIONS, THE TOLERANCE IS INCREASED TO ONE DEGREE
  893    C     IF THE LOOP DOES NOT CLOSE IN 10 MORE ITERATIONS, THE ERROR
  894    C     INDICATOR IS SET TO 15 AND THE TEMPERATURE FROM THE LAST
  895    C     ITERATION IS USED
  896    C
  897    C
  898       59 IPASS = IPASS + 1
  899    C
  900    C     CALL FUNCTION TBL TO DETERMINE THE BOUNDARY LAYER TEMPERATURE
  901    C
  902          BLT = TBL(XMACH,PRESS,TLOC,XSKIN,XLNGTH,SWEEP,TREY,METHO,IER,TTOT)
  903    C
  904    C     CALL FUNCTION HBL TO DETERMINE THE BOUNDARY LAYER
  905    C     HEAT TRANSFER COEFFICIENT
  906    C
  907          BLHTC = HBL(XMACH,PRESS,TLOC,XSKIN,XLNGTH,SWEEP,TREY,METHOD,IER,
  908         *  TTOT,BLT)
  909    C
  910    C     COMPUTE THE VALUES OF A AND B FOR THE EQUATION TEMP=A-B*TEMP**4
  911    C     THE ABSORPTIVITY (ABSORP) AND EMMISSIVITY (EMISS) ARE SET
  912    C     TO .85 IN THE PERMANENT DATA IN DATA(306) AND DATA(307)
  913    C
  914    C     *** NOTE THAT THE TERMS FOR THE HEAT TRANSFERRED TO THE SKIN ***
  915    C     *** FROM A HEAT SINK AND FROM AN EXTERNAL SOURCE, AND THE    ***
  916    C     *** TERMS FOR THE HEAT RADIATED TO A HEAT SINK, HAVE BEEN    ***
  917    C     *** OMITTED FROM THE EQUATIONS FOR A AND B. THIS IS THE SAME ***
  918    C     *** AS INPUTTING A VALUE OF 0.0 IN DD(9),DD(10),DD(11) AND   ***
  919    C     *** DD(15) IN THE ORIGINAL TEMPERATURE PROGRAM OBTAINED      ***
  920    C     *** FROM H. HAROLDSON                                        ***
  921    C
  922          A = (BLHTC*BLT + SUN*ABSORP) / BLHTC
```

```
CARD NO  ****                          CONTENTS                          ****
     923        B = 1714 E-12 * EMISS / BLHTC
     924   C
     925   C    CALL FUNCTION TSKIN TO SOLVE THE EQUATION TEMP=A-B*TEMP**4
     926   C
     927        XSKIN2 = TSKIN(A,B,CRIT,IER)
     928   C
     929   C    DETERMINE THE DIFFERENCE BETWEEN THE ASSUMED AND
     930   C    COMPUTED TEMPERATURE
     931   C
     932        XY = ABS(XSKIN2 - XSKIN)
     933   C
     934   C    SET THE ASSUMED TEMPERATURE FOR THE NEXT ITERATION EQUAL TO
     935   C    THE TEMPERATURE COMPUTED IN THIS ITERATION
     936   C
     937        XSKIN = XSKIN2
     938   C
     939        IPTEN = IPASS/10
     940   C
     941        IF(IPTEN - 9)103,101,102
     942   C
     943   101  CRIT = 1.0
     944        GO TO 103
     945   C
     946   102  IER = 15
     947        GO TO 105
     948   C
     949   C    COMPARE THE DIFFERENCE BETWEEN THE ASSUMED TEMPERATURE AND THE
     950   C    CALCULATED TEMPERATURE WITH THE TOLERANCE
     951   C
     952   103  IF(XY - CRIT)105,105,99
     953   C
     954   C    DETERMINE THE FINAL TEMPERATURE IN DEGREES F
     955   C
     956   105  XSKINF = AMAX1(XSKIN - 459.67 , 0.0)
     957   C
     958        RETURN
     959        END
     960   C
     961   C )))))))
```

```
CARD NO ****                                CONTENTS                                ****
  994       15 XP =(A/B)**0.25                                                    00000980
  995          YP = 0.0                                                           00000990
  996          XR =(XP * A)/ (XP + A)                                             00001000
  997          YR = A * (1.- (A/(XP +A))**4)                                      00001010
  998       C     ICOUNT IS A COUNTER FOR THE NUMBER OF PASSES USED IN CONVERGING. 00000934
  999          ICOUNT = 0                                                         00000935
 1000       C     AT THIS POINT WE START ITERATING                                00000936
 1001       21 ICOUNT = ICOUNT + 1                                               00000937
 1002          XNUM = XR*YP - XP*YR                                               00000940
 1003          DENOM = XR - XP - YR + YP                                          00000941
 1004       25 IF ( ABS(DENOM)-C)30,30,40                                        00000942
 1005       30 TSKIN = YR                                                        00000943
 1006          GO TO 70                                                           00000944
 1007       40 XS = XNUM / DENOM                                                 00000950
 1008          YS = A - B * XS**N                                                 00000951
 1009       C     COMPARE TRIAL (XS) OF SKIN TEMPERATURE WITH COMPUTED VALUE (YS). 00000960
 1010       C     IF SATISFACTORILY CLOSE RETURN TOMAIN PROGRAM. OTHERWISE SELLECT 00000961
 1011       C     A NEW TRIAL VALUE BASED ON THE TWO PREVIOUS SETS OF NUMBERS.     00000962
 1012       45 IF( ABS(XS-YS) -C)60,60,50                                        00000963
 1013       50 XP = XR                                                           00000970
 1014          YP = YR                                                           00000971
 1015          XR = XS                                                           00000972
 1016          YR = YS                                                           00000973
 1017          IF( ICOUNT - 50 )21,21,55                                         00000974
 1018       55 IER = 16                                                          00000975
 1019       60 TSKIN = YS                                                        00000980
 1020       70 RETURN                                                            00000981
 1021          END
 1022    C
 1023    C )))))))
```

```
CARD NO  ****                          CONTENTS                          ****
1085            IER = 0                                                  TOT=0195
1086          10 DELTAT = VEL**2/2./32 174/778 26/SPHTI                  TOT=0200
1087            TTO = TO + DELTAT                                        TOT=0205
1088            EXP2 =  EXP(5526./TTO)                                   TOT=0210
1089            SPHTA = 0.06856/DELTAT * ( 3.5*DELTAT + 5526 /( EXP2 - 1.000)  TOT=0215
1090           |   -5526./(EXP1 - 1.000 ))                               TOT=0220
1091            IND = IND+1                                              TOT=0225
1092            IF( ABS(SPHTA-SPHTI)/SPHTI)-.0001)50,20,20               TOT=0230
1093          20 IF(IND-100)30,30,40                                     TOT=0235
1094          30 SPHTI = SPHTA                                           TOT=0240
1095             GO TO 10                                                TOT=0245
1096          40 TTO = TO * (1. + XMACH**2/5.)                           TOT=0250
1097             IER = 1                                                 TOT=0255
1098          50 RETURN                                                  TOT=0260
1099             END                                                     TOT=0265
1100       C
1101       C )))))))
```

```
1136            ST(N) = TH(NN)
1137            NN = 175 + 25*N
1138            TEMP(N) = TH(NN)
1139            IF(TH(NN+2))838,838,839
1140          838 Q(N) = 0.0
1141            GO TO 840
1142          839 Q(N) = TH(NN+4) / TH(NN+2) / 2.0 / (1.0+TH(NN+1))
1143          840 CONTINUE
1144        C
1145        C     **** DETERMINE S80, THE STRESS LEVEL AT 80 DEGREES,****
1146        C     **** AND NTEMP, THE NUMBER OF VALUES IN THE        ****
1147        C     **** STRESS AND TEMPERATURE TABLES                 ****
1148        C
1149            IF(TEMP(2))801,801,805
1150        C
1151          801 NTEMP = 1
1152            S80 = ST(1)
1153            GO TO 850
1154        C
1155          805 NTEMP = 6
1156        C
1157            DO 810 N=3,6
1158            IF(TEMP(N))807,807,810
1159          807 NTEMP = N - 1
1160            GO TO 815
1161          810 CONTINUE
1162        C
1163          815 IF(80.0 - TEMP(1))820,820,825
1164        C
1165          820 L1 = 1
1166            L2 = 2
1167            GO TO 845
1168        C
1169          825 IF(80.0 - TEMP(NTEMP))835,835,830
1170        C
1171          830 L1 = NTEMP - 1
1172            L2 = NTEMP
1173            GO TO 845
1174        C
1175          835 DO 840 N=2,NTEMP
1176            IF(80.0 - TEMP(N))836,836,840
1177          836 L1 = N - 1
1178            L2 = N
1179            GO TO 845
1180          840 CONTINUE
1181        C
1.82          845 S80 = ST(L2) - (ST(L2) - ST(L1)) *
1133             *   (TEMP(L2) - 80.0) / (TEMP(L2) - TEMP(L1))
1184        C
1185          850 CONTINUE
1186        C
1187          852 IF(IP(4))5001,5001,5002
1188         5001 CONTINUE
1189            IF(IND)669,669,668
1190          669 WRITE(6,670)
1191          670 FORMAT(1H1,80X,21H** WWVMAT - IP(4)) **)
1192            IND = 1
1193          668 CONTINUE
1194        C
1195            GO TO(671,672,673),I
1196        C
1197          671 WRITE(6,685)
1198          685 FORMAT(  45X,12H*** WING *** )
1199            GO TO 650
.200        C
:201          672 WRITE(6,686)
:202          686 FORMAT(  /40X,23H*** HORIZONTAL TAIL *** )
:203            GO TO 650
:204        C
:205          673 WRITE(6,687)
:206          687 FORMAT(  /40X,21H*** VERTICAL TAIL *** )
```

```
      C
      C
        850 WRITE(6,49)(TH(N),N=285,300)
        49 FORMAT(10X,8A10/10X,8A10//30X,11HTEMPERATURE,5X,12HSTRESS (PSI),
       *  10X,7H0 (PSI)/)
      C
            DO 50 N=1,6
        50 WRITE(6,51)TEMP(N),ST(N),O(N)
        51 FORMAT(33X,F6.0,9X,F8.0,9X,F11.0)
      C
            WRITE(6,52)S80
        52 FORMAT(/30X,20HSTRESS AT 80 DEGREES,F10.0)
      C
      5002 CONTINUE
      C
            GO TO (681,682,683),I
      C
        681 DO 691 N=1,6
            OW(N) = O(N)
            STW(N) = ST(N)
        691 TEMPW(N) = TEMP(N)
            NWING = NTEMP
            S80W = S80
            GO TO 600
      C
        682 DO 692 N=1,6
            OH(N) = O(N)
            STH(N) = ST(N)
        692 TEMPH(N) = TEMP(N)
            NHOR  = NTEMP
            S80H = S80
            GO TO 600
      C
        683 DO 693 N=1,6
            OV(N) = O(N)
            STV(N) = ST(N)
        693 TEMPV(N) = TEMP(N)
            NVER  = NTEMP
            S80V = S80
      C
        600 CONTINUE
            RETURN
            END
      C
      C !!!!
```

```
CARD NO  ****                          CONTENTS                          ****
 1278          EQUIVALENCE (DATA(305),VFF)
 1279     C
 1280          EQUIVALENCE (SWF(145),TEMPV(1)),(SWF(159),TEMPH(1))
 1281         * , (SWF(173),TEMPV(11)),(SWF(151),NWING),(SWF(165),NHOR)
 1282         * , (SWF(179),NVER)
 1283     C
 1284          EQUIVALENCE (SPAL(16),FM),(SPAL(17),ALTA(1))
 1285         * , (SPAL(26),XMA(1)),(SPAL(35),ALTF(1)),(SPAL(38),XMF(1))
 1286         * , (SPAL(41),AMF),(SPAL(42),XMMF),(SPAL(43),TMF)
 1287         * , (SPAL(44),QQMF),(SPAL(45),GMF)
 1288          EQUIVALENCE (QTT,SPAL(9)),(CTT,SPAL(11)),(XMTD,SPAL(8))
 1289         * ,(TSF(1),SPAL(46)),(TFTT,SPAL(49))
 1290          EQUIVALENCE (PC,GJDAT(18)),(CTTD1,GJDAT(19)),(CTTD2,GJDAT(20))
 1291         * , (CTTM(1),GJDAT(21)),(CTT1(1),GJDAT(41)),(CTT2(1),GJDAT(61))
 1292     C
 1293     C       CALL MMVMAT TO GET MATERIAL PROPERTIES FOR CRITICAL LOAD
 1294     C       CALCULATION IN OVERLAY 4
 1295     C       ALSO FOR CALCULATION OF SHEAR MODULUS AT CRITICAL
 1296     C       FLUTTER CONDITIONS
 1297          CALL MMVMAT
 1298     C
 1299     C       READ SPEED PROFILE RECORD 38
 1300     C       RECORD 38 WRITTEN IN DATA MANAGEMENT MODULE
 1301     C
 1302          CALL READMS(1,SPAL(1),50,38)
 1303     C
 1304     C       CALCULATE FLUTTER PARAMETER, CALL SWFTAB
 1305          CALL SWFTAB
 1306          DO 10 I=1,3
 1307          IT(I) = 0
 1308       10 CONTINUE
 1309     C
 1310     C       TEST IF FLUTTER MARGIN SETUP IN RECORD 38
 1311     C       IF NOT USE LIBRARY VALUE
 1312          IF(FM) 12,12,14
 1313       12 FM = VFF
 1314       14 FMM = FM**2
 1315     C
 1316          IF(IP(4)) 20,20,30
 1317       20 WRITE(6,24) FM
 1318       24 FORMAT(1H1,40X,22HFLUTTER SPEED MARGIN =,F5.2,22X,
 1319         * 20H** MMVOO - IP(4) **)
 1320     C
 1321     C       J = 1 PASS THROUGH LOOP 500 FOR MARGIN ON FLUTTER SPEED
 1322       30 J = 1
 1323     C
 1324     C       N = 9 IS NUMBER OF SPEED ALTITUDE PROFILE POINTS
 1325          N = 7
 1326     C
 1327     C       CALCULATE INCOMPRESSIBLE Q FOR MIL) DIAGRAM WINGS FIXED OR AFT
 1328          DO 35 I=1,N
 1329          PO = PRESH(ALTA(I))
 1330          TO = TEMALT(ALTA(I),1.0)
 1331          CALL QINC(XMA(I),PO,TO,QA(I))
 1332          XMN(I) = FM*XMA(I)
 1333          Q(I) = FMM*QA(I)
 1334       35 CONTINUE
 1335     C
 1336     C
 1337     C
 1338     C       LOOP ENTERED THICE ONCE FOR FLUTTER SPEED MARGIN AND
 1339     C       AGAIN FOR FLUTTER Q MARGIN
 1340     C       J = 2 IS PASS THROUGH LOOP 500 FOR FLUTTER Q MARGIN
 1341       99 DO 500 K=1,3
 1342     C
 1343     C       K = 1 WING     K = 2 HORIZONTAL    K = 3 VERTICAL
 1344          GO TO (100,200,300),K
 1345      100 IF(TFM(2)) 500,500,102
 1346      102 DO 110 I=1,38
 1347          TF(I) = TFM(I)
 1348      110 CONTINUE
```

```
CARD NO  ****                          CONTENTS                          ****
1349        115 CALL OSUB(N)
1350            DO 120 I=1,N
1351            IF(XMISC(K+4) - QQ(I)) 122,120,120
1352        122 XMISC(K+4) = QQ(I)
1353            IF(K) = 1
1354            XM(K) = XMATOP(I)
1355        120 CONTINUE
1356            GO TO 400
1357        200 IF(TFH(2)) 500,500,202
1358        202 DO 210 I=1,38
1359            TF(I) = TFH(I)
1360        210 CONTINUE
1361            GO TO 115
1362        300 IF(TFV(2)) 500,500,302
1363        302 DO 310 I=1,38
1364            TF(I) = TFV(I)
1365        310 CONTINUE
1366            GO TO 115
1367        400 IF(IP(41)) 402,402,500
1368        402 GO TO (410,420,430),K
1369        410 WRITE(6,412)
1370        412 FORMAT(1H0,45X,17HWING FIXED OR AFT)
1371            GO TO 440
1372        420 WRITE(6,422)
1373        422 FORMAT(1H0,46X,15HHORIZONTAL TAIL)
1374            GO TO 440
1375        430 WRITE(6,432)
1376        432 FORMAT(1H0,47X,13HVERTICAL TAIL)
1377        440 WRITE(6,442)
1378        442 FORMAT(19X,29HSPEED-ALTITUDE PROFILE POINTS,12X,14HFLUTTER DESIGN/
1379           * 82X,12HCOMPRESSIBLE/19X,8HALTITUDE,6X,4HMACH,5X,7HDYNAMIC,11X,
1380           * 4HMACH,5X,7HDYNAMIC,9X,7HDYNAMIC / 21X,4HFEET,7X,6HNUMBER,3X,
1381           * 8HPRESSURE,10X,6HNUMBER,3X,8HPRESSURE,8X,8HPRESSURE)
1382            WRITE(6,444) (ALTA(I),XMA(I),QA(I),XMNI(I),QI(I),QQ(I),I=1,N)
1383        444 FORMAT(16X,F11.0,F11.4,F11.1,5X,F11.4,F11.1,5X,F11.1)
1384        500 CONTINUE
1385        C
1386        C       END LOOP 500 PASS THROUGH CRITICAL COMPRESSIBLE Q
1387            IF(J-1) 510,510,600
1388        510 J = 2
1389            IF(IP(41)) 512,512,520
1390        512 WRITE(6,514) FMM
1391        514 FORMAT(1H1,42X,18HFLUTTER Q MARGIN =,F7.4,22X,
1392           *    20H** MMVQQ - IP(41) **)
1393        520 DO 530 I=1,N
1394            XMNI(I) = XMA(I)
1395        530 CONTINUE
1396            GO TO 99
1397        C
1398        C       CHECK FOR VARIABLE SWEEP WING VEHICLE WITH WING IN
1399        C       FORWARD POSITION  STATEMENTS 600 THROUGH 672
1400        600 IF(TFWF(2)) 700,700,602
1401        602 IF(IP(41)) 604,604,610
1402        604 WRITE(6,22)
1403         22 FORMAT(1H1,88X,20H** MMVQQ - IP(41) **)
1404            WRITE(6,606)
1405        606 FORMAT(1H0,48X,12HWING FORWARD)
1406            WRITE(6,25) FM
1407         25 FORMAT(1H0,40X,22HFLUTTER SPEED MARGIN =,F5.2)
1408        C
1409        C       N = 3 IS NUMBER OF SPEED ALTITUDE PROFILE POINTS
1410        610 N = 3
1411            J = 1
1412            DO 620 I=1,N
1413            PO = PRESH(ALTF(I))
1414            TO = TEMALT(ALTF(I),1.0)
1415            CALL QINC(XMF(I),PO,TO,QA(I))
1416            XMNI(I) = FM*XMF(I)
1417            Q(I) = FMM*QA(I)
1418        620 CONTINUE
1419            DO 630 I=1,38
```

```
1420            TF(I) = TFMF(I)
1421          630 CONTINUE
1422            QQMF = 0.0
1423            ITM = 0
1424          640 CALL QSUBIN(I)
1425            DO 642 I=1,N
1426            IF(QQMF - QQ(I)) 644,642,642
1427          644 QQMF = QQ(I)
1428            ITM = I
1429            XMMF = XMATOP(I)
1430          642 CONTINUE
1431            IF(J-1) 650,650,670
1432          650 IF(IP(4)) 652,652,660
1433          652 WRITE(6,442)
74              WRITE(6,444) (ALTF(I),XMF(I),QA(I),XMN(I),Q(I),QQ(I),I=1,N)
1435          660 J = 2
1436            DO 662 I=1,N
1437            XMN(I) = XMF(I)
1438          662 CONTINUE
1439            GO TO 640
1440          670 IF(IP(4)) 672,672,700
1441          672 WRITE(6,515) FMM
1442          515 FORMAT(1H0,42X,18HFLUTTER Q MARGIN =,F7.4)
1443            WRITE(6,442)
1444            WRITE(6,444) (ALTF(I),XMF(I),QA(I),XMN(I),Q(I),QQ(I),I=1,N)
1445        C
1446        C       * * *  T-TAIL FLUTTER  * * *
1447        C
1448          700 IF(XMISC(53)) 800,800,702
1449          702 CALL READMS(I,GJDAT(1),100,37)
1450            N = 9
1451            J = 1
1452            CTT = 0.0
1453            ITT = 0
1454            QTT = 0.0
1455            FACTI = 0.0
1456            NP = PC
1457            DTT = ABS(SPAL(12))
1458            DO 710 I=1,N
1459            XMN(I) = FMM*XMA(I)
1460            Q(I) = FMM*QA(I)
1461          710 CONTINUE
1462        C
1463        C       * * *  START LOOP 760  * * *
1464        C
1465          712 DO 760 I=1,N
1466        C     FIND CTT VALUE FROM CURVE DATA - - -
1467        C         CTTD1, CTTD2  TWO DIHEDRAL ANGLES FOR WHICH CURVES ARE GIVEN
1468        C
1469            IFEXT = 1
1470            IF(XMN(I) - CTTM(1)) 714,724,716
1471          714 IC = 2
1472            GO TO 720
1473          716 DO 718 K=2,NP
1474            IC = K
1475            IF(XMN(I) - CTTM(K)) 722,726,718
1476          718 CONTINUE
1477          720 IFEXT = 2
1478        C       2 POINT INTERPOLATION OR EXTRAPOLATION.
1479          722 TMP = (XMN(I) - CTTM(IC-1))/(CTTM(IC) - CTTM(IC-1))
1480            CTTL = CTT1(IC-1) + (CTT1(IC) - CTT1(IC-1))*TMP
1481            CTTU = CTT2(IC-1) + (CTT2(IC) - CTT2(IC-1))*TMP
1482            GO TO 728
1483        C       1 POINT - MACH EQUAL TO CURVE POINT.
1484          724 IC = 1
1485          726 CTTL = CTT1(IC)
1486            CTTU = CTT2(IC)
1487        C     CROSS PLOT
1488          728 IF(DTT - CTTD1) 738,730,732
1489          730 TT(I) = CTTL
1490            GO TO 740
```

```
CARD NO      ****                          CONTENTS                          ****
    1491        732 IF(DTT - CTTD2) 738,734,736
    1492        734 TT(I) = CTTU
                    GO TO 740
    1494        736 IFEXT = 2
    1495        738 TT(I) = CTTL + (DTT - CTTD1)/(CTTD2 - CTTD1)*(CTTU - CTTL)
    1496          C
    1497        740 IF(IFEXT - 2) 746,742,746
    1498        742 WRITE(6,744) XMN(I),TT(I)
    1499        744   FORMAT( 6OH0***** EXTRAPOLATED ON T-TAIL STIFFNESS COEFF. FOR M
                   1ACH NO.,  1F6.2,  6H, CTT = , 1E9.3 )
    1501        746 FACT(I) = Q(I)*TT(I)
    1502            IF(FACTI - FACT(I)) 740,760,760
    1503        748 CTT = TT(I)
    1504            QTT = Q(I)
    1505            ITT = I
    1506            FACTI = FACT(I)
    1507            XMTO = XMN(I)
    1508        760 CONTINUE
    1509          C
    1510          C       * * *  END LOOP 760  * * *
    1511          C
    1512            IF(J-1) 762,762,780
    1513        762 IF(IP(4)) 764,764,772
    1514        764 WRITE(6,22)
    1515            WRITE(6,766) SPAL(12)
    1516        766 FORMAT(1H0,37X,14HT-TAIL FLUTTER,5X,10HDIHEDRAL =,F5.1)
    1517            WRITE(6,25) FM
    1518            WRITE(6,768)
    1519        768 FORMAT(11X,29HSPEED-ALTITUDE PROFILE POINTS,12X,14HFLUTTER DESIGN/
                   * 11X,8HALTITUDE,6X,4HMACH,5X,7HDYNAMIC,11X,4HMACH,5X,7HDYNAMIC,
                   *  9X,3HCTT,12X,5HQ*CTT/13X,4HFEET,7X,8HNUMBER,3X,8HPRESSURE,
                   * 10X,8HNUMBER,3X,8HPRESSURE)
                    WRITE(6,770)(ALTA(I),XMA(I),QA(I),XMN(I),Q(I),TT(I),FACT(I),
                   * I=1,N)
    1525        770 FORMAT(8X,F11.0,F11.4,F11.1,5X,F11.4,F11.1,2E16.8)
    1526        772 J = 2
                    DO 774 I=1,N
                    XMN(I) = XMA(I)
    1529        774 CONTINUE
                    GO TO 712
    1531        780 IF(IP(4)) 782,782,800
    1532        782 WRITE(6,515) FM
                    WRITE(6,768)
                    WRITE(6,770)(ALTA(I),XMA(I),QA(I),XMN(I),Q(I),TT(I),FACT(I),
                   * I=1,N)
                    WRITE(6,784)
    1537        784 FORMAT(1H0,48X,12HDESIGN POINT/)
                    WRITE(6,768)
                    WRITE(6,770)ALTA(ITT),XMA(ITT),QA(ITT),XMTO,QTT,CTT,FACTI
    1540          C
    1541          C       CALCULATE SKIN TEMPERATURE AT CRITICAL FLUTTER SPEED AND
    1542          C       ALTITUDE
    1543        800 DO 810 I=1,2
                    IF(IT(I)) 810,810,812
    1545        812 K = IT(I)
                    AL(I) = ALTA(K)
                    CALL TEMPER(XM(I),AL(I),PRE,TLOC,TTOT,SFX,TSKR,TSF(I),IER)
    1548        810 CONTINUE
    1549          C
    1550          C       CALCULATE SKIN TEMPERATURE AT CRITICAL FLUTTER SPEED AND
    1551          C       ALTITUDE FOR WING IN FORWARD POSITION ON VARIABLE SWEEP WING
                    IF(ITWF(2)) 850,850,820
    1553        820 AWF = ALTF(ITW)
                    CALL TEMPER(XMWF,AWF,PRE,TLOC,TTOT,SFX,TSKR,TWF,IER)
    1555          C
    1556          C
    1557          C       CALCULATE TEMPERATURE AT MAXIMUM LIMIT DYNAMIC PRESSURE
    1558          C
    1559        850 IF(XMISC(53)) 899,899,852
    1560        852 XMTT = XMA(ITT)
                    ALTT = ALTA(ITT)
```

```
CARD NO  ****                          CONTENTS                          ****
1562     C        TFTT = SKIN TEMPERATURE AT LIMIT SPEED FOR MAXIMUM Q
1563           CALL TEMPERI(HIT,ALTT,PRE,TLOC,TTOT,SFX,TSKR,TFTT,IER)
1564     C
1565     C     **** LOOP 900                                          ****
1566     C     **** DETERMINE Q FOR THE WING, HORIZONTAL AND VERTICAL  ****
1567     C     **** (QWING,QHT,QVT) AT THE CONDITION WHICH GIVES  **** 
1568     C     **** THE MAXIMUM PRESSURE                              ****
1569     C
1570       899 QWING = 0.0
1571           QHT = 0.0
1572           QVT = 0.0
1573     C
1574           DO 900 K=1,5
1575     C
1576     C
1577     C        K = 1 WING FIXED OR AFT   K = 2 HORIZONTAL     K = 3 VERTICAL
1578     C        K = 4 WING FORWARD, VARIABLE SWEEP WING
1579     C        K = 5 VERTICAL TAIL FOR T-TAIL
1580     C
1581           GO TO (901,902,903,904,903),K
1582     C
1583       901 IF(XMISC(15))900,900,921
1584     C
1585       921 DO 905 N=1,6
1586           TEMP(N) = TEMPW(N)
1587       905 Q(N) = QW(N)
1588           QTEMP = TSF(1)
1589           NTEMP = NWING
1590           GO TO 910
1591     C
1592       902 IF(XMISC(19))900,900,922
1593     C
1594       922 DO 906 N=1,6
1595           TEMP(N) = TEMPH(N)
1596       906 Q(N) = QH(N)
1597           QTEMP = TSF(2)
1598           NTEMP = NHOR
1599           GO TO 910
1600     C
1601       903 IF(XMISC(23))900,900,923
1602     C
1603       923 DO 907 N=1,6
1604           TEMP(N) = TEMPV(N)
1605       907 Q(N) = QV(N)
1606           NTEMP = NVER
1607           IF(K - 3) 908,908,909
1608       908 QTEMP = TSF(3)
1609           GO TO 910
1610       909 IF(XMISC(53)) 909,900,916
1611       916 QTEMP = TFTT
1612           GO TO 910
1613       904 IF(TWF(2)) 900,900,931
1614       931 IF(XMISC(15)) 900,900,932
1615       932 DO 935 N=1,6
1616           TEMP(N) = TEMPW(N)
1617       935 Q(N) = QW(N)
1618           QTEMP = TWF
1619           NTEMP = NWING
1620     C
1621       910 IF(NTEMP - 1)952,952,955
1622     C
1623       952 QQ = Q(1)
1624           GO TO 990
1625     C
1626       955 IF(QTEMP - TEMP(1))960,960,965
1627     C
1628       960 L1 = 1
1629           L2 = 2
1630           GO TO 985
1631     C
1632       965 IF(QTEMP - TEMP(NTEMP))975,975,980
```

```
CARD NO  ****                          CONTENTS                          ****
1633        C
1634          980 L1 = NTEMP - 1
1635              L2 = NTEMP
1636              GO TO 985
1637        C
1638          975 DO 982 N=2,NTEMP
1639              IF(QTEMP - TEMP(N))976,976,982
1640          976 L1 = N-1
1641              L2 = N
1642              GO TO 985
1643          982 CONTINUE
1644        C
1645          985 GG = Q(L2) - (Q(L2)-Q(L1)) * (TEMP(L2)-QTEMP)/(TEMP(L2)-TEMP(L1))
1646        C
1647          990 GO TO (911,912,913,914,915),K
1648        C
1649          911 QWING = GG
1650              GO TO 900
1651        C
1652          912 QHT = GG
1653              GO TO 900
1654        C
1655          913 QVT = GG
1656              GO TO 900
1657        C
1658          914 QWF = GG
1659              GO TO 900
1660        . 915 SPAL(10) = GG
1661          900 CONTINUE
1662        C
1663              XMISC(28) = QWING
1664              XMISC(29) = QHT
1665              XMISC(30) = QVT
1666        C
1667        C       WRITE SUMMARY FOR CRITICAL FLUTTER WING FIXED OR AFT,
1668        C       HORIZONTAL TAIL, AND VERTICAL TAIL
1669        C
1670              IF(IP(4)) 992,992,1000
1671        C
1672          992 IF(TFWF(2))997,997,998
1673          998 WRITE(6,999)
1674          999 FORMAT(///////)
1675              GO TO 1005
1676          997 WRITE(6,22)
1677        C
1678         1005 WRITE(6,994)
1679          994 FORMAT(33X,42H*** DESIGN TEMPERATURE, PRESSURE AND Q *** //18X,
1680             * 13HPROFILE POINT,4X,8HALTITUDE,3X,8HMACH NO.,3X,11HTEMPERATURE,
1681             * 3X,8HPRESSURE,4X,7HQ (PSI) )
1682              WRITE(6,996) (I,T(I),M(I),XM(I),TSF(I),XMISC(I+4),XMISC(I+27),
1683             * I=1,3)
1684          996 FORMAT(6X,4HWING,8X,I7,6X,F11.0,F11.4,F14.1,F11.1,F11.0/
1685             * 6X,10HHORIZONTAL,2X,I7,6X,F11.0,F11.4,F14.1,F11.1,F11.0/
1686             * 6X,8HVERTICAL,4X,I7,6X,F11.0,F11.4,F14.1,F11.1,F11.0)
1687        C
1688        C
1689         1000 CALL WRITMS(1,SPAL(1),50,38)
1690        C
1691        C
1692        C
1693              RETURN
1694              END
```

Section V

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PART 3

FATIGUE MODULE

Section I

INTRODUCTION AND SUMMARY

PROGRAM OBJECTIVES

The objective of the fatigue module is to provide a means for evaluating fatigue requirements commensurate with the preliminary design definitions of structural components. In this phase of vehicle synthesis, it is not practical to examine all of the structural elements. Therefore, the scope of this module has been limited to the evaluation of components which would most probably be designed by fatigue considerations. These components are the wing lower cover subjected to bending loads and fuselage panels subjected to cyclic pressurization.

APPROACH TO FATIGUE EVALUATION

Fatigue life prediction by the method of "strain cycling" has been selected for use in the structural weight estimation program.

Strain cycling evaluates fatigue damage in two categories, or blocks, corresponding to material fatigue behavior observed under cyclic loading. After an unnotched specimen has been cycled between fixed fully reversed strain limits to approximately 20 percent of its fatigue life, the material stabilizes and no further change will take place. These stabilized values of stress and strain more closely represent material behavior than conventional stress-strain diagrams. Stabilized values are plotted in a "cyclic" stress-strain curve. In addition, a curve relating strain amplitude to fatigue life is derived from experimental data. These curves are used to derive fundamental equations, which are summarized in this report.

The stress level at the edge of a notch may often be greater than the yield stress, but the preponderant elastic region forces the limited yield region to be strain controlled. Some tests have shown that failure of the notched specimen is precipitated at the edge of the notch in the same number of cycles as an unnotched specimen subjected to the same strain range. Using equivalent unnotched strain, in conjunction with unnotched strain-cycling material curves, the life of a notched specimen can be predicted for a wide range of strain amplitudes. This range includes the case of fully reversed cycles ($R = -1$). The strain amplitude of the notch is determined from the hysterisis curves, which are defined in this report. Then, by assuming linearity between cyclic strain amplitude and cyclic mean stress for a given life in the modified Goodman Diagram, the equivalent strain at edge of notch is obtained for $R = -1$.

The residual stress used in the second and subsequent blocks is that residual generated by the largest strain range in the first block. The differences between this residual stress and residual stress generated for each level are added to the mean stress for each level in the second and subsequent blocks. This mean stress is next added to stress amplitude to determine the new maximum and minimum stresses. Finally, the life for each load level is determined using the modified Goodman diagram and Miner's rule.

SUMMARY OF ANALYSIS CAPABILITIES

The strain cycling approach is used to obtain allowable design tensile stress for the wing lower cover and for fuselage components. Material property, spectrum, and construction data are used to obtain this fatigue "cutoff stress." Material property and construction data required by this program are:

- Ultimate tensile strength, psi
- Modulus of elasticity, psi
- Reduction of area, RA
- Elastic stress concentration factor, K_t

Required criteria data consist of:

- Spectrum data
- Reference design load
- Service life
- Scatter factor

Wing bending moment spectra are evaluated at two wing stations. Bending moments are correlated to nominal stresses for which life calculations are performed. An iteration procedure is used to solve for nominal spectrum stresses that meet the required vehicle life. Correlation between strength design bending moment and the spectrum bending moments provides an allowable tensile stress at the reference loading.

Fuselage cover and minor frame material fatigue evaluation is performed for pressure cycling and material endurance limit. Spectrum pressures are correlated to nominal stresses, and calculations for life are performed. Assuming that the design pressure is the maximum pressure defined by the spectrum, the allowable tensile stress is also the maximum nominal stress that satisfies required vehicle life.

Endurance limit is required for fuselage acoustic fatigue evaluation. The calculations are performed for:

- Elastic stress concentration factor, K_t, equal to one (polished specimen)
- Fully reversing load (R = -1)
- Infinite number of cycles ($n = 10^9$)

MODULE STRUCTURE AND OPERATION

This program is written in FORTRAN IV extended programming language for operation on the CDC 6600 computer and is structured in a single overlay within 50,000 octal core locations. This module may be executed as a stand-alone program, or as part of the integrated structural weight estimation program. In the stand-alone mode, wing bending moment spectra, fuselage pressure spectrum, and component material identification number are required input. In the integrated mode, wing bending moment spectra is provided by the airload module.

Program printed output is controlled by user specifications. The output consists of input data tables and intermediate steps in the life calculations. Error messages are printed, should certain convergence problems occur. These messages contain pertinent data and description of the calculation process involved.

Section II

METHODS AND FORMULATIONS

GENERAL DISCUSSION OF METHODOLOGY

The analytical foundation for the strain cycling method has been obtained from references 1 through 11. This report discusses some of the background, but is basically oriented toward the discussion of actual programmed equations and solutions. This manual discusses the strain cycling method and its application to vehicle spectrum loading evaluation and life prediction.

FATIGUE FORMULATIONS

CYCLIC STRESS-STRAIN RELATIONSHIPS

The basic equations of all stress analysis are the equilibrium equations involving stresses and the compatibility equations involving total strains. The relationship between stress range and total strain range will suffice in many applications involving cyclic straining, but it is desirable to separate the total strain into elastic and plastic components (equation 1) and to express each of these components in terms of cyclic life.

$$\epsilon_t = \epsilon_{e\ell} + \epsilon_p \tag{1}$$

If a plot is made on logarithmic coordinates of the strain range versus the number of cycles to failure, the result is found to be very nearly two straight lines, as shown in Figure 30.

The cyclic life, N_f, is related to the plastic strain per cycle, ϵ_p, by a power law (equation 2).

$$\epsilon_p = C_2 N_f^{-\gamma} \tag{2}$$

where C_2 and γ are material constants.

If the stress range at the half life is divided by the elastic modulus, the quotient can be regarded as the elastic-strain range associated with the cyclic life N_f. A plot of this strain versus cyclic life on log.-log.

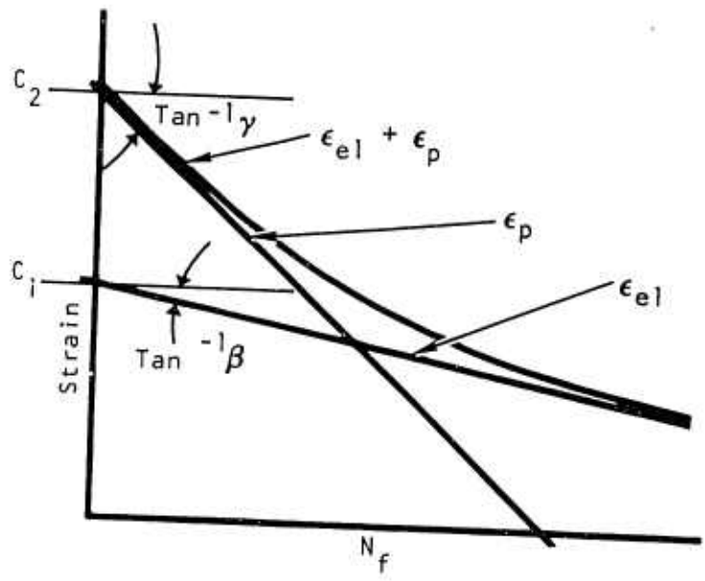


Figure 30. Strain range versus number of cycles to failure.

coordinates also results in a reasonably straight line (Figure 30). This elastic strain, $\epsilon_{e\ell}$, can also be defined by a power law, as shown in equation 3.

$$\epsilon_{e\ell} = C_1 N_f^{-\beta} \tag{3}$$

where C_1 and β are other material constants.

By definition, elastic strain is proportional to stress (equation 4) such that cyclic life can be defined as shown in equation 5.

$$\epsilon_{e\ell} = \frac{\sigma}{E} \tag{4}$$

$$N_f = \left(\frac{C_1 E}{\sigma}\right)^{1/\beta} \tag{5}$$

The total strain can then be defined by equation 6 or 7.

$$\epsilon_t = C_1 N_f^{-\beta} + C_2 N_f^{-\gamma} \tag{6}$$

$$\epsilon_t = \frac{\sigma}{E} + C_2 \left(\frac{\sigma}{C_1 E} \right)^{\gamma/\beta} \tag{7}$$

Material constants C_1, C_2, β, and γ are not readily available for most structural materials. However, these constants can be approximated from empirical relationships which use material properties obtained from tensile tests. Material properties that are determined from tensile tests are E, F_{tu}, and RA.

Where

F_{tu} = ultimate tensile strength, psi

RA = reduction in area as defined by equation 8

$$RA = \frac{A_o - A_f}{A_o} \tag{8}$$

Where

A_o = initial specimen cross-section area

A_f = final fracture cross-section area

Ductility, D, is defined as a logarithmic value based on measurement of area (equation 9).

$$D = \ln\left(\frac{A_o}{A_f}\right) = \ln\left(\frac{1}{1-RA}\right) \tag{9}$$

Fracture stress, σ_f, is determined from equation 10.

$$\sigma_f = F_{tu}(1+D) \tag{10}$$

Equations 11 through 14 can then be used to obtain approximations of the material constants that define the cyclic stress-strain curve.

$$\beta = 0.0792 + 0.179 \log. \left(\frac{\sigma_f}{F_{tu}}\right) \tag{11}$$

$$\gamma = \log. \left[\frac{3.31 \sqrt[4]{D}}{\sqrt[3]{1 - 81.4 \frac{F_{tu}}{E}\left(\frac{\sigma_f}{F_{tu}}\right)^{0.179}}} \right] \tag{12}$$

$$C_1 = 1.12 \frac{F_{tu}}{E} \left(\frac{\sigma_f}{F_{tu}}\right)^{0.893} \tag{13}$$

$$C_2 = 0.125 (D)^{0.75} (10)^{\gamma} \tag{14}$$

STRESS AND STRAIN AT EDGE OF NOTCH

The cyclic stress at the edge of the notch, σ_{max}, is obtained by Neuber's rule (equation 15).

$$E\sigma\varepsilon = \left(K_t f_{max}\right)^2 \tag{15}$$

Where

K_t = elastic stress concentration factor

f_{max} = nominal net section maximum stress for a cycle, psi

If strain at the notch (equation 7) is substituted in equation 15, the maximum stress can be represented by equation 16.

$$E\sigma_{max}\left[\frac{\sigma_{max}}{E} + C_2\left(\frac{\sigma_{max}}{C_1E}\right)^{\gamma/\beta}\right] = (K_t f_{max})^2 \qquad (16)$$

Equation 17 is another form of equation 16 which can be solved for stress by successive iterations.

$$\sigma_{max}^2 + \frac{C_2E}{(C_1E)^{\gamma/\beta}}\sigma_{max}^{(\gamma/\beta + 1)} - (K_t f_{max})^2 = 0 \qquad (17)$$

For this maximum stress at the edge of the notch, the maximum strain, ϵ_{max}, is calculated from equation 7.

HYSTERESIS CURVES

Hysteresis curves are dependent on the relationship between the nominal net section maximum and minimum stress for a cycle. The two unique cases are depicted in Figures 31 and 32.

Points on the hysteresis curves are defined for any stress ratio and effective stress concentration factor K_n. Neuber's formula (equation 18) defines K_n in terms of the elastic stress concentration factor, K_t, and notch geometry.

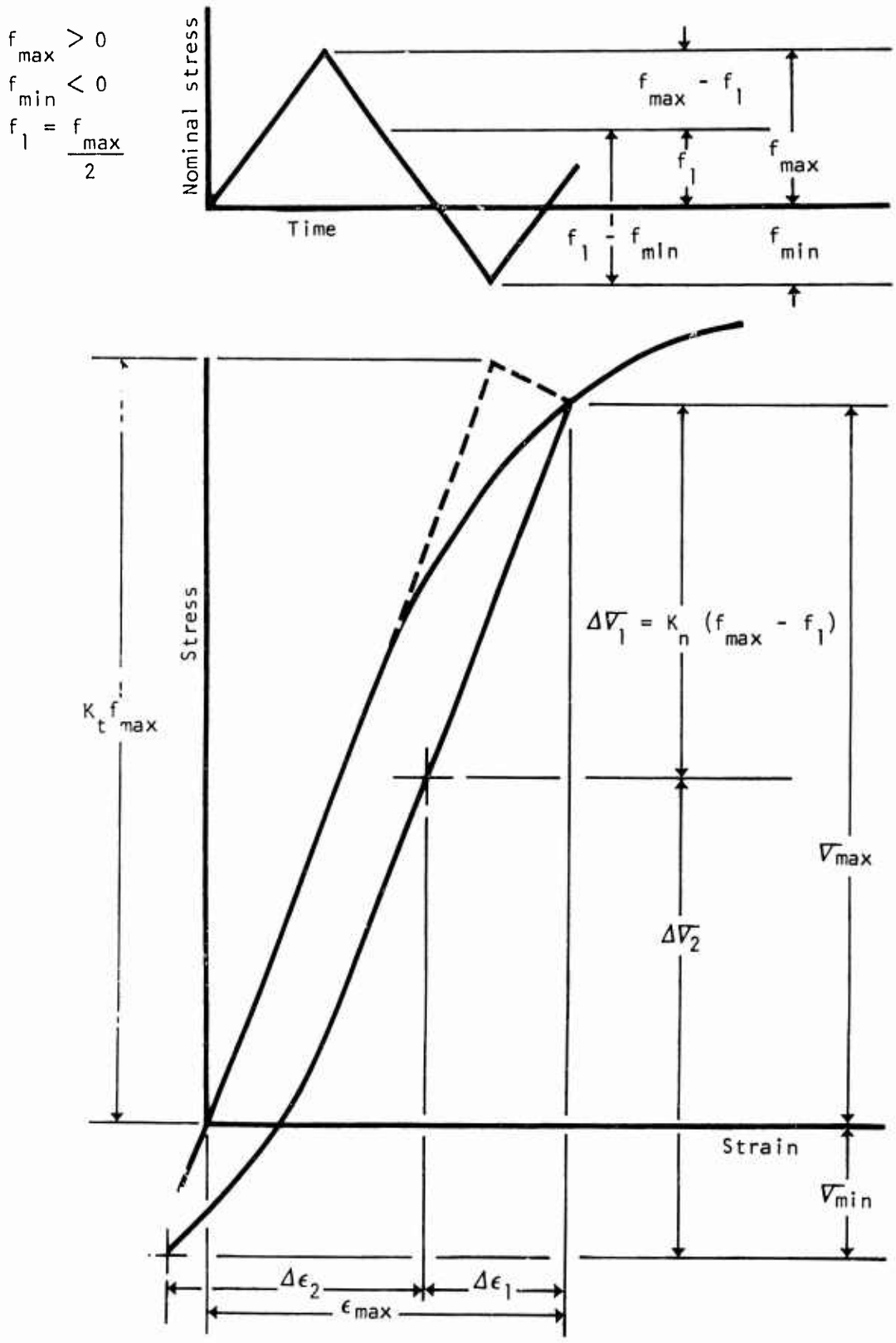


Figure 31. Hysteresis curve for f_{min} less than zero.

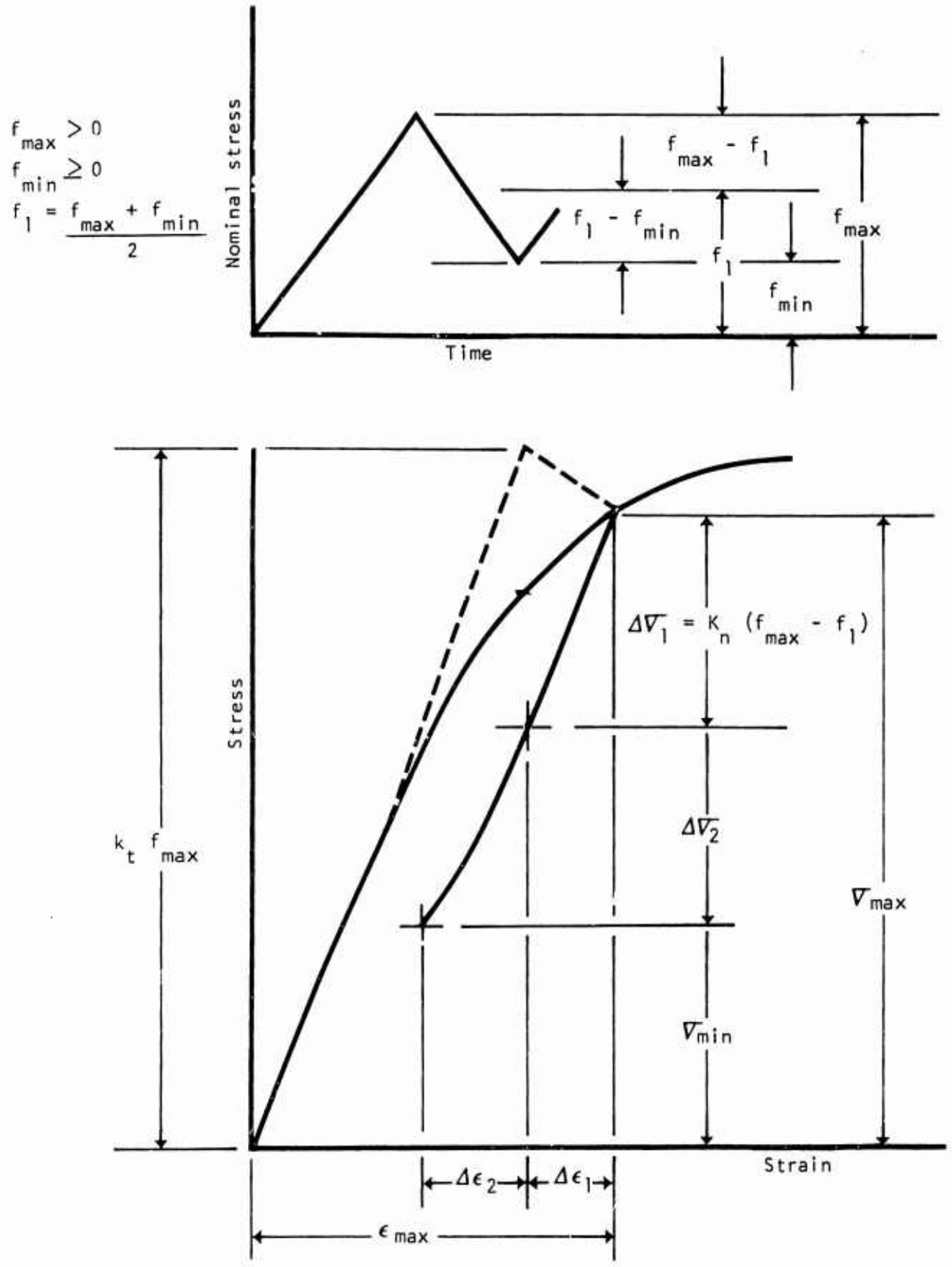


Figure 32. Hysteresis curve for f_{min} greater than zero.

$$K_n = 1 + \frac{K_t - 1}{1 + \frac{\pi}{\pi - w}\sqrt{\frac{A}{r}}} \qquad (18)$$

Where

w = notch angle, radians

r = notch radius, inches

A = material constant, inches (Neuber parameter)

For the purpose of this program, which is intended to evaluate "average" stress concentration rather than a specific notch, K_n is assumed to be equal to K_t. This approximation can be made, since the Neuber parameter, A, is a small number on the order of 0.005. For a given K_t this assumption leads to a slightly conservative fatigue life evaluation.

Unloading along the cyclic stress-strain curve is approximated by considering two segment: (1) an elastic segment $\Delta\sigma_1$, and (2) an elastoplastic segment $\Delta\sigma_2$ due to nonlinearity of the stress-strain curve, as shown by equation 7. Stress and strain for the elastic segment are calculated by equations 19 and 20.

$$\Delta\sigma_1 = K_n (f_{max} - f_1) \approx K_t (f_{max} - f_1) \qquad (19)$$

$$\Delta\epsilon_1 = \frac{\Delta\sigma_1}{E} \qquad (20)$$

The elastoplastic segment of the hysteresis curve is assumed to be proportional to the loading curve, as shown by equation 21.

$$\frac{K_n (f_1 - f_{min})}{\Delta\epsilon_2} = \frac{K_n f_{max}}{\epsilon_{max}} \qquad (21)$$

Then

$$\Delta\epsilon_1 = \frac{(f_1 - f_{min})\,\epsilon_{max}}{f_{max}} \qquad (21a)$$

and $\Delta\sigma_2$ is obtained by substituting $\Delta\varepsilon_2$ in the cyclic stress-strain equation and solving for stress (equation 7).

Then

$$\sigma_{min} = \sigma_{max} - \Delta\sigma_1 - \Delta\sigma_2 \tag{22}$$

Strain amplitude, ε_a, and mean stress, σ_{mean}, at the notch for a cycle of maximum-to-minimum nominal stress can then be calculated (equations 23 and 24)

$$\varepsilon_a = \frac{\Delta\varepsilon_1 + \Delta\varepsilon_2}{2} \tag{23}$$

$$\sigma_{mean} = \frac{\sigma_{max} + \sigma_{min}}{2} \tag{24}$$

Every level of load in a spectrum produces a residual stress. Residual stress is that stress at the notch corresponding to a zero nominal stress. Residual stress is dependent on the stress ratio, as shown in Figures 31 and 32.

For the loading cycle shown in Figure 31, where:

$$f_{max} > 0$$

$$f_{min} < 0$$

$$\sigma_{Res} = \sigma_{min} - \frac{K_n f_{min}}{2} - \Delta\sigma_{Res2} \tag{25}$$

Where $\Delta\sigma_{Res2}$ corresponds to $\Delta\varepsilon_{Res2}$, which is determined from equation 26.

$$\Delta\varepsilon_{Res2} = \frac{f_{min}\,\varepsilon_{max}}{2\,f_{max}} \tag{26}$$

Then, $\Delta\sigma_{Res2}$ is obtained by an approximation-iteration solution of equation 7.

For the loading cycle shown in Figure 32, where:

$$f_{max} > 0$$

$$f_{min} \geq 0$$

$$\sigma_{RES} = \sigma_{max} - \frac{K_n f_{max}}{2} - \Delta\sigma_{Res2} \tag{27}$$

Where $\Delta\sigma_{Res2}$ corresponds to $\Delta\varepsilon_{Res2}$, which is determined from equation 28.

$$\Delta\varepsilon_{Res2} = \frac{f_{max}}{2} \tag{28}$$

Then, $\Delta\sigma_{Res2}$ is obtained by solving equation 7.

LIFE CALCULATION

Figure 33 shows a modified Goodman diagram assuming linearity between cyclic strain amplitude and cyclic mean stress for a given life. From this relationship, the equivalent strain, ε_T, at the edge of a notch for fully reversed loading (R = -1) can be determined (equation 29).

$$\varepsilon_T = \frac{\sigma_a}{1 - \frac{\sigma_{mean}}{\sigma_f}} \tag{29}$$

The number of cycles to failure, N_f, corresponding to ε_T is then obtained by an approximation-iteration approach using equation 6. Cycles to failure calculated for the spectrum loading by this approach constitute the first block.

Each of the load cycle levels in a spectrum generates a residual stress (equation 25 or 27). The residual stress generated by the largest strain

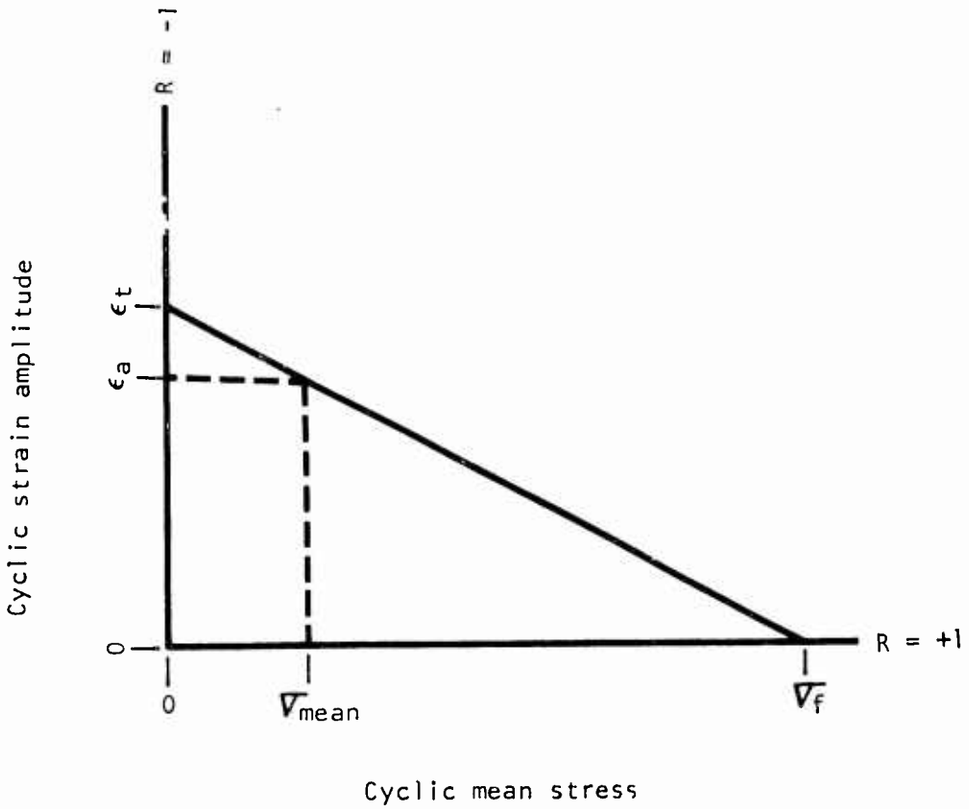


Figure 33. Modified Goodman diagram.

range ($\Delta\sigma_1 + \Delta\sigma_2$) in the first block is used in the second block. The difference between this residual stress, σ^*_{RES}, and the residuals calculated for each of the load cycle levels is used to determine the mean stress for the second block (equation 30).

$$\sigma_{mean2} = \sigma_{mean} + \sigma^*_{RES} - \sigma_{RES} \tag{30}$$

Equivalent strain for the second block is then calculated by equation 31, and cycles to failure are calculated in the same manner as used in the first block.

$$\varepsilon_{T_2} = \frac{\varepsilon_a}{1 - \frac{\sigma_{mean_2}}{\sigma_f}} \tag{31}$$

The damage ratio, the ratio of applied cycles to the number of cycles to failure, is then calculated and the total life is obtained by using Miner's cumulative damage rule (equation 32).

$$\sum\left(\frac{n}{N_f}\right)_1 + B\sum\left(\frac{n}{N_f}\right)_2 = 1 \tag{32}$$

Where

B = number of blocks to failure after first block of loading

Scatter factor, SF, in fatigue evaluation is analogous to safety factor in strength design. Equation 32 represents one lifetime of the structural member (SF = 1) such that the cumulative damage rule, including scatter factor, is shown in equation 33.

$$\sum\left(\frac{n}{N_f}\right)_1 + B\sum\left(\frac{n}{N_f}\right)_2 = \frac{1}{SF} \tag{33}$$

Solving equation 33 for B,

$$B = \frac{\frac{1}{SF} - \sum\left(\frac{n}{N_f}\right)_1}{\sum\left(\frac{n}{N_f}\right)_2} \tag{34}$$

Life in hours is then calculated by equation 35.

$$\text{Life (SF)} = (1 + B)\, H \tag{35}$$

Where

H = number of hours in each block associated with applied cycles, n, in each block

DESIGN TO LIFE

Material ultimate tensile strength is an allowable or not-to-exceed stress level in static strength analysis. If vehicle service life requirements could also be represented by not-to-exceed or fatigue "cutoff" stress, design to life can be incorporated into the strength sizing procedure. The strain cycle analysis method provides an approach for deriving this cutoff stress from spectrum and material property data. The following formulations present programmed approaches used to evaluate different forms of wing bending moment spectrum and fuselage pressure cycle data.

WING SPECTRA

Wing bending moment-exceedances spectra are provided by the airload module or through user input to this module. Blocked spectra are provided for eight flight segments, two taxi segments, and a ground-air-ground segment. Net bending moments are provided at the wing side of the fuselage station and at an outboard wing station. Moments at the side of the fuselage station are in the fuselage reference system, and moments at the outboard station are in the wing structural reference system. Table 19 shows bending moments and associated gust and maneuver exceedances for a typical flight segment. Table 20 shows typical ground-air-ground data.

TABLE 19. TYPICAL FLIGHT SEGMENT SPECTRA

Spectra Segment No. 7					
Point	SOF Bend MOM	WOS Bend MOM	Exceedances - Gust	Exceedances - Man.	Load Factor
1	101856512.0	93595488.0	0.12013E-08	0.0	3.8
2	93815232.0	86206400.0	0.20802E-07	0.0	3.5
3	85773920.0	78817264.0	0.36023E-06	0.0	3.2
4	77732608.0	71428144.0	0.62380E-05	0.0	2.9
5	69691296.0	64039024.0	0.10802E-03	0.81000E-03	2.6
6	61649984.0	56649888.0	0.18706E-02	0.13500E-01	2.3
7	53608704.0	49260800.0	0.32394E-01	0.27000E 00	2.0
8	45567392.0	41871664.0	0.56168E 00	0.67500E 01	1.7
9	37526080.0	34482544.0	0.11690E 02	0.22275E 03	1.4
10	29484768.0	27093424.0	0.55710E 04	0.81000E 04	1.1
11	24123904.0	22167344.0	0.55709E 04	0.51840E 03	0.9
12	16082610.0	14778239.0	0.11690E 02	0.59400E 01	0.6
13	8041304.0	7389118.0	0.56168E 00	0.40500E-01	0.3
14	0.0	0.0	0.32394E-01	0.27000E-03	0.0
15	-8041304.0	-7389118.0	0.18706E-02	0.0	-0.3
16	-16082610.0	-14778239.0	0.10802E-03	0.0	-0.6
17	-24123904.0	-22167344.0	0.62380E-05	0.0	-0.9
18	-32165216.0	-29556464.0	0.36023E-06	0.0	-1.2
19	-40206528.0	-36945600.0	0.20802E-07	0.0	-1.5
20	-48247808.0	-44334688.0	0.12013E-08	0.0	-1.8
1G SOF M = 26804352.0 1G WOS M = 24630400.0					

TABLE 20. TYPICAL GROUND-AIR-GROUND SEGMENT SPECTRA

Spectra Segment No. 11 - Ground-Air-Ground Occurrences		
SOF Bend MOM	WOS Bend MOM	Occurrences
33515408.0	31016528.0	0.20000E 04
-34969344.0	-27504432.0	0.20000E 04

Flight spectra load factors, Table 19, are preselected such that symmetry about a reference 1g condition is maintained. This preselection of spectra load factors results in symmetry such that gust exceedances for the second 10 points in Table 19 are mirror images of the first 10 points. Figure 34 shows a typical plot of bending moments versus gust exceedances. The upper curve is obtained by plotting points 1 through 10, and the lower curve from points 11 through 20.

Occurrence data (cycles) are obtained by blocking this diagram as depicted by the region bounded by points 3, 4, 17, and 18. Occurrences for this portion of the spectra are calculated from equation 36.

$$n_3 = Ex_4 - Ex_3 = Ex_{17} - Ex_{18} \tag{36}$$

where

n = number of applied cycles for the specific range of bending moments

Ex = exceedances associated with each bending moment

Average maximum and minimum bending for this portion of the spectra (region 3-4-17-18 in Figure 34) are calculated by equations 37 and 38, respectively.

$$M_{max3} = M_4 + \frac{M_3 - M_4}{3} \tag{37}$$

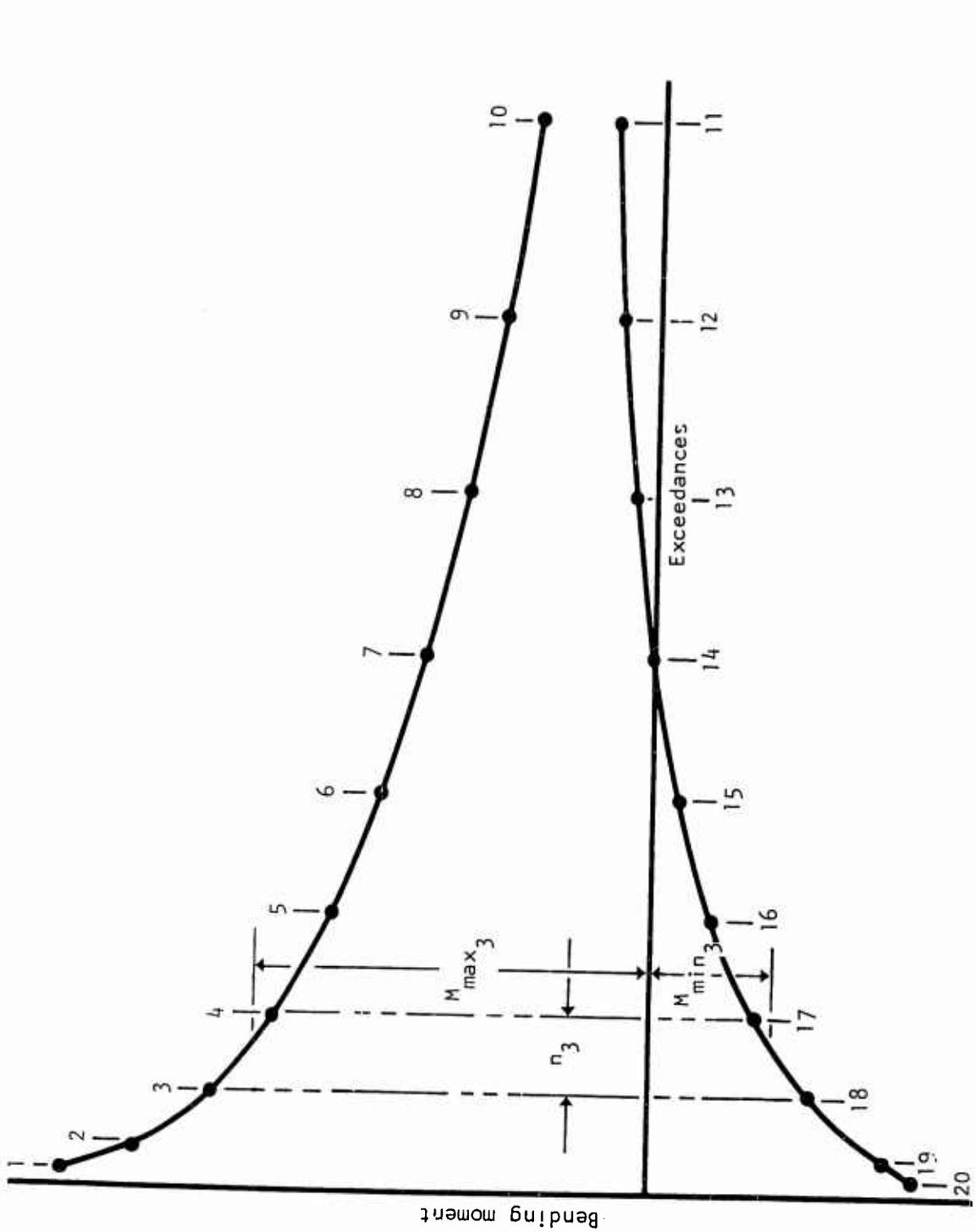


Figure 34. Wing bending moment versus gust exceedances.

$$M_{min3} = M_{17} + \frac{M_{18} - M_{17}}{3} \tag{38}$$

These equations give weighted average moment values which account for curvature of the bending moment exceedance plot. Nine moment-gust occurrence sets are calculated for each of the eight flight segments.

Vehicle maneuvers are assumed to start from a balanced 1g condition such that 1g loads describe one limit of the load range. Figure 35 depicts the first 10 points of a flight segment. Occurrences for each block of this diagram are calculated by equation 36. Should this calculation result in zero occurrences (refer to Table 19), the load range block does not exist and, therefore, is not used in the analysis. Average bending moment for one part of the load range is calculated by either equation 37 or 38, and the other moment is obtained from the 1g condition. The greater of these two moments is the maximum, and the other value is the minimum moment. Eighteen, or less if occurrence is zero, moment-maneuver occurrence sets are calculated for each of the eight flight segments.

Taxi spectra bending moment-occurence values are calculated in the same manner as those used for gust maneuvers.

Ground-air-ground data are in the form of maximum and minimum bending moments and occurrences, which do not require any additional computations.

Load-occurrence data from the flight, taxi, and ground-air-ground segments constitute the total spectrum. As previously discussed, zero occurrence sets are not used. Except for possible residual stress effects, compression-compression cycles have no impact on fatigue life. Therefore, should the maximum bending moment be negative (compression in the lower cover), those cyclic load sets are not used in the fatigue calculations.

Conversion of Bending Moments to Nominal Stress

Axial load in the lower cover can be approximated by equation 39. The assumption is that all of the structure which resists bending loads is concentrated in the cover panels.

$$F = \frac{M}{H} \tag{39}$$

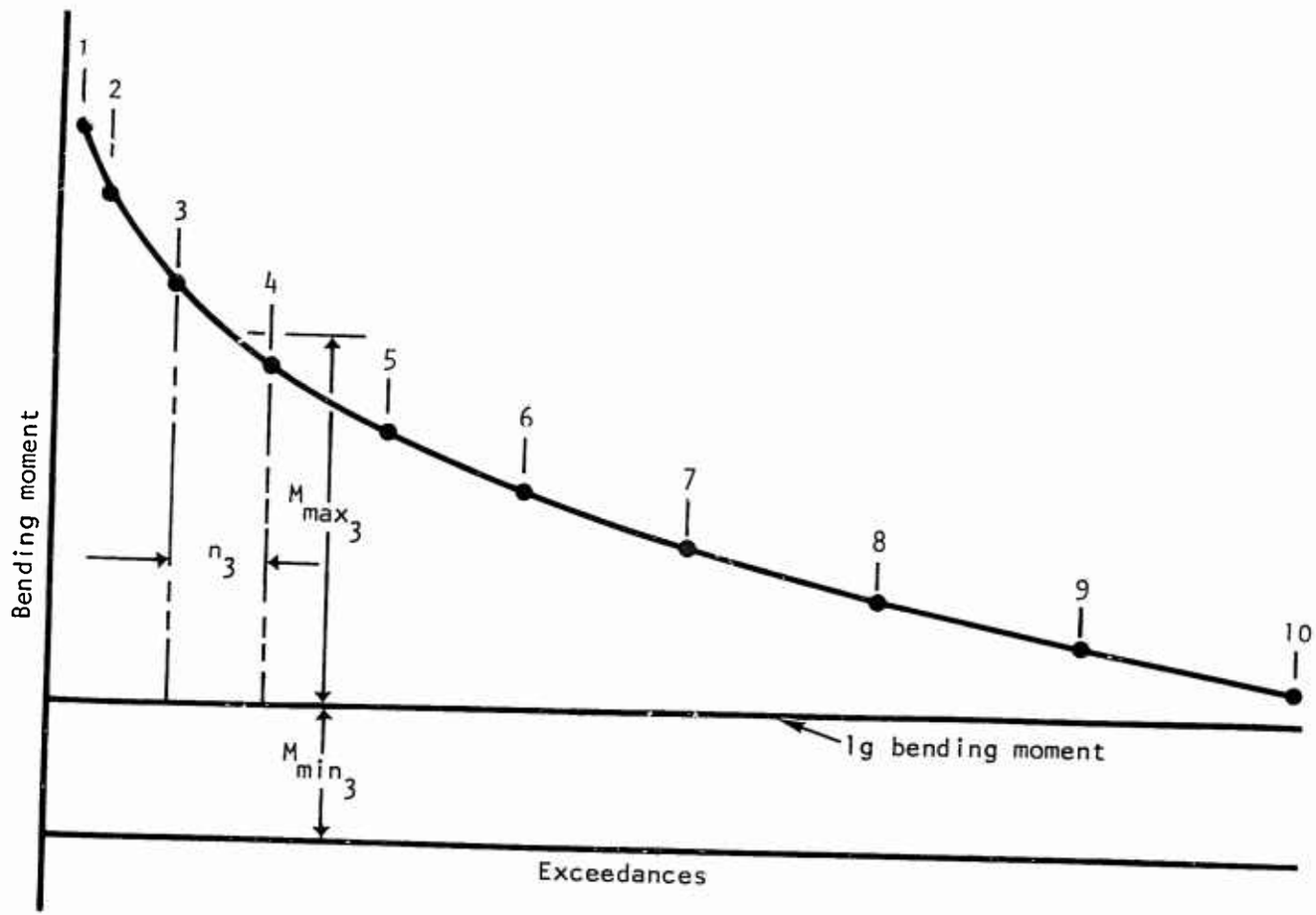


Figure 35. Wing bending moment versus maneuver exceedances.

where

F = Axial load, lb

H = average wing structural box depth, in.

If the area (thickness times width) of the cover panel is known, the stress can then be determined by equation 40.

$$f = \frac{M}{HA} \tag{40}$$

where

A = lower cover cross-section area, $in.^2$

f = average lower cover nominal stress, psi

Both wing depth and section area are fixed quantities for the final sized structure such that stress is directly proportional to bending moment.

$$f = KM \tag{41}$$

where

K = proportionality constant

Application of equation 41 to the average spectrum moments provides the nominal stress data required for life calculation.

Block Size

In general, spectrum block sizes for fatigue calculations are determined for one flight; another rule is to set the block size at a fraction of vehicle service life. The latter approach is used in this program. This fraction (FL) is part of the user input data set. Each of the applied cycles in the

spectrum is multiplied by FL to obtain the appropriate load-cycle data per block. The number of hours (H) associated with these cycles is obtained by multiplying vehicle life by FL.

Determination of Fatigue Cutoff Stress

For a given value of the proportionality constant, K, life can be calculated. If the summation of nominal net section maximum stress versus life is plotted on log.-log. coordinates, the result is very nearly a straight line, as shown in Figure 36. Equation 42 defines the slope of this curve.

$$m = \frac{\log. (K_1 \Sigma M_{max}) - \log. (K_2 \Sigma M_{max})}{\log. L_2 - \log. L_1} \tag{42}$$

If the slope of the curve, m, is known, the proportionality constant that satisfies the required life can be solved by a single life calculation.

$$K_2 = K_1 e^{m(\log. L_2 - \log. L_1)} \tag{43}$$

For a given problem, both K_2 and m are unknown. Initial estimates K_o and m_o are used in a successive iteration solution.

$$K_o = \frac{F_{tu}}{2M_o} \tag{44}$$

$$m_o = -0.1666667 \tag{45}$$

where

K_o = initial estimate of the proportionality constant

M_o = the largest average bending moment for the spectrum

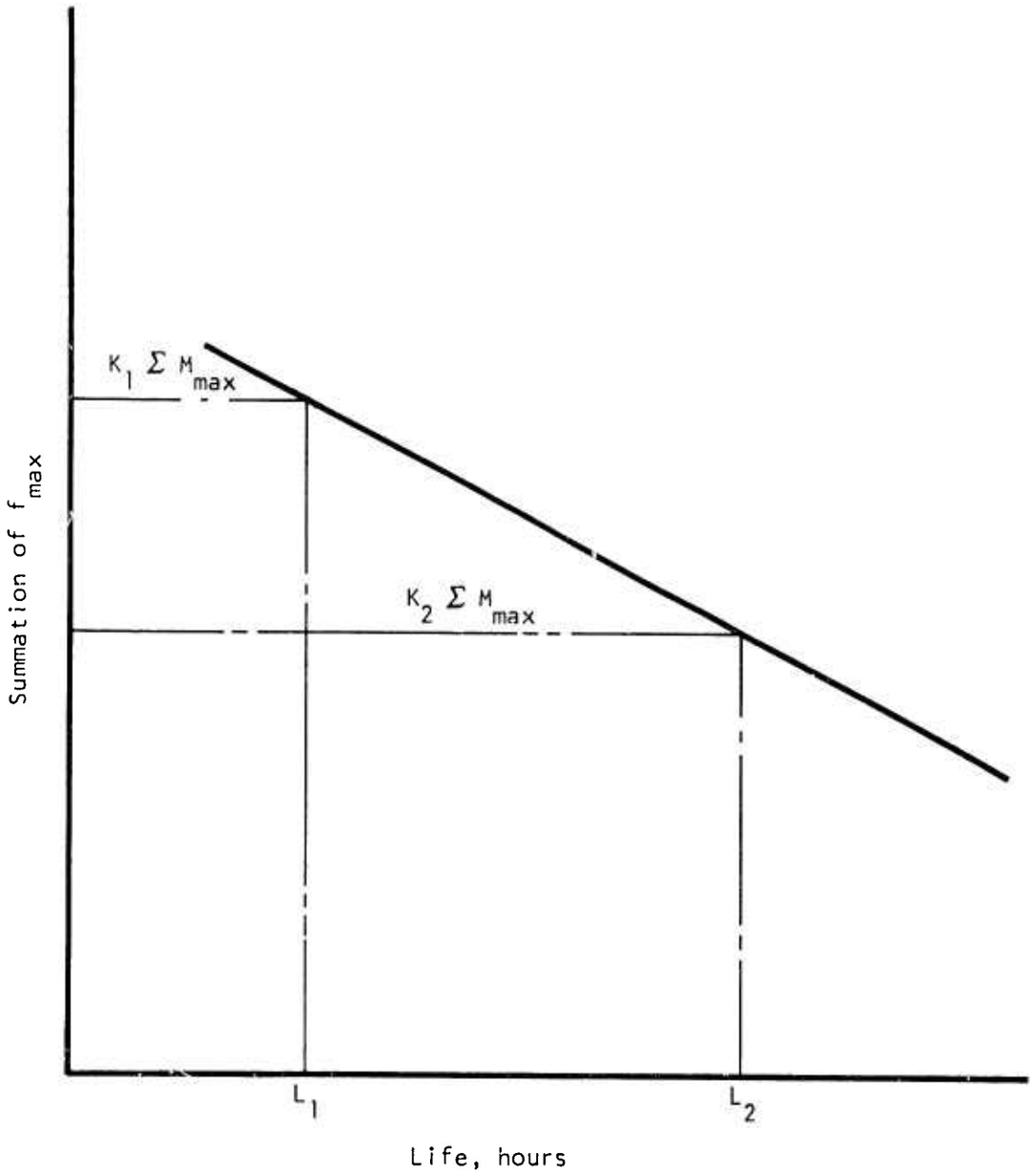


Figure 36. Summation of nominal net section stress versus life.

The initial K_0 is used to calculate nominal stresses and life by the strain cycle method.[9] By using the estimated slope m_0 in equation 43, K_2 can be calculated for the required life L_2. However, life calculated by using K_2 in the strain cycle solution will not be the required life. The K and L at the two points are used to calculate a new slope estimate (equation 42). The point closest to the required life is then used to repeat the calculation of K and life until the calculated life is within a tolerance (1 percent) of the required life.

As previously defined in equation 41, stress is proportional to bending moment. If the static strength design bending moment is known, the not-to-exceed or cutoff stress at this load, commensurate with the required life, can be calculated by equation 46.

$$f_{allow} = K_2 M_{Ref} \tag{46}$$

where

f_{allow} = cutoff or not-to-exceed stress to satisfy vehicle life requirement

M_{Ref} = static limit strength design bending moment

The foregoing procedure is used to determine the cutoff stress at the two wing stations. Both allowables are stored in the material files as fractions of ultimate tensile strength (equation 47) for access by the wing and empennage weight-estimating module.

$$K_{F_{tu}} = \frac{f_{allow}}{F_{tu}} \tag{47}$$

FUSELAGE STRUCTURE FATIGUE

Fuselage cover and minor frame material fatigue life is examined for pressurization cycles and endurance limit. Material endurance limit is used in the fuselage module for the evaluation of acoustic fatigue.

Pressurization Spectrum

Pressure cycle data are user input to this module. As many as 100 maximum-minimum pressure-cycle sets may be used to describe the pressurization during the vehicle life.

Pressure is equated to stress by the hoop stress analogy (equation 48).

$$f = \frac{Pr}{t} \tag{48}$$

where

P = pressure, psi

r = fuselage radius, in.

t = fuselage panel thickness, in.

Similar to the wing approach, the proportionality can be represented by equation 49.

$$f = KP \tag{49}$$

where

K = proportionality constant

The solution for K is identical to that used for the wing. The maximum spectrum pressure is also the static strength design pressure and, therefore, the cutoff stress is calculated by equation 50.

$$f_{allow} = K_2 P_{max} \tag{50}$$

where

K_3 = proportionality constant which results in spectrum stresses which meet vehicle life requirements

P_{max} = maximum spectrum pressure

This cutoff stress is stored in the material files as a fraction of ultimate tensile strength (equation 45).

Endurance Limit

Endurance limit stress is calculated for the following conditions:

- K_t = 1, polished specimen
- R = -1, fully reversing loading
- n = 10^9

The initial estimate for f_{max} is half of the ultimate tensile strength. The endurance limit stress is determined by the successive iteration solution used for the wing. The proportionality constant K is also the stress, and life is 10^9 cycles.

Section III

PROGRAM DESCRIPTION

GENERAL DISCUSSION

The purpose of the fatigue module is to derive the stress level that will give the required life with the specified material so that the factor for ultimate fatigue effect (KF_{tu}) can be placed in the material library for use by the weight modules. This calculation can be performed for four distinct conditions.

Two locations on the wing, the side of the fuselage (SOF) and the second wing station (WOS), can be analyzed using a function of bending moments for starting stress levels and cycles based on the corresponding exceedances. These bending moments and exceedances usually come from the loads module, but can be input data.

Two other conditions are analyzed; if the fuselage structure fatigue effect is requested, pressure cycling and endurance limit factors are calculated. Maximum and minimum pressures are used to determine starting stress levels, and the corresponding cycles must also be input. For the endurance limit calculation, one point is set up with maximum and minimum starting stress levels at plus and minus one-half of F_{tu} and for 1 billion cycles. Also, the notch factor and scatter factor are set to 1.0 for the endurance limit, but are determined by the user for the other calculations. If fuselage minor frame fatigue effect is requested, it is computed in the same manner as for the cover.

PROGRAM FUNCTIONS

The fatigue module consists of a main program (FATGUE), three subroutines, and two function routines. Figure 37 shows the logical flow diagram of this module. The subroutine tree, including system routines READMS and WRITMS, is shown in Figure 38.

GENERAL MAPS

Data storage and transmittal is accomplished through the use of common, labeled common, and mass storage file records. Mass storage file records are read into, and written from, regions in common. Table 21 presents an alphabetical listing of all program arrays and variables. Table 22 presents descriptions of the input data.

General logic flow:

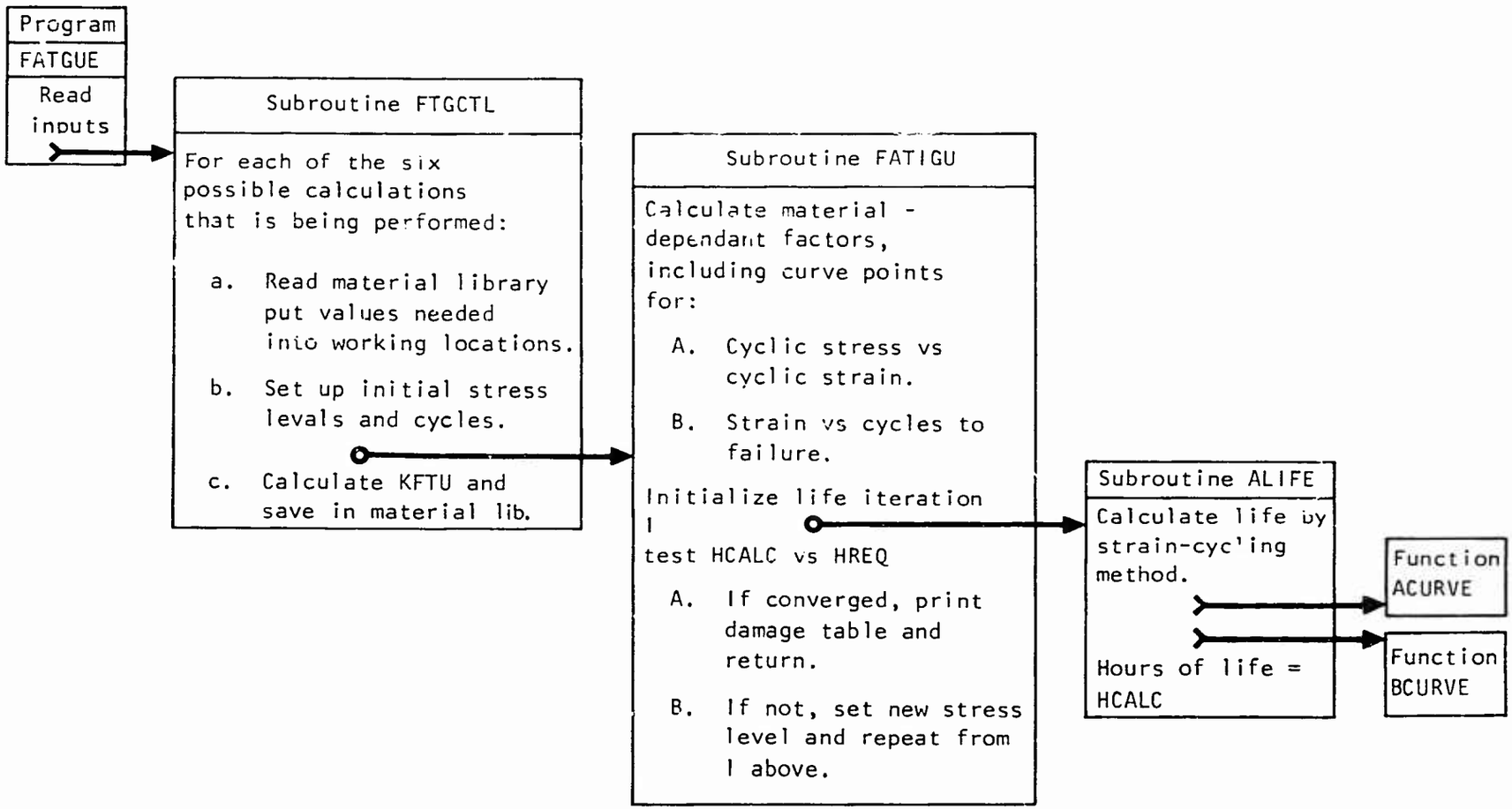


Figure 37. Fatigue module logic flow.

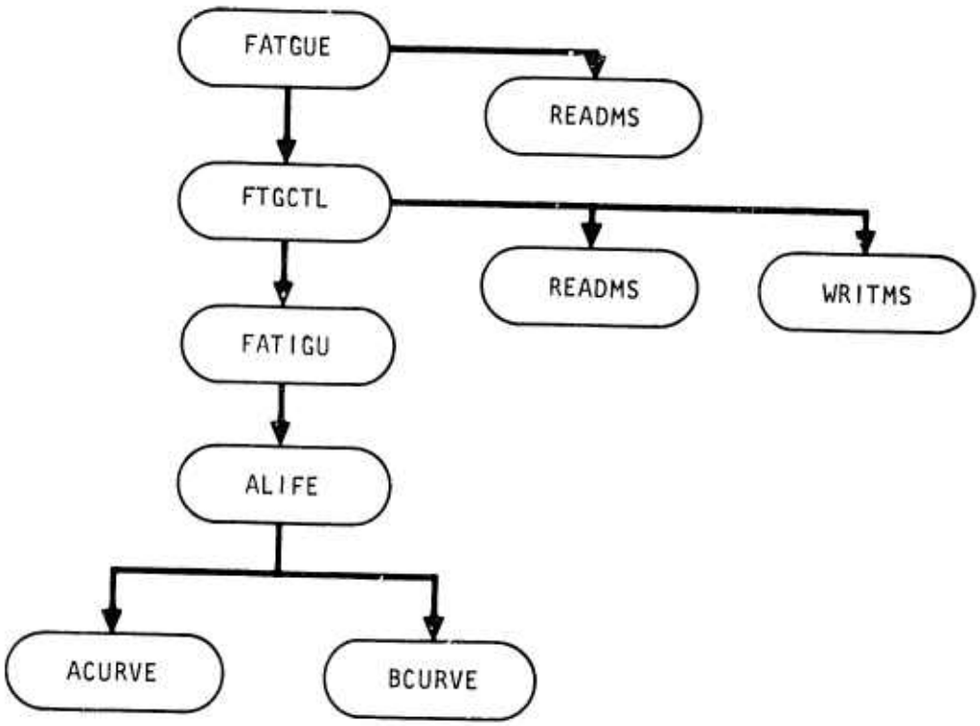


Figure 38. Fatigue module subroutine tree.

TABLE 21. VARIABLE LIST

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
A	1	2451	C	Upper range estimate of cyclic stress at notch in iteration for SGMX	ALIFE
AN	300	801	C	Applied cycles, set up from exceedances or pressure cycles	FTGCTL, FATIGU
ANPT	1	107	C	Number of points in AN for current condition being calculated	FTGCTL, FATIGU
B	1	2452	C	Lower range estimate of cyclic stress at notch in iteration for SGMX	ALIFE
BETA	1	71	C	Material-dependent factor, β, defining cyclic stress-strain curve	FATIGU, BCURVE
BLOCK	1	81	I	Block size, fraction of required life for each block	FTGCTL, FATIGU
BMA	660	1501	I/IM	Bending moment - gust exceedance array	FATIGUE, FTGCTL
BMMX	1	1161	C	Maximum of FMAX, calculated for wing points only	FTGCTL
BMREF	20	2107	I/IM	1 g inertia bending moments for each spectra segment for both wing stations	FTGCTL
BMSMX	2	1162	I/IM	Maximum strength design bending moment	FATGUE, FTGCTL

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
CON	50	51	I,C	Input and calculated factors required in strain-cycling fatigue life calculation	FTGCTL, FATIGU, ALIFE, ACURVE, BCURVE
CYC	300	2501	C	Cycles for condition in work, (AN times BLOCK)	FATIGU, ALIFE
C1	1	69	C	Material-dependent factor, C_1, defining cyclic stress-strain curve	FATIGU, BCURVE
C1E	1	76	C	Factor in cyclic stress-strain equation, CON(26)	FATIGU, ALIFE, ACURVE
C1X	10	3401	C	Natural log. of strains for cyclic stress versus cyclic strain equation	FATIGU, ACURVE
C1Y	10	3411	C	Natural log. of stresses for cyclic stress versus cyclic strain equation	FATIGU, ACURVE
C2	1	69	C	Material dependent factor, C_2, defining cyclic stress-strain equation	FATIGU, ALIFE, ACURVE BCURVE
C2X	10	3421	C	Natural log. of strains for strain versus cycles to failure equation	FATIGU, BCURVE
C2Y	10	3431	C	Natural log. of number of cycles to failure for strain versus cycles to failure equation	FATIGU, BCURVE
DAM1	300	3801	C	Damage ratios for first block	ALIFE, FATIGU

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
DAM2	300	4101	C	Damage ratios for second block	ALIFE, FATIGU
DEPS	300	4401	C	Strain range for each load cycle in first block	ALIFE
DEPSMX	1	2482	C	Maximum from DEPS array	ALIFE
DEPSR2	1	2483	C	Incremental residual strain for any load cycle in second block	ALIFE
DEPS1	1	2471	C	Incremental strain 1 for any cycle in first block	ALIFE
DEPS2	1	2472	C	Incremental strain 2 for any cycle in first block	ALIFE
DF2	1	2457	C	Mean nominal positive stress minus minimum nominal stress for a cycle (F1-FMIN)	ALIFE
DSGR1	1	2473	C	Incremental residual stress 1 for any load cycle in second block	ALIFE
DSGR2	1	2474	C	Incremental residual stress 2 for any load cycle in second block	ALIFE
DSG1	1	2463	C	Incremental stress 1 for any cycle in first block	ALIFE
DSG2	1	2464	C	Incremental stress 2 for any cycle in first block	ALIFE

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
DUMMY	830	1501	I/IM	Block of bending moment and related data from file 35 (refer to Table 4, locations 1501 to 2330)	FATGUE
E	1	105	C	Young's modulus, material-dependent factor	FTGCTL, FATIGU, ALIFE, ACURVE
EM	220	2127	I/IM	Exceedances for maneuver to correspond to bending moments in BMA	FATGUE, FTGCTL
EPSA	1	2465	C	Cyclic strain amplitude for cycle from FMAX to FMIN for any load cycle in first block	ALIFE
EPSBT	1	2475	C	Equivalent strain at edge of notch for fully reversed cycles (R = -1) for any load cycle in second block	ALIFE
EPSMX	1	2476	C	Cyclic maximum strain corresponding to SGMX (at edge of notch)	ALIFE
EPSTJ	1	2477	C	Absolute value of EPST2	ALIFE
EPST2	1	2478	C	Equivalent strain at edge of notch for fully reversed cycles (R = -1) for any load cycle in first block	ALIFE
F	1	2453	C	Discrepancy in solution for maximum stress for assumed cyclic stress at notch	ALIFE

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
FA	1	2455	C	Discrepancy in solution for maximum stress for upper range estimate of cyclic stress at notch	ALIFE
FACT	1	2497	C	Multiplying factor for FMAX and FMIN arrays to adjust level for next iteration for life	FATIGU
FFIND	1	112	I/IM	Fuselage minor frame material number indicator: • 0 = set from fuselage module data if it is loaded • + = use value input here • - = do not calculate for fuselage minor frames	FTGCTL
FIND	1	111	I/IM	Fuselage cover material no. indicator: • 0 = set up from fuselage module data • + = use value here • - = do not calculate fuselage cover	FTGCTL
FKT	1	103	C	Working location for elastic stress concentration factor	FTGCTL, ALIFE
FKTFP	1	118	I	Fuselage structure elastic stress concentration factor	FTGCTL
FKTW	2	115	I	Wing elastic stress concentration factor for SOF and WOS	FTGCTL
FMAX	300	201	C	Working locations for maximum nominal stresses	FTGCTL, FATIGU, ALIFE

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
FMIN	300	501	C	Working locations for minimum nominal stresses	FTGCTL, FATIGU, ALIFE
FPT	1	1200	I	Number of points input for fuselage pressures	FTGCTL
FSQ	1	2459	C	Intermediate calculation in iteration for SGMX	ALIFE
FTOP	1	2489	C	Highest initial FMAX used in search to get subscript (NTOP) of that point	FATIGU
FTU	1	104	C	Working location for ultimate tensile strength	FTGCTL, FATIGU
F1	1	2456	C	Mean nominal positive stress for a cycle, F_1	ALIFE
GAMMA	1	72	C	Material-dependent factor, γ, defining cyclic stress-strain curve	FATIGU, BCURVE
H	1	101	I/IM	Specified vehicle life	FTGCTL, FATIGU
HCALC	1	2500	C	Calculated hours of vehicle life	ALIFE, FATIGU
HN	1	2494	C	Factor in life iteration, natural log. of HCALC	FATIGU
HR	1	2496	C	Factor in life iteration, natural log. of HREQ	FATIGU
HRBL	1	2441	C	Hours per block	FTGCTL, ALIFE
HREQ	1	2499	C	Required vehicle life, specified life multiplied by scatter factor	FATIGU

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
H1	1	2490	C	A point in iteration calculation for life, ln (life)	FATIGU
H2	1	2492	C	Second point in iteration calculation for life, ln (life)	FATIGU
I	1	--	C	General index	FATGUE, FTGCTL, ALIFE
IFERR	1	5444	C	Error indicator, nonzero value when failed to find life ND(44)	FTGCTL, FATIGU
IFUP	1	--	C	Extrapolation indicator	ACURVE
IND	1	--	C	Index for SAVE array	FTGCTL
IP	80	IPRINT	I	Print/no-print indicators	FATGUE, FTGCTL, FATIGU
IREF	1	--	C	Index for lg bending moments	FTGCTL
J	1	--	C	General index	FTGCTL, ALIFE
JMAX	1	5441	C	Index of point with largest incremental strain range (DEPS) to get SGRMX	ALIFE
K	1	--	C	General index	FTGCTL, ACURVE, BCURVE
L	1	--	C	Index in bending moments to stresses loop, first point in each spectra	FTGCTL

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
LL	1	--	C	Count for input spectra	FTGCTL
M	1	--	C	Index in bending moments to stresses loop, last point in each spectra	FTGCTL
MI	1	5445	C	Same or new material indicator, to save repeat calculation	FTGCTL, FATIGU
MTIME	1	5446	C	Counter for number of times try restart if HCALC negative	FATIGU
N	1	--	C	General index	FATGUE, FTGCTL, FATIGU, ACURVE, BCURVE
ND	200	5401	C	Fixed indicators	general
NMATL	1	5459	C	Number of material decks in library	FATGUE, FTGCTL
NPT	1	5440	C	Number of points in FMAX FMIN CYC set in work	FTGCTL, FATIGU, ALIFE
NSEG	20	5521	C	Index in FMAX, FMIN, CYC, DAM1, DAM2, etc, to indicate end of each original spectra segment	FTGCTL
NTIME	1	5443	C	Counter for number of iterations for life	FATIGU
NTOP	1	5442	C	Index value for highest FMAX	FTGCTL, FATIGU
P	1	75	C	Intermediate calculation in iteration for SGMX	FATIGU, ALIFE

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
PCY	100	1401	I	Cycles for fuselage pressures	FTGCTL
PC1	300	2801	C	Percent of total damage for each point in first block	FATIGU
PC2	300	3101	C	Percent of total damage for each point in second block	FATIGU
PMN	100	1301	I	Minimum pressures for fuselage pressures	FTGCTL
PMX	100	1201	I	Maximum pressures for fuselage pressures	FTGCTL
Q	1	55	C	Material-dependent factor, γ/s	FATIGU, ALIFE, ACURVE
QP1	1	57	C	Material-dependent factor, Q+1, power in SGMX calculation	FATIGU, ALIFE
RA	1	106	C	Materia' property, reduction in area, from library for material in work	FTGCTL, FATIGU
RE	1	74	C	Material-dependent factor, E/1000	FATIGU
RSF	1	2442	C	Reciprocal of scatter factor	FATIGU, ALIFE
RTO	1	65	C	Material-dependent factor, ductility	FATIGU
RTO1	1	67	C	Material-dependent factor, FTU/E	FATIGU

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine reference
RTO2	1	68	C	Material dependent factor, 1.0+RTO	FATIGU
S	100	2401	C	Scratch, misc intermediate values	FATIGU, ALIFE
SAVF	16	--	C	Print array for old and new values of KFIU to show changes in material record by fatigue calculation	FTGCTL
SDAM1	1	2479	C	Sum of damages from first block	ALIFE
SDAM2	1	2480	C	Sum of damages from second block	ALIFE
SF	1	102	C	Scatter factor for condition in work	FTGCTL, FATIGU
SFFP	1	117	I	Scatter factor for fuselage pressure condition	FTGCTL
SFM	1	2487	C	A point in iteration for life, $\ln(\Sigma FMAX)_{prior}$	FATIGU
SFN	1	2495	C	A point in iteration for life, $\ln(\Sigma FMAX)_{new}$	FATIGU
SFW	2	113	I	Scatter factors for SOF and WOS	FTGCTL
SF1	1	2491	C	A point in iteration calculation for life, ln(ΣFMAX) corresponds to H1	FATIGU
SF2	1	2493	C	Second point in iteration calculation for life, ln(ΣFMAX) corresponds to H2	FATIGU

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
SGBMEN	1	2484	C	Cyclic mean stress at notch for a cycle from FMAX to FMIN for second block	ALIFE
SGF	1	56	C	Material-dependent factor, fracture stress	FATIGU, ALIFE
SGMEN	300	5001	C	Cyclic mean stress at notch for a cycle from FMAX to FMIN for first block	ALIFE
SGMN	1	2466	C	Minimum stress at notch for a cycle from FMAX to FMIN	ALIFE
SGMX	1	2467	C	Maximum stress at notch for a cycle from FMAX to FMIN	ALIFE
SGR1	300	4701	C	Residual stress for each load cycle in first block	ALIFE
SGR1MX	1	2485	C	Point in SGR1 corresponding to DEPSMX; this is residual stress carried over from first to second block	ALIFE
SUMF	1	2488	C	Sum of FMAX values for first pass	FATIGU
T	3000	2401	C	General area for calculated values, scratch	FTGCTL
TCOM	5600	1	C	Common area, cleared in control program	FATGUE
TEPSTJ	1	2486	C	Absolute value of EPST2 and EPSBT for any point	ALIFE

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
TF	1	2498	C	Total multiplying factor used for EMAX, EMIN in life iteration for any condition	FATIGU
TMD	300	3501	IL	Block that material record from library is read into	FRGCTL
TNF1	1	2469	C	Cycles to failure corresponding to EPST2	ALIFE
TNF2	1	2470	C	Cycles to failure corresponding to EPSBT	ALIFE
WIND	2	109	I/IM	Wing material number indicators, (SOF, WOS) • 0 = set up from wing module data if it is loaded • + = use no.'s in input stream • - = do not calculate for this station	FTGCTL
X	1	2454	C	Solution for SGMX, ksi	ALIFE
XCL	1	2421	C	X calculated, ln.	ACURVE
XCL	1	2431	C	X calculated, ln.	BCURVE
XCR	1	2428	C	X calculated, real	ACURVE
XCR	1	2438	C	X-calculated, real	BCURVE
XI	1	2420	C	Curve point used in interpolation ln of input x	ACURVE

TABLE 21. VARIABLE LIST (CONT)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
XI	1	2430	C	Curve point used in interpolation In of input x	BCURVE
XJ	1	2422	C	Curve point used in interpolation	ACURVE
XJ	1	2432	C	Curve point used in interpolation	BCURVE
XK	1	2424	C	Curve point used in interpolation	ACURVE
XK	1	2434	C	Curve point used in interpolation	BCURVE
XMISC	100	MISC	IM	Labeled common array used to convey single items from one module to another	FATGUE, FTGCTL
XPRIOR	1	--	C	Value of previous x-argument	ACURVE
YI	1	2426	C	Curve point calculated by interpolation correspond to XI	ACURVE

TABLE 21. VARIABLE LIST (CONCL)

Var Name	Size	Common Loc	Type*	Description	Subroutine Reference
YI	1	2436	C	Curve point calculated by interpolation, correspond to XI	BCURVE
YJ	1	2423	C	Curve point used in interpolation	ACURVE
YJ	1	2433	C	Curve point used in interpolation	BCURVE
YK	1	2425	C	Curve point used in interpolation	ACURVE
YK	1	2435	C	Curve point used in interpolation	BCURVE
YPRIOR	1	--	C	Values of y-calculated for XPRIOR	ACURVE
YREAL	1	2427	C	Real value of interpolated value to check in stress-strain equation	ACURVE
YREAL	1	2437	C	Real value of interpolated value to check in strain versus cycles equation	BCURVE

*Symbols used to designate type represent:

C - stored during calculation
I - input through data stream
IL - input from library files
IM - input from another module

TABLE 22. FATIGUE INPUT DATA

D Loc	Var Name	Description ((I/L) = Input or From Loads Module)
1		1.0
2		2.0
3		3.0
4		4.0
5		5.0
6		6.0
7		7.0
8		8.0
9		9.0
10		10.0
11		11.0
12		12.0
13		20.0
14		1000.0
15		3.1415927, pi
16		0.01745329, deg to radians factor
17		144.0
18		24.0
19		0.5
20		1.5
21		0.3333333
22		0.95
23		0.25
24		0.0
25 through 50		Not used

TABLE 22. FATIGUE INPUT DATA (CONT)

D Loc	Var Name	Description ((I/L) = Input or From Loads Module)
51	CON(1)	1.12
52	CON(2)	0.893
53	CON(3)	0.0792
54	CON(4)	0.179
55	CON(5)	3.31
56	CON(6)	0.25
57	CON(7)	81.4
58	CON(8)	0.75
59	CON(9)	1.0×10^8
60	CON(10)	1.0×10^6
61	CON(11)	0.015, tolerance in σ_{MAX} root iteration - ALIFE
62	CON(12)	0.001, tolerance in ACURVE and BCURVE
63	CON(13)	0.01, tolerance in iteration for life - FATIGU
64	CON(14)	-0.1666667, factor in '2nd stress' level estimate - FATIGU in life iteration
65 through 77		Used for calculated values of material-dependent data
78	CON(28)	0.5, factor in initial stress level - FTGCIL
79	CON(29)	1.0×10^9, cycles for endurance limit
80	CON(30)	1.0, notch factor for endurance limit
81	BLOCK	0.05, block size, fraction of required life
82 through 100		Not used
101	H	Hours of vehicle life (I or trans from Data Management)
102 through 107		Used for calculations

TABLE 22. FATIGUE INPUT DATA (CONT)

D Loc	Var Name	Description ((I/L) - Input or From Loads Module)
108		Not used
109	WIND(1)	SOF, wing
110	WIND(2)	WOS, wing
111	FIND	Fuselage cover
112	FFIND	Fuselage minor frames

Material number indicator:
- 0 value = set from corresponding weight module data
- + value = used from FATIGUE input
- - value = no fatigue calculation for that item

113	SFW(1)	Wing scatter factor for SOF
114	SFW(2)	Wing scatter factor for WOS
115	FKTW(1)	Wing notch factor for SOF
116	FKTW(2)	Wing notch factor for WOS
117	SFFP	Scatter factor for fuselage pressure cycles
118	FKTFP	Notch factor for fuselage pressure cycles
119 through 200		Not used
201 through 1100		Set up during calculation
1101 through 1160		Not used
1161		Used for calculated variable BMMX
1162	BMSMX(1)	(I/L) maximum static bending moment SOF
1163	BMSMX(2)	(I/L) maximum static bending moment WOS
1164 through 1199		Not used
1200	FPT	Number of points in fuselage pressure array (1 to 100)
1201 through 1300	FPR(1) through FPR(100)	Maximum fuselage pressures, PMX

TABLE 22. FATIGUE INPUT DATA (CONT)

D Loc	Var Name	Description ((I/L) - Input or From Loads Module)
1301 through 1400	FPR(101) through FPR(200)	Minimum fuselage pressures, PMN, corresponding to PMX
1401 through 1500	FPR(201) through FPR(300)	Applied cycles for fuselage pressures, PCY, corresponding to PMX, PMN
1501	BMA(1,1)	(I/L) Maximum bending moment, SOF, 1st point, 1st spectra seg
1502	BMA(2,1)	(I/L) Maximum bending moment, WOS, 1st point, 1st spectra seg
1503	BMA(3,1)	(I/L) Exceedance for gust, 1st point, 1st spectra seg
1504 through	BMA(1,2) through	(I/L) Maximum bending moment, SOF, 2nd point, 1st spectra seg
1558	BMA(1,20)	(I/L) Minimum bending moment, SOF, 20th point, 1st spectra seg
1559	BMA(2,20)	(I/L) Minimum bending moment, WOS, 20th point, 1st spectra seg
1560	BMA(3,20)	(I/L) Exceedance for gust, 20th point, 1st spectra seg
1561 through 2100	BMA(1,21) through BMA(3,200)	(I/L) Maximum bending moment, SOF, 1st point, 2nd spectra seg (I/L) Exceedance for gust, 20th point, 10th spectra seg
2101	BMA(1,201)	(I/L) Positive bending moment, SOF, Ground-air-ground spectra seg
2102	BMA(2,201)	(I/L) Positive bending moment, WOS, Ground-air-ground spectra seg
2103	BMA(3,201)	(I/L) Occurrences, Ground-air-ground spectra seg
2104	BMA(1,202)	(I/L) Negative bending moment, SOF, Ground-air-ground spectra seg
2105	BMA(2,202)	(I/L) Negative bending moment, WOS, Ground-air-ground spectra seg

TABLE 22. FATIGUE INPUT DATA (CONCL)

D Loc	Var Name	Description ((I/L) - Input or From Loads Module)
2106	BMA(3,202)	(I/L) Occurrences, ground-air-ground spectra seg
2107 through 2116	BMREF(1) through BMREF(10)	(I/L) 1 g net bending moments, SOF, for spectra segments 1 through 10
2117 through 2126	BMREF(11) through BMREF(20)	(I/L) 1 g net bending moments, WOS, for spectra segments 1 through 10
2127 through 2346	EM(1) through EM(220)	(I/L) Exceedances for maneuver, 20 for each spectra segment, only 1 through 10 have data as not used on ground-air-ground (after 202 could be used)
2347 through 2400		Not used

COMMON

Common consists of 5,600 cells which are divided into the major regions, as follows:

Common Location	Variable Name	Description
1 through 2400	D(1) D(2400)	Physical constants, equation constants, input data, and material-dependent factors
2401 through 5400	T(1) T(3000)	Calculated variables and storage of material library file data
5401 through 5600	ND(1) ND(200)	Storage regions for indicators and counters

LABELED COMMON

Labeled common arrays are used to transfer program control words and certain vehicle design data. These arrays are as follows:

1. XMISC (Block MISC) - This array is used to transmit certain vehicle design data as shown in Table 23.

2. IP (Block IPRINT) - This array is used to transmit the following print controls:

   a. IP(56) - This indicator is used in subroutine FATGUE to designate output print of bending moment exceedance data. (See Figure 39.)

   b. IP(57) - This indicator is used in subroutines FTGCTL and FATIGU to designate output print of input factors, initial stress-occurrence array, and final damage tables. (See Figures 40 through 44.)

   c. IP(58) - This indicator is used in subroutine FATIGU to designate output print of intermediate program calculations. (See Figures 45 and 46.)

      For Figure 45, the data are arranged in the following manner:

      1. Three lines of material-dependent factors from CON array:

65	RTO	SEG	RT01	RT02	C1
70	C2	BETA	GAMMA	Q	RE
75	P	C1E	QPI	-	-

      2. Four columns of calculated coordinates for stress-strain curve and strain versus cycles to failure curve, and natural logarithms of the coordinates as used for interpolation:
         C1X C1Y C2X C2Y

      For Figure 46, the three lines of printed data are arranged in the following manner:

      NTIME, HCALC, FACT, TF
      H1, SF1, H2, SF2
      HN, SFN, HR, *

      *Natural logarithm of FACT for NTIME = 1 only.

TABLE 23. XMISC ARRAY VARIABLES (MISC BLOCK)

Loc	Description	Subroutine Reference
1	Number of material records in material library	FATGUE
2 through 14	Controls and design data used by other program modules	
15	Wing structure material identification number; established in executive module	FTGCTL
16 through 30	Controls and design data used by other program modules	
31	Fuselage cover material identification number; established in executive module	FTGCTL
32	Maximum net unswept bending moment at wing side of fuselage station (in.-lb); established in airload module	FATGUE
33	Maximum net swept bending moment at outboard wing fatigue evaluation station (in.-lb); established in airload module	FATGUE
34	Required vehicle life (hr); established in data management module	FATGUE
35 through 40	Controls and design data used by other program modules	
41	Fuselage minor frame material identification number; established in executive module	FTGCTL
42 through 100	Controls and design data used by other program modules	

*** BC(3,220) FROM SUBROUTINE FATMG IN LOADS PROGRAM IN RECORD 35 *** ** FATIGUE - IP(56) **

	SOE BEND MOM	WOS BEND MOM	EXCEEDANCES-GUST	EXCEEDANCES-MANU
1	2[illegible]4220.	2529334912.	0.72702E-42	0.0
2	1324671?0.	2328674256.	0.50260E-37	0.0
3	1755[illegible]220.	2124[illegible]3600.	0.34746E-32	0.75000E-01
4	1534772736.	1926[illegible].	0.24020E-27	0.42500E+00
5	1429756?0.	1799323?0.	0.16605E-22	0.22500E+01
6	1264?8400.	1530?1664.	0.11480E-17	0.10000E+02
7	1099[illegible]216.	1330?1?04.	0.79363E-13	0.47500E+02
8	934984016.	1131103?6.	0.54866E-08	0.26250E+03
9	76086816.	9?14?6?0.	0.37930E-03	0.36750E+04
10	60489680.	7314?0?2.	0.26765E+02	0.17500E+06
11	43491536.	5?8?1?5?.	0.26765E+02	0.20000E+05
12	3?0?4352.	3?3?1?36.	0.37930E-03	0.34000E+03
13	16497184.	1?3?0640.	0.54866E-08	0.75000E+00
14	0.	0.	0.79363E-13	0.25000E-02
15	-16497184.	-1?6?0640.	0.11480E-17	0.0
16	-3?0?4352.	-3?3?1?36.	0.16606E-22	0.0
		(≈≈≈)		
196	-1033?900.	-8410162.	0.22500E+02	0.0
197	-812?8425.	-6?07622.	0.75000E+00	0.0
198	-5418950.	-4?65081.	0.25010E-01	0.0
199	-4054212.	-3153810.	0.50000E-02	0.0
200	-2709475.	-2102541.	0.10000E-02	0.0
201	68738256.	83169376.	0.25000E+05	0.0
202	-64562304.	-50146560.	0.25000E+05	0.0

REFERENCE BENDING MOMENTS FOR MANEUVER

SEGMENT	SOE	WOS
1	54990608.	66535504.
2	46380208.	5643?400.
3	50366784.	6?794464.
4	43902768.	64913616.
5	51637872.	68770848.
6	45424368.	59545680.
7	45?0416?.	59534400.
8	46685?24.	59473472.

BMSMX(1) = 32051?464.

BMSMX(2) = 253423024.

Figure 39. Sample output - bending moment - exceedance data.

FATIGUE INPUT DATA ** FTGCTL - IP(57) **

E= 0.5000000E+05 SE= 0.4000001E+01 KT= 0.3000000E+01

ETU= 0.1300000E+06 E= 0.1640022E+08 PA= 0.2700000E+00 NPT= 157

WING OUTBOARD STATION

STRESS LEVELS SET UP FROM BENDING MOMENTS TIMES 0.260627E-03

1	0.6721781E+05	-0.2987461E+05	0.5025913E-37
2	0.6161628E+05	-0.2427312E+05	0.3474500E-32
3	0.6161628E+05	0.1867163E+05	0.7499999E-01
4	0.5601488E+05	-0.1867162E+05	0.2401981E-27
5	0.5601488E+05	0.1867163E+05	0.3500000E+00
6	0.5041340E+05	-0.1307014E+05	0.1660504E-22
7	0.5041340E+05	0.1867163E+05	0.1824999E+01
8	0.4481191E+05	-0.7468648E+04	0.1147952E-17
9	0.4481191E+05	0.1867163E+05	0.7750001E+01
10	0.3921043E+05	-0.1867162E+04	0.7936224E-13
	(≈≈≈≈≈)		
145	0.3514366E+05	-0.1668993E+04	0.8765712E-08
146	0.3514366E+05	0.1668994E+05	0.2375000E+01
147	0.1668984E+05	-0.1668983E+04	0.2499999E-02
148	0.3004170E+05	0.3337966E+04	0.5370368E-04
149	0.3004170E+05	0.1668984E+05	0.6000000E+02
150	0.1668984E+05	0.3337966E+04	0.3724997E+00
151	0.2503475E+05	0.8344914E+04	0.3288534E+00
152	0.2503475E+05	0.1669984E+05	0.2000000E+04
153	0.1668384E+05	0.8344914E+04	0.5462500E+02
154	0.2002780E+05	0.1335186E+05	0.2292679E+05
155	0.2002780E+05	0.1668984E+05	0.7293750E+05
156	0.1668384E+05	0.1335186E+05	0.4745000E+04
157	0.2333954E+05	-0.1407246E+05	0.2500000E+05

Figure 40. Sample output - fatigue input data.

MASS STORAGE FILES

Mass storage file records used in this program are described in Table 24.

TABLE 24. MASS STORAGE FILE RECORDS

Record No.	Variable and Length	Write Routine	Read Routine	Description
29	D(2400)	Executive module	FATGUE	Fatigue module input data file
35	DUMM (830)	Executive and airload modules	FATGUE	Wing bending moment fatigue spectra data
41 through 60	TMD(5000)	Executive module	FTGCTL	Material library files for 20 different materials

SUBROUTINE DESCRIPTIONS

PROGRAM FATGUE

General Description

Deck name: FATGUE
Entry name: OVERLAY (5HALPHA,3,0)
Called by: PROGRAM OLAY00
Subroutines called: FTGCTL

This is the control program for the fatigue module. This routine reads the required data and calls FTGCTL to perform the calculations.

The data are read from record 29. The maximum static bending moments for the wing at the side of the fuselage (SOF) and the wing outer panel station (WOS) are initialized from data if present or from values saved during the loads calculation. Bending moments and exceedances calculated in the loads module or input with fatigue data are read from record 35, and are printed if IP(56) is zero.

NUMBER OF ITERATIONS IN SUBROUTINE FATIGU = 3 ** FATIGU - IP(57) **

CALC. LIFE(HR) REQUIRED LIFE(HR)
0.1[illegible]E+06 0.200000E+06 HIGHEST EMAX= 0.605[illegible]E+05 = 43.59PCT ETU

N	EMAX	EMIN	APP.CYC.	DAMAGE 1	PCT	DAMAGE 2	PCT
1	55533.	-26044.	0.	0.+201+3E-41	0.00	0.427119E-+1	0.00
2	53716.	-21161.	0.	0.175451E-36	0.00	0.221442E-36	0.00
3	53716.	16278.	0.	0.344587E-06	0.00	0.613378E-05	0.19
4	49833.	-16278.	0.	0.648662E-32	0.00	0.106803E-31	0.00
5	49833.	16278.	0.	0.673641E-06	0.00	0.121253E-04	0.38
6	43351.	-11394.	0.	0.197909E-27	0.00	0.446992E-27	0.00
7	43351.	16278.	0.	0.107857E-05	0.00	0.202511E-04	0.64
8	39066.	-6511.	0.	0.447830E-23	0.00	0.142544E-22	0.00
9	39066.	16278.	0.	0.380615E-06	0.00	0.159449E-04	0.50
10	34183.	-1628.	0.	0.610379E-19	0.00	0.260038E-18	0.00
11	34183.	16278.	2.	0.405906E-06	0.00	0.525043E-05	0.17
12	16278.	-1628.	0.	0.991924E-12	0.00	0.280420E-11	0.00
13	23300.	3256.	0.	0.354150E-15	0.00	0.148309E-14	0.00
14	23300.	16278.	11.	0.801787E-07	0.00	0.551655E-06	0.02
				(≈≈≈≈≈≈≈≈≈≈)			
149	26130.	14550.	3.	0.466546E-08	0.00	0.207360E-07	0.00
150	14550.	2910.	0.	0.267166E-11	0.00	0.540217E-11	0.00
151	21225.	7275.	0.	0.684729E-10	0.00	0.185777E-09	0.00
152	21225.	14550.	100.	0.958663E-09	0.00	0.287346E-08	0.00
153	14550.	7275.	3.	0.559942E-11	0.00	0.117725E-10	0.00
154	17460.	11640.	1146.	0.542415E-09	0.00	0.127038E-08	0.00
155	17460.	14550.	3647.	0.239417E-11	0.00	0.577302E-11	0.00
156	14550.	11640.	237.	0.831622E-12	0.00	0.191164E-12	0.00
157	21347.	-12268.	1250.	0.195677E-02	0.78	0.30537[illegible]E-02	96.35
	CUMULATIVE DAMAGE FOR EACH BLOCK			0.196257E-02	0.79	0.314390E-02	99.21

NUMBER OF RESIDUAL DAMAGE BLOCKS 78.895

Figure 41. Sample output - final damage table for wing outboard station.

N FOR END OF EACH SPECTRA SEGMENT FOLLOWS ** ETGCTL - IP(57) **

1	21
2	42
3	61
4	90
5	99
6	119
7	137
8	156
9	156
10	156

NOTE Each of the spectra segments in Figure 10 is defined by 20 bending moment exceedance points. This table correlates the number of pertinent bending moment occurrance sets obtained with that spectra data. N given here is the index shown in Figures 11 and 12.

Figure 42. Sample output - index at the end of each spectra segment.

FATIGUE INPUT DATA ** FTGCTL - IP(57) **

H= 0.5300000E+05 SF= 1.4000000E+01 KT= 0.3000000E+01

FTU= 0.7300000E+06 E= 0.1643032E+08 PA= 0.2700000E+00 NPT= 1

FUSELAGE COVER

STRESS LEVELS SET UP FROM FUSELAGE PRESSURES TIMES 0.3154409E+04

1	0.3474099E+05	0.0	0.2500000E+05

NUMBER OF ITERATIONS IN SUBROUTINE FATIGU = 3 ** FATIGU - IP(57) **

CALC. LIFE(HR) REQUIRED LIFE(HR)
0.1995045E+06 0.2000000E+06 HIGHEST FMAX= 0.2908957E+05 = 90.92PCT FTU

N	FMAX	FMIN	APP.CYC.	DAMAGE 1	PCT	DAMAGE 2	PCT
1	29086.	0.	1250.	0.313277E-02	1.25	0.313277E-02	98.75
	CUMULATIVE DAMAGE FOR EACH BLOCK			0.313277E-02	1.25	0.313277E-02	98.75

NUMBER OF RESIDUAL DAMAGE BLOCKS 78.801

Figure 43. Sample output - fuselage pressure cycle input and damage table.

```
ENDURANCE LIMIT
        1       0.4550000E+05       -0.4550000E+05       0.1000000E+10

NUMBER OF ITERATIONS IN SUBROUTINE FATIGU =    3                    ** FATIGU - IP(57) **

     CALC. LIFE(HR)          REQUIRED LIFE(HR)
     0.4529852E+05           0.5000000E+05      HIGHEST FMAX= 0.2478205E+05 =  17.83PCT FTU

 N       FMAX        FMIN      APP.CYC.       DAMAGE 1        PCT        DAMAGE 2        PCT

 1       24782.      -24782.   50000000.      0.500007E-01    5.00       0.500007E-01    95.00

     CUMULATIVE DAMAGE FOR EACH BLOCK         0.500007E-01    5.00       0.500007E-01    95.00

NUMBER OF RESIDUAL DAMAGE BLOCKS   19.000
```

Figure 44. Sample output - endurance limit starting values and damage table.

65	0.3147104E+00	0.1827400E+06	0.8475497E-02	0.1314710E+01	0.1211987E-01
70	0.2001215E+00	0.1004705E+06	0.5805507E+03	0.5782299E+01	0.1640021E+05
75	0.1684268E-09	0.1887686E+06	0.6793299E+01	0.5000000E+00	0.1000000E+10

CURVE SET-UP

0.6057480E-07	0.1000000E+01	0.2122413E+00	0.1000000E+01
0.2322958E-05	0.3809702E+02	0.6213898E-01	0.1000000E+02
0.8849776E-04	0.1451383E+04	0.2141511E-01	0.1000000E+03
0.3494026E-03	0.5529337E+05	0.9672381E-02	0.1000000E+04
0.1348615E-01	0.1105867E+06	0.5753633E-02	0.1000000E+05
0.8043385E-01	0.1658801E+06	0.4061129E-02	0.1000000E+06
0.1605555E+05	0.1401294E+07	0.2417130E-02	0.1000000E+08
0.3667668E+10	0.1183762E+08	0.1199237E-02	0.9999999E+10
0.8376300E+15	0.1000000E+09	0.4752390E-03	0.9999998E+14
		0.1494713E-03	0.9999997E+19

-16.612793	0.0	-1.550031	0.0
-12.972670	3.640136	-2.778381	2.302585
-9.332534	7.280272	-3.843658	4.605170
-5.656701	10.920409	-4.638481	6.907756
-4.306092	11.613556	-5.157924	9.210340
-2.520320	12.019021	-5.506294	11.512926
0.684050	14.152907	-6.025174	16.118098
22.022812	16.286789	-6.726069	23.025849
34.361588	18.420670	-7.551693	32.236191
		-8.908406	43.749115

Figure 45. Sample output - material-dependent factors and curve coordinate.

```
***** NTIME=  1        HCALC=  0.4948021E+05        FACTOR=  0.7923194E+00  TF=  0.7923194E+00
      0.1089093E+02     0.1552383E+02     0.0               0.0
      0.0               0.1529704E+02     0.1220607E+02    -0.2327908E+00

***** NTIME=  2        HCALC=  0.5758477E+06        FACTOR=  0.1105511E+01  TF=  0.8759175E+00
      0.1089093E+02     0.1552383E+02     0.1326360E+02     0.1529704E+02
      0.1326360E+02     0.1536735E+02     0.1220607E+02    -0.3237671E+05

***** NTIME=  3        HCALC=  0.1838014E+06        FACTOR=  0.9952809E+00  TF=  0.8717839E+00
      0.1215373E+02     0.1533735E+02     0.1326360E+02     0.1529704E+02
      0.1215373E+02     0.1533262E+02     0.1220607E+02    -0.3537054E+05
```


Figure 46. Sample output - intermediate values in life interpolation calculation.

Arrays and Variables Used

BMA, BMREF, BMSMX, D, DUMMY, EM, IP, NMATL, TCOM, XMISC

Arrays and Variables Calculated

None

Scratch Arrays

None

Labeled Common Arrays

IP, XMISC

IP(56) - controls printing of bending moments and exceedances, reference bending moments, and maximum static bending moments.

XMISC(1) - the number of material records in the material library, is placed in NMATL.

XMISC(32) - the maximum static bending moment for SOF from the loads module, is placed in BMSMX(1) if not input in data stream.

XMISC(33) - the maximum static bending moment for WOS from the loads module, is placed in BMSMX(2) if not input in data stream.

XMISC(34) - required vehicle life in hours (H) is put in D(101).

Mass Storage File Records Used

Record 29 - data entered through the input stream (Table 22).

Record 35 - bending moments, exceedances, etc, usually from the loads module routine FATMG, locations 1501 through 2346 in Table 22.

Error Messages

None

SUBROUTINE FTGCTL

General Description

Deck name: FTGCTL
Entry name: FTGCTL
Called by: FATGUE
Subroutine called: FATIGU

This routine performs the setup operations for the four conditions that can be handled, and gives a summary of the KF_{tu} values calculated. (See Figure 47.)

For the two wing stations, initial stress levels are calculated from the bending moments and exceedances which usually come from the loads module. Each spectra segment has 20 points; each bending moment has a gust exceedance and a maneuver exceedance. Preliminary stress values and the number of occurrences are obtained from these in the following manner:

Let

B = bending moments

gb = 1 g bending moment for this spectra segment

G = gust exceedances

M = maneuver exceedances

F' = preliminary stresses

C = occurrences

then

$$F'_{max_1} = B_2 + (B_1 - B_2)/3$$

$$F'_{min_1} = B_{19} + (B_{20} - B_{19})/3$$

```
CHANGES MADE TO MATERIAL PROPERTIES BY FATIGUE PROGRAM                    ** FTGCTL **

     SIDE OF FUSELAGE ** MATL NO  8.
TMD(133) CHANGED FROM   0.0     TO    0.0

     WING STATION 2 ** MATL NO 13.
TMD(134) CHANGED FROM   1.0000 TO    0.4460

     FUSELAGE COVER ** MATL NO 13.
TMD(131) CHANGED FROM   0.2800 TO    0.1783
TMD(132) CHANGED FROM   0.5000 TO    0.2092

  FUSELAGE MINOR FRAME ** MATL NO 13.
TMD(131) CHANGED FROM   0.2800 TO    0.1783
TMD(132) CHANGED FROM   0.5000 TO    0.2092
```


Figure 47. Sample output - summary of KF_{tu} values put into the library.

$$C_1 = G_2 - G_1 \qquad \text{due to symmetry}$$

$$F'_{max_2} = B_2 + (B_1 - B_2)/3$$

$$F'_{min_2} = gb$$

} or max and min switched, depending on which is larger

$$C_2 = M_2 - M_1$$

$$F'_{max_3} = gb$$

$$F'_{min_3} = B_{19} + (B_{20} - B_{19})/3$$

} or max and min switched, depending on which is larger

$$C_3 = M_{19} - M_{20}$$

If F'_{max_1} is zero or negative, that point is not used and the next set of B-points is tried. Also, if any C-value is zero or negative, the corresponding F' values are not used. The F'_{max} and F'_{min} arrays are always kept compact, and a total count is thus generated.

The initial stress level to use for the life iteration is:

$$FMAX_i = F'_{max_i} (1/2 \text{ FTU}/F''_{max})$$

and

$$FMIN_i = F'_{min_i} (1/2 \text{ FTU}/F''_{max})$$

where

F''_{max} is the maximum of all F'_{max} values

For fuselage pressure cycling, the initial stress level is calculated from the input values:

PMX_i = maximum pressure

PMN_i = minimum pressure

PCY_i = occurrences of this max-min cycle

then

$$FMAX_i = PMX_i \ (1/4 \ FTU/PMX_{max})$$

and

$$FMIN_i = PMN_i \ (1/4 \ FTU/PMX_{max})$$

$$C_i = PCY_i$$

where PMX_{max} is the maximum of all PMX values.

KF_{tu} ultimate fatigue factor is calculated by this routine after the life calculation has reached convergence.

For the wing stations

$$KF_{tu} = (f_{max}/F_{tu})(BM/B_{max})$$

where

f_{max} = highest value in the FMAX array after adjustment to give the desired life

BM = maximum static bending moment for that station

B_{max} = maximum value in the preliminary stress array (F''_{max} in the foregoing discussion)

F_{tu} = ultimate tensile strength

For the fuselage cover, factor for pressure cycles and endurance limit is:

$$KF_{tu} = f_{max}/F_{tu}$$

Logic Flow Outline

1. Calculate for SOF(WOS) material record is read (if necessary) and FTU, RA, and E are placed in working locations.

   a. Set up SAVE with KFTU value and material number from library.

   b. Calculate initial stress and occurrences.

   c. Put scatter factor, notch factor, and number of stress points in working locations.

   d. Print factors and stress-occurrences array if IP(57) = 0.

   e. Call FATIGU.

   f. Calculate ultimate fatigue factor, and place in SAVE and in material working area

   g. Put material record back in library.

2. Repeat from step 1 for WOS.

3. Calculate for fuselage cover, read material (if necessary), and put FTU, EA, and E in working locations.

   a. Put library value of KFTU and material number in SAVE.

   b. Put scatter factor, notch factor, and number of stress points in working locations.

   c. Calculate initial stress and occurrences.

   d. Print factors and stress-occurrence array if IP(57) = 0.

   e. Call FATIGU.

   f. Calculate ultimate fatigue factor, and place in SAVE and material working area.

g. Set up stress and occurrence, scatter factor, and notch factor for endurance limit.

h. Call FATIGU.

i. Calculate ultimate fatigue factor, and place in SAVE and material working area.

j. Put material record back in library.

4. Repeat from 3 for fuselage minor frame only if material is different.

5. Print from SAVE, showing changes made in material properties by fatigue module.

Arrays and Variables Used

ANPT, BLOCK, BMA, BMMX, BMREF, BMSMX, CON, EM, FIND, FKTFP, FKTW, FMAX, FMIN, FPT, FTU, H, IFERR, MI, NMATL, NPT, NSEG, NTOP, PCY, PMN, PMX, RA, SF, SFW, TMD, WIND

From the material record, TMD, the routine uses:

RA TMD(5) reduction in area
TMD(119) tension strain at the proportional limit
TMD(121) tension stress at the proportional limit

F_{tu} TMD(126) ultimate tension stress.

Arrays and Variables Calculated

AN, ANPT, BMMX, E, FKT, FMAX, FMIN, HRBL, MI, NPT, NSEG, NTOP, TMD

TMD is the array used for the material record from the library. The fatigue module stores KF_{tu} for each condition in all six of the possible temperature groups of material data, Table 25.

TABLE 25. FATIGUE ALLOWABLE FACTOR, $K_{F_{tu}}$, RELATIVE LOCATION IN TMD ARRAY

Temp No.	KF_{tu} Location in TMD			
	Fuselage Endurance Limit	Fuselage Pressure	SOF	WOS
1	130	132	133	134
2	155	157	158	159
3	180	182	183	184
4	205	207	208	209
5	230	232	233	234
6	255	257	258	259

If the life calculation failed to converge, no value is stored in the KF_{tu} locations for that condition; the value in the library will be used in later calculations.

MI is set up to designate if the material involved is the same as the previous one. A nonzero value indicates it is the same as previous. Used here and in FATIGU to avoid repeat calculation.

Scratch Arrays

T(1) through T(4) are used for partial values and miscellaneous temporary storage.

Labeled Common Arrays

IP, XMISC

IP(57) - print control for input factors: H, SF, FKT, FTU, E, RA, and NPT, and for the initial stress-occurrence array.

XMISC(15) - wing material number. This number is used for both SOF and WOS if material numbers are not input in fatigue input data locations 109 and/or 110.

XMISC(31) - fuselage cover material number. This number is used unless a value is input in fatigue input data location 111.

XMISC(41) - fuselage minor frame material number. This number is used unless a value is input in fatigue input data location 112.

Mass Storage File Records Used

The material library consists of records 41 through 60. In this routine, records specified by material number plus 40 are read into the TMD array and are rewritten after insertion of the appropriate KF_{tu} values.

Error Messages

*****MATERIAL NO. XX. BEYOND YY, USED MATL. NO. 1

where XX is the input material number and YY is the number of materials in the library.

SUBROUTINE FATIGU

General Description

Deck name: FATIGU
Entry name: FATIGU
Called by: FTGCTL
Subroutines called: ALIFE

This routine initializes and controls the iteration for life. Material dependent factors, including points on the cyclic stress-strain and strain versus cycles to failure curves, are calculated when MI is zero (for each new material).

The following are the material dependent factors, including variable names, engineering symbols, and equations.

$$RTO = D = \ln [1.0/(1.0-R_A)] = \text{ductility}$$

$$SGF = \sigma_f = F_{tu}\,(1.0+D) = \text{fracture stress}$$

$$C1 = C_1 = 1.12\,(F_{tu}/E)\left(\sigma_f/F_{tu}\right)^{0.893}$$

$$BETA = \beta = 0.0792 + 0.179 \log.(\sigma_f/F_{tu})$$

$$GAMMA = \gamma = \log.\left\{\frac{3.31\ D^{1/4}}{\left[1.0 - 81.4\,(F_{tu}/E)\ \sigma_f/F_{tu}^{\ 0.179}\right]^{1/3}}\right\}$$

$$C2 = C_2 = 0.125\ D^{0.75}\ 10^{\gamma}$$

Other collected terms used are:

$$Q = \gamma/\beta$$

$$P = \left[(C2)\ \frac{E}{1,000}\right] / \left[(C1)\ \frac{E}{1,000}\right]^{-Q}$$

$$C1E = (C1)(E)$$

$$QP1 = Q + 1.0$$

The cyclic stress - cyclic strain equation is

$$\varepsilon_t = \sigma_a/E + C_2\left(\sigma_a/C_1E\right)^{\gamma/\beta}$$

Since this equation cannot be solved directly for σ_a, nine pairs of σ_a, ε_t values are set up for use by the interpolation-iteration routine ACURVE which returns σ_a for a given ε_t.

The ln ln plot of the equation has a change of slope where the dominant term changes and the nine sigmas are calculated to cover the expected range adequately. Let σ_a for this curve array be y_i.

First point $\quad y_1 = 1.0$

Last point $\quad y_9 = 100{,}000{,}000$

Midpoint of curved portion

$$y_5 = E \left(C_1^{\gamma/\beta} / C_2 \right)^{\frac{1.0}{\gamma/\beta - 1.0}}$$

$$y_4 = y_5/2.0$$

$$y_2 = \left(y_4 \right)^{1/3}$$

$$y_3 = \left(y_2 \right)^2$$

$$y_6 = y_5 + y_4$$

$$y_7 = \left(y_9/y_6 \right)^{1/3} \left(y_6 \right)$$

$$y_8 = \left(y_9/y_6 \right)^{2/3} \left(y_6 \right)$$

σ_a is calculated for each of these sigmas to form the x array. The natural logarithms of these x and y arrays are placed in C1X and C1Y, respectively, for use by ACURVE.

Ten points are calculated for the strain versus cycles-to-failure equation

$$\varepsilon_t = C_1/N_f^{\beta} + C_2/N_f^{\gamma}.$$

The N_f values used are 1.0, 10.0, 100.0, 1,000.0, 1.0×10^4, 1.0×10^5, 1.0×10^6, 1.0×10^8, 1.0×10^{11}, 1.0×10^{15}, 1.0×10^{20}. ε_t values are calculated for these N_f's. The natural logarithms of ε_t and N_f values are stored in C2X and C2Y, respectively. These are the arrays used by the interpolation-iteration routine BCURVE.

The initial occurrences for each max-min stress are multiplied by the fraction of life per block and placed in array CYC. Also specified life, H, is multiplied by scatter factor to give hours required, HREQ.

The iteration for life is also aided by a ln-ln line estimation. This line is hours of life versus summation of the maximum stresses (FMAX). The first point is the initial stress level and the life (HCALC) that it yields. The second point is estimated by a point-slope calculation to obtain a stress level for the required life (HREQ). The initial estimate of the slope is the value in data location 64 (CON(14)).

The third and subsequent estimates are obtained by using two-point line calculation, always keeping the two points nearest the desired life value (HREQ). When a summation of FMAX has been estimated, the factor to adjust the input stress levels is the ratio of the new estimate to the previous one. Iteration proceeds until HCALC is within ±1 percent of HREQ. This tolerance is in data location 63 (CON(13)), and can of course be modified by the user.

Arrays and Variables Used

AN, ANPT, BLOCK, CON, DAM1, DAM2, E, FMAX, FMIN, FTU, H, HCALC, IP, MI, NPT, RA, SF.

Arrays and Variables Calculated

BETA, CYC, C1, C1E, C1X, C1Y, C2, C2X, C2Y, FMAX, FMIN, FTOP, GAMMA, HREQ, ND(44)[IFERR], NTIME, NTOP, P, PC1, PC2, Q, QP1, RSF, SGF.

Scratch Variables [used only in this routine and not for output, except for checkout, IP(58)]

HN, HR, H1, H2, MTIME, RE, RTO, RTO2, S, SFM, SFN, SF1, SF2, SUMF, TF.

S(42) RSF reciprocal of scatter factor

S(87) SFM ln (SUMF) initialized to first value and thereafter is the prior value.

S(88) SUMF summation of initial FMAX array.

S(89) FTOP largest initial FMAX.

S(90) HI In (HCALC) first time, and maintained as the life coordinate of the left point.

S(91) SFI In (SUMF) first time, and thereafter the Σf_{max} coordinate of the left point.

S(92) H2 second time set as life coordinate of right point, from HI or HN

S(93) SF2 second time set as the Σf_{max} coordinate of the right point, from SFI or SFN

S(94) HN In (HCALC) second time and after

S(95) SFN calculated ln (Σf_{max}) coordinate to correspond to HR each time, to get new a FACT.

S(96) HR ln (HREQ)

S(97) FACT FACT = $e^{(SFN-SFM)}$; this is the factor applied to FMAX and FMIN array values for each new iteration.

S(98) TF product of all FACT values used

S(99) HREQ hours required life

S(100) HCALC hours calculated life each pass.

ND(46) MTIME counter for repeat attempts to get positive life if first life is negative; after 5, get error print.

Labeled Common Arrays

IP

IP(57) Final damage table (see Figure 41)

IP(58) Checkout-type print, material dependent factors, and curve points, both real and logarithmic values, are printed if the material is different from the condition before (MI=1) shown in Figure 45.

Also, a three-line print each life iteration, as in Figure 46.
NTIME, HCALC, FACT, TF
H1, SF1, H2, SF2
HN, SFN, HR, ln(FACT) first time only

Mass Storage File Records Used

None

Error Messages

When the life calculation fails to converge, the following printout is produced:

One of the following heading lines

1. WORKING ON WING AT SIDE OF FUSELAGE

2. WORKING ON WING OUTER PANEL STATION

3. WORKING ON FUSELAGE PRESSURE CYCLES

4. WORKING ON FUSELAGE ENDURANCE LIMIT

*** ERROR IN FATIGUE, PERTINENT DATA FOLLOWS...
NTIME= ____ , HCALC= ____ , FTU= _____ , E= ____ , RA= _____
HREQ= ____ , ANPT= ____ , SF= _____

FMAX	FMIN	CYC
.	.	.
.	.	.
.	.	.

The arrays at the time are printed. Followed by the S array, five values per line.

S(20) through S(28), refer to ACURVE, page 343

S(30) through S(33), refer to BCURVE, page 345

S(41) HRBL hours per block

S(42) RSF reciprocal of scatter factor

S(51) through S(86), refer to ALIFE, page 339

S(87) through S(100) used in this routine, refer to descriptions under "Scratch Variables"

If the value of HCALC is zero, the trouble occurred in ALIFE in the search for σ_{max}. If there is a value in HCALC, the failure was in FATIGU. either NTIME=500, or the iteration cannot converge to HREQ. In this case, HN=H1, H2, or HR. Check the value used for tolerances D(61) and D(63).

The first line of the printing may be "NEGATIVE LIFE THRU 5 ITERATIONS". When the initial stresses are too high, the first calculated life, HCALC, can be negative. The program divides the stress by two and goes through the life calculation again until HCALC is positive, but no more than five times.

SUBROUTINE ALIFE

General Description

Deck name: ALIFE
Entry name: ALIFE
Called by: FATIGU
Subroutines called: ACURVE, BCURVE

This is the routine that calculates life by the strain-cycling method. The calculation procedure is as follows: To facilitate the comparison of these equations with those in the methods section, the dependent variable is given in engineering notation and program variable name.

f_{maxj} = FMAX = maximum stress

f_{minj} = FMIN = minimum stress

n_j = CYC = number of occurrences

σ_{max} = SGMX = 1000.x for f(x) = 0

where

$$f(x) = x^2 + Px^{\gamma/\beta} + 1 - (K_N f_{maxj})^2/10^6$$

$$\varepsilon_{max} = \text{EPSMX} = \sigma_{max}/E + C_2 (\sigma_{max}/C_1 E)^{\gamma/\beta}$$

$$f_1 = F1 = \frac{1}{2}(f_{max_j} - f_{min_j}) \text{ if } f_{min_j} \geq 0.0$$

$$\text{or } \frac{1}{2} f_{max_j} \text{ if } f_{min_j} < 0.0$$

$$\Delta f_2 = DF2 = f_1 - f_{min_j}$$

$$\Delta\sigma_1 = DSG1 = K_N (f_{max_j} - \Delta f_2)$$

$$\Delta\varepsilon_1 = DEPS1 = \Delta\sigma_1/E$$

$$\Delta\varepsilon_2 = DEPS2 = \Delta f_2 \, \varepsilon_{max}/f_{max_j}$$

$$\Delta\sigma_2 = DSG2 = ACURVE\ (|\Delta\varepsilon_2|);$$ i.e., from cyclic stress-strain curve

$$\Delta\varepsilon_{range_j} = DEPS_j = \Delta\varepsilon_1 + \Delta\varepsilon_2$$

$$\sigma_{min} = SGMN = \sigma_{max} - \Delta\sigma_1 - \Delta\sigma_2$$

$$\sigma_{mean_j} = SGMEN_j = \frac{1}{2}(\sigma_{max} - \sigma_{min})$$

$$\varepsilon_a = EPSA = \frac{1}{2} \Delta \varepsilon_{range_j}$$

$$\varepsilon_t = EPST2 = \varepsilon_a/(1.0 - \sigma_{mean_j}/\sigma_f)$$

$$N_1 = TNF1 = BCURVE\ (|\varepsilon_t|);$$ i.e., from strain versus cycles to failure curve

$$d_{1_j} = DAM1_j = nj/N_1 =$$ damage for one max-min pair for first block

$$SDAM1 = \Sigma\ DAM1j$$

		f_{max}, f_{min} opposite sign	f_{max}, f_{min} same sign
$\Delta\sigma_{res_1}$	=	DSGR1 = $\frac{1}{2} K_N f_{min_j}$	or $\frac{1}{2} K_N f_{max_j}$
$\Delta\varepsilon_{res_2}$	=	DEPSR2 = $\frac{1}{2} f_{min_j} \varepsilon_{max}/f_{max_j}$	or $\frac{1}{2}\varepsilon_{max}$
		S(1) = σ_{min}	or σ_{max}
$\Delta\sigma_{res_2}$	=	DSGR2 = ACURVE ($\lvert\Delta\varepsilon_{res_2}\rvert$)	
σ_{res_j}	=	SGR1$_j$ = S(1) - $\Delta\sigma_{res_1}$ - $\Delta\sigma_{res_2}$	
$\Delta\varepsilon_{max}$	=	DEPSMX = largest $\Delta\varepsilon_{range_j}$ (subscript value of this point is saved in JMAX)	
σ_{res}^*	=	SGR1MX = σ_{res} that corresponds to $\Delta\varepsilon_{max}$; i.e., SGR1(JMAX)	
$\bar{\sigma}_{mean}$	=	SGBMEN = σ_{mean_j} + σ_{res}^* - σ_{resj}	
$\bar{\varepsilon}_t$	=	EPSBT = $\frac{1}{2} \Delta\varepsilon_{range_j}/(1.0 - \bar{\sigma}_{mean}/\sigma_f)$	
N_2	=	TNF2 = BCURVE ($\lvert\bar{\varepsilon}_t\rvert$); i.e., from strain versus cycles to failure curve	
d_{2_j}	=	DAM2j = nj/N_2 = damage for one max-min pair for second block	
		SDAM2 = Σ DAM2j	
Life	=	HCALC = [(RSF - Σd_{1j})/Σd_{2_j} + 1.0] HRBL	

Arrays and Variables Used

CON, CYC, CIE, C2, E, FKT, FMAX, FMIN, HRBL, NPT, P, Q, QP1, RSF, SGF

Arrays and Variables Caclulated

DAM1, DAM2, HCALC

Scratch Arrays and Variables

A, B, DEPS, DEPSMX, DEPSR2, DEPS1, DEPS2, DF2, DSGR1, DSGR2, DSG1, DSG2, EPSA, EPSBT, EPSMX, EPSTJ, EPST2, F, FA, FSQ, F1, JMAX, S(1), SDAM1, SDAM2, SGBMEN, SGMEN, SGMN, SGMX, SGR1, SGR1MX, TEPSTJ, TNF1, TNF2

S(51) through S(56) and S(59) are used in the search for sigma max (σ_{max}); refer to the foregoing equation.

S(51)	A	S(55)	FA
S(52)	B		
S(53)	F	S(59)	$FSQ = (K_N f_{max_j})^2/10^6$
S(54)	X		

A and B are the bracketing values of X being used, F is the value of the function at X, and FA is the value at A.

The description of the remaining values is best found in the foregoing calculation procedure.

S(56)	F1
S(57)	DF2
S(58)	not used
S(60)	through S(62) not used
S(63)	DSG1
S(64)	DSG2
S(65)	EPSA
S(66)	SGMN
S(67)	SGMX
S(68)	not used
S(69)	TNF1
S(70)	TNF2
S(71)	DEPS1
S(72)	DEPS2
S(73)	DSGR1
S(74)	DSGR2
S(75)	EPSBT
S(76)	EPSMX
S(77)	EPSTJ = absolute value of DEPS2 and DEPSR2
S(78)	EPST2
S(79)	SDAM1
S(80)	SDAM2
S(81)	not used
S(82)	DEPSMX
S(83)	DEPSR2

S(84) SGBMEN
S(85) SGRIMX
S(86) TEPSTJ = absolute value of EPST2 and EPSBT

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

FAILED TO FIND SGMX IN ALIFE SUBROUTINE *******
I = _____ X = ____ F = _____ A =_____ FA = _____ B =_____

This will be followed by the error print from FATIGU which is described therein. Probable cause of this failure would be errors in input fuselage pressure data.

FUNCTION ACURVE

General Description

Deck name: ACURVE
Entry name. ACURVE(x)
Called by: ALIFE
Subroutines called: none

This routine uses a linear interpolation and iteration scheme to evaluate the cyclic stress-strain equation and return a value of y for a given x in the following equation.

$$x = y/E + C_2 (y/C_1E)^{\gamma/\beta}$$

The required constants and nine points (C1X, C1Y) of the curve are calculated in FATIGU.

The procedure followed is:

1. Linear interpolation to get y for argument x.

2. Calculate x for the interpolated y.

3. If the x calculated is within tolerance, return that y.

4. If not within tolerance, use the interpolated y and calculated x as one of the points in the linear interpolation - continuing until the calculated x is near enough to the argument x. The tolerance is in data location 62 (CON(12)).

If the argument is lower than the first point, use the y for the first point but extrapolate on the high end if necessary.

Arrays and Variables Used

CON, C1E, C1X, C1Y, C2, E, C

The tolerance is in CON(12), data location 62.

Arrays and Variables Calculated

Since this is a function subprogram, the result is returned directly to the equation where it appears.

Scratch Arrays and Variables

S(20)	XI	=	natural logarithm (ln) of the argument
S(21)	XCL	=	ln of XCR
S(22)	XJ	=	curve point lower than XI
S(23)	YJ	=	curve y for XJ
S(24)	XK	=	curve point higher than XI, or highest point if extrapolated.
S(25)	YK	=	curve y for XK

S(26) YI = interpolated (ln) value for XI

S(27) YREAL = e^{YI}, real value of interpolated YI

S(28) XCR = value of x from stress-strain equation using y = YREAL

In subroutine area only: IFUP set to 1 when extrapolating. XPRIOR, YPRIOR set to real values of input and calculated result, respectively, so that the next argument may be checked against XPRIOR. This was set up because, when $f_{min} = 0$, the arguments $\Delta\varepsilon_2$ and $\Delta\varepsilon_{res_2}$ are the same and this arrangement avoided the duplicate search.

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

FUNCTION BCURVE

General Description

Deck name: BCURVE
Entry name: BCURVE(x)
Called by: ALIFE
Subroutines called: none

This routine uses a linear interpolation and iteration scheme to evaluate the equation relating strain to cycles-to-failure. The routine returns the value of y for a given x for the following equation.

$$x = c_1/y^{\beta} + C_2/y^{\gamma}$$

The required constants and 10 points on the curve (C2X, C2Y) are calculated in FATIGU.

The procedure followed is:

1. Linear interpolation to get y for the argument x.

2. Calculation of x for the interpolated y.

3. If the calculated x is within the tolerance, return that y for the result. The tolerance is in data location 62 (CON(12)). The test is $|\Delta x|/x \cdot$ CON(12).

4. If not within tolerance, the point defined by x calculated and y iterated is used as one of the points in the linear interpolation and the procedure is repeated.

This curve is not extrapolated; a value beyond either and returns the end value.

Arrays and Variables Used

BETA, CON, C1, C2, C2X, C2Y, GAMMA

Calculation tolerance is CON(12), data location 62.

Arrays and Variables Calculated

Since this is a function subprogram, the result is returned directly to the equation where it appears.

Scratch Arrays and Variables

S(30)	XI	=	natural logarithm (ln) of the argument
S(31)	XCL	=	ln of XCR
S(32)	XJ	=	x of curve higher than XI
S(33)	XK	=	y of curve corresponding to XJ

S(34)	XK	=	x of curve point lower than XI
S(35)	YK	=	y of curve corresponding to XK
S(36)	YI	=	interpolated value for XI
S(37)	YREAL	=	e^{YI}, real value of interpolated y
S(38)	XCR	=	value of x from the equation using y = YREAL. It is this value that is tested against the argument for agreement.

Note that, in this curve, x decreases for increasing y.

Labeled Common Arrays

None

Mass Storage File Records Used

None

Error Messages

None

Section IV

MODULE FLOW CHARTS AND FORTRAN LISTS

FLOW CHART USAGE

The automatically generated computer program flow charts (AUTOFLOW) presented in this document include a table of contents, flow charts, and FORTRAN lists of all routines in the module. The 80-column card lists are sequenced and grouped by routine.

Because the AUTOFLOW system used is IBM-oriented, the functions of the BUFFERIN and BUFFEROUT statements are not recognized, but these statements appear in proper order in note boxes. Also, the PROGRAM name does not appear on the main program, and library routines READMS and WRITMS are listed as undefined external references.

CROSS-REFERENCE LIST

The AUTOFLOW table of contents which precedes the flow charts and FORTRAN lists serves to cross reference the latter two. This table lists the following from left to right:

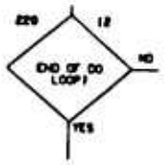
- The card identification from columns 73 through 80 of this card, or card sequence number. When sequence number is used in place of card identification, it is enclosed in parentheses.
- The page and box number where this card is displayed in a flow chart.
- The FORTRAN statement number from columns 1 through 5 of this card.
- The card identification(s) or sequence number(s) of the card(s) referring to this card (repeated as required).
- The pages and box numbers where the cards referring to this card are displayed in a flow chart (repeated as required).

FLOW CHARTS

The flow charts produced by AUTOFLOW use USASI conventional symbols. Since the flow charts are mechanically drawn from the program source deck, there are no omissions or vague generalizations about the processing within the boxes.

Every box on each page is uniquely numbered and may be referred to from elsewhere in the program. The source of a reference to a box will be indicated by showing the page and box number. If the number is followed by an asterisk, there are multiple references to this point, and the others may be found by using the cross-reference list.

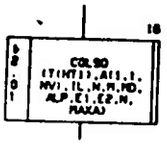
The most-often-used symbol is the decision box. Like all boxes, its box number is above and to the right of the box. Its FORTRAN statement number is above and to the left of the box. The decision choices for the paths are printed.



The unconditional transfer connecter has its page number destination printed above or to the left of the box number destination within the connecter. If there is a FORTRAN statement number at the destination, it is printed below the connecter.

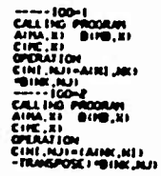
The exit box example shows a connecter from page 9, box 15.

The subroutine call box includes the calling sequence. The page and box numbers of the flow chart of the called subroutine are shown on the left-hand side of the box. The page number is above the box number.

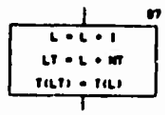


The note box encloses comments of a functional nature,

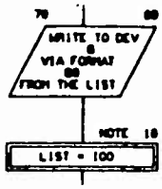
as differentiated from the 21 column comments, which are left justified without a box, that show the comment cards included in the FORTRAN deck.



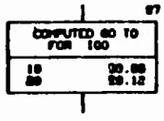
The process box is used to enclose FORTRAN arithmetic statements.



Input and output are shown as communicating with a device. The list used follows, if appropriate:

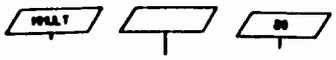


The computed GØ TØ becomes a branch table showing the page and box number of each of the ordered branches.



The column connecters and initial connecters are the only boxes without external box numbers. The function of the initial connecter is always clear,

but the label given is the symbol in the next FORTRAN card, which is often blank.



The column connecter identifies the page and box number to which it connects.

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FOR

AUTOFLOW CHART SET

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FORTRAN MODULE FATIGUE MODULE

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(0000017) 2.02 (0000017) 2.03
(0000022) 2.06 20
(0000023) 2.07 22 (0000021) 2.05
(0000024) 2.08 23
(0000025) 2.09 24 (0000023) 2.07
(0000026) 2.10 25
(0000027) 2.11 26 (0000025) 2.09
(0000038) 2.17 5001
(0000045) 2.19 150
(0000053) 2.25 5002 (0000037) 2.16

CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

CHART TITLE - FUNCTION ACURVE(X)

(0000087) 5.05 10 (0000085) 5.04 (0000090) 5.07 (0000095) 6.03
(0000089) 5.06 15 (0000085) 5.04
(0000091) 5.08 20
(0000093) 6.01 30 (0000090) 5.07
(0000094) 6.02 (0000096) 6.04
(0000096) 6.04 35
(0000097) 6.05 40 (0000092. 5.08 (0000095) 6.03
(0000101) 6.06 45 (0000122) 6.16 (0000115) 6.17 (0000112) 6.18
(0000108) 6.09 50
(0000109) 6.10 55
(0000124) 6.11 998 (0000107) 6.08 (0000109) 6.10 (0000116) 6.14
(0000125) 6.12 999 (0000081) 5.02 (0000088) 5.05
(0000116) 6.14 70 (0000108) 6.09
(0000117) 6.15 72
(0000118) 6.16 75 (0000116) 6.14
(0000113) 6.17 65 (0000109) 6.10
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CHART TITLE - NON-PROCEDURAL STATEMENTS

CHART TITLE - INTRODUCTORY COMMENTS

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(0000135) 9.01 ALIFE (0000501) 10.12-X
(0000173) 9.03 (0000248) 10.23
(0000177) 9.04 90 (0000183) 9.08
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(0000185) 9.10 100 (0000195) 9.19 (0000198) 9.20
(0000190) 9.13 110
(0000200) 9.14 166 (0000181) 9.07 (0000185) 9.10
(0000191) 9.16 120 (0000189) 9.12
(0000192) 9.17 130 (0000190) 9.13
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(0000194) 9.19 150
(0000198) 9.20 160 (0000192) 9.17
(0000208) 10.01 170 (0000179) 9.05 (0000189) 9.12 (0000190) 9.13 (0000191) 9.16 (0000192) 9.17
(0000193) 9.18
(0000210) 10.04 (0000209) 10.02
(0000211) 10.06 (0000210) 10.04
(0000219) 10.10 (0000218) 10.08
(0000238) 10.16 200 (0000230) 10.13 (0000231) 10.14
(0000239) 10.17 210 (0000235) 10.15
(0000242) 10.20 (0000241) 10.18
(0000248) 10.23 250 (0000245) 10.21

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(000258) 10.26 (000283) 10.28
(000263) 10.28 300
(000268) 10.30 999 (000204) 9.15

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(000299) 13.03 10 (000302) 13.05 (000308) 13.08
(000301) 13.04 20 (000298) 13.02
(000304) 13.06 30 (000302) 13.05
(000275) 13.07 (000307) 13.09
(000307) 13.09 35
(000308) 13.1 40 (000306) 13.08
(000313) 13.11 45 (000323) 13.15 (000328) 13.18
(000320) 13.14 50
(000321) 13.15 55
(000327) 13.18 999 (000300) 13.03 (000319) 13.13 (000320) 13.14
(000324) 13.18 60 (000320) 13.14

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(000403) 16.12 17 (000399) 16.08
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(000437) 16.18 30
(000441) 16.21 (000442) 16.22
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(000448) 16.25 (000448) 16.26
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(000450) 16.28 (000451) 16.29
(000451) 16.29 38
(000454) 16.31 5003
(000459) 16.36 42 (000453) 16.30
(000462) 17.01 (000466) 17.02
(000465) 17.02 45
(000471) 17.05 5005
(000478) 17.10 49 (000381) 16.02 (000470) 17.04
(000815) 18.01 800 (000503) 18.13 (000802) 18.14 (000508) 18.16 (000946) 19.22 (000578) 19.25
(000504) 20.19 (000595) 20.20 (000598) 20.21
(000816) 18.02 801 (000515) 18.01
(000488) 18.04 (000491) 18.07
(000491) 18.07 100 (000488) 18.05
(000494) 18.09 110
(000494) 18.09 (000494) 18.10
(000501) 18 2 150 (000562) 20.07 (000571) 20.13
(000502) 18.14 500 (000503) 18.13
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(000523) 19.01 220
(000504) 19.10 160
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(000507) 19.13 5007
(000511) 19.16 (000513) 19.17
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(000545) 19.21 300 (000504) 19.10
(000547) 19.23 301
(000574) 19.24 350 (000547) 19.23
(000577) 19.26 360 (000598) 20.21 (000599) 20.22
(000550) 20.01 305 (000547) 19.23
(000557) 20.03 320 (000609) 18.17 (000588) 20.17
(000558) 20.04 (000560) 20.05
(000560) 20.05 325
(000563) 20.08 5009

CARD ID PAGE/BOX NAME REFERENCES (SOURCE SEQUENCE NO. AND PAGE/BOX)

(000564) 20.09 5010
(000568) 20.10 5011 (000563) 20.08
(000580) 20.14 365 (000578) 19.25 (000594) 20.19
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(000622) 21.02 805 (000615) 18.01
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(000638) 21.09 999 (000543) 19.09 (000508) 19.12

CHART TITLE - NON-PROCEDURAL STATEMENTS

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(000672) 24.01 FTOCTL (000055) 2.26-X
(000687) 24.02 10
(000687) 24.02 (000687) 24.03
(000702) 24.05 100
(000704) 24.06 101 (000701) 24.04
(000705) 24.07 105 (000701) 24.04 (000703) 24.05
(000706) 24.08 106
(000708) 24.09 107 (000705) 24.07
(000709) 24.10 110 (000705) 24.07 (000707) 24.08
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(000712) 24.12 112 (000709) 24.10
(000713) 24.13 113 (000709) 24.10 (000711) 24.11
(000714) 24.14 114
(000716) 25.01 115 (000713) 24.13
(000717) 25.02 116 (000713) 24.13 (000715) 24.14
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(000740) 25.06 201 (000884) 27.14
(000742) 25.08 2011
(000743) 25.09 2012 (000741) 25.07
(000748) 25.12 2015 (000742) 25.08
(000756) 25.18 202 (000866) 27.15
(000763) 25.19 (000802) 26.05
(000767) 25.21 (000799) 26.03
(000780) 25.29 203
(000784) 25.30 204 (000779) 25.28
(000787) 25.31 205 (000783) 25.29
(000788) 25.32 206 (000778) 25.27 (000779) 25.28
(000791) 25.35 207
(000795) 26.01 208 (000790) 25.34
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(000826) 26.16 5002 (000811) 26.08
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(000843) 26.32 5004 (000837) 26.27
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(000855) 27.06 260 (000849) 26.35
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(0000859)	27.09 5008	(0000855) 27.06	
(0000862)	27.12 266	(0007211 25.04	
(0000881)	28.01 503	(0000878) 28.10	(0000973) 30.02 (0000976) 30.05
(0000871)	28.04 500	(0000861) 27.11	(0000862) 27.12
(0000876)	28.08 5001	(0000873) 28.06	
(0000878)	28.10 501		
(0000879)	28 11 502	(0000877) 28.09	
(0000880)	28.14 507	(0000874) 28.07	
(0000890)	28.15 510	(0000887) 28.03	
(0000900)	28.19 5005		
(0000905)	29.01 5052	(0000901) 28.21	
(0000907)	29.02 5006	(0000899) 28.18	(0000904) 28.22
(0000914)	29.05	(0000918) 29.08	
(0000918)	29.08 520		
(0000918)	29.08	(0000917) 29.06	
(0000921)	29.11	(0000923) 29.12	
(0000923)	29.12 525		
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(0000974)	30.03 802	(0000972) 30.01	
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(0000979)	30.18	(0000880) 30.19	
(0000980)	30.19 822		
(0000982)	30.20 999	(0000957) 30.13	(0000968) 30.14
(0000984)	30.21 5013		
(0000988)	30.23 5014		

CHART TITLE - NON-PROCEDURAL STATEMENTS

LABEL ID	PAGE LOC	
(000019)	2.04	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(000034)	2.15	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(000749)	25.13	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(000860)	27.10	UNDEFINED - 'WRITMS' EXTERNAL REFERENCE
(000802)	28.02	UNDEFINED - 'READMS' EXTERNAL REFERENCE
(000965)	30.12	UNDEFINED - 'WRITMS' EXTERNAL REFERENCE

PROGRAM FLOW CHARTS

OF

FATIGUE MODULE

CHART TITLE - PROCEDURES

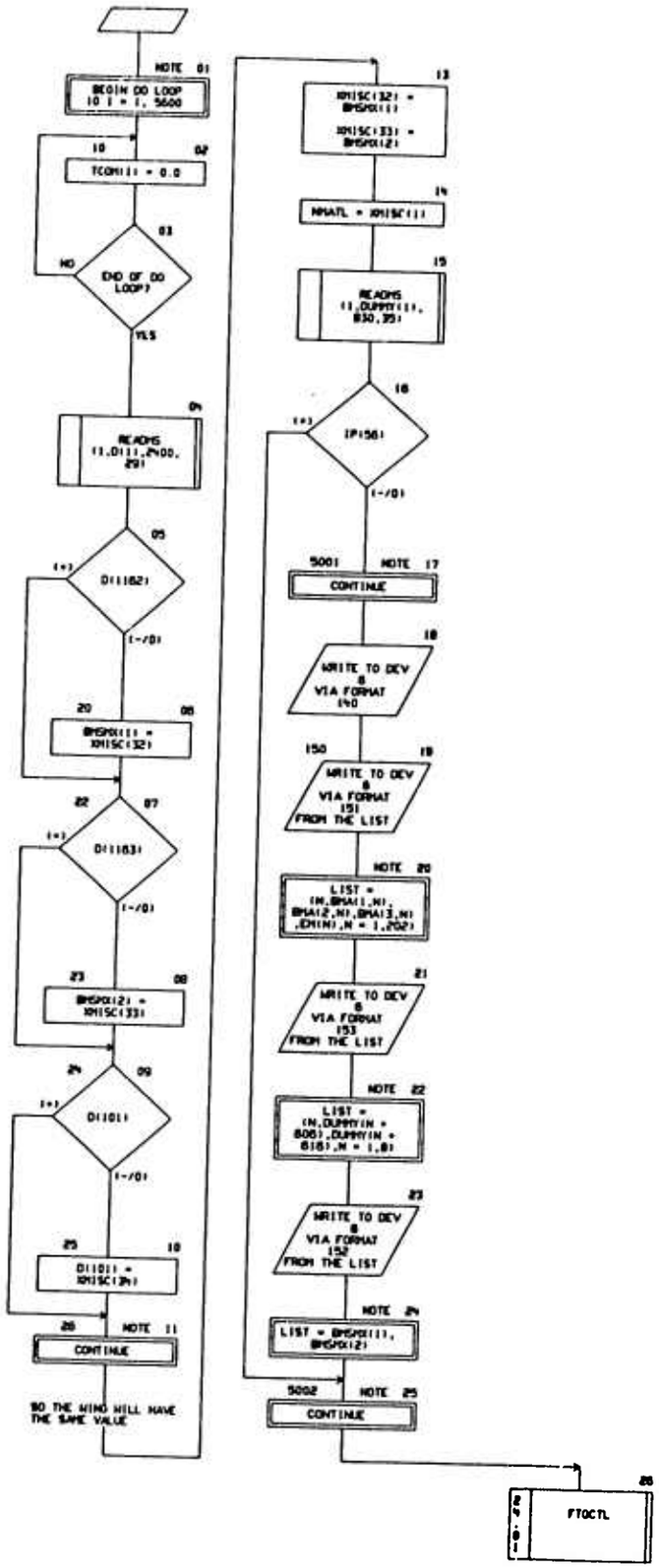

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      PROGRAM FATIGUE
      COMMON TCOM(5600)
      COMMON /MISC/XMISC(100)
      COMMON /IPRINT/IP(80)
      DIMENSION D(2400), T(3000), ND(200)
     , BHA(3,220), DUMMY(830), EX(220), BMREF(20), BMSPX(2)
      EQUIVALENCE (D(1),TCOM(1)), (T(1),TCOM(2401)), (ND(1),TCOM(5401))
     , (BHA(1,1),DUMMY(1),D(150)), (BMREF(1),D(2107)), (EX(1),D(2127))
     , (BMSPX(1),D(1162))
     , (ND(59),NMATL)
  140 FORMAT(1HI,70H*** BHA(3,220) FROM SUBROUTINE FATHD IN LOADS PROGRA
     M IN RECORD 35 ***,10X,21H** FATIGUE - IP(58) **//
       8X, 12HSOF BEND MOM, 3X, 12HAOS BEND MOM, 2X,
       10HEXCEEDANCES-OUST, 2X, 10HEXCEEDANCES-MANU  )
  151 FORMAT( 115,2F15.0,2E10. 5)
  153 FORMAT( 39HREFERENCE BENDING MOMENTS FOR MANEUVER / 4X, 7HSEGMENT
       8X, 3HSOF, 10X, 3HAOS /(110, 2F15.0 ) )
  152 FORMAT(//10X,10HBMSPX(1) =,F15.0/10X,10HBMSPX(2) =,F15.0//)
```

CHART TITLE - INTRODUCTORY COMMENTS

FUNCTION ACURVE

CHART TITLE - FUNCTION ACURVE(X)

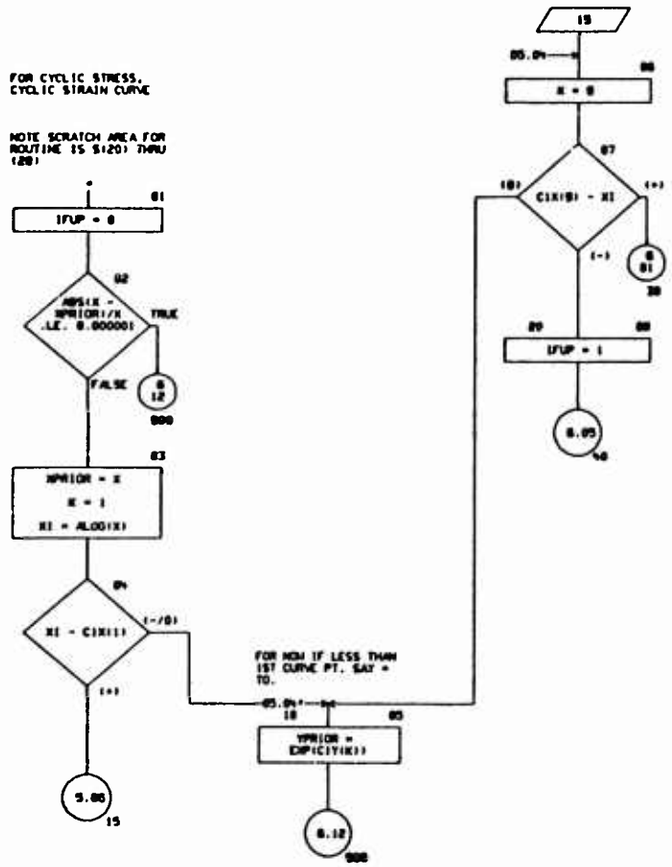

CHART TITLE - FUNCTION ACURVE(X)

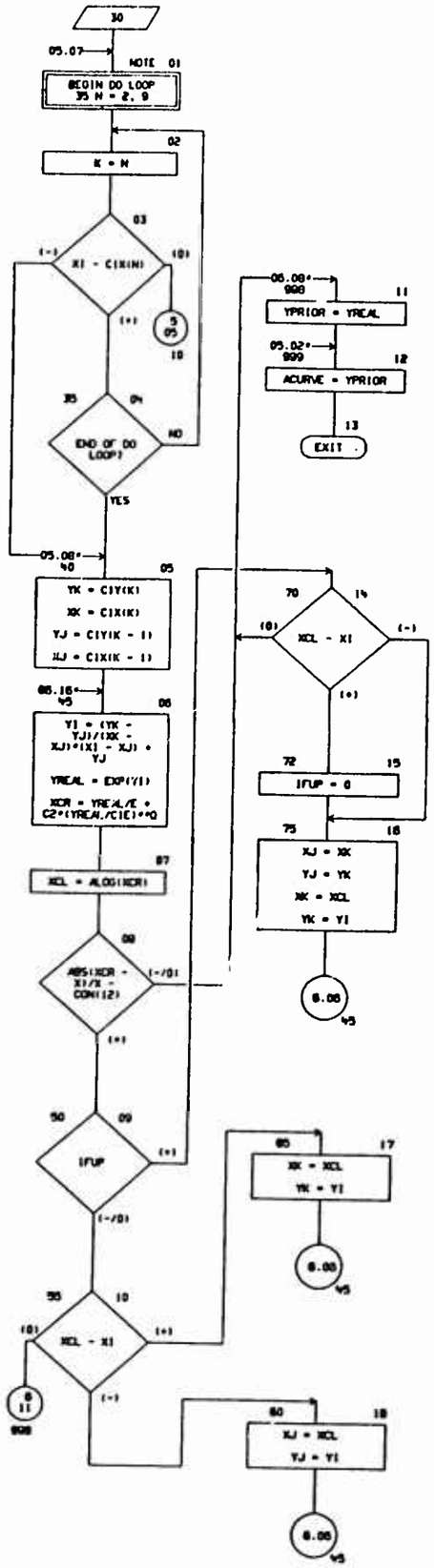

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON TCON(5600)
      DIMENSION D(2400), T(3000), ND(200)
     . CON(50), S(100)
     . CIX(10), CIY(10)
      EQUIVALENCE (D(1),TCON(1)), (T(1),TCON(2401)), (ND(1),TCON(5401))
     . (D(5)),CON(1)), (D(105),E)
     . (T(1),S(1))
     . (T(100)),CIX(1)), (T(110)1),CIY(1))
     .                (CON(20),C2), (CON(23),O), (CON(26),CIE)
      EQUIVALENCE (S(20),XI), (S(21),XCL), (S(22),XJ), (S(23),YJ)
     . (S(24),XK), (S(25),YK), (S(26),YI), (S(27),YREAL), (S(28),XCR)
      DATA XPRIOR/0.0/, YPRIOR/0.0/
```

CHART TITLE - INTRODUCTORY COMMENTS

SUBROUTINE ALIFE

CHART TITLE - SUBROUTINE ALIFE

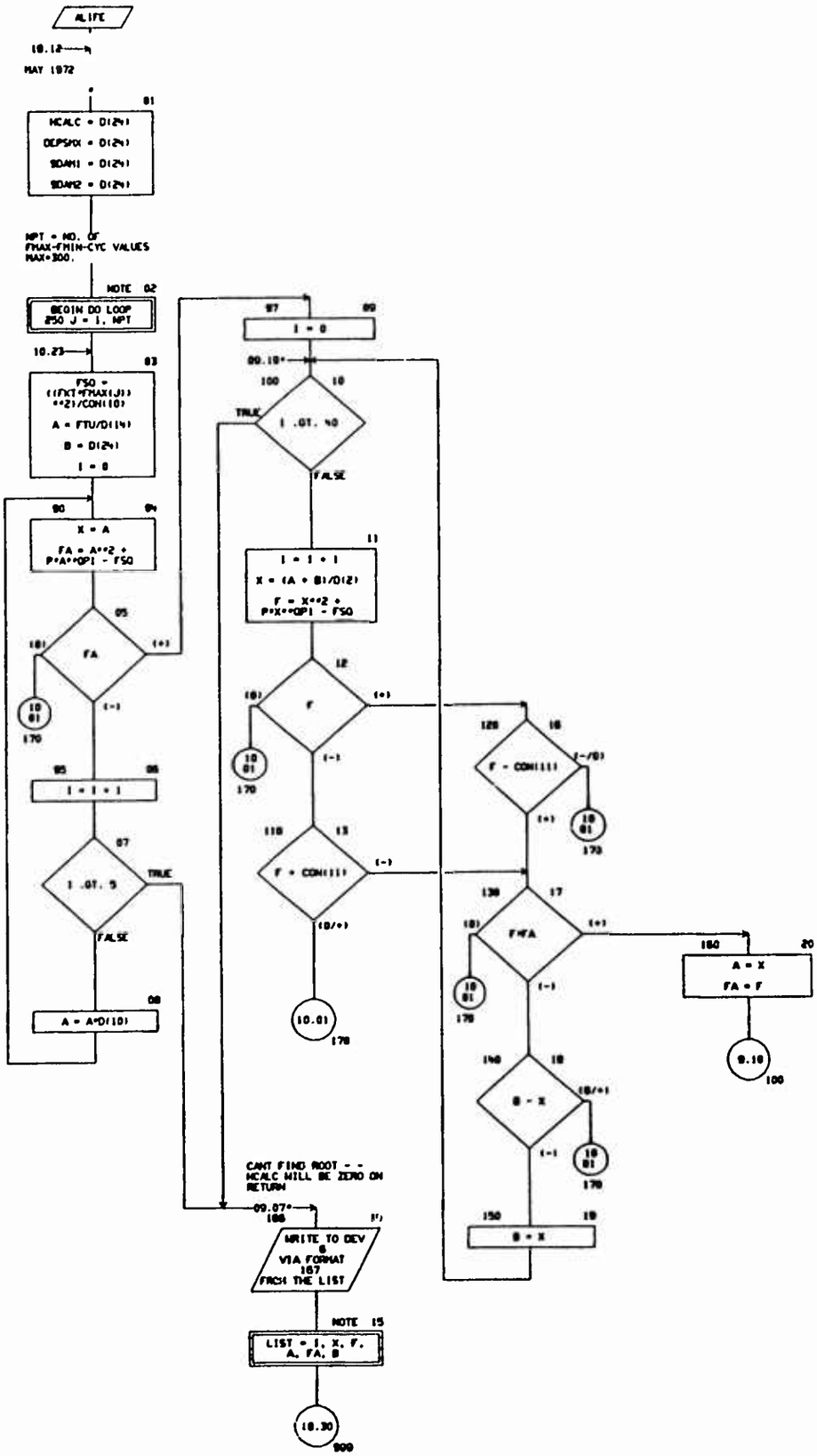

CHART TITLE - SUBROUTINE ALIFE

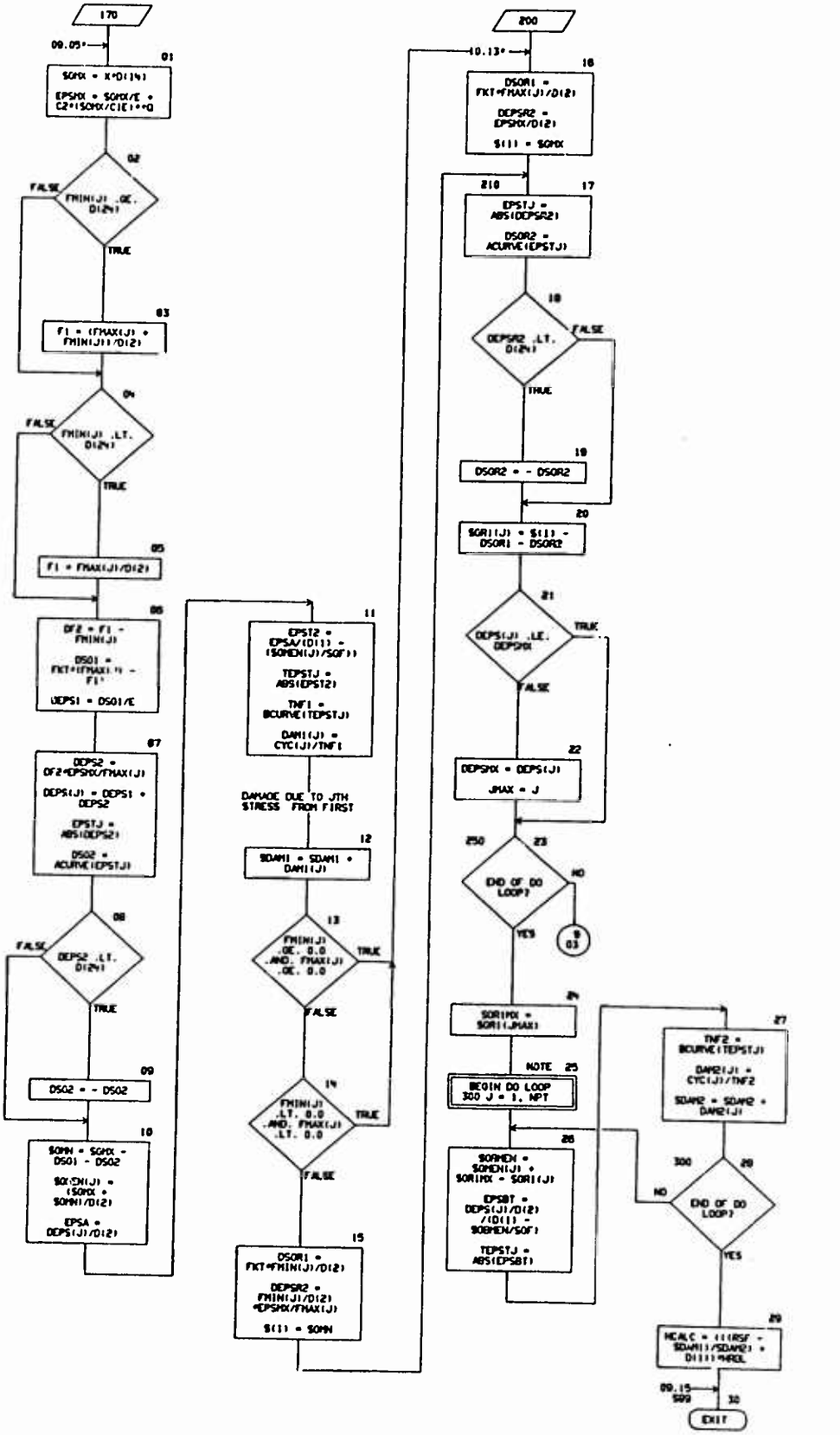

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON TCOM(5600)
      DIMENSION D(2400), T(3000), ND(200)
     , CON(30), S(100), FMAX(300), FMIN(300),          CYC(300)
     , DEPS(300), SGMEN(300), SOR1(300), DAM1(300), DAM2(300)
      EQUIVALENCE (D(1),TCOM(1)), (T(1),TCOM(2401)), (ND(1),TCOM(5401))
     , (D(51),CON(1)),                              (D(103),FKT)
     , (D(104),FTU), (D(105),E)
     , (D(201),FMAX(1)), (D(501),FMIN(1))
     , (T(1),S(1)), (T(101),CYC(1)), (T(199),MREQ), (T(100),MCALC)
     , (T(1401),DAM1(1)), (T(1701),DAM2(1))
     , (T(2001),DEPS(1)), (T(2301),SOR1(1)), (T(2601),SGMEN(1))
     ,               (CON(16),SOF), (CON(20),C2)
     , (CON(23),Q),                (CON(25),P), (CON(28),CIE)
     , (CON(27),OPT)
     ,(ND(401),NPT), (ND(4),JMAX)
      EQUIVALENCE (S(41),MRBL), (S(42),RSF)
      EQUIVALENCE (S(51),A), (S(52),B), (S(53),F), (S(54),X), (S(55),FA)
     , (S(56),FT), (S(57),DF2),                (S(59),FSO)
     ,                              (S(63),DSO1), (S(64),DSO2)
     , (S(65),EPSA), (S(66),SOMN), (S(67),SOMX)
     , (S(69),TNF1), (S(70),TNF2), (S(71),DEPS1), (S(72),DEPS2)
     , (S(73),DSOR1), (S(74),DSOR2), (S(75),EPSBT), (S(76),EPSMX)
     , (S(77),EPSTJ), (S(78),EPST2), (S(79),SDAM1), (S(80),SDAM2)
     ,               (S(82),DEPSMX), (S(83),DEPSR2), (S(84),SGBMEN)
     , (S(85),SORIMX), (S(86),TEPSTJ)
  187 FORMAT(1H1,47HFAILED TO FIND SOMX IN ALIFE SUBROUTINE ******* //
     3H I=,I13, 2X,2HX=,1E14.8,2X,2HF=,1E14.8,2X,2HA=,1E14.8,2X,3HFA=,
     1E14.8,2X,2HB=,1E14.8 )
```

CHART TITLE - INTRODUCTORY COMMENTS

FUNCTION BCURVE

CHART TITLE - FUNCTION BCURVE(X)

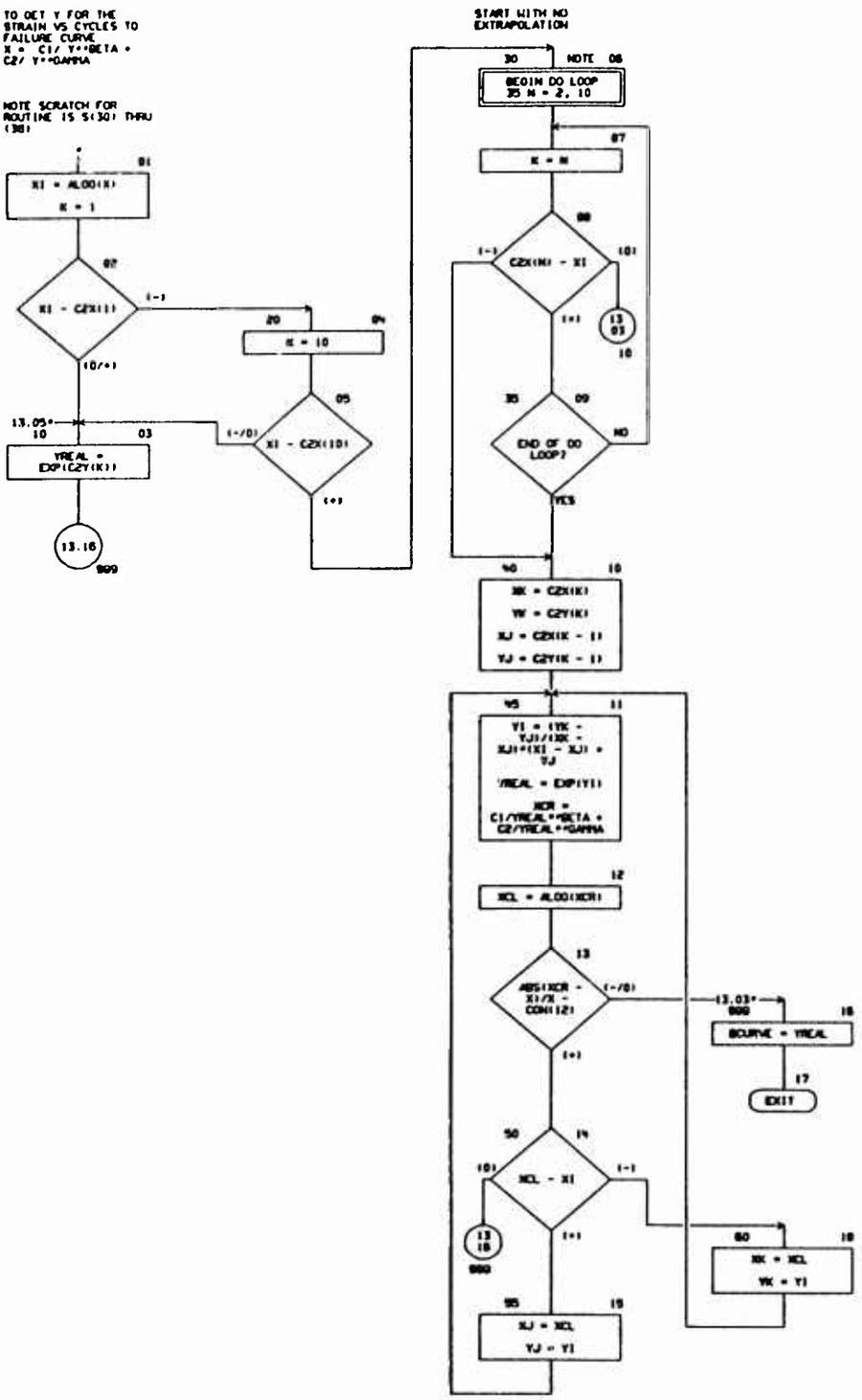

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
COMMON TCON(5600)
DIMENSION D(2400), T(3000), ND(200)
. CON(50), $(100)
.                  C2X(10), C2Y(10)
EQUIVALENCE (D(1),TCON(1)), (T(1),TCON(2401)), (ND(1),TCON(5401))
. (D(5)),CON(1))
. (T(1)),$(1))
. (T(1021)),C2X(1)), (T(1031)),C2Y(1))
. (CON(19),C1), (CON(20),C2), (CON(21),BETA), (CON(22),GAMMA)
EQUIVALENCE ($(30),XI), ($(31),XCL), ($(32),XJ), ($(33),YJ)
. ($(34),XK), ($(35),YK), ($(36),YI), ($(37),YREAL), ($(38),XCR)
```

CHART TITLE - INTRODUCTORY COMMENTS

SUBROUTINE FATIOU

CHART TITLE - SUBROUTINE FATIGU

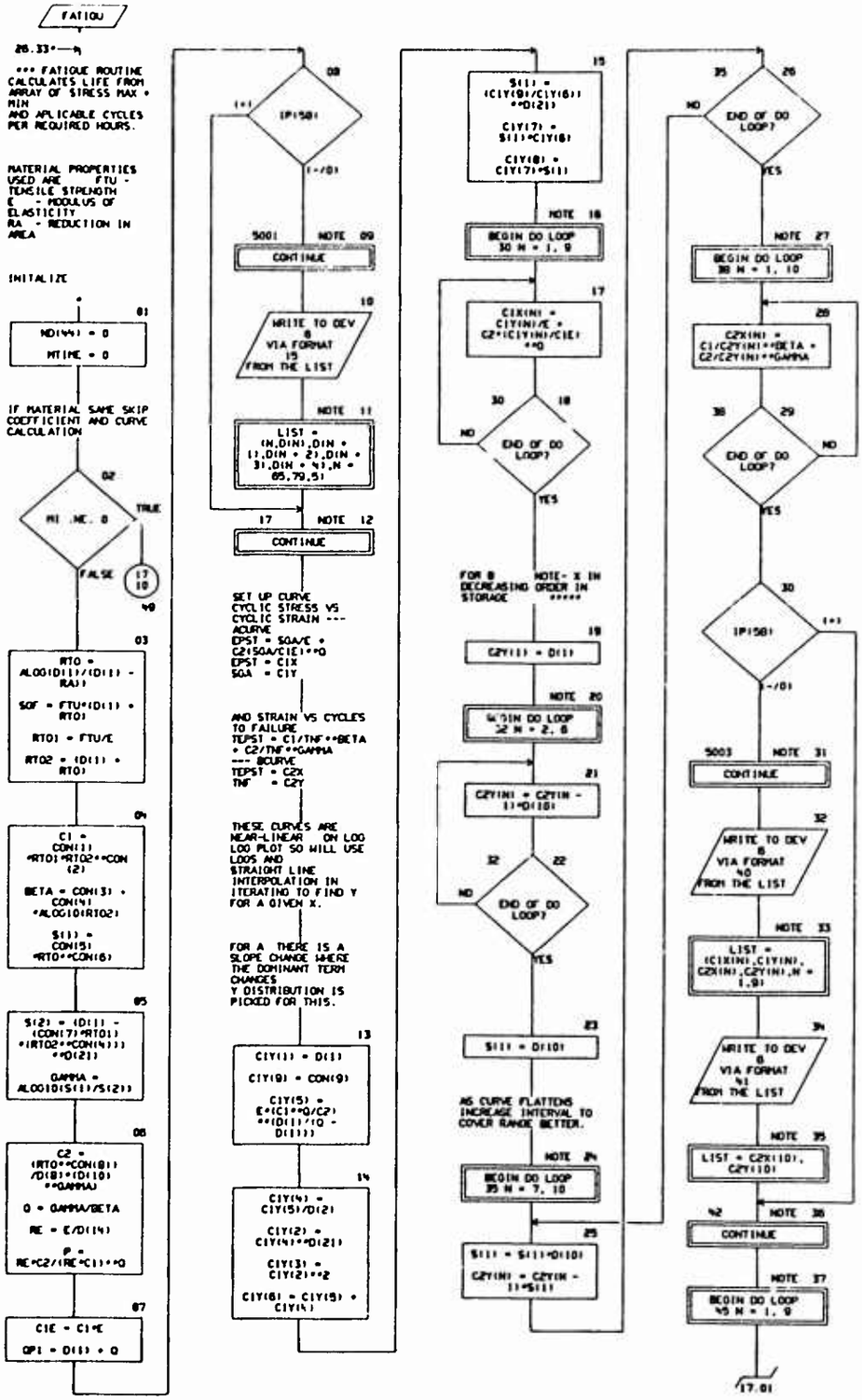

CHART TITLE - SUBROUTINE FATIGU

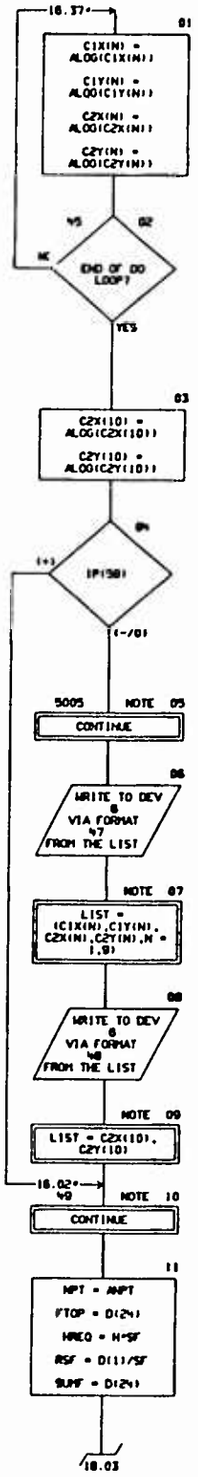

CHART TITLE - SUBROUTINE FATIGU

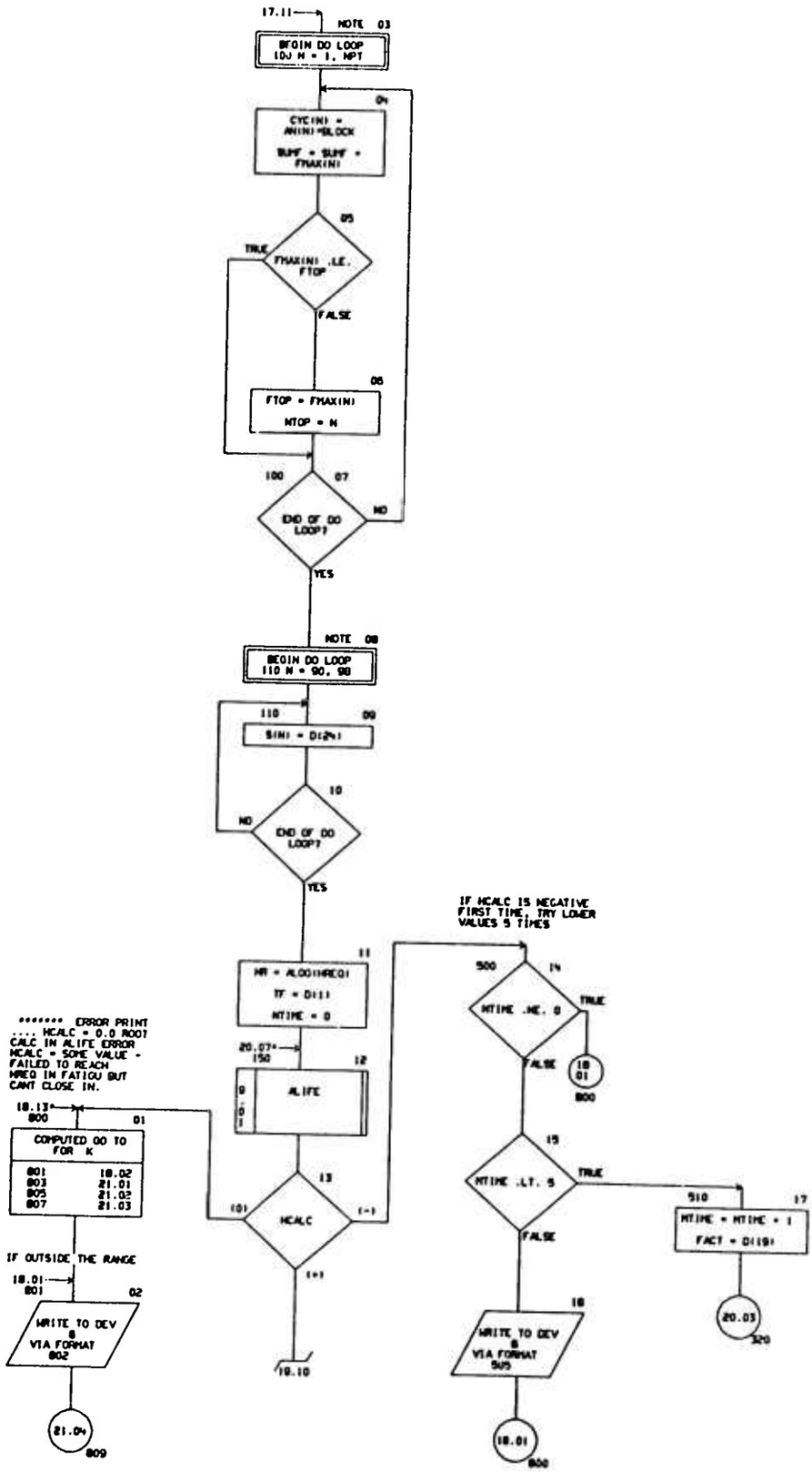

CHART TITLE - SUBROUTINE FATIGU

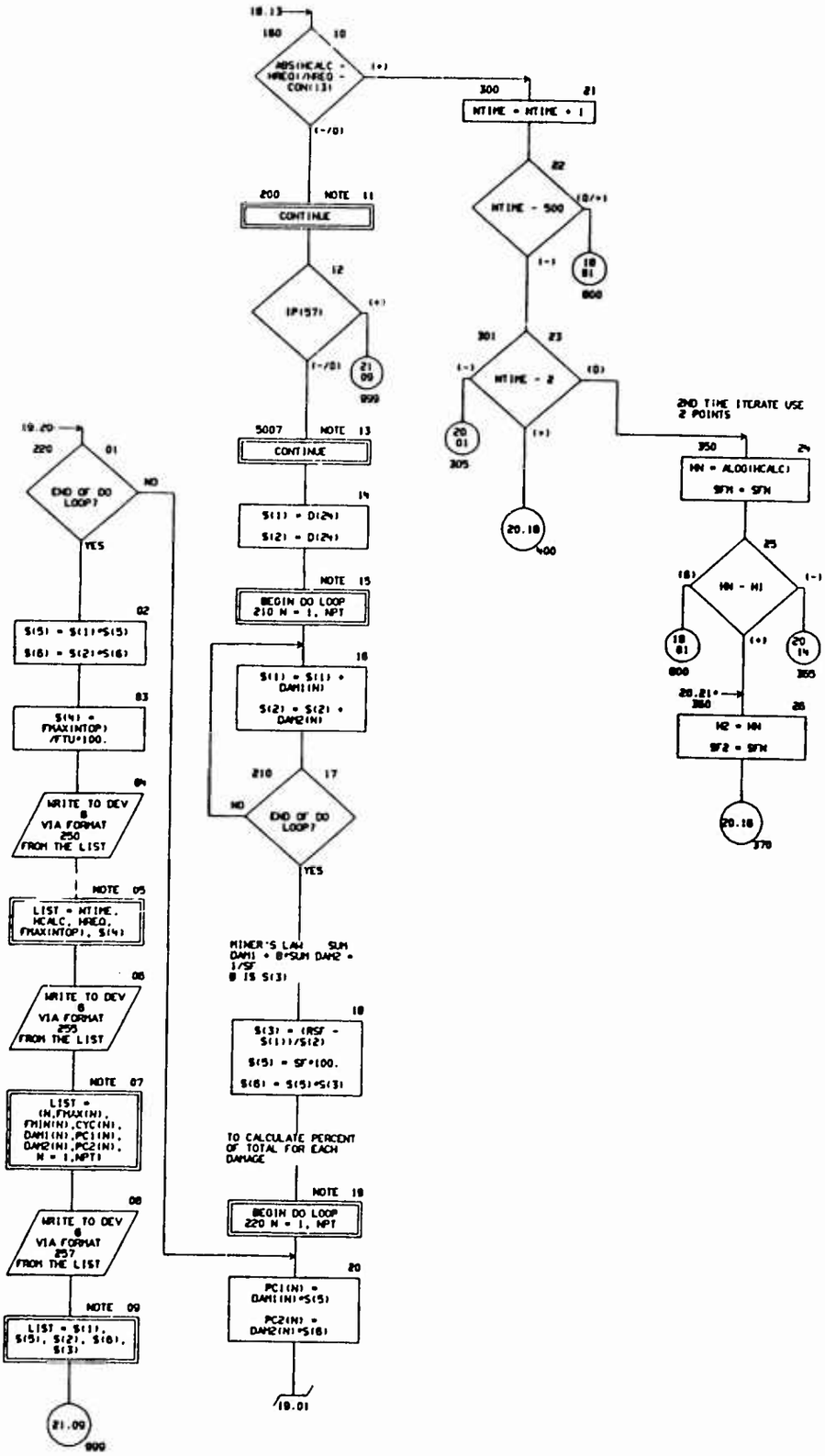

CHART TITLE - SUBROUTINE FATIQU

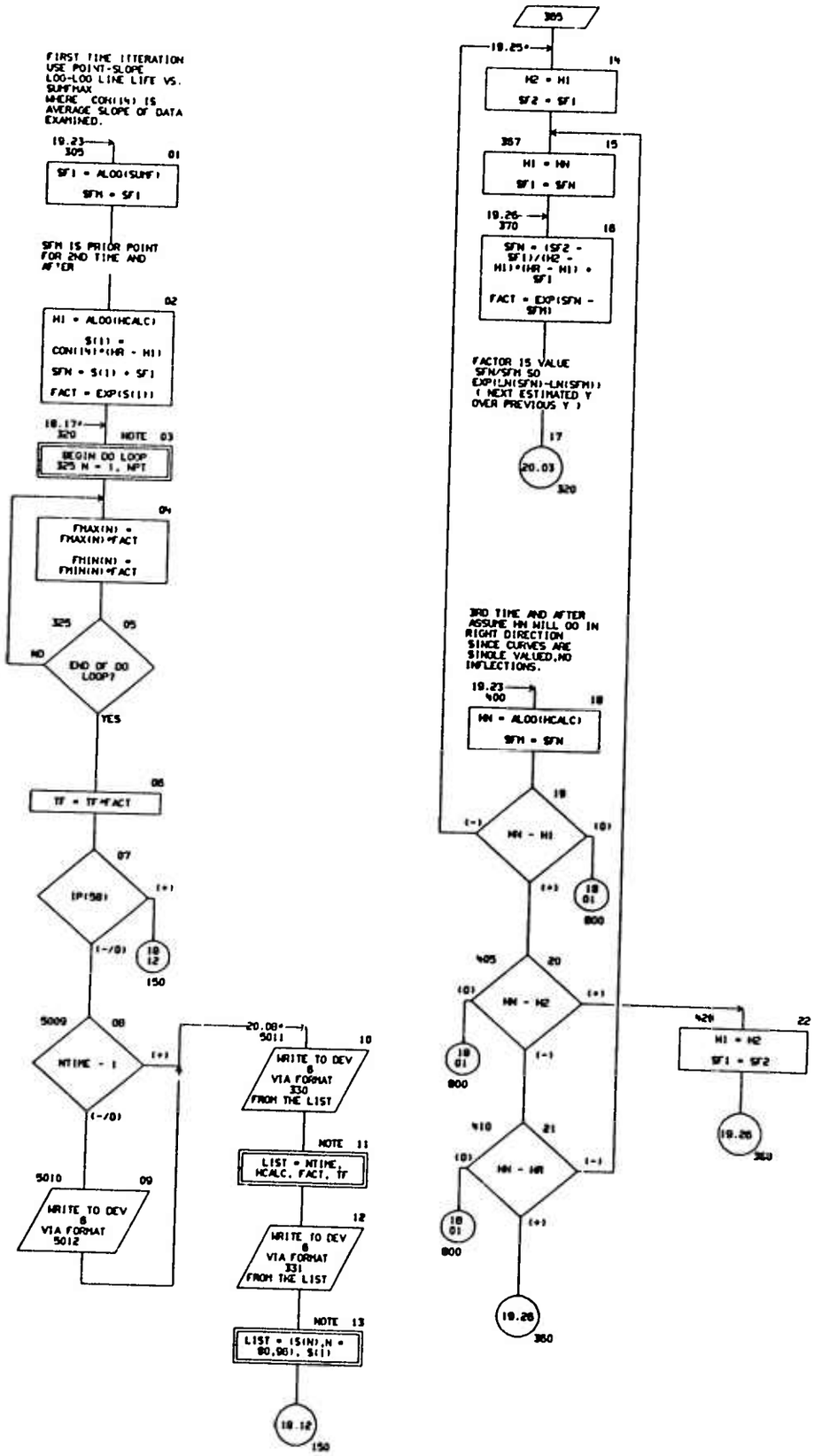

CHART TITLE - SUBROUTINE FATIGU

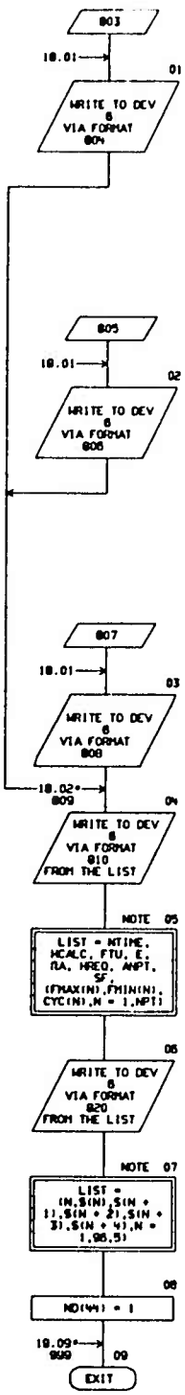

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON TCON(5600)
      COMMON /IPRINT/ IP(80)
      DIMENSION D(2400), T(3000), ND(200)
     , CON(30), S(100), FMAX(300), FMIN(300), AN(300), CYC(300)
     , DAM1(300), DAM2(300)
     , PC1(300), PC2(300)
     , C1X(10), C1Y(10), C2X(10), C2Y(10)
      EQUIVALENCE (D(1),TCON(1)), (T(1),TCON(2401)), (ND(1),TCON(5401))
     , (D(5)),CON(1)), (D(101),H), (D(102),SF), (D(81),BLOCK)
     , (D(104),FTU), (D(105),E), (D(106),RA), (D(107),ANPT)
     , (D(201),FMAX(1)), (D(501),FMIN(1)), (D(801),AN(1))
     , (T(1),S(1)), (T(101),CYC(1)), (T(99),HREQ), (T(100),HCALC)
     , (T(401),PC1(1)), (T(701),PC2(1)),                    (S(42),RSF)
     , (T(401),DAM1(1)), (T(1701),DAM2(1))
     , (T(1001),C1X(1)), (T(1011),C1Y(1)), (T(1021),C2X(1))
     , (T(1031),C2Y(1))
     , (CON(15),RTO), (CON(16),SGF), (CON(17),RTO1), (CON(18),RTO2)
     , (CON(19),C1), (CON(20),C2), (CON(21),BETA), (CON(22),GAMMA)
     , (CON(23),Q), (CON(24),RE), (CON(25),P), (CON(26),C1E)
     , (CON(27),UP1)
      EQUIVALENCE
       (ND(40),NPT) ,                (ND(42),NTOP)
     , (ND(43),NTIME)
     , (ND(45),MI), (ND(46),MTIME), (ND(47),K)
     , (S(87),SFN)
     , (S(88),SUMF), (S(89),FTOP)
     , (S(90),HI), (S(91),SF1), (S(92),H2), (S(93),SF2), (S(94),HN)
     , (S(95),SFN), (S(96),HR), (S(97),FACT), (S(98),TF)
  15  FORMAT(1HI,88X,21H** FATIQU - IP(58) **//(1I7,5E16.7))
  40   FORMAT(13HOCURVE SET-UP // (4E20.7/ ))
  41   FORMAT( 40X,2E20.7)
  47   FORMAT( //(4F20.6 / ))
  48   FORMAT( 40X,2F20.6 )
 250   FORMAT(1HI,10X,43HNUMBER OF ITERATIONS IN SUBROUTINE FATIQU =,I4,
        31X,21H** FATIQU - IP(57) **/
                /17X, 14HCALC. LIFE(HR), 8X 17HREQUIRED LIFE(HR), /
       16X,1E14.6,10X,1E14.6,6X,13HHIGHEST FMAX=,1E13.6,2H =,1F7.2,
       7HPCT FTU)
 255   FORMAT(//6X,1HN, 7X, 4HFMAX, 8X, 4HFMIN, 5X, 8HAPP.CYC., 7X,
       8HDAMAGE 1,7X,3HPCT, 7X, 8HDAMAGE 2, 7X,3HPCT// (1I9, 3F12.0,
       1E17.6, 1F8.2, 1E17.6, 1F8.2) )
 257   FORMAT(// 13X,32HCUMULATIVE DAMAGE FOR EACH BLOCK, 2(E17.6,F8.2)
        //6X, 32HNUMBER OF RESIDUAL DAMAGE BLOCKS,1F9.3)
5012   FORMAT(1HI,88X,21H** FATIQU - IP(58) **)
 330   FORMAT(13HO***** MTIME=,I13,7X,6HHCALC=,1E15.7,7X,7HFACTOR=,
       1E15.7,7X,3HTF=,1E15.7)
 331   FORMAT (1H , 4E18.7)
 505   FORMAT( 34HO NEGATIVE LIFE THRU 5 ITTERATIONS )
 802   FORMAT( 36HOWORKING ON WING AT SIDE OF FUSELAGE )
 804   FORMAT( 36HOWORKING ON WING OUTER PANEL STATION )
 806   FORMAT( 36HOWORKING OF FUSELAGE PRESSURE CYCLES )
 808   FORMAT( 35HOWORKING ON FUSELAGE ENDURANCE LIMIT )
 810   FORMAT(48HO*** ERROR IN FATIGUE, PERTINENT DATA FOLLOWS... /
       7H MTIME=,I13,4X,6HHCALC=,  1E14.6,4X,4HFTU=,1E14.6,4X,2HE=,
       1E14.6,4X,3HRA=,1E14.6 /14X,6HHREQ =,1E14.6,4X,5HANPT=,1E14.6,
       4X,3HSF=,1E14.6//15X,4HFMAX,14X,4HFMIN,14X,3HCYC /(6X,3E18.6) )
 820   FORMAT(1HO,16HCALCULATION AREA // (1I8, 5E18.7 ))
```

CHART TITLE - INTRODUCTORY COMMENTS

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!!!
```

CHART TITLE - SUBROUTINE FTGCTL

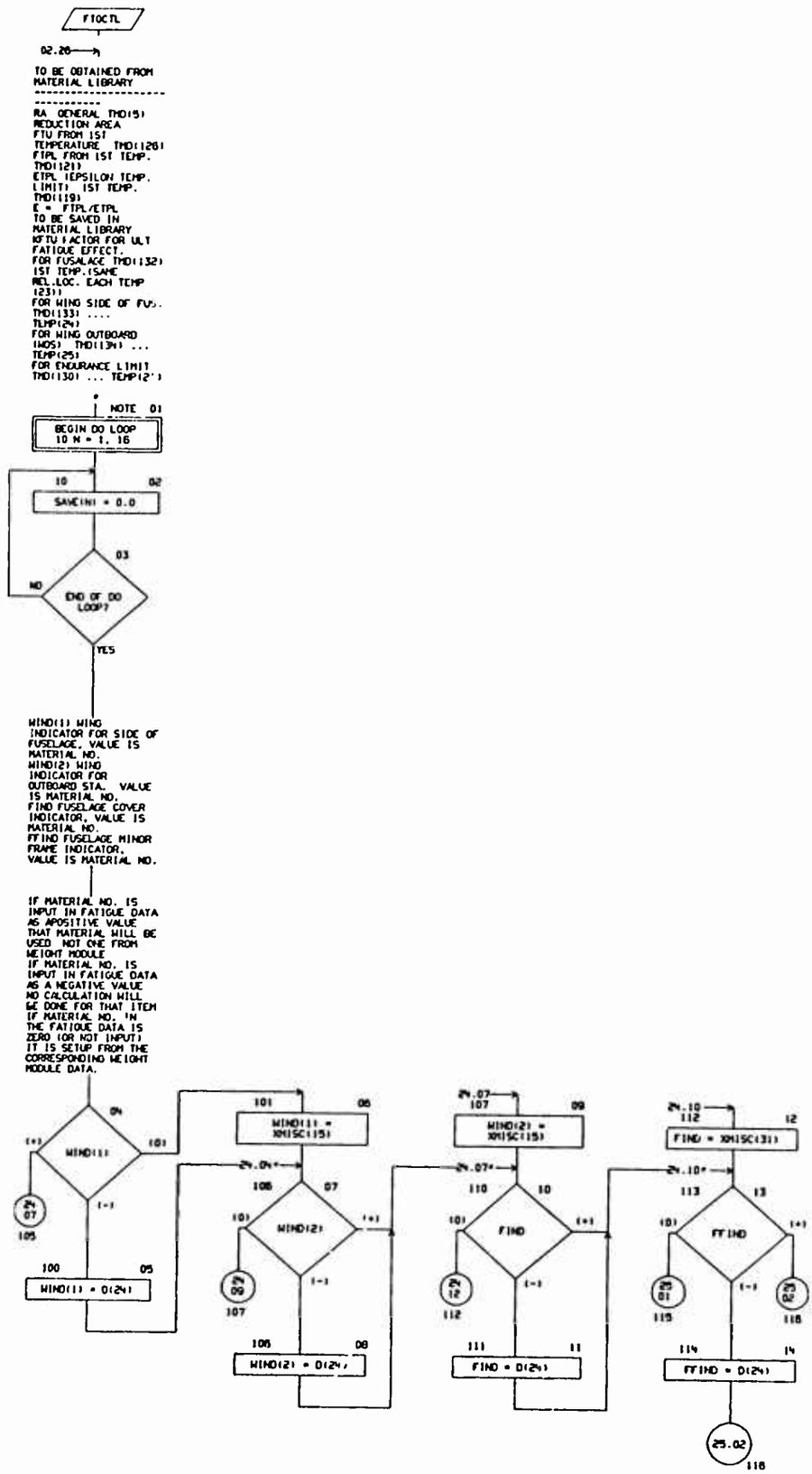

CHART TITLE - SUBROUTINE FTOCTL

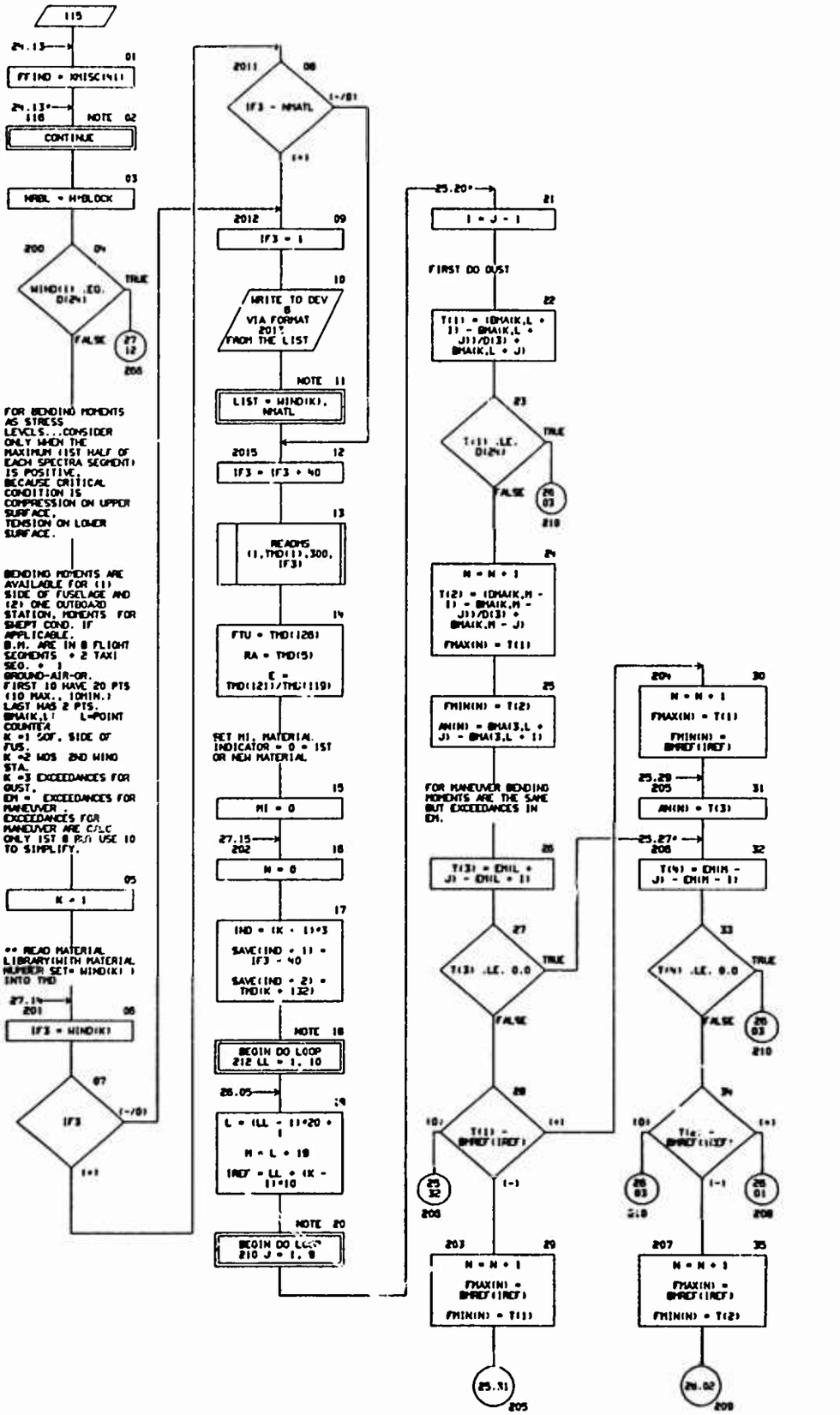

CHART TITLE - SUBROUTINE FTGCTL

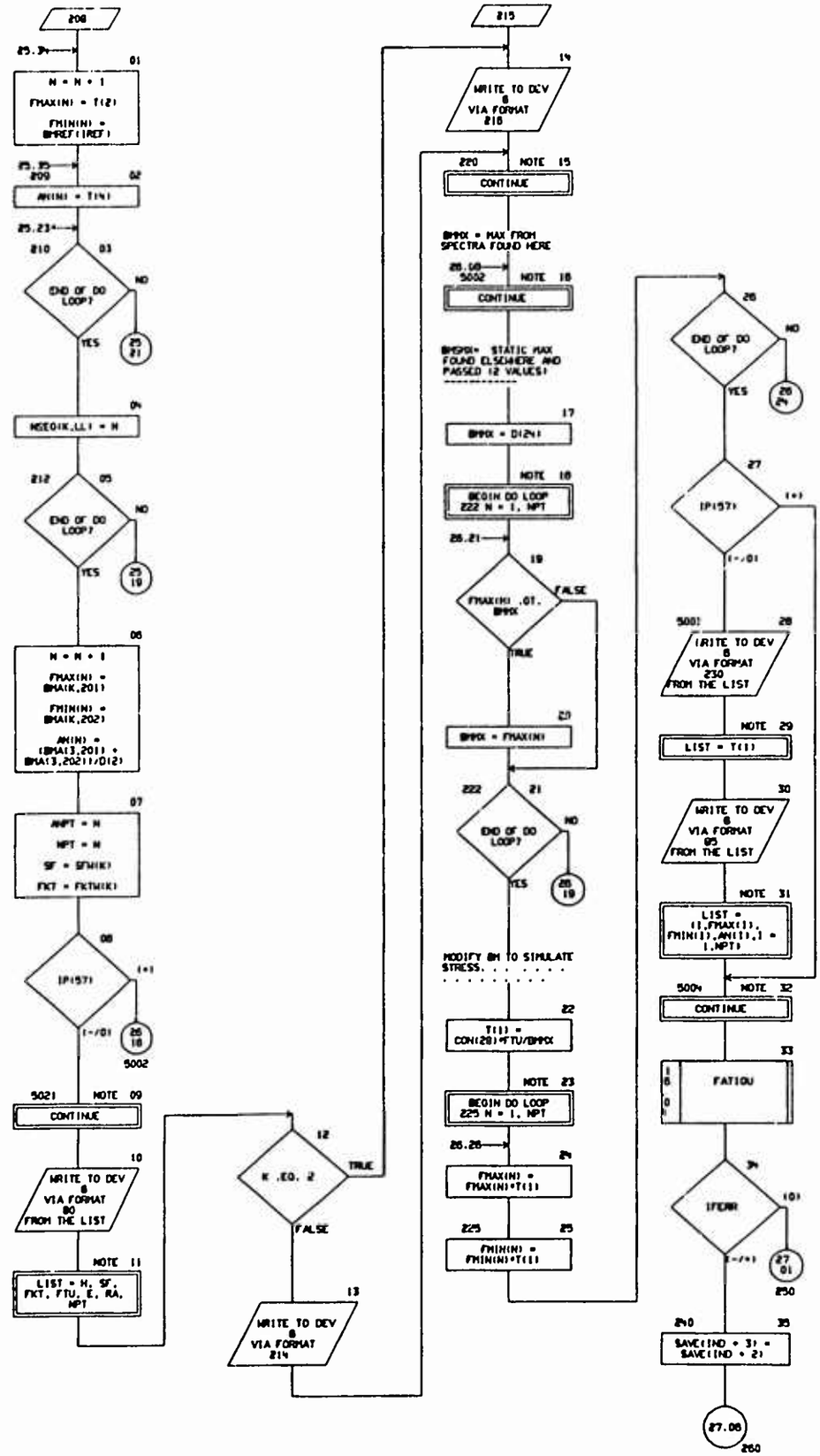

CHART TITLE - SUBROUTINE FTGCTL

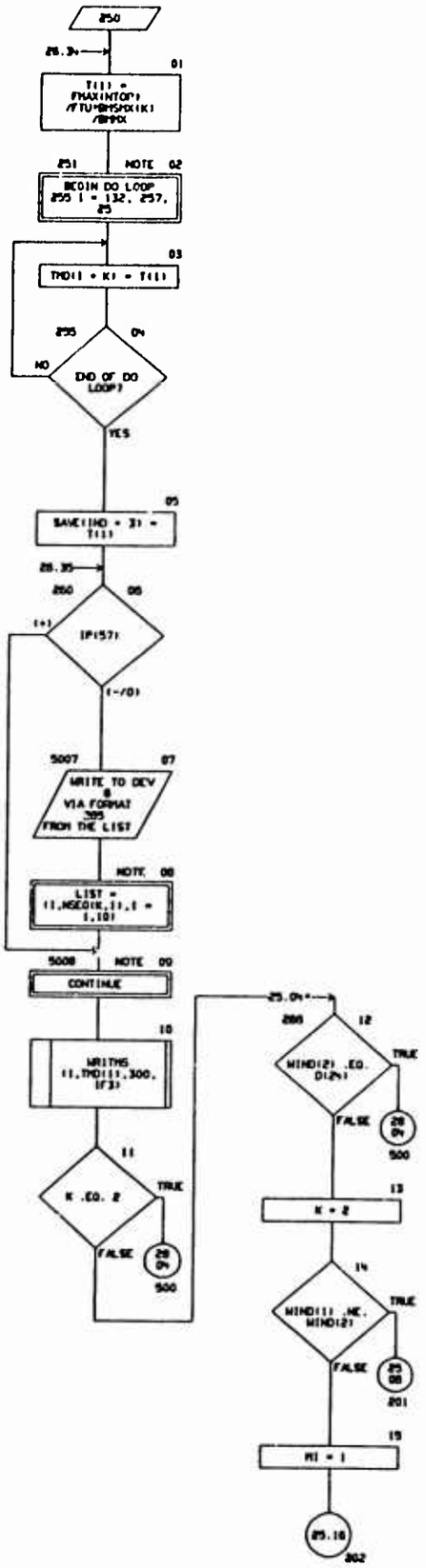

CHART TITLE - SUBROUTINE FTGCTL

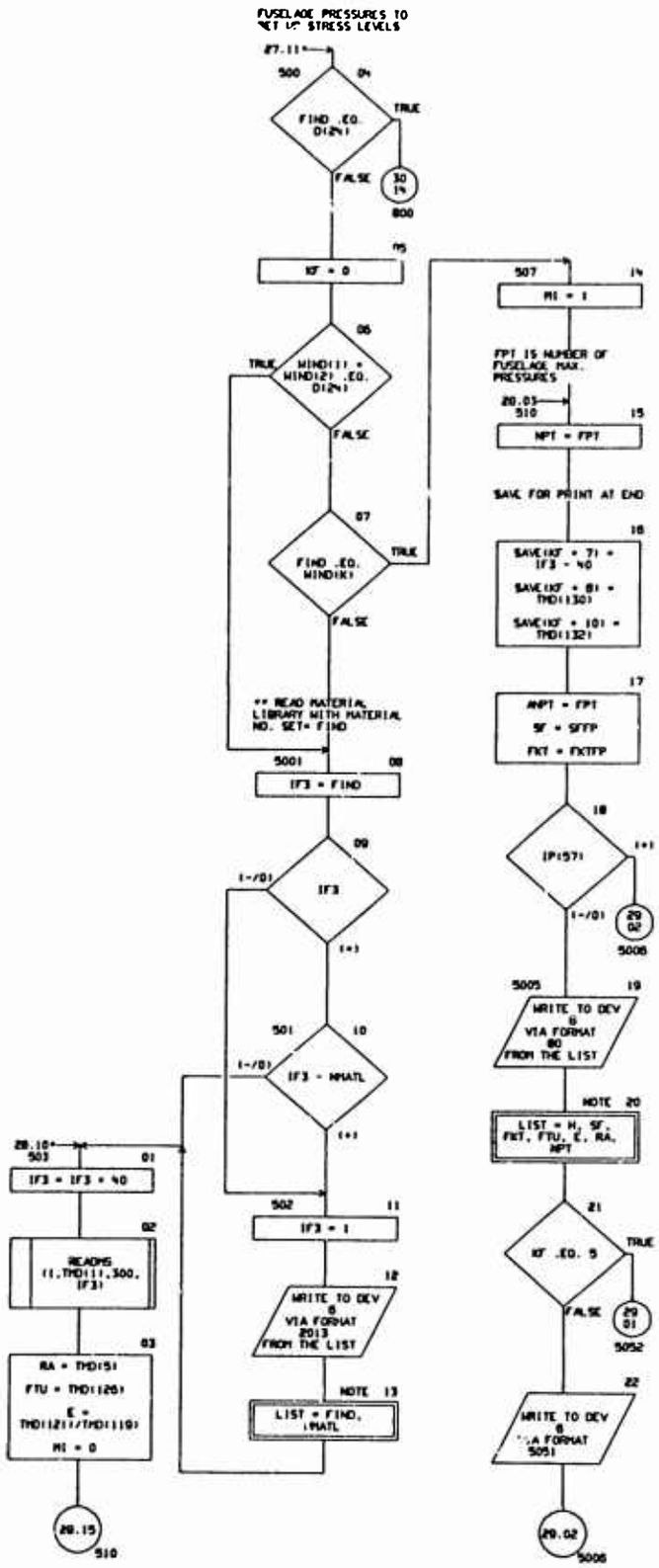

CHART TITLE - SUBROUTINE FTOCTL

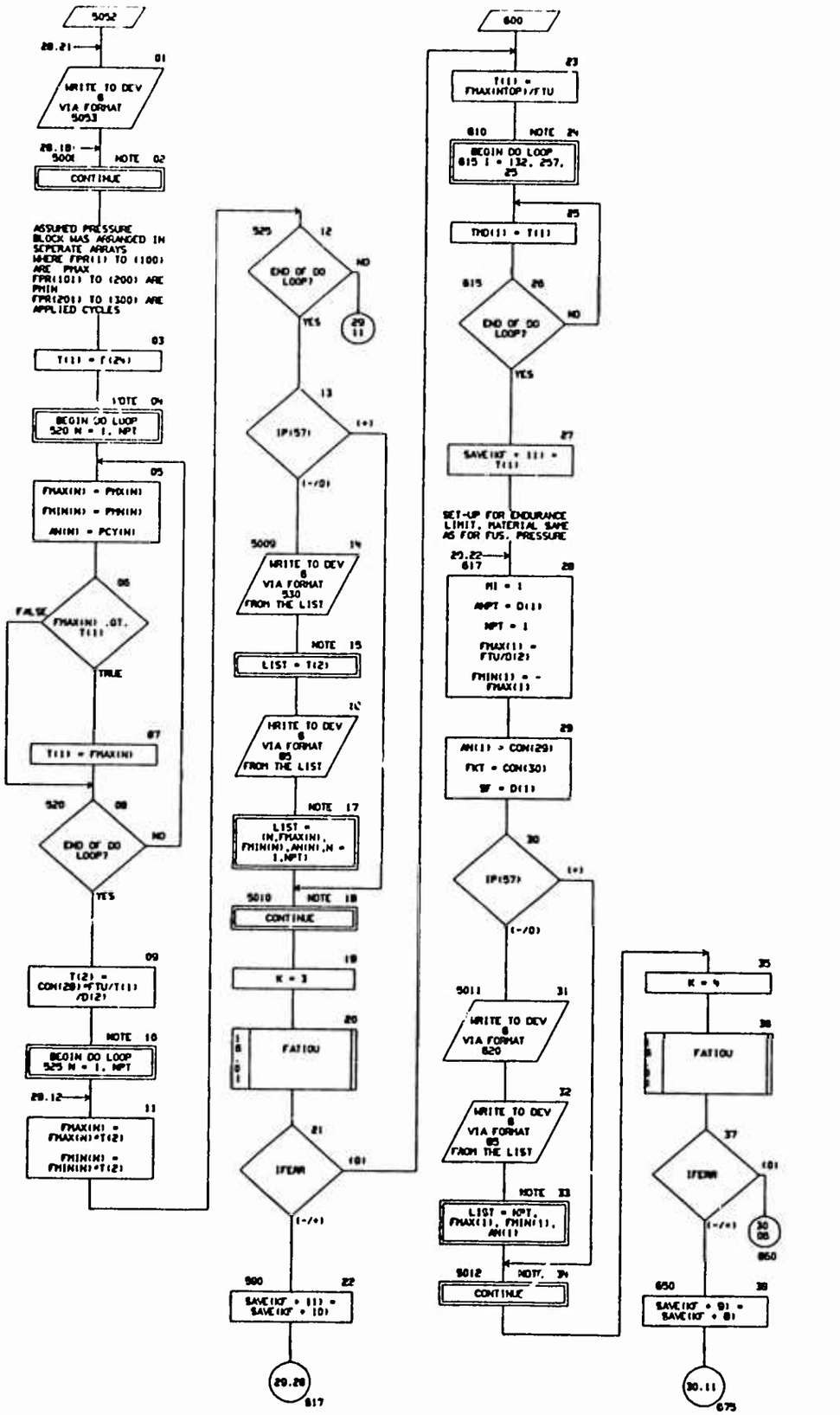

CHART TITLE - SUBROUTINE FTOCTL

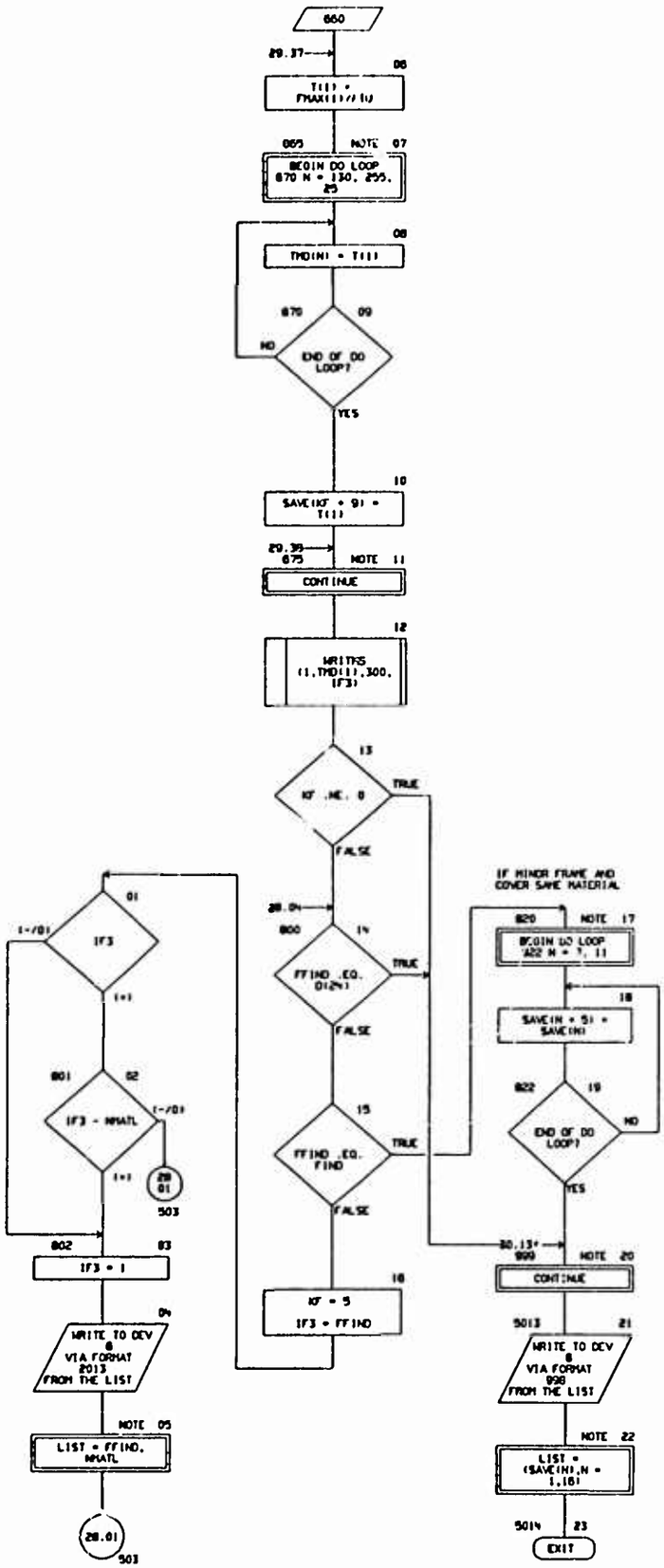

CHART TITLE - NON-PROCEDURAL STATEMENTS

```
      COMMON TCOM(5600)
      COMMON /MISC/XMISC(100)
      COMMON /IPRINT/ IP(80)
      DIMENSION SAVE(16)
      DIMENSION D(2400), T(30000), ND(200)
     , FMAX(300), FMIN(300), AN(300)
     , BMA(3,220), EM(220), BMREF(20), NSEO(2,10)
     , BMSPO(2), THD(300)
     , MIND(2), SF(2), FKTH(2)
     , CON(30)
     , FPR(300), PHX(100), PHN(100), PCY(200)
      EQUIVALENCE (D(1),TCOM(1)), (T(1),TCOM(2401)), (ND(1),TCOM(5401))
     .          (D(101),M), (D(102),SF), (D(103),FKT), (D(104),FTU)
     , (D(105),E), (D(106),RA),(D(107),ANPT)
     , (D(151),CON(1)), (D(181),BLOCK)
     , (D(1091),MIND(1)), (D(1111),FIND), (D(1112),FFIND)
     , (D(1113),SFM(1)), (D(1115),FKTH(1)), (D(1117),SFFP), (D(1118),FKTFP)
     , (D(1201),FMAX(1)), (D(1501),FMIN(1)), (D(1801),AN(1))
     , (D(11861),BMMX), (D(11862),BMSPO(1)), (T(1101),THD(1))
     , (D(12001),FPT), (D(12011),FPR(1)),          (T(141),NRBL)
     , (FPR(1),PHX(1)), (FPR(101),PHN(1)), (FPR(201),PCY(1))
     , (D(11501),BMA(1,1)), (D(12127),EM(1)), (D(2107),BMREF(1))
     , (ND(40),NPT)
     ,  (ND(121),NSEO(1,1)), (ND(142),NTOP), (ND(141),IFORA)
     , (ND(145),MI), (ND(147),K)
     , (ND(193),IF3), (ND(159),NMATL)
2013  FORMAT(///1H0, 18H***** MATERIAL NO., I5,5H.0, 7H BEYOND, 114,
     18H, USED MATL. NO. I  )
80    FORMAT(1HI,20HFATIGUE  INPUT DATA ,68X,21H** FTOCTL - IP(57) **/
                                        /1X, 3HF=,1E14.7, 5X, 3HSF=,
     1E14.7, 5X, 3HKT=,1E14.7//1X,4HFTU=,1E14.7, 5X, 2HE=,1F14.7, 5X,
     3HRA=, 1F14.7, 20X, 4HNPT=,114  ///)
214   FORMAT(1 HOSIDE OF FUSELAGE )
216   FORMAT(22 0WING OUTBOARD STATION )
230   FORMAT( 4H0STRESS LEVELS SET UP FROM BENDING MOMENTS,
     , 2X, 5HTIMES, 1E13.6 ///)
85    FORMAT(1110, 3E19.7)
265   FORMAT(1HI,10X,41HN FOR END OF EACH SPECTRA SEGMENT FOLLOWS ,
     37X,21H** FTOCTL - IP(57) **// (11X,113,118))
5051  FORMAT(/ 15HOFUSELAGE COVER )
5053  FORMAT(/ 22HOFUSELAGE MINOR FRAMES)
530   FORMAT(52HOSTRESS LEVELS SET UP FROM FUSELAGE PRESSURES TIMES ,
      1E13.6 /// )
820   FORMAT(/// 18HOENDURANCE LIMIT  )
998   FORMAT(1HI,54HCHANGES MADE TO MATERIAL PROPERTIES BY FATIGUE PROGR
     AM,43X,12H** FTOCTL **/
        / 15X,27HSIDE OF FUSELAGE ** MATL NO.,F4.0/
       11X,21HTMD(133) CHANGED FROM,F8.4,4H TO ,F8.4//
         16X,25HWING STATION 2 ** MATL NO.,F4.0/
       11X,21HTMD(134) CHANGED FROM,F8.4,4H TO ,F8.4//
         16X,25 FUSELAGE COVER ** MATL NO.,F4.0/
       11X,21HTMD(130) CHANGED FROM,F8.4,4H TO ,F8.4/
       11X,21HTMD(132) CHANGED FROM,F8.4,4H TO ,F8.4//
         13X,31HFUSELAGE MINOR FRAME ** MATL NO.,F4.0/
       11X,21HTMD(130) CHANGED FROM,F8.4,4H TO ,F8.4/
       11X,21HTMD(132) CHANGED FROM,F8.4,4H TO ,F8.4)
```

FORTRAN LISTING

OF

FATIGUE MODULE

```
11/02/73        INPUT LISTING                    AUTOFLOW CHART SET - SWEEP    FATIGUE MODULE

FORTRAN MODULE      (LIST AUTOSEQ)

 CARD NO        ****                          CONTENTS                              ****

     1              PROGRAM FATIGUE
     2          C
     3          C
     4              COMMON TCOM(5600)                                              00000015
     5              COMMON /MISC/XMISC(100)
     6              COMMON /IPRINT/IP(80)
     7          C
     8              DIMENSION D(2400), T(3000), ND(200)                            00000020
     9             1, BMA(3,220), DUMMY(830), EM(220), BMREF(20), BMSPX(2)         00000021
    10          C
    11              EQUIVALENCE (D(1),TCOM(1)), (T(1),TCOM(2401)), (ND(1),TCOM(5401)) 00000030
    12             1, (BMA(1,1),DUMMY(1),D(1150)), (BMREF(1),D(2107)), (EM(1),D(2127))00000031
    13             2, (BMSPX(1),D(1162))                                           00000032
    14             *, (ND(59),NMATL)                                               00000050
    15          C                                                                  00000080
    16              DO 10 I=1,5600                                                 00000090
    17           10 TCOM(I) = 0.0                                                  00000100
    18          C
    19              CALL READMS(1,D(1),2400,29)
    20          C
    21              IF(D(1162))20,20,22
    22           20 BMSPX(1) = XMISC(32)
    23           22 IF(D(1163))23,23,24
    24           23 BMSPX(2) = XMISC(33)
    25           24   IF (D(1101)) 25,25,26
    26           25 D(101) = XMISC(34)
    27           26   CONTINUE
    28          C         SO THE MIND WILL HAVE THE SAME VALUE
    29              XMISC(32)=BMSPX(1)
    30              XMISC(33)=BMSPX(2)
    31          C                                                                  10000130
    32              NMATL = XMISC(1)
    33          C
    34              CALL READMS(1,DUMMY(1),830,35)
    35          C
    36          C
    37              IF(IP(56))5001,5001,5002
    38           5001 CONTINUE
    39              WRITE(6,140)
    40            140 FORMAT(1H1,70H*** BMA(3,220) FROM SUBROUTINE FATMD IN LOADS PROGRA
    41               *M IN RECORD 35 ***,18X,21H** FATIGUE - IP(56) **//
    42               *  8X, 12HGOF BEND MOM, 3X, 12HADS BEND MOM, 2X,
    43               *  18HEXCEEDANCES-GUST, 2X, 18HEXCEEDANCES-MANU  )
    44          C
    45            150  WRITE(6,151) (N,BMA(1,N),BMA(2,N),BMA(3,N),EM(N),N=1,202)
    46            151  FORMAT( I15,2F15.0,2E18. 5)
    47                 WRITE(6,153) (N,DUMMY(N+606), DUMMY(N+818),N=1,8)          9000
    48            153  FORMAT( 39HDREFERENCE BENDING MOMENTS FOR MANEUVER / 4X, 7HSEGMENT9000
    49               1 8X, 3HGOF, 10X, 3HADS /(110, 2F15.0 ) )                    9000
    50          C
    51              WRITE(6,152)BMSPX(1),BMSPX(2)
    52            152 FORMAT(//10X,10HBMSPX(1) =,F15.0/10X,10HBMSPX(2) =,F15.0//)
    53           5002 CONTINUE
    54          C
    55              CALL FTOCTL                                                    00000320
    56          C
    57              END                                                            00000490
    58          C
    59          C $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
    60          C                          FUNCTION ACURVE
    61          C ***************************************************************************
    62          C
    63              FUNCTION ACURVE(X)                                             900N0010
    64          C                            FOR CYCLIC STRESS, CYCLIC STRAIN CURVE 900N0020
    65              COMMON TCOM(5600)                                              900N0030
    66          C                                                                  900N0040
    67              DIMENSION D(2400), T(3000), ND(200)                            900N0050
    68             *, CON(50), S(100)                                              900N0060
    69             *, CIX(10), CIY(10)                                             900N0080
    70          C                                                                  900N0090
```

```
CARD NO  ****                    CONTENTS                                    ****
      EQUIVALENCE (D(1),TCOM(1)), (T(1),TCOM(2401)), (ND(1),TCOM(5401)) 900+0100
     *, (D(5),CON(1)), (D(105),E)                                          900+0110
     *, (T(1),S(1))                                                        900+0140
     *, (T(1001),CIX(1)), (T(1101),CIY(1))                                 900+0170
     *,          (CON(20),C2), (CON(23),Q), (CON(26),CIE)                  900+0200
C              NOTE SCRATCH AREA FOR ROUTINE IS S(20) THRU (28)            900+0240
      EQUIVALENCE (S(20),XI), (S(21),XCL), (S(22),XJ), (S(23),YJ)          900+0250
     *, (S(24),XK), (S(25),YK), (S(26),YI), (S(27),YREAL), (S(28),XCR)     900+0260
      DATA XPRIOR/0.0/, YPRIOR/0.0/                                        900+0270
      IFUP=0                                                               900+0280
      IF(ABS(X-XPRIOR)/X .LE. 0.000001 )  GO TO 999                        900+0290
      XPRIOR = X                                                           900+0300
      K=1                                                                  900+0310
      XI = ALOG(X)                                                         900+0320
      IF(XI - CIX(1)) 10,10,15                                             900+0330
C                    FOR NOW IF LESS THAN 1ST CURVE PT. SAY = TO.          900+0340
   10 YPRIOR = EXP(CIY(K))                                                 900+0350
      GO TO 999                                                            900+0360
   15 K=9                                                                  900+0370
      IF(CIX(9) - XI) 20,10,30                                             900+0380
   20 IFUP=1                                                               900+0390
      GO TO 40                                                             900+0400
   30 DO 35 N=2,9                                                          900+0410
         K=N                                                               900+0420
         IF(XI-CIX(N)) 40,10,35                                            900+0430
   35 CONTINUE                                                             900+0440
   40 YK = CIY(K)                                                          900+0450
      XK = CIX(K)                                                          900+0460
      YJ = CIY(K-1)                                                        900+0470
      XJ = CIX(K-1)                                                        900+0480
   45 YI = (YK-YJ)/(XK-XJ) * (XI-XJ) + YJ                                  900+0490
      YREAL = EXP(YI)                                                      900+0500
      XCR = YREAL/E + C2*(YREAL/CIE)**Q                                    900+0510
      XCL = ALOG(XCR)                                                      900+0520
C                                                                          900+0530
C                                                                          900+0540
      IF ( ABS(XCR-XI)/X - CON(12)) 998,998,50                             900+0550
   50 IF(IFUP) 55,55,70                                                    900+0560
   55 IF(XCL-XI) 60,998,65                                                 900+0570
   60 XJ = XCL                                                             900+0580
      YJ = YI                                                              900+0590
      GO TO 45                                                             900+0600
   65 XK = XCL                                                             900+0610
      YK = YI                                                              900+0620
      GO TO 45                                                             900+0630
   70 IF(XCL-XI) 75,998,72                                                 900+0640
   72 IFUP = 0                                                             900+0650
   75 XJ = XK                                                              900+0660
      YJ = YK                                                              900+0670
      XK = XCL                                                             900+0680
      YK = YI                                                              900+0690
      GO TO 45                                                             900+0700
C                                                                          900+0710
  998 YPRIOR = YREAL                                                       900+0720
  999 ACURVE = YPRIOR                                                      900+0730
      RETURN                                                               900+0740
      END                                                                  900+0750
C
C ))))))
```

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CARD NO  ****                          CONTENTS                          ****
     142      *, (D(51),CON(11),                          (D(103),FKT)          90030110
     143      *, (D(104),FTU), (D(105),E)                                       90030120
     144      *, (D(201),FMAX(1)), (D(501),FMIN(1))                             90030130
     145      *, (T(1),$(1)), (T(101),CYC(1)), (T(99),HREQ), (T(100),HCALC)     90030140
     146      *, (T(1401),DAM1(1)), (T(1701),DAM2(1))                           9003
     147      *, (T(2001),DEPS1(1)), (T(2301),SGR1(1)), (T(2601),SGMEN(1))      9003
     148      *,              (CON(16),SOF), (CON(20),C2)                       90030190
     149      *, (CON(23),0),             (CON(25),PI), (CON(26),C1E)           90030210
     150      *, (CON(27),0.0)                                                  90030220
     151      *,(ND(40),NPT), (ND(41),JMAX)                                     90030230
     152       EQUIVALENCE ($(41),HREQ), ($(42),RSF)                            90030235
     153       EQUIVALENCE ($(51),A), ($(52),B), ($(53),F), ($(54),X), ($(55),FA)90030240
     154      *, ($(58),F1), ($(57),DF2),             ($(59),FSQ)               90030250
     155      *,                          ($(63),DSO1), ($(64),DSO2)            90030260
     156      *, ($(65),EPSA), ($(66),SOMN), ($(67),SOMX)                       90030270
     157      *, ($(69),TNF1), ($(70),TNF2), ($(71),DEPS1), ($(72),DEPS2)       90030280
     158      *, ($(73),DSOR1), ($(74),DSOR2), ($(75),EPSDT), ($(76),EPSMX)     90030290
     159      *, ($(77),EPSTJ), ($(78),EPST2), ($(79),SDA41), ($(80),SDAM2)     90030300
     160      *,              ($(82),DEPSMX), ($(83),DEPSR2), ($(84),SGMEN)     90030310
     161      *, ($(85),SORIMX), ($(86),TEPSTJ)                                 90030320
     162      C                                                                 90030330
     163           HCALC = D(24)                                                90030340
     164           DEPSMX = D(24)                                               90030350
     165           SDAM1 = D(24)                                                90030360
     166           SDAM2 = D(24)                                                90030370
     167      C                                                                 90030380
     168      C     NPT = NO. OF FMAX-FMIN-CYC VALUES       MAX=300.            90030390
     169      C                                                                 90030400
     170      C .....                                                           90030410
     171      C                                                                 90030420
     172           DO 250 J=1,NPT                                               90030430
     173           FSQ=((FKT*FMAX(J))**2)/CON(10)                               90030440
     174           A = FTU/D(14)                                                90030450
     175           B = D(24)                                                    90030460
     176           I=0                                                          90030470
     177      90   X=A                                                          90030480
     178           FA = A**2 + P*A**OPI - FSQ                                   90030490
     179           IF(FA)95,170,97                                              90030500
     180      95   I=I+1                                                        90030510
     181           IF( .GT. 9) GO TO 168                                        90030520
     182           A=A*C(10)                                                    90030530
     183           GO TO 90                                                     90030540
     184      97   I=0                                                          90030550
     185      100  IF(I .GT.  40 ) GO TO 168                                    90030560
     186           I=I+1                                                        90030570
     187           X = (A+B)/D(2)                                               90030580
     188           F = X**2 + P*X**OPI - FSQ                                    90030590
     189           IF(F) 110,170,120                                            90030600
     190      110  IF(F+CON(11)) 130,170,170                                    90030610
     191      120  IF(F-CON(11)) 170,170,130                                    90030620
     192      130  IF(F*FA) 140,170,160                                         90030630
     193      140  IF(B-X) 150,170,170                                          90030640
     194      150  B = X                                                        90030650
     195           GO TO 100                                                    90030660
     196      160  A = X                                                        90030670
     197           FA = F                                                       90030680
     198           GO TO 100                                                    90030690
     199      C      CANT FIND ROOT - - HCALC WILL BE ZERO ON RETURN           90030700
     200      168  WRITE(6,167) I,X,F,A,FA,B                                    90030710
     201      167   FORMAT(1H1,47HFAILED TO FIND SOMX IN ALIFE SUBROUTINE ******* // 90030720
     202          * 3H I=,I3, 2X,2HX=,1E14.6,2X,2HF=,1E14.6,2X,2HA=,1E14.6,2X,3HFA=,90030730
     203          * 1E14.6,2X,2HB=,1E14.6 )                                    90030740
     204           GO TO 999                                                    90030750
     205      C                                                                 90030760
     206      170  SOMX = X*D(14)                                               90030770
     207           EPSMX=SOMX/E + C2*(SOMX/C1E)**0                              90030780
     208      C                                                                 90030790
     209           IF(FMIN(J) .GE. D(24)) F1=(FMAX(J)+FMIN(J))/D(2)             90030800
     210           IF(FMIN(J) .LT. D(24)) F1=FMAX(J)/D(2)                       90030810
     211           DF2 = F1-FMIN(J)                                             90030820
     212           DSO1 = FKT*(FMAX(J)-F1)                                      90010830
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C.MD NO  ****                        CONTENTS                          ****
     213         UE^S1= DS01/E                                          80030840
     214         DEPS2= DF2 * EPSMX/ FMAX(J)                            80030850
     215         DEPS(J)= DEPS1+DEPS2                                   80030860
     216         EPSTJ = ABS(DEPS2)                                     80030870
     217         DS02 = ACURVE(EPSTJ)                                   80030880
     218         IF(DEPS2 .LT. D(24)) DS02=-DS02                        80030890
     219         SGMN = SGMX-DS01-DS02                                  80030900
     220         SGMEN(J) = (SGMX+SGMN)/D(2)                            80030910
     221         EPSA = DEPS(J)/D(2)                                    80030920
     222         EPST2 = EPSA/(D(1)-(SGMEN(J)/SGF))                     80030930
     223         TEPSTJ= ABS(EPST2)                                     80030940
     224         TNF1 = BCURVE(TEPSTJ)                                  80030950
     225         DAM1(J) = CYC(J)/TNF1                                  80030960
     226    C    DAMAGE DUE TO JTH STRESS  FROM FIRST                   80030970
     227    C                                                           80030980
     228         SDAM1 = SDAM1 + DAM1(J)                                80030990
     229    C                                                           80031000
     230         IF(FMIN(J) .GE. 0.0 .AND. FMAX(J) .GE. 0.0 ) GO TO 200 80031010
     231         IF(FMIN(J) .LT. 0.0 .AND. FMAX(J) .LT. 0.0 ) GO TO 200 80031020
     232         DSGR1 = FKT*FMIN(J)/D(2)                               80031030
     233         DEPSR2= FMIN(J)/D(2)*EPSMX/FMAX(J)                     80031040
     234         S(1) = SGMN                                            80031050
     235         GO TO 210                                              80031060
     236   200 DSGR1 = FKT*FMAX(J)/D(2)                                 80031070
     237         DEPSR2= EPSMX/D(2)                                     80031080
     238         S(1) = SGMX                                            80031090
     239   210 EPSTJ = ABS(DEPSR2)                                      80031100
     240         DSGR2 = ACURVE(EPSTJ)                                  80031110
     241         IF(DEPSR2 .LT. D(24)) DSGR2 = -DSGR2                   80031120
     242         SGR1(J) = S(1)-DSGR1-DSGR2                             80031130
     243    C                                                           80031140
     244    C                                                           80031150
     245         IF(DEPS(J) .LE. DEPSMX ) GO TO 250                     80031320
     246              DEPSMX = DEPS(J)                                  80031330
     247              JMAX = J                                          80031340
     248   250 CONTINUE                                                 80031350
     249    C                                                           80031360
     250         SGR1MX = SGR1(JMAX)                                    80031370
     251    C                                                           80031380
     252    C ..........................................................80031390
     253    C                                                           80031400
     254         DO 300 J=1,NPT                                         80031410
     255         SGBMEN = SGMEN(J) + SGR1MX - SGR1(J)                   80031420
     256         EPSBT = DEPS(J)/D(2) / (D(1)-SGBMEN/SGF)               80031430
     257         TEPSTJ = ABS(EPSBT)                                    80031440
     258         TNF2 = BCURVE(TEPSTJ)                                  80031450
     259         DAM2(J) = CYC(J)/TNF2                                  80031460
     260         SDAM2 = SDAM2 + DAM2(J)                                80031470
     261    C                                                           80031480
     262    C                                                           80031530
     263   300 CONTINUE                                                 80031540
     264    C                                                           80031550
     265    C                                                           80031600
     266         CCAL,C = ((( RSF-SDAM1)/SDAM2) + D(1)) * HRBL          80031610
     267    C                                                           80031620
     268   999 RETURN                                                   80031630
     269         END                                                    80031640
     270    C
     271    C ))))))
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CARD NO  ****                          CONTENTS                          ****
  284    C                                                                90050110
  285           EQUIVALENCE (D(1),TCOM(1)), (T(1),TCOM(2401)), (ND(1),TCOM(5401)) 90050120
  286          *, (D(51),CON(1))                                           90050130
  287          *, (T(1),S(1))                                              90050160
  288          *, (T(102),C2X(1)), (T(103),C2Y(1))                         90050200
  289          *, (CON(19),C1), (CON(20),C2), (CON(21),BETA), (CON(22),GAMMA) 90050220
  290    C             NOTE SCRATCH FOR ROUTINE IS S(30) THRU (38)         90050260
  291           EQUIVALENCE (S(30),XI), (S(31),XCL), (S(32),XJ), (S(33),YJ) 90050270
  292          *, (S(34),XK), (S(35),YK), (S(36),YI), (S(37),YREAL), (S(38),XCR) 90050280
  293    C                                                                90050290
  294    C ..... ..... 90050300
  295    C                                                                90050310
  296           XI = ALOG(X)                                              90050320
  297           K=1                                                       90050330
  298           IF(XI-C2X(1)) 20,10,10                                    90050340
  299       10  YREAL = EXP(C2Y(K))                                       90050350
  300           GO TO 999                                                 90050360
  301       20  K=10                                                      90050370
  302           IF(XI-C2X(10)) 10,10,30                                   90050380
  303    C                          START WITH NO EXTRAPOLATION            90050390
  304       30  DO 35 N=2,10                                             90050400
  305               K=N                                                   90050410
  306               IF(C2X(N)-XI) 40,10,35                                90050420
  307       35  CONTINUE                                                  90050430
  308       40  XK=C2X(K)                                                 90050440
  309           YK=C2Y(K)                                                 90050450
  310           XJ=C2X(K-1)                                               90050460
  311           YJ=C2Y(K-1)                                               90050470
  312    C                                                                90050480
  313       45  YI=(YK-YJ)/(XK-XJ)*(XI-XJ) + YJ                          90050490
  314           YREAL = EXP(YI)                                           90050500
  315           XCR = C1/YREAL**BETA + C2/YREAL**GAMMA                    90050510
  316           XCL = ALOG(XCR)                                           90050520
  317    C                                                                90050530
  318    C                                                                90050540
  319           IF( ABS(XCR-XI)/XI - CON(12)) 999,999,50                  90050550
  320       50  IF(XCL-XI) 60,999,55                                      90050560
  321       55  XJ = XCL                                                  90050570
  322           YJ = YI                                                   90050580
  323           GO TO 45                                                  90050596
  324       60  XK = XCL                                                  90050600
  325           YK = YI                                                   90050610
  326           GO TO 45                                                  90050620
  327      999  BCURVE = YREAL                                            90050630
  328           RETURN                                                    90050640
  329           END                                                       90050650
  330    C
  331    C )))))))
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CARD NO  ****                          CONTENTS                          ****
     *, (D(104),FTU), (D(105),E), (D(106),RA), (D(107),ANP1)                  90020200
     *, (D(201),FMAX(1)), (D(501),FMIN(1)), (D(801),AN(1))                    90020210
     *, (T(1),S(1)), (T(101),CYC(1)), (T(99),HREQ), (T(100),HCALC)            90020220
     *, (T(401),PC1(1)), (T(701),PC2(1)),                  (S(42),RSF)        90020230
     *, (T(1401),DAM1(1)), (T(1701),DAM2(1))                                  90020240
     *, (T(2001),C1X(1)), (T(2301),C1Y(1)), (T(2601),C2X(1))                  90020260
     *, (T(2901),C2Y(1))                                                      90020270
     *, (CON(15),RTO), (CON(16),SOF), (CON(17),RTO1), (CON(18),RTO2)          90020280
     *, (CON(19),C1), (CON(20),C2), (CON(21),BETA), (CON(22),GAMMA)           90020290
     *, (CON(23),Q), (CON(24),RE), (CON(25),P), (CON(26),C1E)                 90020300
     *, (CON(27),QP1)                                                         90020310
      EQUIVALENCE                                                             90020320
     * (ND(40),NPT) ,                (ND(42),NTOP)                          90020330
     *, (ND(43),MTIME)                                                        90020340
     *, (ND(45),MI), (ND(46),MTIME), (ND(47),K)                               90020350
     *, (S(87),SFM)                                                           90020370
     *, (S(88),SURF), (S(89),FTOP)                                            90020380
     *, (S(90),HI), (S(91),SF1), (S(92),H2), (S(93),SF2), (S(94),HN)          90020390
     *, (S(95),SFN), (S(96),HR), (S(97),FACT), (S(98),TF)                     90020400
C                                                                             90020410
C ..... ..... 90020420
C    INITALIZE                                                                90020430
C                                                                             90020440
      ND(44) = 0                                                              90020450
      MTIME = 0                                                               90020451
C    IF MATERIAL SAME SKIP COEFFICIENT AND CURVE CALCULATION                  90020460
      IF(MI .NE. 0) GO TO 49                                                  90020470
      RTO = ALOG(D(1)/ (D(1)-RA))                                             90020480
      SOF = FTU*(D(1)+RTO)                                                    90020490
      RTO1= FTU/E                                                             90020500
      RTO2= (D(1)+RTO)                                                        90020510
      C1 = CON(1)*RTO1*RTO2**CON(2)                                           90020520
      BETA = CON(3)+CON(4)*ALOG10(RTO2)                                       90020530
      S(1) = CON(5)* RTO**CON(6)                                              90020540
      S(2) = (D(1)-(CON(7)*RTO1)*(RTO2**CON(4)))**D(21)                       90020550
      GAMMA = ALOG10(S(1)/S(2))                                               90020560
      C2 = (RTO**CON(8))/D(8)*(D(10)**GAMMA)                                  90020570
      Q = GAMMA/BETA                                                          90020580
      RE = E/D(14)                                                            90020590
      P = RE*C2/(RE*C1)**Q                                                    90020600
C                                                                             90020610
      C1E = C1*E                                                              90020620
      QP1 = D(1)+Q                                                            90020630
C                                                                             90020640
      IF(IP(58))5001,5001,17
 5001 CONTINUE
      WRITE (6,15) (N,D(N),D(N+1),D(N+2),D(N+3),D(N+4),N=65,79,5)             90020660
   15 FORMAT(1H1,86X,21H** FATIGU - IP(58) **//(I17,5E16.7))
   17 CONTINUE                                                                90020680
C                                                                             90020690
C ..... 90020700
C                                                                             90020710
C  SET UP CURVE     CYCLIC STRESS VS CYCLIC STRAIN --- ACURVE                 90020720
C          EPST = SOA/E + C2(SOA/C1E)**Q                                      90020730
C                 EPST = C1X                                                  90020740
C                 SOA  = C1Y                                                  90020750
C                                                                             90020760
C     AND STRAIN VS CYCLES TO FAILURE                                         90020770
C          TEPST = C1/TNF**BETA + C2/TNF**GAMMA    --- BCURVE                 90020780
C                 TEPST = C2X                                                 90020790
C                 TNF   = C2Y                                                 90020800
C                                                                             90020810
C  THESE CURVES ARE NEAR-LINEAR  ON LOG LOG PLOT SO WILL USE LOGS AND         90020820
C     STRAIGHT LINE INTERPOLATION IN ITERATING TO FIND Y FOR A GIVEN X.        90020830
C                                                                             90020840
C     FOR A  THERE IS A SLOPE CHANGE WHERE THE DOMINANT TERM CHANGES          90020850
C          Y DISTRIBUTION IS PICKED FOR THIS.                                 90020860
C                                                                             90020870
C ..... 90020880
C                                                                             90020890
      C1Y(1) = D(1)                                                           90020900
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CARD NO ****                    CONTENTS                              ****
      C1Y(9) = CON(9)                                                 90020910
      C1Y(5) = E**(C1**Q/C2)**(D(1)/(Q-D(1)))                         90020920
      C1Y(4) = C1Y(5)/D(2)                                            90020930
      C1Y(2) = C1Y(4)**D(2)                                           90020940
      C1Y(3) = C1Y(2)**2                                              90020950
      C1Y(6) = C1Y(5) * C1Y(4)                                        90020960
      S(1) = (C1Y(9)/C1Y(6))**D(2)                                    90020970
      C1Y(7) = S(1)*C1Y(6)                                            90020980
      C1Y(8) = C1Y(7)*S(1)                                            90020990
      DO 30 N=1,9                                                     90021000
        C1X(N) = C1Y(N)/E * C2**(C1Y(N)/C1E)**Q                       90021010
   30 CONTINUE                                                        90021020
    C FOR B      NOTE- X IN DECREASING ORDER IN STORAGE      *****    90021030
      C2Y(1) = D(1)                                                   90021040
      DO 32 N=2,8                                                     90021050
      C2Y(N) = C2Y(N-1)*D(10)                                         90021060
   32 CONTINUE                                                        90021070
      S(1) = D(10)                                                    90021080
    C AS CURVE FLATTENS INCREASE INTERVAL TO COVER RANGE BETTER.      90021090
      DO 35 N=7,10                                                    90021100
      S(1) = S(1)*D(10)                                               90021110
      C2Y(N) = C2Y(N-1)*S(1)                                          90021120
   35 CONTINUE                                                        90021130
      DO 38 N=1,10                                                    90021140
        C2X(N) = C1/C2Y(N)**BETA + C2/C2Y(N)**GAMMA                   90021150
   38 CONTINUE                                                        90021160
    C                                                                 90021170
      IF(IP(50))5003,5003,42
 5003 CONTINUE
      WRITE(6,40) (C1X(N),C1Y(N),C2X(N),C2Y(N), N=1,9)                90021190
   40 FORMAT(13HOCURVE SET-UP // (4E20.7/ ))                          90021200
      WRITE(6,41) C2X(10),C2Y(10)                                     90021210
   41 FORMAT( 40X,2E20.7)                                             90021220
   42 CONTINUE                                                        90021230
    C                                                                 90021240
      DO 45 N=1,9                                                     90021250
      C1X(N) = ALOG(C1X(N))                                           90021260
      C1Y(N) = ALOG(C1Y(N))                                           90021270
      C2X(N) = ALOG(C2X(N))                                           90021280
      C2Y(N) = ALOG(C2Y(N))                                           90021290
   45 CONTINUE                                                        90021300
      C2X(10) = ALOG(C2X(10))                                         90021310
      C2Y(10) = ALOG(C2Y(10))                                         90021320
    C                                                                 90021330
      IF(IP(50))5005,5005,49
 5005 CONTINUE
      WRITE(6,47) (C1X(N),C1Y(N),C2X(N),C2Y(N), N=1,9)                90021350
   47 FORMAT( //(4E20.6 / ))                                          90021360
      WRITE(6,48) C2X(10),C2Y(10)                                     90021370
   48 FORMAT( 40X,2E20.6 )                                            90021380
   49 CONTINUE                                                        90021390
    C                                                                 90021400
    C ... ..... 90021410
    C                                                                 90021420
      NPT = ANPT                                                      90021430
      FTOP = D(24)                                                    90021440
      NREQ = N*SF                                                     90021450
      RSF=D(11/SF                                                     90021455
      SUMF = D(24)                                                    90021460
      DO 100 N=1,NPT                                                  90021470
      CYC(N) = AN(N)*BLOCK                                            90021480
      SUMF = SUMF + FMAX(N)                                           90021490
      IF(FMAX(N) .LE. FTOP ) GO TO 100                                90021500
                FTOP = FMAX(N)                                        90021510
                NTOP = N                                              90021520
  100 CONTINUE                                                        90021530
    C                                                                 90021540
      DO 110 N=90,98                                                  90021550
  110 S(N) = D(24)                                                    90021560
      NR = ALOG(NREQ)                                                 90021570
      TF = D(1)                                                       90021580
```

```
CARD NO  ****                          CONTENTS                          ****
497            NTIME = 0                                                 90021590
498           C                                                          90021600
499           C ..........................................................90021610
500           C                                                          90021620
501            150  CALL ALIFE                                          90021630
502           C                                                          90021640
503                 IF(HCALC) 500,800,160                                90021650
504            160  IF(ABS(HCALC-HREQ)/HREQ - CON(13)) 200,200,300       90021660
505            200  CONTINUE                                            90021670
506                 IF(IP(57))5007,5007,999
507           5007 CONTINUE
508                 S(1) =D(24)                                          90021679
509                 S(2) = D(24)                                         90021680
510                 DO 210 N=1,NPT                                       90021690
511                 S(1) = S(1)+DAM1(N)                                  90021700
512                 S(2) = S(2)+DAM2(N)                                  90021710
513            210 CONTINUE                                              90021720
514           C  MINER'S LAW    SUM DAM1 + B*SUM DAM2 = 1/SF             90021728
515           C                   B IS 9.0                               90021729
516                 S(3)=(RSF - S(1))/S(2)                               90021730
517                 S(5)= SF*100.                                        90021735
518                 S(6)=S(5)*S(3)                                       90021740
519           C               TO CALCULATE PERCENT OF TOTAL FOR EACH DAMAGE 90021750
520                 DO 220 N=1,NPT                                       90021760
521                 PC1(N) = DAM1(N)*S(5)                                90021770
522                 PC2(N) = DAM2(N)*S(6)                                90021780
523            220 CONTINUE                                              90021790
524           C                                                          90021800
525                 S(5)=S(1)+S(5)                                       90021801
526                 S(6)=S(2)+S(6)                                       90021802
527           C                                                          90021803
528                 S(4) = FMAX(NTOP)/FTU*100.                           90021810
529                 WRITE(6,250)NTIME,HCALC,HREQ,FMAX(NTOP),S(4)
530            250 FORMAT(1H1,10X,43HNUMBER OF ITERATIONS IN SUBROUTINE FATIGU =,I4,
531               1   31X,21H** FATIGU - IP(57) **/
532               *           /17X, 14HCALC. LIFE(HR), 9X 17HREQUIRED LIFE(HR), /
533               * 16X,1E14.6,10X,1E14.6,6X,13H1GHEST FMAX=,1E13.6,2H =,1F7.2,
534               * 7HPCT FTU)
535                 WRITE(6,255)(N,FMAX(N),FMIN(N),CYC(N),DAM1(N),PC1(N),DAM2(N),  90021860
536               * PC2(N), N=1,NPT )                                     90021870
537            255 FORMAT(//8X,1HN, 7X, 4HFMAX, 8X, 4HFMIN, 5X, 8HAPP.CYC., 7X,  90021880
538               * 8HDAMAGE 1,7X,3HPCT, 7X, 8HDAMAGE 2, 7X,3HPCT// (1I9, 3F12.6,  90021890
539               * 1E17.6, 1F8.2, 1E17.6, 1F8.2) )                       90021900
540                 WRITE(6,257) S(1),S(5),S(2),S(6),S(3)                90021901
541            257 FORMAT(// 13X,32HCUMULATIVE DAMAGE FOR EACH BLOCK, 2(E17.6,F8.2)  90021902
542               *  //8X, 32HNUMBER OF RESIDUAL DAMAGE BLOCKS,1F9.3)     90021903
543                 GO TO 999                                            90021910
544           C                                                          90021920
545            300  NTIME = NTIME + 1                                    90021930
546                 IF(NTIME-500)301,800,800
547            301  IF(NTIME - 2) 305,350,400                           90021950
548           C FIRST TIME ITTERATION  USE POINT-SLOPE  LOG-LOG LINE LIFE VS. SUMFMAX90021960
549           C     WHERE  CON(14) IS AVERAGE SLOPE OF DATA EXAMINED.    90021970
550            305  SF1 = ALOG(SUMF)                                     90021980
551                 SFN = SF1                                            90021990
552           C             SFN IS PRIOR POINT FOR 2ND TIME AND AFTER    90022000
553                 H1 = ALOG(HCALC)                                     90022010
554                 S(1) = CON(14)*(HR-H1)                               90022020
555                 SFN = S(1)+SF1                                       90022030
556                 FACT = EXP(S(1))                                     90022040
557            320  DO 325 N=1,NPT                                       90022050
558                 FMAX(N) = FMAX(N)*FACT                               90022060
559                 FMIN(N) = FMIN(N)*FACT                               90022070
560            325  CONTINUE                                            90022080
561                 TF = TF*FACT                                         90022090
562                 IF(IP(58))5009,5009,150
563           5009 IF(NTIME - 1)5010,5010,5011
564           5010 WRITE(6,5012)
565           5012 FORMAT(1H1,88X,21H** FATIGU - IP(58) **)
566           5011 WRITE(6,330) NTIME, HCALC, FACT, TF                   90022110
567            330 FORMAT(1H0***** NTIME=,I13,7X,8HHCALC=,1E15.7,7X,7HFACTOR=,  90022120
```

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CARD NO  ****                          CONTENTS                          ****
     568      * 1E15.7,7X,3HIF=,1E15.7)                                  00022130
     569       WRITE(6,331) (SIN),N=90,95),SIG                           00022140
     570   331 FORMAT (1H , 6E18.7)                                      00022150
     571       GO TO 150                                                 00022160
     572   C                                                             00022170
     573   C                    2ND TIME ITERATE USE 2 POINTS            00022180
     574   350 HN = ALOG(HCALC)                                          00022190
     575       SFN = SFN                                                 00022200
     576       IF(HN-H1) 365,800,360                                     00022210
     577   360 H2 = HN                                                   00022220
     578       SF2= SFN                                                  00022230
     579       GO TO 370                                                 00022240
     580   365 H2 = H1                                                   00022250
     581       SF2= SF1                                                  00022260
     582   367 H1 = HN                                                   00022270
     583       SF1= SFN                                                  00022280
     584   370 SFN = (SF2-SF1)/(H2-H1)*(HR-H1)+SF1                       00022290
     585       FACT = EXP(SFN-SFM)                                       00022300
     586   C                  FACTOR IS VALUE SFN/SFM SO EXP(LN(SFN)-LN(SFM))  00022310
     587   C                     ( NEXT ESTIMATED Y OVER PREVIOUS Y )     00022320
     588       GO TO 320                                                 00022330
     589   C                                                             00022340
     590   C            3RD TIME AND AFTER ASSUME HN WILL GO IN RIGHT DIRECTION 00022350
     591   C                  SINCE CURVES ARE SINGLE VALUED,NO INFLECTIONS.  00022360
     592   400 HN = ALOG(HCALC)                                          00022370
     593       SFN = SFN                                                 00022380
     594       IF(HN-H1) 365,800,405                                     00022390
     595   405 IF(HN-H2) 410,800,420                                     00022400
     596   410 IF(HN-HR) 367,800,360                                     00022410
     597   420 H1 = H2                                                   00022420
     598       SF1=SF2                                                   00022421
     599       GO TO 360                                                 00022422
     600   C                                                             00022423
     601   C  IF HCALC IS NEGATIVE FIRST TIME, TRY LOWER VALUES 5 TIMES  00022430
     602   500 IF(NTIME .NE. 0) GO TO 800                                00022432
     603       IF(NTIME .LT. 5) GO TO 510                                00022434
     604       WRITE(6,505)                                              00022436
     605   505 FORMAT( 3HNO NEGATIVE LIFE THRU 5 ITTERATIONS )           00022438
     606       GO TO 800                                                 00022440
     607   510 NTIME = NTIME + 1                                         00022442
     608       FACT = D(19)                                              00022444
     609       GO TO 320                                                 00022446
     610   C                                                             00022449
     611   C ******* ERROR PRINT .... HCALC = 0.0 ROOT CALC IN ALIFE SUBRT  00022450
     612   C                          HCALC = SOME VALUE - FAILED TO REACH  00022460
     613   C                                HREQ IN FATIQU BUT CANT CLOSE IN.  00022461
     614   C                                                             00022462
     615    800 GO TO (801,803,805,807),K                                00022465
     616    801 WRITE(6,802)                                             00022466
     617    802 FORMAT( 38HOWORKING ON WING AT SIDE OF FUSELAGE )        00022467
     618        GO TO 809                                                00022468
     619    803 WRITE(6,804)                                             00022469
     620    804 FORMAT( 38HOWORKING ON WING OUTER PANEL STATION )        00022470
     621        GO TO 809                                                00022471
     622    805 WRITE(6,806)                                             00022472
     623    806 FORMAT( 38HOWORKING OF FUSELAGE PRESSURE CYCLES )        00022473
     624        GO TO 809                                                00022474
     625    807 WRITE(6,808)                                             00022475
     626    808 FORMAT( 38HOWORKING ON FUSELAGE ENDURANCE LIMIT )        00022476
     627    809 WRITE(6,810) NTIME,HCALC,FTU,E,RA,HREQ,AMPT,SF, ( FMAX(N),FMIN(N),00022480
     628       * CYC(N),N=1,NPT )                                        00022490
     629    810 FORMAT(48H0*** ERROR IN FATIQUE, PERTINENT DATA FOLLOWS... /  00022500
     630       * 7H NTIME=,I3,4X,6HHCALC=,  1E14.6,4X,4HFTU=,1E14.6,4X,2HE=,  00022510
     631       * 1E14.6,4X,3HRA=,1E14.6 /14X,6HHREQ =,1E14.6,4X,5HAMPT=,1E14.6,  00022520
     632       * 4X,3HSF=,1E14.6//15X,4HFMAX,14X,4HFMIN,14X,3HCYC //6X,3E18.6) )  00022530
     633       WRITE(6,820) (N, S(N),S(N+1),S(N+2),S(N+3),S(N+4), N=1,95,5)  00022540
     634   820 FORMAT(1H0,16HCALCULATION AREA // (1I6, 5E18.7 ))         00022550
     635       KD(44) = 1                                                00022560
     636    999 RETURN                                                   00022570
     637        END                                                      00022580
     638   C
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CARD NO  ****                          CONTENTS                          ****
  639    C ))))))
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CARD NO                    ****                    CONTENTS                    ****
  710          111  FIND=D(24)
  711               GO TO 113                                                  90010390
  712          112  FIND=X(15C(3))                                             90010400
  713          113  IF(FFIND) 114,115,116                                      90010402
  714          114  FFIND=D(24)                                                90010404
  715               GO TO 116                                                  90010410
  716          115  FFIND=X(15C(4))                                            90010420
  717          116  CONTINUE                                                   90010430
  718               MRBL=M+BLOCK                                               90010440
  719          C                                                               90010450
  720          C                                                               90010450
  721           200  IF(MIND(I) .EQ. D(24)) GO TO 266                         90010460
  722          C  FOR BEND.MO MOMENTS AS STRESS LEVELS...CONSIDER ONLY WHEN THE 90010470
  723          C  MAXIMUM (1ST HALF OF EACH SPECTRA SEGMENT) IS POSITIVE.      90010480
  724          C  BECAUSE CRITICAL CONDITION IS  COMPRESSION ON UPPER SURFACE. 90010490
  725          C       TENSION ON LOWER SURFACE.                               90010500
  726          C                                                               90010510
  727          C  BENDING MOMENTS ARE AVAILABLE FOR (1) SIDE OF FUSELAGE AND   90010520
  728          C     (2) ONE OUTBOARD STATION. MOMENTS  FOR SWEPT COND. IF APPLICABLE. 90010530
  729          C      B.M. ARE IN 8 FLIGHT SEGMENTS  + 2 TAXI SEG. +  1 GROUND-AIR-GR. 90010540
  730          C      FIRST 10 HAVE 20 PTS (10 MAX., 10MIN.) LAST HAS 2 PTS.   90010550
  731          C      BMAIK,L)    L=POINT COUNTER                              90010560
  732          C      K =1 SOF. SIDE OF FUS.                                   90010570
  733          C      K =2 MOS  2ND WING STA.                                  90010580
  734          C      K =3 EXCEEDANCES FOR GUST,                               90010590
  735          C      EM =  EXCEEDANCES FOR MANEUVER .                         90010600
  736          C  EXCEEDANCES FOR MANEUVER ARE CALC ONLY 1ST 8 BUT USE 10 TO SIMPLIFY. 90010610
  737          C ---------------------------------------------------------------
  738               K=1                                                        90010611
  739          C*** READ MATERIAL LIBRARY(WITH MATERIAL NUMBER SET= MIND(K) ) INTO THD 90010620
  740           201  IF3 = MIND(K)                                            90010630
  741               IF(IF3) 2012,2012,2011                                     90010640
  742          2011 IF(IF3-MMATL) 2015,2015,2012                               90010650
  743          2012 IF3 = 1                                                    90010660
  744               WRITE (6,2013) MIND(K), MMATL                              90010670
  745          2013 FORMAT(///1HO, 18H***** MATERIAL NO., IF5.0, 7H BEYOND, 11H, 90010680
  746             *18H, USED MATL. NO. 1  )                                    90010690
  747          C                                                               90010700
  748           2015 IF3 = IF3 + 40                                            90010710
  749               CALL READMS(1,THD(1),300,IF3)
  750               FTU=THD(126)
  751               RA =THD(5)                                                 90010730
  752               E  =THD(121)/THD(119)                                      90010740
  753          C                                                               90010750
  754          C    SET MI, MATERIAL INDICATOR = 0 = 1ST OR NEW MATERIAL       90010760
  755               MI = 0                                                     90010770
  756           202 N=0                                                        90010780
  757          C                                                               90010790
  758               IND = (K-1) * 3
  759               SAVE(IND+1) = IF3 - 40
  760               SAVE(IND+2) = THD(K+132)
  761          C
  762               DO 212 LL=1,10
  763               L=(LL-1)*20+1                                              90010800
  764               M=L+19                                                     90010810
  765               IREF=LL+(K-1)*10                                           90010820
  766               DO 210  J=1,9                                              90010821
  767               I=J-1                                                      90010830
  768          C              FIRST DO GUST                                    90010840
  769               T(1) = (BMAIK,L+1)-BMAIK,L+J))/D(3) + BMAIK,L+J)           90010850
  770               IF(T(1) .LE. D(24)) GO TO 210                              90010860
  771               N=N+1                                                      90010870
  772               T(2) = (BMAIK,M-I)-BMAIK,M-J))/D(3) + BMAIK,M-J)           90010875
  773               FMAX(N) = T(1)                                             90010880
  774               FMIN(N) = T(2)                                             90010890
  775               AN(N) = BMAI3,L+J) - BMAI3,L+1)                            90010891
  776          C    FOR MANEUVER BENDING MOMENTS ARE THE SAME BUT EXCEEDANCES IN EM. 90010892
  777               T(3) = EMI(L+J) - EMI(L+1)                                 90010893
  778               IF(T(3) .LE. 0.0) GO TO 206                                90010894
  779               IF( T(1) - _ )F(IREF) ) 203,206,204                        90010895
  780           203 N=N+1                                                      90010898
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CARD NO  ****                          CONTENTS                          ****
  781          FMAX(N) = BMREF(IREF)                                      90010897
  782          FMIN(N) = T(1)                                             90010898
  783          GO TO 205                                                  90010899
  784      204 N=N+1                                                      90010900
  785          FMAX(N) = T(1)                                             90010901
  786          FMIN(N) = BMREF(IREF)                                      90010902
  787      205 AN(N) = T(3)                                               90010903
  788      206 T(4) = EMIN-J) - EMIN-1)                                   90010904
  789          IF(T(4) .LE. 0.0) GO TO 210                                90010905
  790          IF(T(2) - BMREF(IREF) ) 207,210,208                        90010906
  791      207 N=N+1                                                      90010907
  792          FMAX(N) = BMREF(IREF)                                      90010908
  793          FMIN(N) = T(2)                                             90010909
  794          GO TO 209                                                  90010910
  795      208 N=N+1                                                      90010911
  796          FMAX(N) = T(2)                                             90010912
  797          FMIN(N) = BMREF(IREF)                                      90010913
  798      209 AN(N) = T(4)                                               90010914
  799      210 CONTINUE                                                   90010915
  800      C                                                              90010916
  801           NSEG(IK,LL)=N                                             90010920
  802      212 CONTINUE                                                   90010930
  803          N=N+1                                                      90010940
  804          FMAX(N) = BMAX(K,201)                                      90010950
  805          FMIN(N) = BMAX(K,202)                                      90010960
  806          AN(N) = (BMAX(3,201)+BMAX(3,202))/D(2)                     90010970
  807          ANPT = N                                                   90010980
  808          NPT = N                                                    90010990
  809          SF = SF(K)                                                 90010991
  810          FKT = FKT(K)                                               90010992
  811          IF(IP(57))5021,5021,5002
  812      5021 CONTINUE
  813          WRITE(6,80) N,SF,FKT,FTU,E,RA,NPT                          90011000
  814       80 FORMAT(1H1,20HFATIGUE  INPUT DATA ,68X,21H** FTGCTL - IP(57) **/
  815         1                                    /1X, 20H=,1E14.7, 5X, 3HSF=,
  816         *1E14.7, 5X, 3HKT=,1E14.7//1X,4HFTU=,1E14.7, 5X, 2HE=,1E14.7, 5X,
  817         *3HRA=, 1E14.7, 20X, 4HNPT=,I14  ///)
  818          IF(K.EQ.2) GO TO 215                                       90011010
  819          WRITE(6,214)                                               90011020
  820      214 FORMAT(17HOSIDE OF FUSELAGE )                              90011030
  821          GO TO 220                                                  90011040
  822      215 WRITE(6,216)                                               90011050
  823      216 FORMAT(22HOWING OUTBOARD STATION )                         90011060
  824      220 CONTINUE                                                   90011070
  825      C BMAX = MAX FROM SPECTRA FOUND HERE                           90011080
  826      5002 CONTINUE
  827      C BMSPX= STATIC MAX FOUND ELSEWHERE AND PASSED (2 VALUES) ---------- 90011090
  828          BMAX = D(24)                                               90011100
  829          DO 222 N=1,NPT                                             90011110
  830          IF(FMAX(N) .GT. BMAX) BMAX=FMAX(N)                         90011120
  831      222 CONTINUE                                                   90011130
  832      C     MODIFY BM TO SIMULATE STRESS. . . . . . . . . . . . . .  90011140
  833          T(1) = CON(28)*FTU/BMAX                                    90011150
  834          DO 225 N=1,NPT                                             90011160
  835          FMAX(N) = FMAX(N)*T(1)                                     90011170
  836      225 FMIN(N) = FMIN(N)*T(1)                                     90011180
  837          IF(IP(57))5003,5003,5004
  838      5003 WRITE(6,230) T(1)                                         90011190
  839      230 FORMAT( 42HSTRESS LEVELS SET UP FROM BENDING MOMENTS,      90011200
  840         *, 2X, 9HTIMES, 1E13.6 ///)                                 90011210
  841          WRITE(6, 85) (I,FMAX(I),FMIN(I),AN(I), I=1,NPT)            90011220
  842       85 FORMAT(1110, 3E19.7)                                       90011230
  843      5004 CONTINUE
  844      C                                                              90011240
  845          CALL FATIOU                                                90011250
  846      C                                                              90011260
  847          IF(IFERR) 240,250,240                                      90011270
  848      240 SAVE(IND+3)=SAVE(IND+2)                                    90011280
  849          GO TO 260                                                  90011290
  850      250 T(1) = FMAXINTOP)/FTU * BMSPX(IK)/BMAX                     90011300
  851      251 DO 255 I=132,257,25                                        90011310
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CARD NO      ****                                                    ****
  852            THD(I+K) = T(I)                                                  90011320
  853        255 CONTINUE                                                         90011330
  854            SAVE(IND+3) = T(1)
  855        260 IF(IP(57))5007,5007,5008
  856       5007 WRITE(6,265) (I,NSEQ(K,I),I=1,10)
  857        265 FORMAT(1H1,10X,41HN FOR END OF EACH SPECTRA SEGMENT FOLLOWS ,   90011350
  858           137X,21H** FTOCTL - IP(57) ***/ (11X,113,1181)
  859       5008 CONTINUE
  860            CALL WRITMS(1,THD(1),300,IF3)
  861            IF(K .EQ. 2) GO TO 500
  862        266 IF(MIND(2) .EQ. D(24)) GO TO 500                                 90011390
  863            K=2                                                              90011400
  864            IF(MIND(1).NE.MIND(2)) GO TO 201                                 90011410
  865            MI = 1                                                           90011420
  866            GO TO 202                                                        90011430
  867       C                                                                     90011440
  868       C ..... .....90011450
  869       C  FUSELAGE PRESSURES TO SET UP STRESS LEVELS                         90011460
  870       C                                                                     90011470
  871        500 IF(FIND .EQ. D(24)) GO TO 800                                    90011480
  872            KF=0                                                             90011490
  873            IF(MIND(1)+MIND(2).EQ.D(24)) GO TO 5001                          90011491
  874            IF(FIND .EQ. MIND(K)) GO TO 507                                  90011500
  875       C*** READ MATERIAL LIBRARY WITH MATERIAL NO. SET= FIND                90011510
  876       5001 IF3=FIND                                                         90011520
  877            IF(IF3)502,502,501                                               90011530
  878        501 IF(IF3-MMATL) 503,503,502                                        90011540
  879        502 IF3=1                                                            90011550
  880            WRITE(6,2013) FIND, MMATL                                        90011560
  881        503 IF3 = IF3 + 40                                                   90011570
  882            CALL READMS(1,THD(1),300,IF3)
  883            RA =THD(5)
  884            FTU=THD(126)                                                     90011590
  885            E =THD(121)/THD(119)                                             90011600
  886            MI = 0                                                           90011610
  887            GO TO 510                                                        90011620
  888        507 MI = 1                                                           90011630
  889       C FPT IS NUMBER OF FUSELAGE AV. PRESSURES                             90011640
  890        510 NPT = FPT                                                        90011650
  891       C                                                                     90011660
  892            SAVE(KF+7)=IF3-40                                  SAVE FOR PRINT AT END  90011661
  893            SAVE(KF+8)=THD(130)                                              90011662
  894            SAVE(KF+10)=THD(132)                                             90011663
  895       C                                                                     90011664
  896            ANPT = FPT                                                       90011665
  897            SF = SFTP                                                        90011670
  898            FKT = FKTFP                                                      90011671
  899            IF(IP(57))5005,5005,5006                                         90011672
  900        5005 WRITE(6,801) H,SF,FKT,FTU,E,RA,NPT
  901            IF(KF .EQ. 5) GO TO 5052                                         90011680
  902            WRITE(6,5051)                                                    90011681
  903       5051 FORMAT(// 19HOFUSELAGE COVER )                                   90011682
  904            GO TO 5008                                                       90011683
  905       5052 WRITE(6,5053)                                                    90011684
  906       5053 FORMAT(// 22HOFUSELAGE MINOR FRAMES)                             90011685
  907       5006 CONTINUE                                                         90011686
  908       C ASSUMED PRESSURE BLOCK HAS ARRANGED IN SEPERATE ARRAYS              90011687
  909       C     WHERE FPR(1) TO (100)  ARE PMAX                                 90011690
  910       C           FPR(101) TO (200) ARE PMIN                                90011700
  911       C           FPR(201) TO (300) ARE APPLIED CYCLES                      90011710
  912            T(1) = D(24)                                                     90011720
  913            DO 520 N=1,NPT                                                   90011730
  914            PMAX(N) = PPX(N)                                                 90011740
  915            PMIN(N) = PPN(N)                                                 90011750
  916            AN(N)   = PCY(N)                                                 90011760
  917            IF(PMAX(N).GT. T(1)) T(1)=PMAX(N)                                90011770
  918        520 CONTINUE                                                         90011780
  919            T(2) = CON(28)*FTU/T(1)/D(2)                                     90011790
  920            DO 525 N=1,NPT                                                   90011800
  921            PMAX(N) = PMAX(N)*T(2)                                           90011810
  922            PMIN(N) = PMIN(N)*T(2)                                           90011820
                                                                                  90011830
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11/02/73      INPUT LISTING                    AUTOFLOW CHART SET - SWEEP   FATIGUE MODULE
CARD NO       ****                CONTENTS                                 ****
  823          525  CONTINUE                                                90011840
  824               IF(IP(57))5009,5009,5010
  825          5009 WRITE(6,530) T(2)                                       90011850
  826          530  FORMAT(52HOSTRESS LEVELS SET UP FROM FUSELAGE PRESSURES TIMES .  90011860
  827               * 1E13.6 /// )                                          90011870
  828               WRITE(6,85) IN, FMAX(N), FMIN(N), AN(N), N=1,NPT )      90011880
  829          5010 CONTINUE
  830               K=3                                                     90011889
  831               CALL FATIQU                                             90011890
  832               IF(IFERR)590,600,590                                    90011900
  833          590  SAVE(KF+11)=SAVE(KF+10)                                 90011910
  834               GO TO 617                                               90011920
  835          600  T(1) = FMAX(NTOP)/FTU                                   90011930
  836          610  DO 615 I=132,257,25                                     90011940
  837               THD(I) = T(I)                                           90011950
  838          615  CONTINUE                                                90011960
  839               SAVE(KF+11)=T(1)                                        90011965
  840          C SET-UP FOR ENDURANCE LIMIT, MATERIAL SAME AS FOR FUS. PRESSURE  90011970
  841          617  NI=1                                                    90011980
  842               ANPT = D(1)                                             90011990
  843               NPT = 1                                                 90012000
  844               FMAX(1)=FTU/D(2)                                        90012010
  845               FMIN(1)=-FMAX(1)                                        90012020
  846               AN(1) = CON(29)                                         90012030
  847               FKT = CON(30)                                           90012031
  848               SF = D(1)                                               90012032
  849               IF(IP(57))5011,5011,5012
  850          5011 WRITE(6,620)                                            90012040
  851          620  FORMAT(/// 16HENDURANCE LIMIT  )                       90012050
  852               WRITE(6,85)  NPT, FMAX(1), FMIN(1), AN(1)               90012060
  853          5012 CONTINUE
  854               K=4                                                     90012069
  855               CALL FATIQU                                             90012070
  856               IF(IFERR) 650,660,650                                   90012080
  857          650  SAVE(KF+9)=SAVE(KF+8)                                   90012090
  858               GO TO 675                                               90012100
  859          660  T(1) = FMAX(1)/FTU                                      90012110
  860           665 DO 670 N=130,255,25                                      90012120
  861               THD(N) = T(1)                                           90012130
  862          670  CONTINUE                                                90012140
  863               SAVE(KF+9)=T(1)                                         90012150
  864          675  CONTINUE                                                90012160
  865               CALL WRITHS(1,THD(1),300,IF3)
  866          C
  867               IF(KF .NE. 0) GO TO 999                                 90012190
  868           800 IF(FFIND .EQ. D(24)) GO TO 999                          90012200
  869               IF(FFIND .EQ. FIND) GO TO 820                           90012210
  870               KF=5                                                    90012220
  871               IF3=FFIND                                               90012230
  872               IF(IF3) 802,802,801                                     90012240
  873           801 IF(IF3-NMATL) 503,503,802                               90012250
  874           802 IF3=1                                                   90012260
  875               WRITE(6,2013) FFIND, NMATL                              90012270
  876               GO TO 503                                               90012280
  877          C                    IF MAJOR FRAME AND COVER SAME MATERIAL  90012290
  878           820 DO 822 N=7,11                                           90012300
  879               SAVE(N+5)=S/AE(N)                                       90012310
  880           822 CONTINUE                                                90012320
  881          C                                                            90012330
  882           999 CONTINUE                                                90012340
  883          C                                                            90012350
  884          5013 WRITE(6,998) (SAVE(N),N=1,18)                           90012360
  885           998 FORMAT(1HI,5HCHANGES MADE TO MATERIAL PROPERTIES BY FATIQUE PROGR
                    *AM,43X,12H** FTOCTL **/
  887               1   / 15X,27HSIDE OF FUSELAGE ** MATL NO,F4.0/
  888               *  11X,21HTMOD(133) CHANGED FROM,F8.4,4H TO ,F8.4//
  889               *     18X,25HWING STATION 2 ** MATL NO,F4.0/
  890               *  11X,21HTMOD(134) CHANGED FROM,F8.4,4H TO ,F8.4//
  891               *     18X,25HFUSELAGE COVER ** MATL NO,F4.0/            90012430
  892               *  11X,21HTMOD(130) CHANGED FROM,F8.4,4H TO ,F8.4/      90012440
  893               *  11X,21HTMOD(132) CHANGED FROM,F8.4,4H TO ,F8.4//     90012450
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CARD NO	**** CONTENTS ****	
894	* 13X,31HFUSELAGE MINOR FRAME ** MATL NO,F4.0/	90012480
895	* 11X,21HTMOI(130) CHANGED FROM,F8.4,4H TO ,F8.4/	90012490
896	* 11X,21HTMOI(132) CHANGED FROM,F8.4,4H TO ,F8.4)	90012490
897	C	90012970
901	5014 RETURN	90012980
999	END	90012990

Section V

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