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CALCULATIONS OF THERMAL PERFORMANCE OF A BUILDING AND ITS AIR CONDITIONING PLANT BY HYBRID COMPUTER

BY

G. P. MITALAS

DBR COMPUTER PROGRAM NO. 21

OTTAWA

MAY 1965

CP 21

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The temperature of the air in an air conditioned room depends on the rate at which heat enters the room, the rate at which heat is removed from the room, and the heat storage capacity of the structure. The calculation of room air temperature or room cooling load is quite involved as the ambient conditions, the characteristics of the cooling plant and the characteristics of the structure must all be considered together. The calculation involves the solution of several equations, both algebraic and differential, that describe the performance of the cooling system and the structure. These equations can be solved quite readily by an electronic computer. This report describes the way that the NRC computer facilities have been used to make air conditioning design calculations.

Computer Facilities Available

The Analysis Section of the NRC Division of Mechanical Engineering has a Pace analogue computer, a Bendix G-15 digital computer, and an analogue-digital digital-analogue coupling unit that allows the two computers to be interconnected. These machines have been used for air conditioning design calculations. The coupled analogue-digital machine is particularly well suited for this type of calculation because the problem involves algebraic and differential equations. The analogue is best suited for solving the differential equations and the digital is superior at algebraic equations. The digital is also used to generate the ambient conditions that are the driving functions for the problem, and the results are recorded in digital form and finally typed by the typewriter associated with the digital machine.

Mathematical Model of the Thermal Energy Balance of a Room and an Air Conditioning Plant

The heat interchange within a room, the heat flow through a room envelope and the heat interchange between an outside wall and its environment, can be described by a set of linear algebraic equations:

$$C_{11}\theta_1 + C_{12}\theta_2 + \ldots + C_{1i}\theta_i + \ldots = K_1 I_1$$

$$C_{j1}\theta_1 + C_{j2}\theta_2 + \ldots + C_{ji}\theta_i + \ldots = K_j I_j \qquad \ldots (1)$$

and by a set of differential equations:

$$\dot{\theta}_i = D_{i-1}\theta_{i-1} + D_{i+1}\theta_{i+1} - D_i\theta_i \qquad \ldots (2)$$

(Ref. 1)

where

C_{ji}, K_i and D_i are coefficients

θ_i = room envelope inner surface temperature

I_j = time dependent variable (i.e. solar radiation, outside air temperature, etc.).

The number of equations in a set is governed by the number and the construction of room envelope components. A room thermal response can be described by approximately ten differential and ten linear algebraic equations.

The room air temperature is given by:

$$\theta_R = \theta_R^* + 0.5\,(\Delta\theta_R + |\Delta\theta_R|) \qquad \ldots (3)$$

where

$$\Delta\theta_R = \int_o^t (C_1\theta_1 + C_2\theta_2 + \ldots - \Sigma_i C_i\theta_R + Q)\,dt - \theta_R^*$$

(Ref. 1)

θ_R = room air temperature

Q = heat addition or extraction

θ_R^* = minimum allowable room air temperature (i.e. thermostat setting).

The continuous solution of the above equations is possible using the three basic analogue circuits given in Figure 1.

The mechanical equipment to control the inside climate in large buildings usually consists of:

(a) chiller

(b) primary air unit

(c) secondary water coils.

Figure 2 is a schematic diagram of this equipment and the room.

The chiller cooling water outlet temperature, at constant water flows and compressor speed, depends on the cooling water inlet temperature and the outside air wet-bulb temperature, and is given by:

$$\theta_{WO} = \theta^*_{WO} + 0.5\,(\Delta\theta_{WO} + |\Delta\theta_{WO}|) \qquad \ldots (4)$$

where

$$\Delta\theta_{WO} = A_1 + A_2\theta_{W\,in} + A_3\theta^2_{W\,in} - \theta^*_{WO}$$

$\theta_{W\,in}$ = inlet cooling water temperature (°F)

θ_{WO} = outlet cooling water temperature (°F)

$A_1 = (a_1 + b_1\,\theta_{WB})$ °F

$A_2 = (a_2 + b_2\,\theta_{WB})$

$A_3 = (a_3 + b_3\,\theta_{WB})$ 1/°F

a and b = constants that are functions of the particular chiller design

θ^*_{WO} = minimum allowable outlet cooling water temperature (°F).

The maximum heat extraction -- per square foot of nominal face area by the primary air unit at the design air and water flows -- is a function of the temperature of the chilled water entering this unit, θ_{WO}; of the inlet air dry bulb, θ_{DB}; and of the inlet air dew-point, θ_{DP}, temperatures. It is given by one of the three following expressions depending on $(\theta_{DP} - \theta_{WO})$ difference:

$$(\theta_{DP} - \theta_{WO}) > 10$$

$$Q_P = c + d(\theta_{DB} - \theta_{WO}) + e(\theta_{DP} - \theta_{WO} - 10)$$

$$10 > (\theta_{DP} - \theta_{WO}) > 0$$

$$Q_P = c + d(\theta_{DB} - \theta_{WO}) + f - g(\theta_{DB} - \theta_{WO})(\theta_{DP} - \theta_{WO} - 10)$$

$$(\theta_{DP} - \theta_{WO}) < 0$$

$$Q_P = m(\theta_{DB} - \theta_{WO})$$

where

c, d, e, f, g and m are constants that are functions of the particular primary air unit design. The temperatures are in °F and Q_P is in Btu/hr ft^2.

The enthalpy of the outlet air is given by:

$$E_o = E_{in} - (Q_P)/(\dot{M}_a)$$

where

E_{in} = enthalpy of outside air (inlet air to primary air unit) (Btu)/(lb of air)

$\dot{M}_a$ = mass flow rate of air through primary air unit (lb)/(hr ft^2).

If it is assumed that the outlet air is saturated, which is a reasonable assumption for a unit with four or more rows of sprayed coils, the outlet air temperature is given by the following equation:

$$\theta_{oa} = (-2.69 + 3.51\, E_o - 0.0518\, E_o^{\,2} + 0.000333\, E_o^{\,3})\ ^\circ F.$$

The heat extraction by the secondary coils is:

$$Q_I = U\,(\theta_R - \theta_{WI})\ (Btu)/(hr)$$

where

U = constant which depends on the particular coil design and water and air flow rates.

θ_{WI} = inlet water temperature to the secondary coil, °F

$= \theta_{WO} + (Q_P)/(X M_W)$

θ_R = room air temperature, °F

X = bypass factor, i.e. the ratio of cooling water flow through the chiller to the cooling water flow through the primary air unit

M_W = water flow rate through the primary air unit, (lb)/(hr ft^2).

The sensible cooling of room air by secondary coils and primary air is:

$$Q = Q_I + 0.24 M_a S (\theta_R - \theta_{oa}) \text{ (Btu)/(hr)}$$

where

S = primary air unit coil nominal face area allocated for this room, ft^2.

The cooling water temperature entering the chiller is:

$$\theta_{W\,in} = (Q_I)/(M_W) + \theta_{WI}.$$

The equations describing the heat balance in the room and the cooling plant must be solved simultaneously because of the interdependence of room air temperature and heat extraction by secondary coils. The solution of this set of equations on a hybrid computer is not a straightforward operation because of the operational difference of the two computers; the digital computer samples the analogue voltages representing $\theta_{W\,in}$ and θ_R at the time, t_s. Using these sampled values it calculates $(\theta_{oa})t_s$ and $(\theta_{WI})t_s$ but the calculations require a small time interval, and therefore the values $(\theta_{oa})t_s$ and $(\theta_{WI})t_s$ are "late". This difficulty can be overcome by noting that the driving functions are periodic with 24-hr period, and that only the periodic steady state conditions are of interest. Therefore, the values $(\theta_{oa})t_s$ and $(\theta_{WI})t_s$

calculated for the time, t_s, are stored in the computer memory and held there until the time, t_s + 24 hr. At this time the values are transmitted to the analogue computer.

Hybrid Computer

The hybrid computer at the Division of Mechanical Engineering, NRC, used for these calculations is made up of:

(a) a Bendix G-15 digital computer, two magnetic tape units, a typewriter, punched paper tape reader and punch.

(b) a Pace 131R electronic analogue computer made up basically of 96 amplifiers, 160 potentiometers, 4 relay amplifiers, digital voltmeters and an analogue recorder.

(c) an Epsco addaverter with an 8 D-A (digital to analogue) and an 8 A-D (analogue to digital) channel capacity.

The D-A converter accepts 12 binary bits with sign, accuracy ± 0.5 bits or 0.02 per cent over the working range of ± 10 volts and the time for conversion ≈ 0.1 ms.

The A-D converter gives 12 binary bits with sign, accuracy ± 2 bits, i.e. 0.1 per cent and time for conversion of 8 channels ≈ 2 ms.

The interval between the conversions can be controlled by the addaverter clock or by the Bendix G-15.

Operation Procedure

The procedure for the solution of the equations describing the room thermal performance and the air conditioning plant can be divided into four major steps:

(1) Preparation of the driving functions

(2) Setting up and checking the analogue circuit

(3) Solution of the equations on the hybrid computer

(4) Tabulation of results.

Preparation of the Driving Functions

The driving functions are calculated by "A Program to Calculate Design Data for Air Conditioning Calculations". This program is designed to calculate various weather parameters from the basic data, to store these in memory and to punch them on paper tape. The detailed description and operational procedure of this program are given in Ref. 2.

The punched paper tape produced by this program is not directly usable as an input for the "Running Program" which is described in the following sections. The numbers listed on the punched paper tape must be converted to the special format acceptable by the D-A converter. The "Driving Function Conversion Program" was written to convert the numbers to the required format, to calculate A_1, A_2, and A_3 constants and to store these on magnetic tape. The detailed description of this program and its operational procedure are given in Appendix I.

Setting Up and Checking of the Analogue Circuit

The method and the detailed description of how to set up an analogue circuit is given by G. P. Mitalas et al (1). Before this circuit is used, it is desirable to check the circuit and the settings of the potentiometers. This can be done simply by noting that:

(a) the temperatures of the room envelope and the room air at steady state conditions must be equal to the temperature at the outside surface of the room envelope, when the other inputs are zero;

(b) the heat extracted from the room air must be equal to the solar radiation input to the room, when the heat flow through the room envelope and the internal heat sources are zero.

Once these verifications are carried out it is reasonable to assume that the analogue circuit and the potentiometer settings are correct and that the analogue circuit components are functioning correctly.

Procedure for Operating the Hybrid Computer

(1) Mount the magnetic tape containing the driving functions on the magnetic tape unit No. 0.

(2) Mount a reel of blank magnetic tape on tape unit No. 1.

(3) Set the addaverter controls:

a) channel capacity = 8

b) channel 8 on "Data" channel

c) time on clock = 1.2 sec.

(4) Load "Running Program" (the description of this program and its operational procedure are given in Appendix II), search the magnetic tape for the required driving functions, and load this set into the computer.

(5) Turn on the analogue recorder and set the analogue computer in operating mode. This puts the hybrid computer in operation.

(6) The heat extraction from the room air can be varied by:

a) a change in bypass factor, X

b) a change in primary air unit coil nominal face area, S

c) a change in constant, U.

(7) The strip chart record of the analogue voltages indicates if the solution is proceeding satisfactorily, and it also indicates when the periodic steady state conditions are reached.

(8) When these latter conditions are reached, the results of this calculation, the driving functions used, and the several constants are recorded on the magnetic tape on unit No. 1. The procedure for this is given in Appendix II.

Tabulation of Results

The "Tabulation Program" was written to type the recorded results from the magnetic tape. This program also performs a limited amount of calculations to present the results in a more comprehensive form. The description of this program and its operational procedure are given in Appendix III.

Acknowledgement

The author wishes to acknowledge the assistance of Mr. G. P, Van Blockland of NRC Mechanical Engineering Division, Analysis Section, who prepared the programs described in Appendices I and II.

References

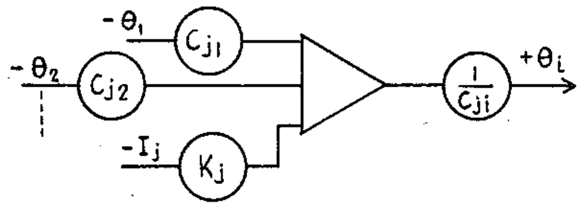
1. Mitalas, G. P., D. G. Stephenson and D. C. Baxter. Use of An Analog Computer for Room Air-conditioning Calculations. Research Paper No. 114 of the Division of Building Research, Ottawa, December 1960 (NRC 6099).

2. Mitalas, G. P. A Program to Calculate Design Data for Air Conditioning Calculations. National Research Council, Division of Building Research, DBR Computer Program No. 20, January 1965.

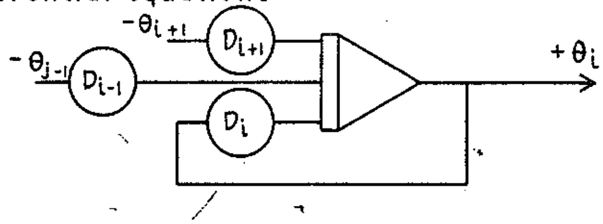
FIGURE 1

ANALOGUE CIRCUIT FOR THE SOLUTION OF

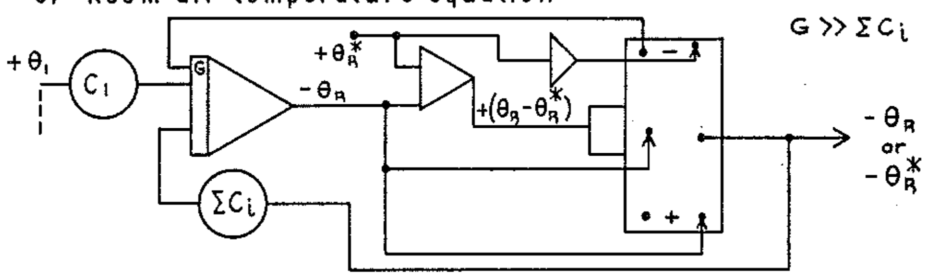
a) Linear algebraic equations



b) Ordinary differential equations

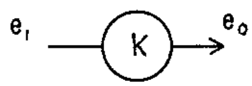


c) Room air temperature equation



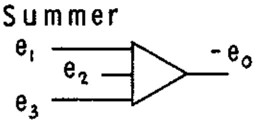
Where

Potentiometer



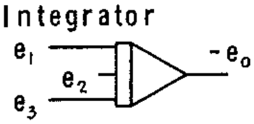
$e_0 = Ke_1$
$K \leqslant 1.$

Summer



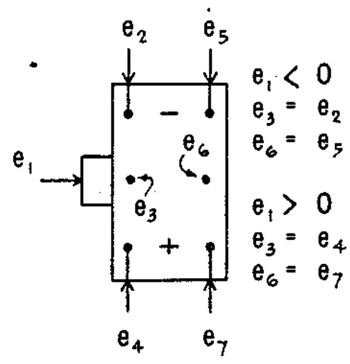
$-e_0 = e_1 + e_2 + e_3$

Integrator



$-e_0 = \int_0^t (e_1 + e_2 + e_3)\, dt$

Relay amplifier



C? 3373-1

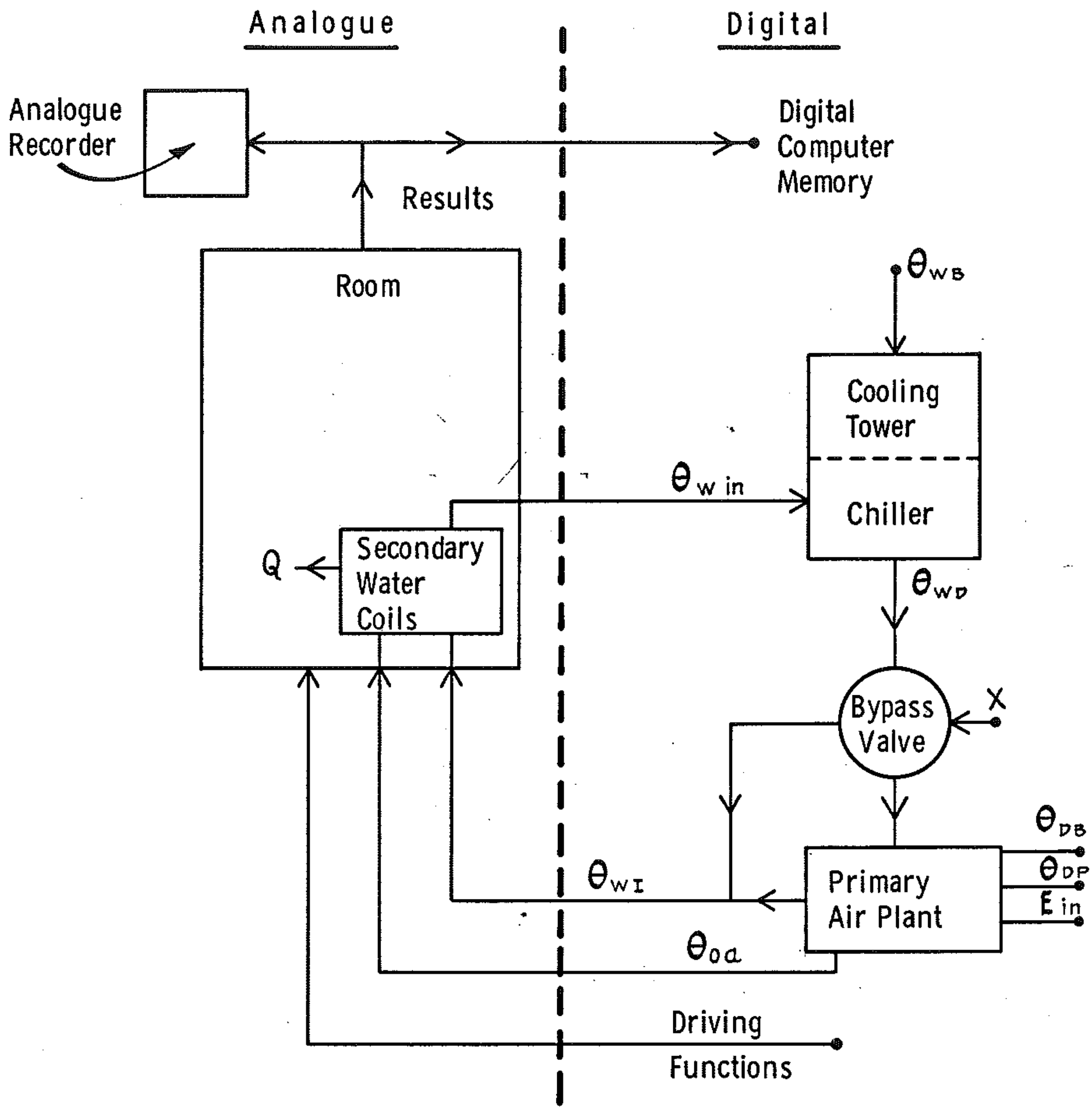


FIGURE 2

SCHEMATIC DIAGRAM OF AIR CONDITIONING PLANT AND ROOM

AR 3373-2

APPENDIX I

CONVERSION PROGRAM

by

G. P. Van Blockland

The driving functions on the punched paper tape generated by the "Program to Calculate Design Data for Air Conditioning Calculations" (2) cannot be used directly as an input to the "Running Program", as the numbers for this program must be specially-scaled machine language numbers. Therefore, this program was written to perform the following operations:

(a) to read punched paper tape prepared by the "Program to Calculate Design Data for Air Conditioning Calculations",

(b) to convert these data to machine language numbers and to shift some of these numbers to the 13 least significant bits of the 29 bit word (this is the number format acceptable by the D-A converter),

(c) to arrange the converted numbers in arrays in such a way that they are easily available for transmission to the D-A converter by the "Running Program",

(d) to calculate A_1, A_2 and A_3 coefficients (A's are defined on page 3) to store the converted numbers and the coefficients in one file on magnetic tape.

Input

All the input is by punched paper tape except the provision by which the driving function set number No can be entered by typewriter. The order of the data on punched paper tape is given in Appendix I. The first paper tape channel read is stored in line 06, the second in 07 and the third in 08.

Arithmetic Operations

This program calculates scaled A_1, A_2 and A_3 coefficients.

$$\frac{A_1}{200} = \frac{1}{200}(a_1 + b_2\ \theta_{WB})$$

$$A_2 = a_2 + b_2\ \theta_{WB}$$

$$200\ A_3 = 200\ (a_3 + b_3\ \theta_{WB})$$

Locations of Constants

0109 - $a_1/200$

0115 - $b_1/200$

0127 - a_2

0114 - b_2

0132 - $200\ a_3$

0135 - $200\ b_3$

Output

The converted numbers and A_1, A_2 and A_3 coefficients are stored in one file on magnetic tape in the following order:

First line = copy of computer memory line 09

Word location	Data
96-4t	$A_1/200$
97-4t	$A_2 + L\ 10^{-5}\ 2^{-16}$
98-4t	$200\ A_3$

96	No/1000
97	S/100
98	$A_g/1000$
99	H/10

Second line = copy of computer memory line 10

96-4t	$\theta_{DP} \times 1/200$
97-4t	$\theta_{DB} \times 1/200$
98-4t	$E \times 1/100$
99-4t	$I_1 \times 1/100 \times 2^{-16}$
96	$A_W/100$
97	No/1000

Third line = copy of computer memory line 11

96-4t	$I_{TD} \times 1/100 \times 2^{-16}$
97-4t	$\theta_W \times 1/200 \times 2^{-16}$
98-4t	$\theta_g \times 1/200 \times 2^{-16}$
99-4t	$I_T \times 1/500 \times 2^{-16}$

where t = 1(1)24.

Memory Allocations

Lines 00, 01, 02, 03 and 04 are used for program and word location.

20:00	mask
20:01	θ_{WB} x 1/100
20:02	T for pickup
20:03	T for storing
21:00	number to be extracted
21:01	scale factor
22:00	temporary storage
22:01	temporary storage
22:02	temporary storage
22:03	temporary storage.

Operation Instructions

1. Mount magnetic tape containing driving functions on magnetic tape unit No. 0. Position the reading-writing head in the blank tape past the last information block.

2. Load the "Driving Function Conversion Program". Enable ON, type P; after the first block has been read, compute GO.

3. Mount input data tape (output of the "Program to Calculate Design Data for Air Conditioning Calculations") on photo reader.

4. Start the program. Enable ON, type (s) cf, compute GO.

5. Three blocks of paper tape containing the driving functions will be read. These functions will be converted and written on magnetic tape.

The program halts automatically as soon as all the input data tape is read and processed.

6. The driving function set number can be changed by the following procedure:

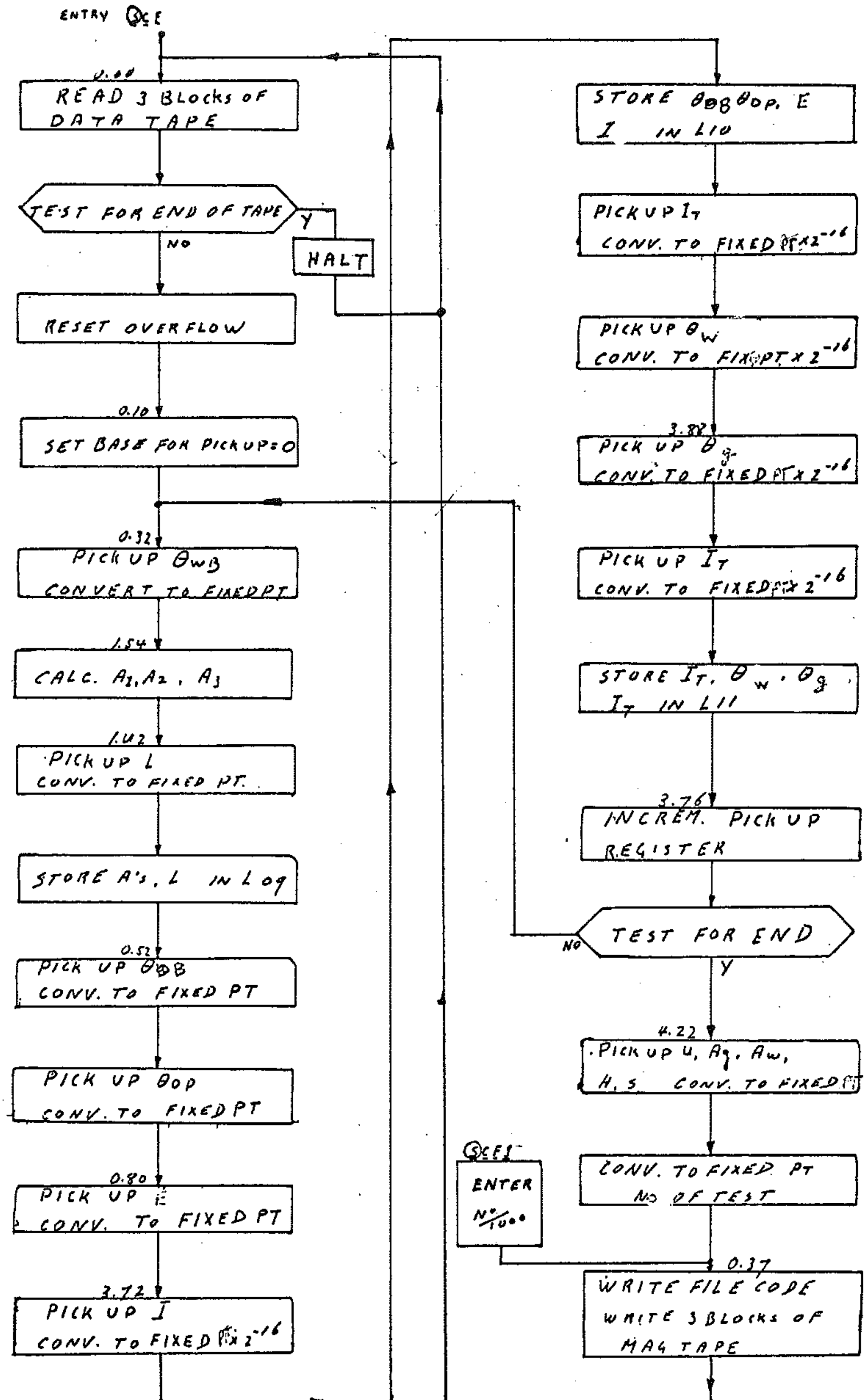
(a) compute switch to BP while the computer is in the process of reading punched paper tape

(b) when all of the three blocks are read, computer halts

(c) Enable ON, type Ⓢ cf, compute GO. Type No x 1/1000 in seven-decimal digit format, e.g. No = 5, type 0050000 tab Ⓢ .

The number No read from the punched paper tape is replaced by the number entered by the typewriter.

FLOW CHART CONVERSION PROGRAM



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G-15D

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Page ___ of ___

Date: ________

Line 00

PROGRAM PROBLEM: CONVERSION PROGRAM

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
00		04	11	0	00	28		00.04 → AR
04		00	00	1	00			256
11		13	17	0	15	31		READ TAPE
17		19	06	0	28	31		TR
06		08	18	7	28	28		NOT READY DAR
18		19	30	0	28	27	/	TNZ AR
30		32	50	0	00	31		=0 SET READY
50		52	00	0	16	31		HALT NC=00
31		33	17	0	01	01		≠0 NC=17
07	u	08	25	0	19	06		READY L19 → L06
25		27	08	0	29	31		} RESET OVERFLOW
08		10	09	0	01	01		
09		11	14	0	15	31		READ TAPE
14		14	14	0	28	31		TR
15	u	16	20	0	19	07		L19 → L07
20		22	22	0	15	31		READ TAPE
22		22	22	0	28	31		TR
21	u	24	26	0	19	08		L19 → L08
26	u	27	54	0	29	09		CLR L09
54	u	55	69	0	29	10		CLR L10
69	u	70	10	0	29	11		CLR L11

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G-15D Prepared by *G V B* Page __ of __

PROGRAM PROBLEM: *CONV. PROG.* Date: ____

Line *00*

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
10		27	29	0	00	20		$T_1 \to 20.03$
Z27		64	00	0	00			100
29		30	45	0	29	20		CLR 20.02
45		97	32	0	00	01		00.97 → 01.97
97	[	99	98	0	20	31	]	R.M.P. IN L00
32		34	40	0	20	28		20.02 → AR
40		41	44	0	00	29		SKEL. $\xrightarrow{+}$ AR
41	[	72	48	0	06	28	]	[06.72 → AR]
44		46	46	0	31	31		NCAR
48		49	51	0	00	21		SCALE FACTOR → 21.01
Z49		00	w8	0	00			100×2^{-15}
51	w	53	54	1	21	31		TRA TO 01.54 CONV. TO FL.P.
54	w	63	08	1	21	31		TRA TO 01.08 CALC. A's
63		66	67	0	20	28		20.02 → AR
67		73	79	0	00	29		SKEL. $\xrightarrow{+}$ AR
73	[	72	u2	0	08	28	]	[08.72 → AR]
79		81	81	0	31	31		NCAR
u2		u5	05	0	00	21		SCALE FACTOR → 21.01
Zu5		ZZ	ZZ	Z	ZZ			1
05	w	87	54	1	21	31		TRA TO 01.54 CONV. TO FL.P.
87		89	59	0	28	25		AR → ID

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Page ___ of ___
Date: ________
Line 00

G-15D
PROGRAM PROBLEM: CONV. PROG.
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Addresses	L	P	T	N	C	S	D	B	NOTES
0 1 2 3									
4 5 6 7									
8 9 10 11	59		38	98	1	26	31		IDR 19
12 13 14 15	98		u0	u1	0	29	25		CLR ID_0
16 17 18 19	u3		52	92	1	26	31		IDR 26
20 21 22 23									
24 25 26 27	92		93	u1	0	22	28		A_2 → AR
28 29 30 31	u1		44	33	0	28	20		AR → 20.00
32 33 34 35	33		36	38	0	00	21	/	MASK → 21.00
36 37 38 39	Z36		ZZ	ZZ	0	00	-		
40 41 42 43	38		40	43	0	31	28		EXTRACTED N° → AR
44 45 46 47	43		44	46	0	25	29		ID_0 +→ AR
48 49 50 51	46		49	02	0	28	22		AR → 22.01
52 53 54 55									
56 57 58 59	02		11	12	0	20	28		T_3 → AR ↑
60 61 62 63	12		13	16	3	00	29		00.13 −→ AR DECREMENT
64 65 66 67	Z13		04	00	0	00			AT T_3
68 69 70 71	16		19	21	0	28	20		AR → 20.03 ↓
72 73 74 75	21		24	28	0	00	29		SKEL +→ AR
76 77 78 79	24	[u	00	52	0	22	09]		[L22 → L09] STORE A's, L_I
80 81 82 83	28		30	u6	0	31	31		NCAR
84 85 86 87									
88 89 90 91	52		54	56	0	20	28		20.02 → AR ↑
92 93 94 95	56		57	60	0	00	29		SKEL +→ AR CONV. 08B
96 97 98 99	60		62	62	0	31	31		N[illegible]AR
u0 u1 u2 u3	57	[	24	64	0	06	28]		[06.-- → AR]
u4 u5 u6	64		65	68	0	00	21		S.F → 21.01 ↓

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G-15 D
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68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
U0	U1	U2	U3
U4	U5	U6	

L	P	T	N	C	S	D	B	NOTES
Z65		019	00	0	0			200×2^{-15}
68	w	62	54	1	21	31		TRA TO 01.54 CONV. TO FL PT
62		65	66	0	28	22		AR → 22.01
66		70	74	0	20	28		Tp → AR
74		75	78	0	00	29		SKEL. +→ AR
75	[	48	58	0	06	28	]	[06.-- → AR]
78		80	80	0	31	31		NCAR
58		65	72	0	00	21		SCALE FR → 21.01
Z65		019	00	0	0			200×2^{-15}
72	w	76	54	1	21	31		TRA TO 01.54 CONV. TO FL PT
76		80	80	0	28	22		AR → 22.00
80		82	84	0	20	28		Tp → AR
84		85	88	0	00	29		SKEL +→ AR
85	[	00	42	0	07	28	]	[07.-- → AR]
88		90	90	0	31	31		NCAR
42		49	94	0	00	21		S.F. → 21.01
Z49		00	w8	0	00			100×2^{-15}
94	w	96	54	1	21	31		TRA TO 01.54 CONV TO FL PT
96		98	40	0	28	22		AR → 22.02
u0		42	72	3	21	31		TRA TO 03.72

CONV. 00B

CONV. 00P

CONV. E

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68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
								RETURN FROM L04
37		42	61	0	30	31		WRITE FILE CODE
61	w	70	87	4	21	31		TRA TO WRITE LEADER
70	u	71	71	0	09	19		L09 → L19
71	w	77	76	4	21	31		TRA TO WMT
77	u	78	81	0	10	19		L10 → L19
81	u	83	76	4	21	31		TRA TO WMT
82	u	83	86	0	11	19		L11 → L19
86	w	91	76	4	21	31		TRA TO WMT
91		93	00	0	01	01		NC = 00

WRITE MAG. TAPE

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80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
08		09	10	0	28	20		AR → 20.01 Awb
10		13	14	0	20	25		20.01 → ID.
14		15	17	0	01	24		C → MQ.
Z15		00	yu	9	y7			·00358
17		56	02	0	24	31		MULTIPLY
02		03	04	0	26	28		PN. → AR
04		05	07	1	28	28		AR -→ AR
07		09	11	1	01	29		C +→ AR
Z09		-.	02	3	x7	0v		−·00875
11		12	16	1	28	22		AR → 22.00
16		17	18	0	20	25		20.01 → ID.
18		19	21	0	01	24		C → MQ.
Z19		23	x7	0	u3			·14
21		56	22	0	24	31		MULTIPLY
22		23	24	0	26	28		PN. → AR
24		25	26	1	28	28		AR → AR
26		27	28	1	01	29		C +→ AR
27		V3	3 3	3	3 3			·700
28		29	30	1	28	22		AR → 22.01
30		33	34	0	20	25		20.01 → ID.
34		35	37	0	01	24		C → MQ.
35	-	1V	7x	9	0z			−·1074
37		56	25	0	24	31		MULTIPLY

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				L	P	T	N	C	S	D	B	NOTES
0	1	2	3									
4	5	6	7									
8	9	10	11	25		27	29	0	26	28		PN. → AR
12	13	14	15	29		30	31	1	28	28		AR —1→ AR
16	17	18	19	31		32	33	1	01	29		C —+→ AR
20	21	22	23	Z32		36	W8	V	43			·214
24	25	26	27	33		34	97	1	28	22		AR → 22.02 A_3
28	29	30	31	97		99	98	0	20	31		RMP IN LO .
32	33	34	35								/	
36	37	38	39	40		43	44	0	23	31		CLR 2WR
40	41	42	43	44		45	47	0	28	25		AR → ID.
44	45	46	47	47		32	88	1	26	31		ID R 16
48	49	50	51	88		89	97	0	25	28		ID. → AR
52	53	54	55	97								RMP
56	57	58	59									
60	61	62	63	54		56	57	0	28	21		AR → 21.00
64	65	66	67	57		60	61	0	01	20		MASK → 20.00
68	69	70	71	Z60	·	ZZ	ZZ	Z	0	0		
72	73	74	75	61		64	64	0	23	31		CLR
76	77	78	79	64		68	69	3	30	28		$\overline{20}$ · 21 —−→ AR_c
80	81	82	83	69		70	71	1	01	29		EXPONENT —+→ AR
84	85	86	87	Z70		00	00	0	71			SCALE FACTOR
88	89	90	91	71		72	73	0	31	25		20·21 → ID.
92	93	94	95	73		56	75	0	26	31		SHIFT UNDER AR
96	97	98	99	75		76	77	0	30	28		$\overline{20}$·21 → AR
u0	u1	u2	u3	77		78	79	3	01	29		01.78 —−→ AR
u4	u5	u6		Z78		00	00	0	ZZ			EXP FOR NO = 0

SHIFT 16 BITS TO RIGHT

- CONVERT TO FIXED POINT

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Line 01

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60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
79		80	81	0	28	29		TNZ AR
81		82	97	0	29	28		= 0 CLEAR AR
82		84	86	0	25	28		≠ 0 $ID_0 \rightarrow AR$
86		89	90	0	21	25		SCALE FACTOR $21.01 \rightarrow ID_1$
90		91	93	0	28	26		$AR \rightarrow PN_1$
93		57	95	1	25	31		DIVIDE
95		96	97	0	20	31		RMP IN L0

CONVERT TO FIXED POINT

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48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
00		02	26	0	21	31		TRA TO 00.26
72		97	24	0	03	01		03.97 → 01.97
97	[	99	98	3	20	31	]	[RMP IN L3]
24		26	28	0	20	28		20.02 → AR
28		29	32	0	03	29		SKEL. +→ AR
29	[	00	36	0	08	28	]	[08.00 → AR]
32		34	34	0	31	31		NCAR
36		49	68	0	00	21		SCALE FACTOR → 21.01
00.49								100/512
68	w	73	54	1	21	31		TRA TO 01.54
73	w	77	40	1	21	31		TRA TO 01.40
77		79	86	0	28	22		AR → 22.03
86		87	89	0	20	28		20.03 → AR
89		09	10	0	03	29		SKEL +→ AR
09	[4	00	98	0	22	10	]	[L22 → L10]
10		12	46	0	31	31		NCAR
98		42	04	0	20	28		20.02 → AR
04		05	08	0	03	29		SKEL +→ AR
05	[	48	12	0	08	28	]	[08.xx → AR]
08		10	10	0	31	31		NCAR

PICK UP, PROCESS

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Line 03

				L	P	T	N	C	S	D	B	NOTES
0	1	2	3									
4	5	6	7	12		65	78	0	00	21		SCALE FACTOR → 21.01
8	9	10	11	78	w	85	54	1	21	31		TRA TO 01.54 CONV. TO FL. PT (I TO 100)
12	13	14	15	85	w	21	40	1	21	31		TRA TO 01.40 $\times 2^{-16}$
16	17	18	19	21	w	23	26	2	28	29		ARL 7
20	21	22	23	26		28	49	0	28	22		AR → 22.00
24	25	26	27									
28	29	30	31	49		50	54	0	20	28		20.02 → AR
32	33	34	35	54		55	58	2	03	29		SKEL $\xrightarrow{+}$ AR
36	37	38	39	55	[	72	80	0	07	28	]	[07.xx → AR]
40	41	42	43	58		60	60	0	31	31		NCAR
44	45	46	47	80	w	83	54	1	21	31		TRA TO CONV.
48	49	50	51	83	w	30	40	1	21	31		TRA TO 2^{-16}
52	53	54	55	30		43	62	3	03	29		03.43 $\xrightarrow{-}$ AR
56	57	58	59	43		0000	600					$\frac{75°}{200} \times 2^{-16}$
60	61	62	63	62		65	88	1	28	22		AR → 22.01
64	65	66	67									
68	69	70	71	88		90	92	0	20	28		T_P → AR.
72	73	74	75	92		93	96	0	03	29		SKEL. $\xrightarrow{+}$ AR
76	77	78	79	93	[	48	40	0	07	28	]	[07.xx → AR]
80	81	82	83	96		98	98	0	31	31		NCAR
84	85	86	87	40	w	42	54	1	21	31		CONV. TO FL. PT.
88	89	90	91	42	w	33	40	1	21	31		$\times 2^{-16}$
92	93	94	95	33		43	87	3	03	29		BIAS $\xrightarrow{-}$ AR
96	97	98	99	87		90	07	1	28	22		AR → 22.02 $\frac{\theta_3}{200}$
u0	u1	u2	u3									
u4	u5	u6		07		10	14	0	20	28		T_P → AR

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				L	P	T	N	C	S	D	B	NOTES
0	1	2	3									
4	5	6	7	14		15	18	0	03	29		SKEL. $\xrightarrow{+}$ AR
8	9	10	11	15	[	24 (25)	52	0	08	28	]	[08.xx → AR]
12	13	14	15	18		20	20	0	31	31		NCAR
16	17	18	19	52		53	56	0	03	21		SCALE FACTOR → 21.01
20	21	22	23	Z 53		03	y8	0	00			500×2^{-15}
24	25	26	27	56	w	74	54	1	21	31		CONV. TO FL. PT.
28	29	30	31	74	w	79	40	1	21	31		$\times 2^{-16}$
32	33	34	35	79		83	57	0	28	22		AR → 22.03 I_T
36	37	38	39									
40	41	42	43	57		63	66	0	20	28		T_3 20.03 → AR
44	45	46	47	66		67	70	0	03	29		SKEL $\xrightarrow{+}$ AR
48	49	50	51	67	[u	00	76	0	22	11	]	[L22 → L11]
52	53	54	55	70		72	u6	0	31	31		NCAR
56	57	58	59									
60	61	62	63	76		78	81	0	20	28		T_P → AR
64	65	66	67	81		82	84	0	03	29		$4T_P \xrightarrow{+}$ AR
68	69	70	71	Z 82		01	00	0	00			1
72	73	74	75	84		86	90	0	28	20		T_P → 20.02
76	77	78	79									
80	81	82	83	90		91	94	3	03	29		$T_{P_{MAX}} \xrightarrow{-}$ AR
84	85	86	87	Z 91		18	00	0	00			24
88	89	90	91	94		95	16	0	28	27		TNZ AR
92	93	94	95									
96	97	98	99	17		19	37	0	21	31		≠ 0 TRA TO 00.37
u0	u1	u2	u3	16		18	72	4	21	31		= 0 TRA TO 04.72
u4	u5	u6										

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				L	P	T	N	C	S	D	B	NOTES
0	1	2	3									
4	5	6	7									
8	9	10	11	72		97	22	0	04	01		04.97 → 01.97
12	13	14	15	97	[	99	98	4	20	31	]	[RMP IN L04]
16	17	18	19									
20	21	22	23	22		96	u1	0	06	28		u → AR
24	25	26	27	u1		13	19	0	04	21		SCALE FACTOR → 21.01
28	29	30	31	Z13		0	Z4	0	00	0		2000×2^{-15}
32	33	34	35	19	w	25	54	1	21	31	✓	TRA TO 01.54
36	37	38	39	25		u3	u5	0	28	09		AR → 09.u3 $\frac{u}{2000}$
40	41	42	43									
44	45	46	47	u5		98	26	0	06	28		A_G → AR
48	49	50	51	26		37	40	0	04	21		SCALE FACTOR → 21.01
52	53	54	55	Z37		07	X0	0	00			1000×2^{-15}
56	57	58	59	40	w	50	54	1	21	31		CONV. TO FL. PT
60	61	62	63	50		98	65	0	28	09		AR → 09.98 $\frac{A_G}{1000}$
64	65	66	67									
68	69	70	71	65		96	34	0	07	28		A_w → AR
72	73	74	75	34	w	44	54	1	21	31		CONV. TO FL. PT
76	77	78	79	44		96	11	0	28	10		$\frac{A_w}{1000}$ → 10.96
80	81	82	83									
84	85	86	87	11		97	35	0	07	28		N° → AR
88	89	90	91	35	w	74	54	1	21	31		CONV. TO FL. PT.
92	93	94	95	74		97	99	0	28	10		$\frac{N°}{1000}$ → 10.97
96	97	98	99	99		96	08	0	28	09		$\frac{N°}{1000}$ → 09.96
u0	u1	u2	u3									
u4	u5	u6		08		98	10	0	07	28		A_F → AR

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52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
10	w	21	54	1	21	31		CONV. TO FL. PT.
21		98	23	0	28	10		AR → 10.98 $\frac{AF}{1000}$
23		99	31	0	06	28		H → AR
31		41	46	0	04	21		SCALE FACTOR → 21.01
41		00	14	0	00			10×2^{-15}
46	w	48	54	1	21	31		CONV. TO FL. PT
48		99	71	0	28	09		$\frac{H}{10}$ → 09.99
71		97	07	0	06	28		S → AR
07		45	47	0	04	21		SCALE FACTOR → 21.01
45		00	0u	0	00			5×2^{-15}
47	w	51	54	1	21	31		CONV. TO FL. PT.
51		97	27	0	28	09		$\frac{S}{S}$ → 09.97
27		29	57	0	28	25		$\frac{S}{S}$ → ID1
57		63	69	0	04	24		C → MQ1
63		87	u4	1	47			·530 $\frac{MA}{1000}$ × .24
69		56	79	0	24	31		MULTIPLY
79		41	42	0	26	09		PN1 → 09.41 $\frac{S}{S} \times \frac{MA}{1000} \times .24$
42		97	38	0	09	25		$\frac{S}{S}$ → ID1
38		39	43	0	04	24		$\frac{Mw}{3000}$ → MQ1
39		X8	27	5	25			·8131
43		56	u3	0	24	31		MULTIPLY
u3		u5	u6	0	26	09		$\frac{Mw}{3000} \times \frac{S}{S}$ → 09.u5

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20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
46		00	20	4	04	02		04.01.02 → L02
00		04	00	0	00			PUNCH
01		00	00	0	00			FORMAT
20		02	32	4	04	02		04.03.04 → L02
02		00	00	0	00			PUNCH
03		80	00	0	00			FORMAT
32		34	37	0	21	31	/	TRA TO 00.37
76		u4	77	0	29	19		CLEAR 19.u4
77		78	80	0	29	28		CLEAR AR
80	u	81	81	1	19	29		L19 $\xrightarrow{+}$ AR
81	u	85	84	3	28	28		INVERT AR
84		u4	85	0	28	19		BALANCER → u4
85	w	00	86	0	01	31		WMT UNIT 0
86		86	86	0	28	31		T.R.
87		u1	92	0	05	31		SEARCH MAG TAPE
92		91	90	0	01	01		WAIT
90		89	89	0	01	01		WAIT
89		92	93	0	00	31		SET READY
93		95	94	0	20	31		RMP IN L0

WRITE MAG TAPE SUB ROUTINE

WRITE LEADER

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G-15D

PROGRAM PROBLEM: LOADER CONVERSION PROGRAM.

Prepared by GVB

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Line 04

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	.

L	P	T	N	C	S	D	B	NOTES
00	u	01	01	0	19	04		L19 → L04
01		03	06	4	21	31		TRA TO 04.06
06	w	08	09	4	21	31		TRA TO SUBROUT.
08	u	09	20	0	19	02		L19 → L02
20		22	09	4	21	31		TO READ TAPE
21	u	22	22	0	19	00	/	L19 → L00
22		24	09	4	21	31		TO READ TAPE
23	u	24	24	0	19	01		L19 → L01
24		26	09	4	21	31		TO READ TAPE
25	u	26	26	0	19	03		L19 → L03
26		28	09	4	21	31		TO READ TAPE
27	u	28	00	0	19	04		L19 → L04
09	u	10	10	0	29	19		CLR L19
10		12	12	0	15	31		READ TAPE
12		12	12	0	28	31		TR
13		14	15	0	29	28		CLR AR
15	u	16	16	1	19	29		L19 $\xrightarrow{+}$ AR
16		02	17	4	04	03		FORMAT → L03
02		1000000						} SPDDD DDDD TE
03		-8W00001						}
17		19	18	0	08	31		TYPE AR
18		18	18	0	28	31		T.R.
19		21	20	4	20	31		RMP

APPENDIX II

RUNNING PROGRAM

by

G. P. Van Blockland

This is the program used to run the digital computer while the digital and analogue computers are in coupled mode solving the set of equations describing room and air conditioning plant thermal performance. It performs two different functions:

1. Every time the signal from an addaverter clock is sensed, it stores the numbers from A-D converter registers, calculates the secondary coil inlet water temperature θ_{WI}, and the primary air temperature θ_{oa}, and loads the D-A converter registers with the required numbers.

2. It searches the magnetic tape for the required driving function set and loads this set into the computer memory. It records the results of the hybrid computation and the driving functions on magnetic tape.

Timing

The analogue computer "time" has to be matched to the function generation by the digital computers. Therefore, the time required for the calculations of this program determines the analogue computer time scaling.

The time taken to perform the required calculations and to load and unload the A-D and D-A converter registers is approximately 0.6 sec and another 0.6 sec is taken by the wait period. Thus, the analogue computer time scaling is set at 1 hr real time = 1.2 sec computer time.

The wait period is required to separate the times for the sampling of the analogue computer voltages and the change of the driving functions so that the transients associated with the change of the driving functions are not picked up in the sampled voltages. The 0.6 sec wait period was chosen so that the change of the driving functions occurs halfway between the two sampling times.

It should be noted that the driving functions generated by the digital computer are "staircase" time functions, the time for a step being one hour of the real time. These "staircase" functions are fed directly into the analogue circuit simulating the room. Thus, the analogue voltages sampled in the middle of a "step" are approximately average values for that hour.

Arithmetic Operations

This program performs the following arithmetic operations after the signal from the addaverter clock is sensed:

1. Chiller outlet water temperature, °F

$$\theta_{WO}/200 = A_1/200 + A_2/200\ \theta_{W\,in} + A_3/200\ (\theta_{W\,in})^2$$

if $\theta_{WO} < 45$, set $\theta_{WO} = 45$

2. Heat extraction by primary air unit, (Btu)/(hr ft^2)

$$Q_P/2 \times 10^5 = \frac{1}{2x10^5} \Big\{ c + d(\theta_{DB} - \theta_{WO})$$

$$+ e(\theta_{DP} - \theta_{WO} - 10) \Big\} \text{ if } (\theta_{DP} - \theta_{WO}) > 10$$

$$+ f - g(\theta_{DB} - \theta_{WO})(\theta_{DP} - \theta_{WO} - 10) \Big\} \text{ if}$$

$$0 < (\theta_{DP} - \theta_{WO}) < 10$$

$$= \frac{1}{2x10^5} \Big\{ m(\theta_{DB} - \theta_{WO}) \Big\} \text{ if } (\theta_{DP} - \theta_{WO}) < 0.$$

3. Primary air unit air outlet temperature, °F

$$\theta_{oa}/800 = 1/800\ (-2.69 + 3.51\ H_o - 0.0518\ H_o^2 + 0.000333\ H_o^3)$$

where $H_o = E_s - Q_P/M_A$

4. Secondary coil water inlet temperature, °F

$$\theta_{WI} = \theta_{WO} + Q_P/X\ M_W\ .$$

Storage Locations

(a) D-A and A-D converter registers:

Word Location	D-A 1 volt (analogue) =		A-D 1 volt (analogue) =	
21:00	I_{TD}	1 Btu/hr ft^2	θ_R	1°F
21:01	θ_W	2°F	$\theta_{W\,in}$	1°F
21:02	θ_g	2°F	θ_{go}	1°F
21:03	I	5 Btu/hr ft^2	θ_{gi}	1°F
22:00	I_A	1 Btu/hr ft^2	θ_{Fur}	1°F
22:01	θ_{WI}	1°F	θ_{Floor}	1°F
22:02	θ_{oa}	1°F	q_w	1 Btu/hr ft^2
22:03	L	328 Btu/hr	Q_T	1000 Btu/hr

(b) The order of data in lines 06, 07 and 08 is the same as the order of data in lines 09, 10 and 11 of the "Conversion Program".

(c) Analogue computer results:

Line 09		Scaling factor	Bias
96-4t	θ_R	2×10^{-5}	75
97-4t	$\theta_{W\,in}$	2×10^{-5}	75
98-4t	θ_{go}	2×10^{-5}	75
99-4t	θ_{gi}	2×10^{-5}	75
Line 10		-	
96-4t	θ_{Fur}	2×10^{-5}	75
97-4t	θ_{Floor}	2×10^{-5}	75

98-4t	g_W	2×10^{-5}	0
99-4t	Q_T	2×10^{-8}	0

(d) Results of digital computations:

Line 11

96-4t	θ_{WI}	2×10^{-2}	0
97-4t	Q_P	2×10^{-5}	0
98-4t	θ_{oa}	8×10^{-2}	0

where t = 1(1)24.

(e) Locations of constants:

Word location		Scaling factor
03:69	c	2×10^{-5}
03:15	d	1×10^{-3}
03:09	e	1×10^{-3}
03:75	f	2×10^{-2}
03:93	10	2×10^{-2}
03:21	g	1×10^{-3}
03:95	m	1×10^{-3}
04:45	0.0003339	8×10^{-4}
04:81	-0.0518	8×10^{-2}
04:19	3.51	8
04:65	-2.69	8×10^{2}

23:00	A_1
23:01	A_2 and H
23:02	A_3
23:03	L and Q_I

Operation Instructions

1. Mount the magnetic tape reel containing the driving functions on unit No. 0 and position the reading-writing head in the data.

2. Mount a blank magnetic tape on unit No. 1.

3. Load the program. Type P, compute GO. After each program channel is read, the check sum of this channel is typed.

4. To load the driving functions:

    (a) Put switch 2 ON.

    (b) Type (s) cf, compute ON.

The magnetic tape on unit No. 0 is searched forward for file code, the data line following this file code is read and the driving set number of this file is typed.

    (c) To load this set: switch 2 OFF, compute OFF, GO.

    (d) To search for next set: compute OFF, GO.

Note: If the check sum of the line read into the computer is not zero, the computer will type "ER"; it will then search backwards for a file code and will reread the set of driving functions following this file code.

    (e) Once the driving functions are loaded the program automatically goes to operating mode.

This program is controlled by the addaverter time signal. Thus the addaverter must be in operating mode and the clock must be set at 1.2 sec.

(f) To store the driving functions and the analogue computer results on magnetic tape:

(i) Put switch 1 ON and wait. The program halts at the end of the run, i. e. it halts at midnight (real time).

(ii) Computer gates for numeric type-in.

Type "S" tab ⓢ i. e. ⓢ = 0. 3 type 3000000

"A_g" tab ⓢ i. e. A_g = 160 type 1600000

"A_W" tab ⓢ i. e. A_W = 40 type 0400000.

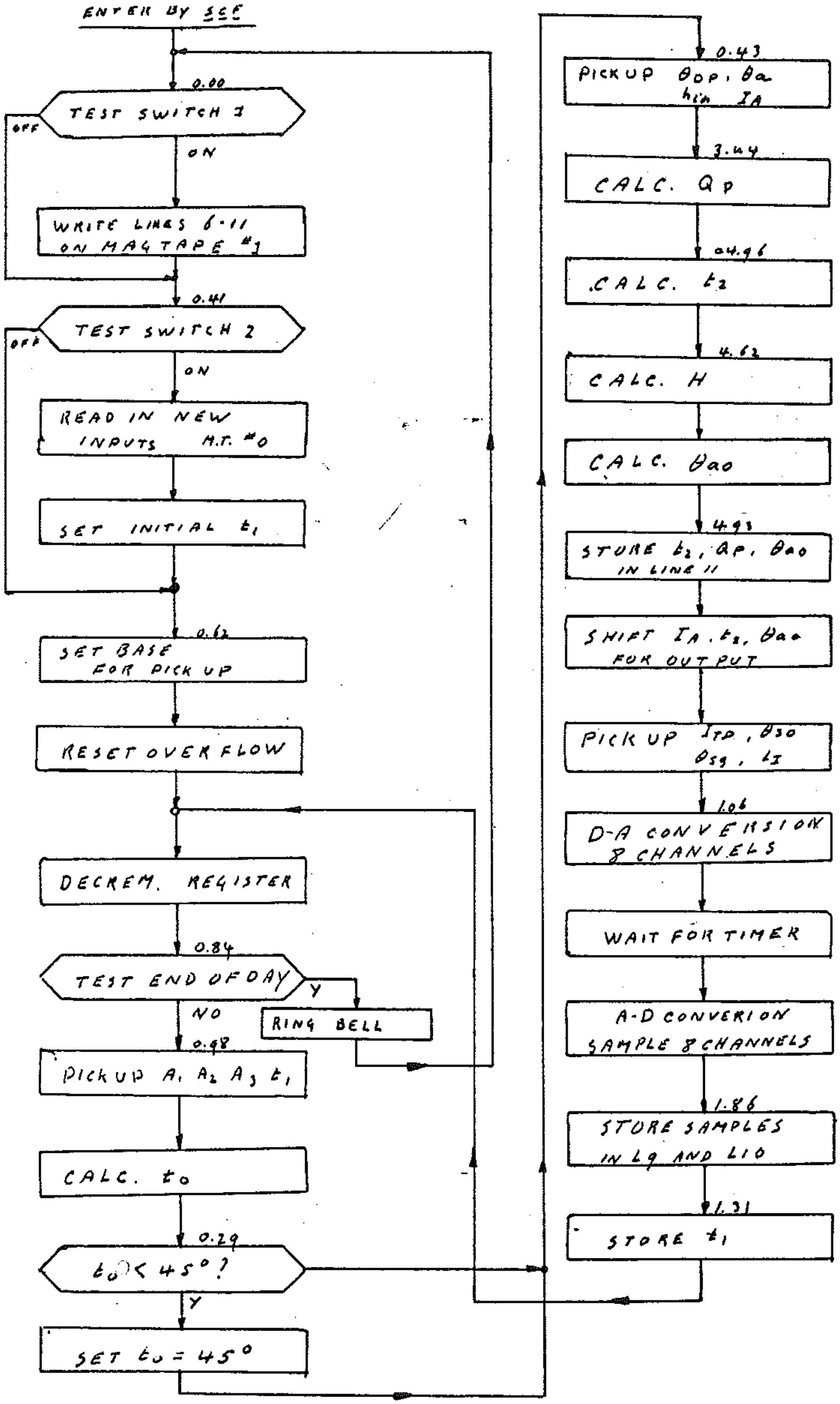
(iii) Computer gates for alpha-numeric type-in. Type alphabetic information (room size, etc.) followed by two carriage references and ⓢ .

Computer writes seven data lines on magnetic tape preceded by a file code and automatically goes to the operating mode.

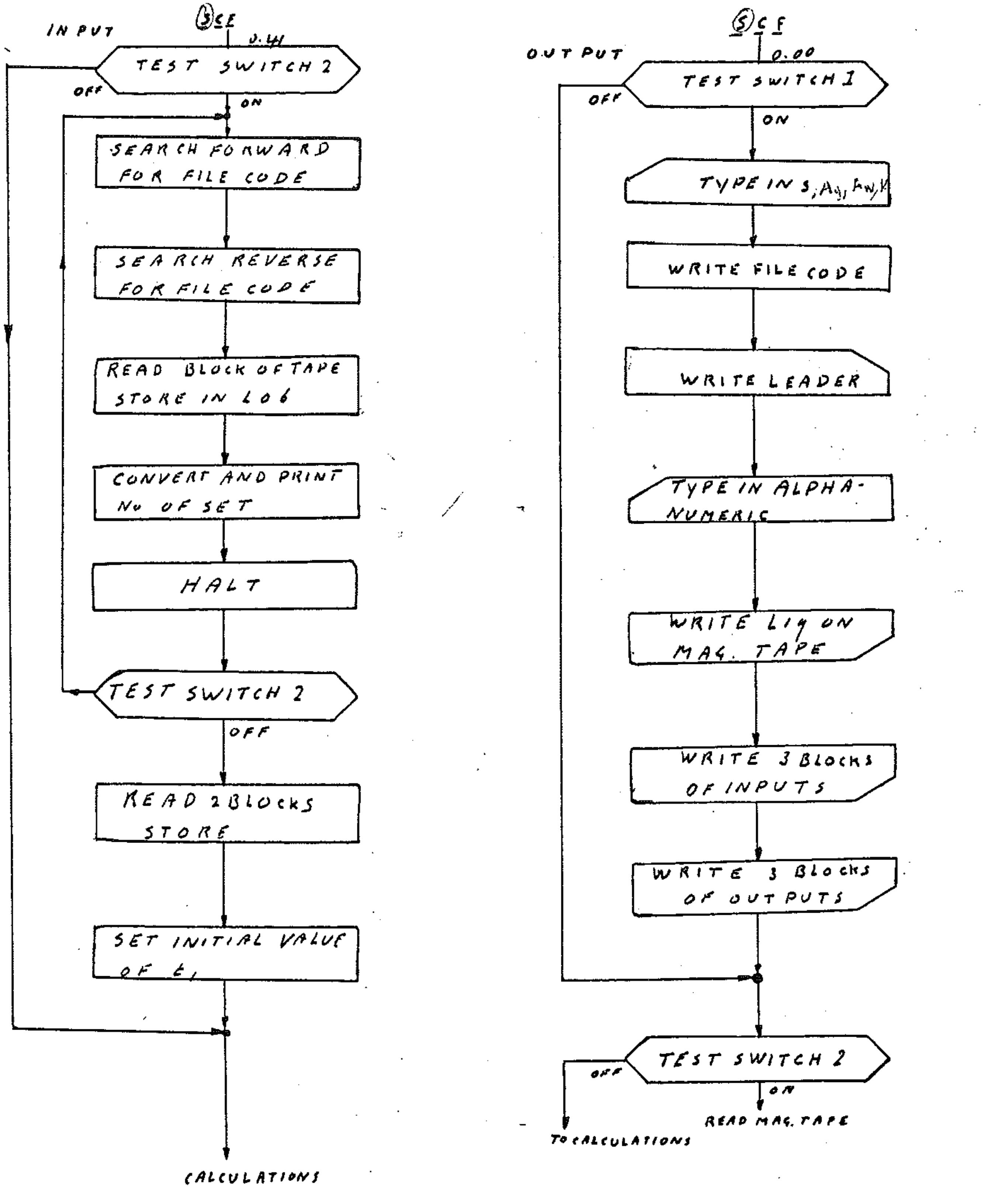
5. To enter "X M_W": compute OFF, type ⓢ c3f, compute GO. This gates the computer for numeric input. Type "X M_W" tab ⓢ (i. e. X M_W = 2656, type 2656000 tab ⓢ). Once this input is completed the program reverts to operating mode.

6. The operations described in Nos. 4 and 5 can be performed any time while the program is in the operating mode.

FLOWCHART RUNNING PROGRAM



FLOW CHART, MAG TAPE INPUT AND OUTPUT OF RUNNING PROGR



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Line 00

G-15 D
Prepared by GvB
PROGRAM PROBLEM: RUNNING PROGRAM

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
U0	U1	U2	U3
U4	U5	U6	

L	P	T	N	C	S	D	B	NOTES
00		02	02	1	28	31		TEST SW1
03		05	28	3	21	31		ON TRA TO 03.28 WRITE MAG TAPE P4L03
02		04	06	2	28	31		OFF TEST SW2
07		23	08	0	05	31		SW2 ON SEARCH FORWARD
08		08	08	0	28	31		TR
09		25	25	0	04	31	1	SEARCH REVERSE
25	W	17	12	1	21	31		TRA TO READ MAG TAPE
17	u	18	20	0	19	06		L19 → L06
20		96	31	0	19	28		19.96 → AR
31	w	33	14	2	21	31		PFC
33		35	41	0	16	31		HALT
41		43	13	2	28	31		TEST SW 2
14		15	07	0	01	01		SW2 ON TO SEARCH FORWARD
13	W	52	12	1	21	31		SW2 OFF TRA TO RMT
52	u	53	21	0	19	07		L19 → L07
21	W	77	12	1	21	31		READ MAG TAPE
77	u	78	22	0	19	08		L19 → L08
22		53	56	0	00	25		$t_1 \rightarrow 1D_1$
53		40	00	0	00			50/200
56		58	64	0	00	25		$T_0 \rightarrow 1D_0$
58		63	00	0	00			99

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Line 00

G-15 D
Prepared by GVB
PROGRAM PROBLEM: RUN. PROG.

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
64		66	80	0	25	28		1D0 → AR
80		81	87	3	00	29		ΔT +→ AR
81		04	00	0	00			04
87		88	89	0	28	25		AR → 1D0
89		91	54	0	22	31		TNE AR
54		61	75	0	00	29		POS SKEL. → AR
61	[	00	64	0	25	06	]	[1D1 → 06xx]
75		77	77	0	31	31		NCAR
55	u	56	06	0	29	18		NEG : END CLR L18
06		24	27	0	00	20		SW2 OFF T0 → 20.00
24		64	00	0	00			
27		29	62	0	29	31		} RESET OVERFLOW
63		64	62	0	01	01		
62		64	67	0	20	01		STORE T IN L01
67		68	69	0	20	28		T → AR
69		71	72	3	00	29		ΔT −→ AR
71		04	00	0	00			
72		76	84	1	28	20		AR → 20.00
84		85	90	0	28	27		TNZ AR
90		92	96	1	21	31		=0 END TMA TO 01.96 → RING BELL
91		92	98	0	00	29		≠0 SKEL → AR

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PROGRAM PROBLEM: RUN. PROG
Line 00

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
92	[	u00	99	0	06	22	]	[L06 → L22]
98		40	40	0	31	31		NCAR
99		u2	u6	6	22	25		$A_1 \rightarrow ID_1$
u6		47	01	0	22	24		$t_1 \rightarrow MQ_1$
01		30	32	0	24	31		MULTIPLY
32		53	65	0	22	04		$L_I \rightarrow 04.53$
65		67	70	0	26	28		$PN_1 \rightarrow AR$
70		71	74	1	28	28		$AR \xrightarrow{'} AR$
74		77	79	1	22	29		$A_2 \xrightarrow{+} AR$
79		80	83	1	28	28		$AR \xrightarrow{'} AR$
83		85	86	0	28	25		$AR \rightarrow ID_1$
86		87	93	0	22	24		$t_1 \rightarrow MQ_1$
93		24	12	0	24	31		MULTIPLY
12		13	15	0	26	28		$PN_1 \rightarrow AR$
15		16	18	1	28	28		$AR \rightarrow AR$
18		20	23	1	22	29		$A_1 \xrightarrow{+} AR$
23		24	29	1	28	21		$AR \rightarrow 21.00$ $\frac{t_0}{200}$
29		30	34	3	00	29		$\frac{45}{200} \xrightarrow{-} AR$
30		39	99	9	99			·225
34		36	38	0	22	31		TNF
39		40	43	0	00	21		NEG $\frac{t_0}{200} \cdot \frac{45}{200}$
40		39	99	9	99			·225
38		39	43	0	00	00		POS NC = 43

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PROGRAM PROBLEM: RUN. PROG.

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Line 00

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
43		44	47	0	20	28		20.00 → AR
47		48	50	1	00	29		SKEL. →(+) AR
48	[u	00	u0	0	07	22]		[L07 → L22]
50		52	55	0	31	31		NC AR
u0		u2	u4	3	21	31		TRA TO 03.u4 →
	RETURN FROM 04.98							
u1		u3	u4	0	22	28		I_A → AR
u4		00	05	0	28	22		AR → 22.00
05		07	10	0	20	25		$\frac{t_2}{200}$ → ID_1
10		14	19	0	21	25		$\frac{\theta_{a0}}{200}$ → ID_0
19		26	49	1	26	31		IDR 13
49		50	51	0	25	22		θ_{a0} → 22.02
51		53	57	0	04	28		L_I → AR
57		58	59	0	29	25		CLR ID_0
59		04	66	1	26	31		IDR 2
66		69	73	0	25	22		$\frac{t_2}{100}$ → 22.01
73		75	88	0	28	22		AR → 22.03
88		92	94	0	20	28		T → AR
94		95	u2	0	00	29		SKEL →(+) AR
95	[u	00	u5	0	08	21]		[L08 → L21]
u2		u4	u4	0	31	31		NCAR
u5		u7	06	1	21	31		TRA TO 01.06 → P2 L01

Pick up L07

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G-15 D

PROGRAM PROBLEM: RUN PROG

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Line 03

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
u4		u5	u6	1	22	28		$\theta_a \longrightarrow AR$
u6		04	06	3	21	29		$t_0 \xrightarrow{-} AR$
06		07	10	1	28	21		AR → 21.03
10		11	14	0	21	25		21.03 → ID_1
14		15	17	0	03	24		$B_2 \longrightarrow MQ_1$
15		·5	47	u	y1	5		·33
17		40	60	0	24	31		MULTIPLY
60		61	64	0	26	28		$PN_1 \longrightarrow AR$
64		65	68	1	28	28		AR → AR
68		69	72	1	03	29		$B_1 \xrightarrow{+} AR$
69		·04	18	9	37			·016
72		75	78	1	28	20		$\{B_1 + B_2(\theta_a - t_0)\} \longrightarrow 20.03$
78		80	82	1	22	28		$\theta_{OP} \longrightarrow AR$
82		84	85	3	21	29		$t_0 \xrightarrow{-} AR$
85		87	88	0	22	31		TNE
89		91	94	0	21	25		NEG. $\theta_a - t_0 \longrightarrow ID_1$
94		95	97	0	03	24		$B_9 \longrightarrow MQ$
95		·62	44	2	Z			·384
97		40	45	0	24	31		MULTIPLY
45		49	84	0	26	28		$PN_1 \longrightarrow AR$
88		93	96	3	03	29		POS $B_5 \xrightarrow{-} AR$
93		·0	ww	w	ww	w	X	·05
96		98	01	1	28	21		$\theta_{OP} - t_0 - .05 \longrightarrow 21.02$

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PROGRAM PROBLEM: RUN PROG.

Prepared by GvB

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Line 03

L	P	T	N	C	S	D	B	NOTES
01		03	04	0	22	31		TNE
04		09	73	0	05	25		POS ·44 → ID1
09		·70	u3	x	71			·44
73		74	77	6	21	24		θop-to-.05 → MQ1
77		40	74	0	24	31		MULTIPLY
05		07	08	0	21	28		NEG θa-to → AR
08		09	12	2	28	29		ARLI
12		13	19	0	28	25		AR → ID1
19		21	25	0	03	24		·532 → MQ1
21		·88	31	2	6z			·532
25		40	67	0	24	31		MULT.
67		69	70	0	26	28		PN1 → AR
70		71	75	3	28	28		AR $\xrightarrow{3}$ AR
75		79	81	1	03	29		·319 $\xrightarrow{+}$ AR
79		·51	u9	z	vz			·319
81		82	23	1	28	28		AR → AR
23		25	26	0	28	25		AR → ID1
26		30	31	6	21	24		(θop-to-.05) → MQ1
31		40	74	0	24	31		MULT.
74		75	76	0	26	28		PN1 → AR
76		77	80	1	28	28		AR → AR
80		83	84	1	20	29		20.03 $\xrightarrow{+}$ AR
84		86	86	0	22	31		TNE

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

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Line 03

G-15 D
Prepared by GvB
PROGRAM PROBLEM: RUN. PROG.

				L	P	T	N	C	S	D	B	NOTES
0	1	2	3									
4	5	6	7	86		89	90	0	28	21		POS Q̄P × 1/200,000 → 21.01
8	9	10	11	87		89	90	0	29	21		NEG Q̄P = 0
12	13	14	15									
16	17	18	19	90		92	96	4	21	31		TRA TO 04.96 ⟶
20	21	22	23									
24	25	26	27									
28	29	30	31									
32	33	34	35									
36	37	38	39									
40	41	42	43									
44	45	46	47	00	W	11	56	2	21	31		TIF TYPE IN $Mw \times 10^4$
48	49	50	51	11		14	22	0	23	31		CLR
52	53	54	55	22		23	36	0	28	25		$AR \rightarrow ID_1$
56	57	58	59	36		37	47	0	03	26		$\cdot 1 \rightarrow PN_1$
60	61	62	63	37		:19	9	9	99			1000×10^{-4}
64	65	66	67	47		57	46	1	25	31		DIVIDE
68	69	70	71	46		48	49	0	24	28		$MQ_0 \rightarrow AR$
72	73	74	75	49		97	48	0	28	04		$AR \rightarrow 04.97$
76	77	78	79	48		50	00	0	21	31		TRA TO 00.00
80	81	82	83									
84	85	86	87	33		35	34	0	20	31		RMP IN LO
88	89	90	91									
92	93	94	95									
96	97	98	99									
u0	u1	u2	u3									
u4	u5	u6										

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G-15 D
Prepared by G.V.B
PROGRAM PROBLEM: RUN. PROG.

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
28	w	30	56	2	21	31		TIF TYPE IN S
30		97	24	0	28	09		AR → 09.97
24		97	29	0	04	10		04.97 → 10.97 1000/MW
29		35	42	1	30	31		WRITE FILE CODE UNIT 1
42	w	32	35	4	21	31		TO WRITE LEADER
32	u	33	39	0	29	19		CLR L19
39		44	34	4	12	31		TYPE IN A.N
34		34	34	0	28	31		T.R.
35	w	38	90	4	21	31		WRITE MAG TAPE
38	u	39	40	0	06	19		L06 → L19
40	u	42	90	4	21	31		WRITE MAG TAPE
41	u	42	44	0	07	19		L07 → L19
44	w	52	90	4	21	31		WRITE MAG TAPE
52	u	53	53	0	08	19		L08 → L19
53	w	58	90	4	21	31		WRITE MT
58	u	59	61	0	09	19		L09 → L19
61	u	63	90	4	21	31		WRITE MT
62	u	63	66	0	10	19		L10 → L19
66	w	07	90	4	21	31		WRITE MT
07	u	08	16	0	11	19		L11 → L19
16	w	18	90	4	21	31		WRITE MT
18		20	02	0	21	31		TRA TO 00.02 PILO TEST SW 2

WRITE MAG TAPE
ENTER "S"

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Line 04

G-15D
Prepared by G.V.B.
PROGRAM PROBLEM: RUN. PROG.

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
00		02	22	0	21	31		TKA TO 00.22
96		97	40	0	04	25		$\frac{1000}{M} \rightarrow$ ID,
97		·68yv031						·409836
40		41	45	0	21	24		$Q_P \rightarrow$ MQ,
45		40	42	0	24	31		MULT.
42		43	46	0	26	21		$PN_1 \rightarrow$ AR
46		47	51	1	28	28		AR → AR
51		52	55	1	21	29		$t_0 \xrightarrow{+}$ AR
55		59	62	1	28	20		$\frac{t_2}{100} \rightarrow$ 20.03
62		63	67	0	04	25		$\frac{2000}{MA} \rightarrow$ ID,
63		·y395811						889
67		69	71	0	21	24		$Q_P \rightarrow$ MQi
71		56	23	0	24	31		MULT.
23		25	28	0	26	28		$PN_1 \rightarrow$ AR
28		29	32	3	28	28		$AR \xrightarrow{3} AR$
32		34	36	1	22	29		$h_{in} \xrightarrow{+}$ AR
36		37	40	1	28	23		H → 23.01
40		41	44	0	23	25		H → ID,
44		45	47	0	04	24		$-C_4 \rightarrow$ MQ,
45		·6u7yz9x						416
47		24	73	0	24	31		MULT.
73		75	77	0	26	28		$PN_1 \rightarrow$ AR
77		78	80	1	28	28		AR → AR

CALC. t_2

CALC. H

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G-15 D
PROGRAM PROBLEM: RUN. PROG.

Prepared by GVB

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Line 04

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
80		81	84	1	04	29		$C_3 \xrightarrow{+} AR$
81	-	.u	5w	2	8z	5		-.6475
84		85	88	1	28	28		AR → AR
88		89	92	0	28	25		AR → ID.
92		93	95	0	23	24		H → MQ.
95		24	14	0	24	31		MULT.
14		15	16	0	26	28		PN. → AR
16		17	18	1	28	28		$AR \xrightarrow{'} AR$
18		19	20	1	04	29		$C_2 \xrightarrow{+} AR$
19		.70	51	y	v9			.43875
20		21	22	1	28	28		$AR \xrightarrow{'} AR$
22		23	24	0	28	25		AR → ID.
24		25	29	0	23	24		H → MQ.
29		24	56	0	24	31		MULT.
56		57	60	0	26	28		PN. → AR
60		61	64	1	28	28		$AR \xrightarrow{'} AR$
64		65	66	1	04	29		$C_1 \xrightarrow{+} AR$
65	-	00	xw	5	x7			-.0033625
66		70	74	1	28	21		$\frac{\theta_{xu}}{800} \longrightarrow 21.02$
74		75	78	0	20	28		t_2 → AR
78		80	82	0	28	21		t_2 → 21.00
82		84	87	0	20	28		T → AR
87		93	u2	1	04	29		SKEL → AR

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G-15D
PROGRAM PROBLEM: RUN PROG.

Prepared by G.V.B

Line 04

0	1	2	3	L	P	T	N	C	S	D	B	NOTES
4	5	6	7	93	[u	00	98	0	21	11	]	[L21 → L11]
8	9	10	11	u2		u4	u6	0	31	31		NCAR
12	13	14	15									
16	17	18	19	98		u0	u1	0	21	31		TKA TO 00.u1 —P4 L00→
20	21	22	23									
24	25	26	27			WRITE MAG TAPE SUBROUTINE						
28	29	30	31	90		u4	04	0	29	19		CLR 19u4
32	33	34	35	04		05	08	0	29	28		CLR AR
36	37	38	39	08	u	09	12	1	19	29		L19 →(+) AR
40	41	42	43	12	u	16	26	3	28	28		INVERT AR
44	45	46	47	26		u4	30	0	28	19		BALANCER → 19u4
48	49	50	51	30	w	00	34	1	01	31		WRITE M.T.
52	53	54	55	34		34	34	0	28	31		TR
56	57	58	59									
60	61	62	63	35		51	76	1	05	31		SEARCH FORW
64	65	66	67	76		75	72	0	01	01		WAIT
68	69	70	71	72		71	69	0	02	02		WAIT
72	73	74	75	69		68	61	0	03	03		WAIT
76	77	78	79	61		64	38	0	00	31		SET READY
80	81	82	83	38		40	39	3	20	31		RMP IN L03
84	85	86	87									
88	89	90	91									
92	93	94	95									
96	97	98	99									
u0	u1	u2	u3									
u4	u5	u6										

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Line *01*

G-15D
PROGRAM PROBLEM: ___

Prepared by ___

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
					READ MAG TAPE SUBROUTINE			
12		12	12	0	28	31		TR
13		12	09	0	01	01		WAIT
09	W	08	14	0	13	31		WRITE MAG TAPE UNIT 0
14		14	14	0	28	31		TR
15		16	17	0	29	28		CLR AR
17	u	18	18	1	19	29		SUM L19
18		19	26	0	28	27		TNZ AR
26		28	27	0	20	31		=0 RMP IN L0
27		28	29	0	01	28		≠0 01.28 → AR
28		9	5Y	9	Z0	x		• ER
29		31	36	4	08	31		PR. AR A.N.
36		38	40	0	16	31		HALT
40		42	09	0	21	31		TO SEARCH REVERSE
96		13	20	0	01	01		NC = 20
20		21	24	0	17	31		RING BELL
24		26	38	0	29	31		RESET OVERFLOW
38		40	00	0	21	31		} TRA TO 00.00 →
39		41	00	0	21	31		}

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PROGRAM PROBLEM:

Prepared by

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Line 01

0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15
16	17	18	19
20	21	22	23
24	25	26	27
28	29	30	31
32	33	34	35
36	37	38	39
40	41	42	43
44	45	46	47
48	49	50	51
52	53	54	55
56	57	58	59
60	61	62	63
64	65	66	67
68	69	70	71
72	73	74	75
76	77	78	79
80	81	82	83
84	85	86	87
88	89	90	91
92	93	94	95
96	97	98	99
u0	u1	u2	u3
u4	u5	u6	

L	P	T	N	C	S	D	B	NOTES
06	u	08	72	1	19	31		D-A CONV.
72		74	80	3	28	31		TEST TIMER OFF
80		83	72	0	02	02		NC=72 RETEST
81	u	86	u1	0	29	22		ON CLK L22
u1	w	u3	86	0	19	31		A-D CONV.
86		92	93	0	20	28		20.00 T → AR
93		94	40	0	01	29		DUMMY +→ AR
94	[u	00	95	0	21	09]		[L21 → L09]
u0		u2	u6	0	31	31		NCAR
95		96	98	0	20	28		T → AR
98		99	u3	0	01	29		SKEL +→ AR
99	[u	00	31	0	22	10]		[L22 → L10]
u3		u5	u5	0	31	31		NCAR
31		33	35	0	21	28		t_1 → AR
35	u	51	54	2	28	29		ARL 15
54		55	57	0	28	25		AR → ID.
57		58	60	0	01	28		SKEL. → AR
58	[u	w3	59	0	25	06]		[ID → L06]
60		64	65	0	01	29		T_{n-1} → AR
65		67	67	0	31	31		NCAR
59		61	62	0	21	31		TRA TO 00.62 — P2 L00 →

STORE L21

STORE L22

APPENDIX III

TABULATION PROGRAM

by

G. P. Mitalas

This program tabulates the results of the air conditioning calculations performed by the hybrid computer.

The results of the hybrid computer calculation, the copy of the driving functions, the alphabetic heading, and some pertinent constants are stored on the magnetic tape by the "Running Program". This program reads the magnetic tape containing hybrid computation results, converts the numbers into floating point decimal numbers, applies scaling factors, adds reference and performs a limited amount of arithmetic operations. All of the output by this program is listed by typewriter on 12-in. paper sheets.

Order of Input Data on Magnetic Tape

All of the input data for the "Tabulation Program" are on the magnetic tape in one file. This file consists of a file code followed by data lines. The order of the data in each line is as follows:

First line:

The description of the calculations in alphabetical form. This information is stored in 00-nn word locations where nn depends on the length of the heading.

Word location	Data	Scaling factor	Reference
Second line:			
98-4t	L_i	$1/32768 \times 2^{-16}$	0
98	A_g	1/1000	0
99	H	1/10	0

Third line:

96-4t	θ_{DP}	1/200	0
97-4t	θ_{DB}	1/200	0
98-4t	E	1/100	0
99-4t	I_1	1/100	0
96	A_W	1/500	0
97	No	1/1000	0

Fourth line:

96-4t	I_{TD}	$1/100 \times 2^{-16}$	0
97-4t	θ_{sO}	$1/200 \times 2^{-16}$	0
98-4t	θ_{sg}	$1/200 \times 2^{-16}$	0
99-4t	I_T	$1/500 \times 2^{-16}$	0

Fifth line:

96-4t	θ_R	$1/100 \times 2^{-16}$	75
97-4t	$\theta_{W\ in}$	$1/100 \times 2^{-16}$	0
98-4t	θ_{go}	$1/100 \times 2^{-16}$	75
99-4t	θ_{gi}	$1/100 \times 2^{-16}$	75
97	S	1	0

Sixth line:

96-4t	θ_{Fur}	$1/100 \times 2^{-6}$	75
97-4t	θ_F	$1/100 \times 2^{-16}$	75
98-4t	q_w	$1/100 \times 2^{-16}$	0

99-4t	Q_{1T}	1/100 x 2^{-6}	0
97	M_W	1000	0

Seventh line:

96-4t	θ_{WO}	1/200	0
97-4t	Q_P	1/2 x 10^{-5}	0
98-4t	θ_{oa}	1/800	0

where

$t = 1(1)24$

q_w = heat flux through inside surface of outside wall in (Btu)/(hr ft^2)

Other symbols are defined in the previous text.

Arithmetic Operations

This program performs the following arithmetic operations:

1. Heat gain by conduction through window

$$q_c = A_g \ H \ (\theta_{sa} - \theta_{go}) \ \text{(Btu)/(hr)}$$

2. Heat gain by solar radiation through window

$$q_I = A_g \ (I_T + I_{DT} + I_1) \ \text{(Btu)/(hr)}$$

3. Total instantaneous heat gain by the room

$$q_T = q_c + q_I = q_w A_W + L_i$$

4. Sensible cooling of room air by primary air

$$Q_{ps} = M_a \ S \ C_p \ (\theta_R - \theta_{oa}) \ \text{(Btu)/(hr)}$$

5. Sensible cooling by secondary coils

$$Q_I = M_W \ S \ F \ (\theta_R - \theta_{WI}) \ \text{(Btu)/(hr)}$$

6. Sensible cooling load on primary air unit

$$Q_{po} = M_a \; S \; C_p \; (\theta_{DB} - \theta_{oa}) \; (Btu)/(hr)$$

7. Latent load on cooling plant

$$Q_{pL} = Q_p - Q_{po} \quad (Btu)/(hr)$$

8. Ratio of maximum rate of cooling over maximum instantaneous heat gain

$$R = Q_{T\,max}/q_{T\,max}.$$

Output

The output is the tabulation at temperatures, heat gains, and cooling loads versus time. Sample output sheet is given on page III-6.

Program Details

Memory allocations

Program - line 08, 09, 10, 11, 12, 13

Input data - line 14, 15, 16, 17, 18

Subroutine - line 10

The subroutine performs the following functions:

(a) reads magnetic tape, verifies the check sum of the line. If the check sum $\neq 0$, it types ER

(b) types contents of line 19 in alpha-numeric mode

(c) converts machine language number into floating point number

(d) shifts machine language number by 16 bits right and converts this shifted number into floating point number

(e) backs up magnetic tape to first file code.

Execution time

One set of results is typed out in approximately 20 min.

Operation Instructions

1. Mount the magnetic tape containing hybrid calculation results on the magnetic tape unit No. 1. Position the reading-writing head in the first file of data to be tabulated. Mount 12-in. paper on typewriter and clear all of the tabs.

2. Load Intercom 500 and "Type-out subroutine -1".

3. Load program. Enable ON, type P and wait for photo reader light to go off. Compute switch GO. The rest of the program is loaded into the computer memory.

4. Type 0690972 tab Ⓢ and position typewriter paper.

5. Compute switch OFF and GO. This starts the program. The program will operate by itself until all of the data from the magnetic tape are tabulated.

SAMPLE OUTPUT SHEET

DOUBLE GLAZED A=120 KL=.6 16.1.64 21

Time, hr	Room air temp., θ_R °F	Window: Outside pane temp., θ_{go} °F	Window: Inside pane temp., θ_{gi} °F	Furniture temp., θ_{Fur} °F	Floor temp., θ_F °F	Secondary Coil Water: Inlet temp., θ_{WI} °F	Secondary Coil Water: Outlet temp., $\theta_{W\,in}$ °F	Primary air temp., θ_{oa} °F
1.0	75.0	73.5	74.8	75.6	77.9	48.5	48.6	57.6
2.0	75.0	73.4	74.7	75.5	77.6	48.5	48.6	57.6
3.0	75.0	72.7	74.3	75.4	77.3	48.4	48.5	57.4
4.0	75.0	71.9	73.9	75.3	77.0	48.4	48.5	57.3
5.0	75.0	71.9	73.9	75.2	76.8	48.4	48.5	57.3
6.0	75.0	73.3	74.6	75.5	76.6	48.4	48.5	57.3
7.0	75.0	75.4	75.6	75.8	76.5	48.4	48.5	57.4
8.0	75.0	78.1	76.9	76.1	76.5	48.6	48.7	57.7
9.0	75.0	81.2	78.4	76.4	76.5	48.8	48.9	58.2
10.0	75.0	84.1	79.7	76.7	76.6	49.0	49.1	58.6
11.0	75.0	87.5	81.2	76.9	76.6	49.3	49.3	59.2
12.0	75.0	89.9	82.3	77.1	76.7	49.6	49.6	59.7
13.0	75.0	103.4	88.9	79.8	77.3	51.0	49.8	60.1
14.0	75.0	114.6	95.0	85.7	78.8	53.0	49.8	60.3
15.0	75.0	122.6	99.5	90.6	80.4	57.2	52.1	61.7
16.0	75.0	123.5	100.4	93.4	81.9	61.7	55.2	63.3
17.0	75.0	118.4	98.1	93.0	82.8	61.7	55.1	63.2
18.0	75.0	103.4	90.4	86.8	82.3	54.1	49.6	59.8
19.0	75.0	81.6	79.0	77.2	80.6	50.7	49.3	59.2
20.0	75.0	80.1	78.1	76.7	80.0	49.9	49.2	58.9
21.0	75.0	78.6	77.3	76.4	79.5	49.3	49.1	58.6
22.0	75.0	77.1	76.5	76.2	79.0	48.9	48.9	58.3
23.0	75.0	75.6	75.8	76.0	78.6	48.7	48.8	58.0
24.0	75.0	74.2	75.1	75.8	78.2	48.6	48.7	57.7

A_g	H	S	(I+x) M_{Wi}	A_W
120.0	51.26399	50.30000	4880.0	80.0

52.20000 - Driving function set number LNO

Time, hr	Heat gain by conduction $q_c + q_w A_w$ Btu/hr	Heat gain by solar radiation through window q_I Btu/hr	Total instantaneous heat gain q_T Btu/hr	Sensible cooling of room air by primary air θ_{ps} Btu/hr	Sensible cooling by secondary coils Q_I Btu/hr	Total cooling of room air Q_T Btu/hr	Sensible cooling load on primary air unit θ_{po} Btu/hr	Latent cooling load on cooling plant Btu/hr	Total cooling load on cooling plant Btu/hr
1.0	- 77.9	.0	- 77.9	2815.7	.0	1611.3	2977.7	2371.2	3982.6
2.0	- 130.7	.0	- 130.7	2815.7	.0	1367.2	2977.7	2371.2	3738.4
3.0	- 229.8	.0	- 229.8	2840.5	.0	1098.6	2840.5	2409.5	3508.1
4.0	- 317.1	.0	- 317.1	2865.2	.0	927.7	2703.2	2447.7	3375.5
5.0	- 334.6	.0	- 334.6	2865.2	.0	732.4	2703.2	2447.7	3180.2
6.0	226.4	386.7	160.3	2865.2	.0	903.3	2703.2	2447.7	3351.1
7.0	13.5	837.8	851.4	2840.5	.0	1196.3	2840.5	2409.5	3605.8
8.0	269.2	1195.3	1464.5	2791.2	.0	1538.1	3115.2	2332.7	3870.8
9.0	581.9	1476.6	2058.5	2717.9	.0	1928.7	3527.9	2217.0	4145.7
10.0	876.4	1681.6	2558.1	2645.4	.0	2319.3	3941.4	2100.5	4419.8
11.0	1228.0	1810.5	3038.6	2544.8	.0	2734.4	4488.8	1949.1	4683.5
12.0	1511.9	1857.4	3369.4	2474.0	120.7	3051.8	4904.0	1830.9	4882.7
13.0	2847.3	3562.5	6409.8	2403.9	1860.8	4809.6	5319.9	1712.0	6521.6
14.0	4004.0	7418.0	11422.0	2380.7	4657.1	7641.6	5458.6	1672.3	9313.9
15.0	4891.1	10497.0	15388.0	2148.5	7535.9	10278.0	5388.5	1241.0	11519.0
16.0	5171.5	12103.0	17274.0	1880.1	9462.3	11914.0	4958.1	689.2	12603.0
17.0	4879.2	11402.0	16282.0	1902.0	9621.9	12134.0	4818.0	735.0	12869.0
18.0	3657.3	6764.7	10422.0	2450.5	6598.1	9619.1	5042.5	1791.4	11411.0
19.0	1641.9	.0	1641.9	2544.8	1954.5	5029.3	4488.8	1949.1	6978.4
20.0	1307.1	.0	1307.1	2597.5	1008.6	4077.2	4217.5	2022.5	6099.6
21.0	933.2	.0	933.2	2645.4	277.2	3369.1	3941.4	2100.5	5469.7
22.0	590.7	.0	590.7	2693.7	.0	2832.0	3665.7	2178.3	5010.3
23.0	320.3	.0	320.3	2742.2	.0	2343.7	3390.2	2255.7	4599.4
24.0	62.1	.0	62.1	2791.2	.0	1953.1	3115.2	2332.7	4285.9

50.70243 = $Q_{T\,max}/q_{T\,max}$

Cooling	Heat gain
94464.0	95410.0

Daily totals

TABULATION PROGRAM

80	.1421392	-80.21550	
801	.1421388	-80.21303	
802	.1421384	-80.21055	
803	.1421380	-80.20807	
804	.1421376	-80.20560	Pick up
805	.1421372	-80.20312	Instr.
806	.1421368	-80.20065	
807	.1421364	-80.19817	
808	.1421360	-80.19569	
809	.1421356	-80.19322	
810	.1421352	-80.19074	
811	.1421348	-80.18827	
812	.1421344	-80.18579	
813	.1421340	-80.18331	
814	.1421336	-80.18084	
815	.1421332	-80.17836	
816	.1421328	-80.17589	
817	.1421324	-80.17341	
818	.1421320	-80.17094	
819	.1421316	-80.16846	
820	.1421312	-80.16598	
821	.1421308	-80.16351	
822	.1421304	-80.16103	
823	.1421300	-80.15856	
824	.2420800	-83.32462	
825	.0490826	88.34816	(Shift 16 bits left
826	.1421344	-80.18579	x100) + 75
827	.0491000	69.00139	
828	.0081010	69.07229	
829	.0421000	64.00181	
830	.0480893	84.18901	
831	.0430892	84.18694	
832	.0491000	69.00139	
833	.0160000	88.00083	
834	.2420800	-83.32462	(No shift) x 100
835	.0490836	88.48108	
836	.1421348	-80.18827	
837	.0491000	69.00139	
838	.0081020	69.14435	
839	.0421000	64.00181	
840	.0480891	84.18495	
841	.0491000	69.00139	
842	.0160000	88.00083	
843	.00003w2	53.50000	
844	.0520000	86.00212	Constants
845	.0000324	54.24400	
846	.0000464	50.75000	and temporary
847	.0042403	86.03132	
848	.0000700	.00000	storage locations
849	.000352	52.90000	
850	.04011v3	55.30932	

851	.u042656	-54.13083
852	.0151192	54.17605
853	.0u72791	56.11260
854	.0511936	55.84326
855	.0402795	55.14282
856	.04011v3	55.30932
857	.0402795	55.14282
858	.0281112	54.89670
859	.00003w2	54.20000
860	.00003w2	54.10000
861	.0100349	52.88770
862	.0610326	52.77120
863	.0632733	54.51760
864	.0w603v7	52.61499
865	.0u60358	52.93457
866	.0871135	53.32768
867	.0v20009	86.02451
868	.0221136	52.82294
869	.0000332	51.50000
870	.0w00329	52.78735
871	.0v00312	52.35107
872	.0760301	51.80810
873	.0v20359	52.93970
874	.0330354	52.91064
875	.09204w7	50.99945
876	.0000300	51.10000
877	.00003w2	54.10000
878	.0000332	51.50000
879	.0640435	48.99945
880	.0000332	52.10000
881	.00003w2	54.10000
882	.0000300	51.80000
883	.0320312	54.22500
884	.0000324	54.24400
885	.0152025	50.29993
886	.06612v7	50.24000
887	.0v51940	51.26399
888	.0w72771	53.20000
889	.0300001	88.01485
890	.0291176	60.12770
891	.0871235	49.10000
892	.0000322	52.75000
893	.0871235	49.10000
894	.0000700	.00000
895	.0000364	52.24000
896	.0000308	52.17000
897	.0000316	51.90000
898	.0000300	51.10000
899	.0000380	52.13000

	900	.2700000	-69.23071	Set
	901	.2710001	-69.23116	I.R.
	902	.2730000	-69.23071	
	903	.2740100	-68.57678	
	904	.2750500	-66.22531	
	905	.0630000	88.00328	
	906	.0081031	69.22361	Type heading
	907	.0630000	88.00328	
	908	.0081021	69.15155	
	909	.0081031	69.22361	Read
	910	.0421899	65.10903	
	911	.0291052	69.3752	
	912	.0420894	84.19099	Reset
	913	.0490899	89.13185	time
Start of	914	.2700000	-69.23071	
temp. cal.	915	.2730000	-69.23071	
loop →	916	.0260985	79.26338	Exit to time sub.
	917	.1700000	-69.11541	
	918	.1730300	-67.18034	
	919	.0260824	88.32036	
	920	.0331000	64.00143	θ_R
	921	.1700002	-69.11631	
	922	.1730300	-67.18034	
	923	.0260824	88.32036	
	924	.0331000	64.00143	θ_{go}
	925	.1700003	-69.11676	
	926	.1730300	-67.18034	
	927	.0260824	88.32036	
	928	.0331000	64.00143	θ_{g2}
	929	.1700000	-69.11541	
	930	.1730400	-67.04509	
	931	.0260824	88.32036	
	932	.0261063	69.45470	θ_{floor}
	933	.1700001	-69.11587	
	934	.1730400	-67.04509	
	935	.0260824	88.32036	
	936	.0261063	69.45470	$\theta_{furn.}$
	937	.0290941	79.12724	
	938	.1730400	-67.04509	
	939	.0260824	88.32036	
	940	.0261063	69.45470	
	941	.1700001	-69.11587	
	942	.1730300	-67.18034	
	943	.0260824	88.32036	
	944	.0421000	64.00181	
	945	.0410892	84.18692	
	946	.0332101	35.01568	z_1
	947	.1700000	-69.11541	
	948	.1730500	-66.11272	
	949	.0260834	88.45329	

	950	.0421000	64.00181	
	951	.0431000	64.00185	
	952	.0332101	35.01568	z_2
	953	.1700002	-69.11631	
	954	.1730500	-66.11272	
	955	.0260834	88.45329	
	956	.0421000	64.00181	
	957	.0440882	84.16666	
	958	.0382101	35.01596	θ_{oa}
	959	.2760960	-63.98319	inc. i.k.
	960	.0290916	78.49869	
	961	.1700002	-69.11631	
	962	.1730400	-67.04509	
	963	.0260824	88.32036	
	964	.0401000	64.00172	
	965	.0430892	84.18694	
	966	.0440879	84.16058	q_w
	967	.0430868	84.13626	
	968	.0490868	88.90643	[illegible]
	969	.0330868	84.13818	q_c
	970	.0291277	50.30122	
	971	.33931v5	-69.79592	
start →	972	.0680000	88.00354	Backup magnetic tape
	973	.0081018	69.12994	store exit inst,
	974	.0420889	84.18085	Clear storage
	975	.0491200	50.00075	locations
	976	.0420894	84.19099	
	977	.0490856	88.74692	
	978	.0490855	88.73363	
	979	.0490854	88.72034	
	980	.0490853	88.70705	
	981	.0490852	88.69376	
	982	.0490848	88.64059	
	983	.0290900	78.00351	
	984	.0390900	74.00072	
	985	.0420899	84.20113	
	986	.0430898	84.19911	Time
	987	.0490899	89.13185	Subroutine
	988	.0410897	84.19706	
	989	.0230998	79.30357	
	990	.0420899	84.20113	
	991	.0410896	84.19504	
	992	.0230998	79.30357	
	993	.0420895	84.19302	
	994	.0410899	84.20112	
	995	.0221200	50.00034	→ Exit at the
	996	.0330899	84.20106	end of 24-hr loop
	997	.0160000	88.00083	
	998	.0300001	88.01485	
	999	.0290993	79.28817	

1000	.0v60353	52.90747
1001	.0000400	.00000
1002	.0030003	89.17414
1003	.0060501	32.43715
1004	.0000700	.00000
1005	.0032632	60.10742
1006	.0072408	80.33679
1007	.0122800	47.48846
1008	.0173016	23.11365
1009	.0000000	.00000
1010	.0142313	11.29972
1011	.0080504	35.11452
1012	.0122812	40.21914
1013	.0152915	31.06378
1014	.0050500	33.69399
1015	.0u70616	29.10864
1016	.0u70617	29.11526
1017	.0070501	32.21858
1018	.0182818	40.32871
1019	.0120439	40.71027
1020	.0110500	34.55530
1021	.0212821	40.38349
1022	.0491823	63.31874
1023	.0000800	88.00000
1024	.0280826	79.16161
1025	.0252825	40.45654
1026	.02919u7	52.29389
1027	.0350523	32.51207
1028	.0250030	79.18629
1029	.0240040	89.22343
1030	.2653148	-69.50508
1031	.0312831	40.56610
1032	.0271334	31.14445
1033	.0472235	21.34694
1034	.2491566	-79.22387
1035	.0452835	40.63986
1036	.0372936	32.55615
1037	.0391938	51.11923
1038	.0121640	79.24788
1039	.0402841	42.11978
1040	.0121941	54.26270
1041	.0340543	32.14614
1042	.0u53021	26.48440
1043	.0432843	40.78523
1044	.0400000	89.17035
1045	.0330509	32.23231
1046	.0372936	32.55615
1047	.0350000	89.17032
1048	.0380050	79.31040
1049	.0242900	34.00164
1050	.0081031	69.22361

Machine language subroutine

1051	.0421899	65.10903	
1052	.0491399	40.90215	Data from Magnetic tape and store in 14, 15, 16, 17 and 18 lines
1053	.0081031	69.22361	
1054	.6811899	-59.10717	
1055	.0081031	69.22361	
1056	.7811899	-59.12395	
1057	.0081031	69.22361	
1058	.8811899	-59.14073	
1059	.0081031	69.22361	
1060	.9811899	-59.15750	
1061	.0081031	69.22361	
1062	.0290912	78.37489	
1063	.0401000	64.00172	
1064	.0430892	84.18694	θFloor+
1065	.0430892	84.18694	θFurn.
1066	.0332101	35.01568	Sub.
1067	.0160000	88.00083	
1068	.1700001	-69.11587	
1069	.1730100	-68.28855	
1070	.0260834	88.45329	
1071	.0421000	64.00181	
1072	.0432101	35.01621	
1073	.0490849	88.65388	
1074	.0410864	84.13013	
1075	.0440886	84.17478	
1076	.0440885	84.17275	
1077	.0440883	84.16869	
1078	.0332101	35.01568	QPL
1079	.0291154	59.90787	
1080	.0491000	69.00139	
1081	.0420848	83.97688	
1082	.0490870	88.93302	
1083	.0421000	64.00181	
1084	.0490848	88.64059	
1085	.0291284	50.32857	
1086	.0420861	84.12406	
1087	.0410862	84.12608	
1088	.0440884	84.17072	
1089	.0440885	84.17275	
1090	.0490858	88.77351	QI
1091	.0291189	60.14951	
1092	.0420865	84.13217	
1093	.0410862	84.12608	
1094	.0440846	83.93648	
1095	.0291088	69.63492	
1096	.0430857	84.11595	
1097	.0382101	35.01596	
1098	.0420850	84.10175	
1099	.0291158	59.97498	

1100	.0430868	84.13826	
1101	.0490850	88.66717	
1102	.0330850	84.10168	q_T
1103	.1700002	-69.11631	
1104	.1730500	-66.11272	
1105	.0260834	88.45329	
1106	.0421000	64.00181	
1107	.0440882	84.16666	
1108	.0490864	88.85326	θ_{oa}
1109	.1700000	-69.11541	
1110	.1730300	-67.18034	
1111	.0260824	88.32036	
1112	.0421000	64.00181	
1113	.0630000	88.00328	
1114	.0490865	88.86656	θ_R
1115	.0410864	84.13013	
1116	.0440886	84.17478	
1117	.0440885	84.17275	
1118	.0440883	84.16869	
1119	.0490863	88.83997	
1120	.0330863	84.12804	Q_{RS}
1121	.1700001	-69.11587	
1122	.1730300	-67.18034	
1123	.0260824	88.32036	
1124	.0421000	64.00181	
1125	.0410892	84.18692	
1126	.0490861	88.81339	z_1
1127	.1700000	-69.11541	
1128	.1730500	-66.11272	
1129	.0260834	88.45329	
1130	.0421000	64.00181	
1131	.0431000	64.00185	
1132	.0490862	88.82668	z_2
1133	.0420865	84.13217	
1134	.0410892	84.18692	
1135	.0410891	84.18489	
1136	.0291086	69.62051	
1137	.0291086	69.62051	
1138	.1700003	-69.11676	
1139	.1730400	-67.04509	
1140	.0260824	88.32036	
1141	.0421000	64.00181	
1142	.0410892	84.18692	
1143	.0440860	84.12204	
1144	.0490857	88.76022	Q_T analogue
1145	.0330857	84.11587	
1146	.1700001	-69.11587	
1147	.1730500	-66.11272	
1148	.0260834	88.45329	
1149	.0421000	64.00181	
1150	.0440859	84.12002	

1151	.0440885	84.17275	
1152	.0490852	88.69376	Q^*_P
1153	.0291068	69.49081	
1154	.0402101	35.01605	
1155	.0430852	84.10581	
1156	.0332101	35.01568	
1157	.0291096	69.69257	Q_{PL}
1158	.0410856	84.11391	
1159	.0221162	60.10416	Check for
1160	.0420850	84.10175	Max
1161	.0490856	88.74692	
1162	.0420857	84.11594	q_T
1163	.0410855	84.11188	
1164	.0221168	60.11423	
1165	.0420857	84.11594	
1166	.0490855	88.73363	
1167	.0630000	88.00328	Q_T
1168	.0420854	84.10986	
1169	.0430857	84.11595	Σq_T
1170	.0490854	88.72034	
1171	.0420853	84.10783	ΣQ_T
1172	.0430850	84.10175	
1173	.0490853	88.70705	
1174	.2761175	-62.63060	
1175	.0291250	50.19576	End of loop
1176	.0300001	88.01485	
1177	.0420855	84.11189	
1178	.0480856	84.11396	
1179	.0342101	35.01574	R
1180	.0330853	84.10776	Σq_T
1181	.0380854	84.10983	ΣQ_T
1182	.0300005	88.06802	
1183	.0290974	79.22937	End of tabulation
1184	.0440888	84.17883	
1185	.0490849	88.65388	
1186	.0330849	83.99647	I
1187	.0291292	50.35982	
1188	.0490858	88.77351	
1189	.0221192	60.15449	$Q_I<0$
1190	.0330858	84.11790	
1191	.0291138	59.63944	
1192	.0420894	84.19099	
1193	.0490858	88.77351	
1194	.0291190	60.15119	
1195	.0430868	84.13826	
1196	.0291100	59.00190	
1197	.0421000	64.00181	
1198	.0440880	84.16261	
1199	.0291216	50.06294	

1200	.0291176	60.12770	or 0300001
1201	.0420894	84.19099	Reset time
1202	.0490899	89.13185	
1203	.0420890	84.18287	Reset exit
1204	.0491200	50.00075	Instr.
1205	.0421596	16.72346	
1206	.0491000	69.00139	
1207	.0081020	69.14435	
1208	.0421000	64.00181	
1209	.0440881	84.16464	
1210	.0490888	89.11723	
1211	.0330888	84.17875	Ag
1212	.0421399	36.13762	
1213	.0491000	69.00139	
1214	.0081020	69.14435	
1215	.0291197	60.16293	
1216	.0490887	89.11590	
1217	.0320887	84.17671	H
1218	.0421697	84.19707	
1219	.0491000	69.00139	
1220	.0081020	69.14435	
1221	.042100	64.00181	
1222	.0440898	84.19912	
1223	.0490885	89.11324	
1224	.0320885	84.17266	S
1225	.0421797	74.45885	
1226	.0491000	69.00139	
1227	.0081020	69.14435	
1228	.0421000	64.00181	
1229	.0440898	84.19912	
1230	.0470877	84.15655	
1231	.0490884	89.11191	
1232	.0330884	84.17064	MW
1233	.0421597	16.73098	
1234	.0491000	69.00139	
1235	.0081020	69.14435	
1236	.0421000	64.00181	
1237	.0440881	84.16464	
1238	.0490879	89.10526	
1239	.0380879	84.16053	Aw
1240	.0421497	26.31395	
1241	.0491000	69.00139	
1242	.0081020	69.14435	
1243	.0421000	64.00181	
1244	.0440881	84.16464	
1245	.0490875	88.99948	
1246	.0320875	84.15237	
1247	.0291300	40.00103	No
1248	.2700000	-69.23071	
1249	.0630000	88.00328	
1250	.0260985	79.26338	Time sub.

1251	.1700002	-69.11631	
1252	.1730200	-68.07214	
1253	.0260824	88.32036	
1254	.0421000	64.00181	
1255	.0410892	84.18692	
1256	.0432101	35.01621	
1257	.0430892	84.18694	
1258	.0490874	88.98619	θ≈g
1259	.1700002	-69.11631	
1260	.1730300	-67.18034	
1261	.0260824	88.32036	
1262	.0421000	64.00181	
1263	.0490873	88.97289	θ≈g
1264	.1700003	-69.11676	
1265	.1730100	-68.28855	
1266	.0260824	88.32036	
1267	.0421000	64.00181	
1268	.0410892	84.18692	
1269	.0490872	88.95960	I_1
1270	.0420874	84.15042	
1271	.0410873	84.14839	
1272	.0440887	84.17681	
1273	.0430872	84.14637	
1274	.0440888	84.17883	
1275	.0490868	88.90643	$q_g + I_1$
1276	.0290961	79.18914	
1277	.1700003	-69.11676	
1278	.1730200	-68.07214	
1279	.0260824	88.32036	
1280	.0421000	64.00181	
1281	.0410892	84.18692	
1282	.0440869	84.14030	
1283	.0490870	88.93302	I_T
1284	.1700000	-69.11541	
1285	.1730200	-68.07214	
1286	.0260824	88.32036	
1287	.0421000	64.00181	
1288	.0410892	84.18692	
1289	.0490871	88.94631	I_{TD}
1290	.0430870	84.14232	
1291	.0291184	60.14112	
1292	.1700001	-69.11587	
1293	.1730000	-69.11542	
1294	.0260824	88.32036	L_i
1295	.0421000	64.00181	
1296	.0410892	84.18692	
1297	.0420894	84.19099	$L_1 = 0$
1298	.0430849	83.99724	
1299	.0291100	59.00190	

1300	.0421598	16.73850	
1301	.0491000	69.00139	
1302	.0081020	69.14435	
1303	.0421000	64.00181	
1304	.0441397	36.13485	
1305	.0491396	40.87487	
1306	.0321396	36.13340	N_1
1307	.0421599	16.74603	
1308	.0491000	69.00139	
1309	.0081020	69.14435	
1310	.0421000	64.00181	
1311	.0441398	36.13624	
1312	.0491395	40.86577	
1313	.0381395	36.13205	N_2
1314	.0300001	88.01485	
1315	.0291248	50.18794	
1316	.0000700	.00000	

1390	.0000700	.00000	
1391	.0000700	.00000	
1392	.0000700	.00000	
1393	.0000700	.00000	
1394	.0000700	.00000	
1395	.0000700	.00000	
1396	.0000700	.00000	
1397	.0000300	51.10000	K_1
1398	.0000300	51.10000	K_2
1399	.0000700	.00000	

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G-15D
Prepared by ___
Date: ___
PROGRAM PROBLEM: Machine language subroutine for tabulation program
Line 05

				L	P	T or L_k	N	C	S	D	BP	NOTES
~~0~~	~~1~~	2	~~3~~			Shift 16 places left						
~~4~~	~~5~~	~~6~~	~~7~~			and add 0000080						
~~8~~	~~9~~	10	~~11~~	10		13	14	0	23	31		Clear Reg.
~~12~~	~~13~~	~~14~~	~~15~~	14		00	05	0	05	24		X → MQ
~~16~~	~~17~~	~~18~~	~~19~~	05		32	03	1	26	31		Shift MQ left 16 bits
~~20~~	~~21~~	~~22~~	~~23~~	03		01	06	0	05	28		0000080 → AR
~~24~~	~~25~~	~~26~~	27	06		08	07	0	24	29		AR+MQ → AR
~~28~~	~~29~~	~~30~~	~~31~~	07		00	12	0	28	10		X → 1000
~~32~~	~~33~~	~~34~~	~~35~~			Add 0000080						
~~36~~	~~37~~	~~38~~	~~39~~	20		00	11	0	05	21		X → 21:00
~~40~~	~~41~~	~~42~~	~~43~~	11		04	08	0	05	20		00000ZZ → 20:00
~~44~~	~~45~~	46	~~47~~	08		16	17	0	30	28		Extract → AR
~~48~~	~~49~~	50	51	17		01	07	0	05	29		
52	53	54	55									
56	57	58	59			Exit to Intercom						
60	61	62	63	12		12	12	0	28	31		Test for ready
64	65	66	67	13		15	15	0	29	31		Test for overflow
68	69	70	71	15	u	16	u7	0	06	05		line 06 → 05
72	73	74	75	16	u	17	u7	0	06	05		line 06 → 05
76	77	78	79									
80	81	82	83									
84	85	86	87			Constants						
88	89	90	91	00			X					temporary storage
92	93	94	95	04		00000ZZ						
96	97	98	99	01		0000080						
u0	u1	u2	u3	42		95Y9ZX0						=ER.
u4	u5	u6		09		0000001						
				23		0000100						

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Prepared by ____________
Date: ____________
PROGRAM PROBLEM: ____________
Line ____________

	L	P	T or L_k	N	C	S	D	BP	NOTES
0 1 2 3									
4 5 6 7			Back up magnetic tape						
8 9 10 11			to first file code						
12 13 14 15	18		18	18	0	28	31		Test for ready
16 17 18 19	19		39	12	1	04	31		Search backward
20 21 22 23			Type Heading						
24 25 26 27	21		21	21	0	28	31		Test for ready
28 29 30 31	22	u	23	49	0	18	19		18-19
32 33 34 35	49	u	00	24	0	29	19		clear 19:49-19:u7
36 37 38 39	24		26	28	0	08	31		Process line 19 - by 4 words
40 41 42 43	28		30	25	0	00	31		
44 45 46 47	25		25	25	0	28	31		
48 49 50 51	26		u7	29	0	19	27		Test u7 = 0
52 53 54 55	29		40	24	0	00	00		u7 ≠ 0
56 57 58 59	30		35	12	4	09	31		Type Heading
60 61 62 63			Reading Magnetic Tape						
64 65 66 67	31		31	31	0	28	31		Test for ready
68 69 70 71	32		34	27	1	13	31		Read mag. tape
72 73 74 75	35		35	45	0	28	31		Test for ready
76 77 78 79	36		36	37	1	29	28		zero → AR
80 81 82 83	37	u	38	39	1	19	29		Σ19
84 85 86 87	39		40	40	0	28	27		AR=0?
88 89 90 91	40	u	41	12	0	19	18		AR=0, 19→18
92 93 94 95	41		42	34	0	05	28		AR≠0, ER→AR
96 97 98 99	34		36	43	4	08	31		Type ER
u0 u1 u2 u3	43		43	43	0	28	31		Test for ready
u4 u5 u6	44		00	40	0	00	00		

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PROGRAM PROBLEM: ____________ Line ________

				L	P	T or Lk	N	C	S	D	BP	NOTES
0	1	2	3									
4	5	6	7	27		23	35	1	05	28		
8	9	10	11	45		09	33	3	05	29		
12	13	14	15	33		35	47	0	22	31		test for sign
16	17	18	19	47		00	35	0	00	00		+
20	21	22	23	48		50	38	0	00	31		- set ready.
24	25	26	27	38		40	12	0	16	31		Halt.
28	29	30	31									
32	33	34	35									
36	37	38	39									
40	41	42	43									
44	45	46	47									
48	49	50	51									
52	53	54	55									
56	57	58	59									
60	61	62	63									
64	65	66	67									
68	69	70	71									
72	73	74	75									
76	77	78	79									
80	81	82	83									
84	85	86	87									
88	89	90	91									
92	93	94	95									
96	97	98	99									
u0	u1	u2	u3									
u4	u5	u6										