A DIGITAL PROGRAM FOR DESIGNING MINIMUM WEIGHT FUEL CELL POWER SYSTEMS

PREPARED UNDER CONTRACT NAS 8-5392

by

RESEARCH DIVISION

ALLIS-CHALMERS

MILWAUKEE, WISCONSIN 53201

JUNE 1965

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Milwaukee, Wisconsin

Author: Ramesh R. Desai

Programmers: Jayesh Dalal and
Paul Callen

ABSTRACT

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This document presents an IBM-704 FORTRAN program to design minimum weight fuel cell power systems. For a selected power profile, i.e., power versus mission time, and voltage requirements; this program provides the significant parameters of a system. In addition, it permits computing design parameters for a combined fuel cell-battery system, where batteries supply power for peak loads.

Approved: ______________________

J. R. Hurley, Manager
Systems Research and
Development Section

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1.0 INTRODUCTION

Determination of a minimum weight fuel cell power system design requires the solution of a complex system of equations. Therefore, a digital computer program has been developed to improve accuracy and conserve time. This document explaining methods of solution, and use of the program, was written to aid in the optimization of a fuel cell power system with respect to weight.

It should be noted that the subsystems are optimized, i.e., for a given problem both the fuel storage and heat sink subsystems are designed for minimum weight. Several methods for designing these subsystems are included in the program.

2.0 DESCRIPTION OF THE PROGRAM

Among devices presently under consideration for supplying auxiliary power to space vehicles, fuel cells are gaining more and more prominence. A system consisting of fuel cells and batteries presents some interesting advantages; fuel cells would supply the normal or base power, and the batteries would supply part of the peak power.

An auxiliary power system for space vehicles is weight limited. This report presents a general method for minimizing the weight of a combined fuel cell and battery system, and describes a digital computer program for performing the necessary calculations. Basically, the method consists of determining the minimum weight when fuel cells are the only source of power and then checking whether the use of storage batteries leads to further weight reduction.

The basic power system shown in Figure 1 contains a fuel cell stack, reactant supply, heat sink, and auxiliaries. The weight of each of the first three items can be expressed in terms of a single independent parameter. The most convenient variable is the individual cell operating voltage.

From the appropriate expressions for subsystem weights, that value of voltage can be found for which the total system weight is a minimum. The minimum system weight is not necessarily coincident with minimum fuel cell, reactant, or heat sink weight. Hence, the weight of a complete power system must be minimized as a whole. Once the minimum weight of a pure fuel cell system is known, one can determine whether the use of batteries would further reduce this weight. In these analyses, the amount of power provided by batteries is gradually increased until the weight of the combined system reaches a minimum.

When power requirements are constant and continuous, and when voltage is a linear function of power density, simple explicit solutions for the optimum operating voltage can be obtained. Most space vehicles, however, require several levels of auxiliary power during a mission. Typical profiles show a large difference between peak and minimum power levels and in the duration of these levels. Additionally, voltage must be regulated within specified limits throughout the load profile. Finally, the voltage-power density relationship is generally non-linear, further complicating an analytical solution of the minimum weight problem.

In view of these complications, this problem was programmed for a solution by a digital computer. The program can determine:

- Area of cells
- Number of cells
- Operating voltage for each power level
- Operating current at each power level
- Rate of heat dissipation
- Total heat load
- Rate of reactant consumption
- Total reactant consumption
- Optimum cell voltage
- Optimum system weight and system weights at different cell voltages
- Weights of each subsystem at optimum and other cell voltages
- Fuel cell stack weight and reliability.

2.1 Analysis

The analysis is conducted in two stages. First, the minimum weight of a system using only fuel cells is computed. Then, the proportion of load to be assigned to batteries is determined, and finally the weight of the combined system is calculated.

2.1.1 Analysis to Determine the Minimum Weight of a System Using Fuel Cells Only

The system weight is computed for several values of individual cell voltage, V. The optimum system is selected on the basis of minimum weight.

$$W_T = W_C + W_A + W_F + W_R$$

Where W_T, W_C, W_A, W_F, and W_R are the weights of total system, stack, auxiliaries, reactant storage and supply, and radiator, respectively.

The weight of the stack, W_C, is based on the cell area A and cell constant, S_C.

$$W_C = AS_C = \frac{PS_C}{V\,J}$$

The weight of the reactant storage and supply subsystem, W_F, is based on the energy supplied by fuel cells. It is computed for three different methods of fuel storage:

(1) Supercritical Method of Storage [1]

$$W_F = 30.29 + \left[\frac{11.3\ (1+a)}{F} \sum_{i=1}^{S} \frac{P_i\, t_i}{V_i} \right]$$

$$+ (0.00345\ T) \left[\frac{(1+a)}{F} \sum_{i=1}^{S} \frac{P_i\, t_i}{V_i} \right]^{2/3}$$

(2) Subcritical Method of Storage [1]

$$W_F = 30.29 + \left[\frac{9.7\ (1+a)}{F} \sum_{i=1}^{S} \frac{P_i\, t_i}{V_i} \right]$$

$$+ (0.00345\ T) \left[\frac{(1+a)}{F} \sum_{i=1}^{S} \frac{P_i\, t_i}{V_i} \right]^{2/3}$$

(3) Empirical Method [2]

$$W_F = \frac{A_H + 7.95\ A_o\ (1+a)}{F} \sum_{i=1}^{S} \frac{P_i\, t_i}{V_i}$$

Where P_i, t_i, and V_i, are power, time and voltage, respectively, corresponding to the ith period of the power profile. S is the total power profile and F is Faraday's constant.

The weight of the heat sink subsystem, W_R, is based on the heat generated by the fuel cell. It is computed for four different kinds of radiators.

(1) Flat Radiator With No Environmental Heat Input [3]

$$W_R = \frac{55.6\ (P_{PR})^{1.533}\ (T_T)^{0.5}}{(1 - R_{PS})^{0.5}\ (T_C - 220)^{3.57}}$$

(2) Cylindrical Radiator With No Environmental Heat Input [4]

$$W_R = \left[(0.0001138\ P_{PR})^{W_1}\right] (W_2) + (W_3)\ (W_4)\ (W_6)$$

Where:

$$W_1 = (0.906)\ (0.0833\ T_T)^{W_5}$$

$$W_5 = 0.015\ (0.0001138\ P_{PR})^{0.1974}$$

$$W_2 = \left[27.3 + (0.0833\ T_T)^{0.3065}\right]\left[(0.04166\ T_T)^{0.0314}\right]$$

$$W_3 = \left[\frac{0.4343\ (\text{Ln}\ R_{PS} - \text{Ln}\ 0.99)}{2.82}\right]^{1.07} - 34.6$$

$$W_4 = (0.0001141\ T_T)^{0.2467}$$

$$W_6 = (0.00003412\ P_{PR})^{1.227}$$

(3) Empirical Method[5]

$$W_R = \frac{(1.975 \times 10^9)\ (P_{PR})\ (K_R)}{e\ (T_C^4 - T_S^4)}$$

(4) Flat Radiator with Provision for Environmental Heat Input[6, 7]

$$W_R = C_1\ (0.0043\ P_{PR})^{C_2} \left(\frac{T_T}{24}\right)^{C_3} \left(\frac{0.01}{1 - R_{PS}}\right)^{C_4} \left(\frac{559.8}{T_C}\right)^{C_5}$$

Where:

$$C_1 = 0.70935$$

$$C_2 = 1.56 + (2.15 \times 10^{-6})\ P_{PR} + \frac{2 \times 10^{-6}}{1 - R_{PS}}$$

$$+ (1.667 \times 10^{-5})\ T_T$$

$$C_3 = 0.208 \left(\frac{0.01}{1 - R_{PS}}\right)^{C_6} + (2.0833 \times 10^{-5})\ T_T$$

$$C_4 = 0.2088 + 0.000521 \left(\frac{0.01}{1 - R_{PS}}\right)^{1.04}$$

$$C_5 = -31.6 + \frac{8.6 \times 10^{-5}}{1 - R_{PS}} + (2.917 \times 10^{-5})\ T_T$$

$$+ \frac{29389.5}{T_C} + (1.29 \times 10^{-4})\ P_{PR}$$

$$C_6 = 0.20808 - \frac{4.08 \times 10^{-6}}{1 - R_{PS}}$$

In all the equations for W_R, P_{PR} can be expressed as below:

$$P_{PR} = (1 - 0.67\ V)\ (P_{max}) + \frac{P_p}{0.67} - \frac{0.0002165\ P_{max}\ Q_W}{V}$$

Where P_{max} is the maximum power supplied by the fuel cells, T_T is the mission duration, and P_p is the total parasitic power.

The weight of auxiliaries, W_A, is based on the maximum power supplied by the fuel cells.

$$W_A = K + P_{max}\ S'_A$$

The values of individual cell voltage and number of cells in a fuel cell stack are so selected that the stack voltage is always within specified limits. Hence, a particular cell voltage that yields minimum system weight will not be accepted if a corresponding value for number of cells cannot be found to meet the stack voltage regulation limits. For example, let the cell voltage for minimum weight be 0.8 volt, corresponding to a maximum power level of 2,000 watts. Also, let the value of minimum power be 200 watts and the regulation requirement be 28 ± 2 volts. Cell voltage corresponding to minimum power will be 1.021 volts. At minimum voltage, 33 cells are required; at maximum voltage, 29 cells. This indicates that voltage regulation is not possible for a cell voltage of 0.8, and $V = 0.8$ is not acceptable. For P_{max}, V should be at least 0.929 for these requirements. The fuel cell system is thus at minimum weight and within voltage regulation limits.

2.1.2 Analysis to Size a Fuel Cell-Battery Combination for Minimum Weight

This minimization is obtained by an iterative procedure. At each step, a slightly larger fraction of the peak power is allocated to the battery. A check is then made to determine whether the secondary battery can be recharged during normal power demand periods. The process continues until the weight of the combined system reaches a minimum.

A summary of the procedure for a simple profile with two power levels, shown in Figure 2, is given below:

Step 1 Divide $(P_{max} - P_{min})$ into N equal intervals with

$$dP = \frac{P_{max} - P_{min}}{N}$$

where, P_{min} is the minimum power supplied by fuel cells, and P_{max} is the maximum power supplied by fuel cells.

Step 2 Calculate the optimum weight W_o of the system when $P_{fc\ max}$, maximum power supplied by fuel cells, is equal to P_{max} by using the analysis given in 2. 1. 1.

Step 3 Set $i = 1$

Step 4 Reduce P_{max} by idP. Go to Step 5 in the case of a rechargeable battery. Go directly to Step 28 in the case of a primary battery.

Step 5 Determine first profile segment where battery power will be needed; segment number two in this case.

Step 6 Determine next load segment where battery power will be needed; segment number four in this case.

Step 7 Determine available charging time, T_A, between above two peaks.

Step 8 Calculate the discharging current, I_{BD}.

$$I_{BD} = \frac{i\ (dP)}{(V_{BMIN})\ (E_{RD})}$$

Step 9 Set the depth of battery discharge, α, equal to its maximum allowable value, α_{max}, which is an input quantity. This is done in an attempt to use a battery of as low a capacity as possible.

Step 10 Calculate C, capacity of the battery.

$$C = \frac{I_{BD} \, t_d}{\alpha}$$

Also, obtain the corresponding energy density, R_D, by referring to the table of C versus R_D.

Step 11 Set $\left(\frac{I_{BC}}{C}\right) = \left(\frac{I_{BC}}{C}\right)_{MIN}$

This is done to increase the charging efficiency of battery.

Step 12 Calculate the charging current, I_{BC}.

$$I_{BC} = C\left(\frac{I_{BC}}{C}\right)$$

Step 13 Calculate the current corresponding to the power for load segment three. (The segment during which battery charging will take place.)

$$I_{LOAD} = \frac{P_{LOAD}}{V_{P\,LOAD}}$$

Step 14 — Since fuel cells will have to supply both charging and load currents, total current supplied by fuel cells, I_{FC}, will be the sum of these.

$$I_{FC} = I_{BC} + I_{LOAD}$$

Step 15 — Calculate J_{FC}, the current density corresponding to Step 14.

$$J_{FC} = \frac{I_{FC}}{\text{Cell Area}}$$

Calculate corresponding power density, VJ_{FC}, by referring to the V-J table, and then calculate power, P_{charge} (P_{ch})

$$P_{ch} = VJ_{FC}\ \text{(cell area) (Number of cells)}$$

Step 16 — Compare P_{ch} with P_{FCMX}. If P_{FCMX} is less than P_{ch}, combine load profile segment two and four. Then go back to Step 5 to determine whether the total time for recharging (now the combined segments three and five) can recharge the battery. Continue this process until P_{FCMX} is equal to or greater than P_{ch}. Then continue with Step 17.

Step 17 — Calculate required charging time, T_c

$$T_c = \frac{\alpha}{(E_{RC})\ (E_C)\ \left[\frac{I_{BC}}{C}\right]}$$

This formula is valid if the battery can be recharged at constant current. However, if the maximum allowable charging voltage V_{MAXB} is reached during charge, it is necessary to reduce the charging current so that V_{MAXB} is not exceeded. Should this occur the charge time T_c will be computed by subroutines SUBA and SUBA1.

Step 18 Compare T_c with the available charging time, T_A. If T_c is greater than T_A, increase $\left(\frac{I_{BC}}{C}\right)$ by $\Delta\left(\frac{I_{BC}}{C}\right)$ and repeat steps 12 through 17. Again compare T_c with T_A and if T_c is greater than T_A, continue increasing $\left(\frac{I_{BC}}{C}\right)$ until it has reached the value $\left(\frac{I_{BC}}{C}\right)$max. If T_c is still greater than T_A, start reducing α by $\Delta\alpha$ until α becomes α min. If T_c is still greater than T_A, combine two adjacent power peaks (segment 2 and 4 in this case) and repeat this process until T_c is equal to or less than T_A. (See listing of subroutine SUBP.)

Step 19 Repeat Steps 2 through 18 for the rest of the power profile. Compare the required capacities of the battery for each peak, and thus determine the maximum capacity of the battery. Recalculate the depth of discharge for each peak.

Step 20 Modify the original power profile by using the calculated charging power, P_{charge}.

Step 21 Calculate the optimum weight, W_{fc1}, for the modified power profile by using the method given in 2.1.1.

Step 22 Corresponding to the recalculated values of α and $\left(\frac{I_{BD}}{C}\right)$, determine V_{min} by referring to the discharge table for the battery.

Step 23 Calculate, n the number of cells required in the battery.

$$n = \frac{V_{BMIN}}{V_{min}}$$

If n is not an integer, then use the next integer as the value for n.

Step 24 Calculate the maximum voltage for the battery consisting of n cells.

$$V_{BMAX} = nV_{maxB}$$

Step 25 Calculate W_{Ri}, the weight of voltage regulator

$$W_{Ri} = (V_{BMAX})\ (I_{BD})\ (0.005)$$

Step 26 Calculate the weight of rechargeable battery, W_{RBi}.

$$W_{RBi} = \frac{(dP)(t_d)}{\propto R_D}$$

Step 27 Calculate W_{TRBi}, total weight of a system using both fuel cells and a rechargeable battery.

$$W_{TRBi} = W_{fci} + W_{RBi} + W_{Ri}$$

Go to Step 29.

Step 28 Calculate W_{TPBi}, total weight of a system using both fuel cells and a primary battery.

$$W_{TPBi} = (dP)\ (t_d)\ (B) + (W_{fci})$$

Step 29 Repeat Steps 4 through 28 for $i = 2, 3, 4,$ and so on up to $i = n$. The optimum combination is the one that weighs the least.

This method has been extended in the computer program to a multi-step power profile with a maximum of fifty steps.

3.0 EXPLANATION OF THE TERMS USED IN THE PROGRAM

The following is an explanation of the terms and symbols used in the program. Typical values of some of the terms are provided as an aid to the use of the program.

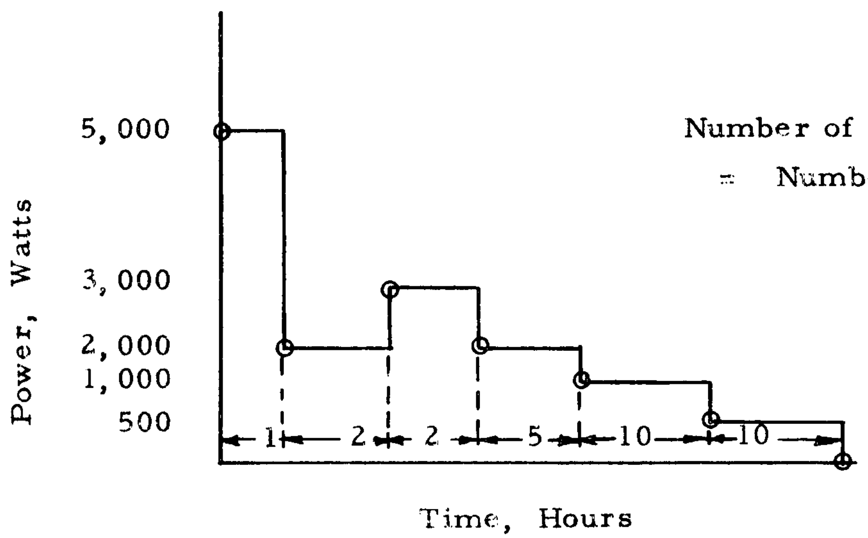
3.1 Terms Used in the Input

Except for the power profile, all terms used in preparing the input are printed on Page one of the output. Input power profile is printed on output Page two.

3.1.1 Power Profile

NOPROF = Number of points on power profile.

Time and power values for the profile. This can best be explained by the following example.



Number of points on the power profile = Number of power stages + 1

In the above power profile, there are six power stages and hence seven points. Each point to be considered in the preparation of input is circled. The card input should be prepared as follows

T	P	T	P	T	P
0	5,000	1	2,000	3	3,000
5	2,000	10	1,000	20	500
30	0				

Where P is power in watts and T is time in hours. Thus, the points at which both the power and time change should be listed in the input. Note that number of points on the power profile should not be greater than fifty.

3.1.2 Voltage-Current Density Curve of the Fuel Cell

NXP is the number of values selected to represent the V-J curve, where V is the individual cell voltage in volts and J is the current density of the cell in amperes per square foot. Note that a product of V and J, power density of the cell, is tabulated on page one of the output. Also note that the maximum allowable value of NXP is thirty.

3.1.3 Explanation of Constants and Nomenclature

The following pages contain the explanation of constants and nomenclature.

Equations	Computer Program	Definition	Units	Used For	Typical Value
S_C	SC	Cell constant	lbs/sq. ft.	Weight of cell	7.0
S'_A	SAP	Auxiliary constant	lb/watt	Variable part of weight of auxiliaries	0.00548 to 0.00748
K	CON	Auxiliary constant	lbs	Constant part of weight of auxiliaries	14.5 to 16.5
-	VOC	Open-circuit cell voltage	volt	Upper cell voltage limits	1.10
-	VAB	Minimum cell voltage	volts	Lower cell voltage limits	0.7
-	PPC	Constant parasitic power	watts	Parasitic power	60
-	PPV	Variable parasitic power	watts/watt	Variable part of parasitic power	0.005 to 0.01
a	ADD	Additional reactants for residual and safety factor	-	Weight of reactants and reactant storage packages	0.12
B	BATT	Battery constant for primary batteries	lb/watt-hr	Weight of primary batteries	0.02
I_{BD}	FIBD	Battery discharge current	Amperes	Capacity of rechargeable batteries	0.1 to 200

Equations	Computer Program	Definition	Units	Used For	Typical Value
T_C	TC	Average radiator coolant temperature	° R	Weight of radiator	560° R to 640° R
Q_W	QW	Heat content of one pound of evaporated water	BTU/lb	Weight of Radiator	1100
-	SP2	Spare Location	-	Future Use	-
$\alpha_{max.}$	ALFMX	Maximum depth of battery discharge	-	Depth of discharge	0.75
$\alpha_{min.}$	ALFMN	Minimum depth of battery discharge	-	Depth of discharge	0.01
$\left(\frac{I_{BC}}{C}\right)_{min}$	BCMIN	Minimum ratio of charging current to the capacity of the battery	hr^{-1}	Charging current	0.01 to 0.1
$\Delta\left(\frac{I_{BC}}{C}\right)$	DBC	Arbitrarily selected increment in the value of the ratio of charging current to the capacity of the battery	hr^{-1}	Charging current	0.01 to 0.1
$\left(\frac{I_{BC}}{C}\right)_{max}$	BCMAX	Maximum ratio of charging current to the capacity of the battery	hr^{-1}	Charging current	0.50 to 0.75
E_C	EC	Charging efficiency of the battery	-	Charging current and charging time	0.90

Equations	Computer Program	Definition	Units	Used For	Typical Value
E_{RC}	ERC	Charging efficiency of the regulator	-	Charging current and charging time	0.90
E_{RD}	ERD	Discharging efficiency of the regulator	-	Discharge current of the battery	0.90
-	SP3	Spare location	-	Future Use	-
-	XNAM	Number of operating fuel cell stacks	-	Reliability and weight of fuel cell subsystems	1 to 4
-	FR	Failure rate of fuel cell stack	Failure/hr	Reliability of fuel cell subsystem	0.000025 to 0.000040
R_{PS}	RPS	Radiator probability of survival	-	Weight of radiator	0.99 to 0.9999
-	XNRM	Number of redundant fuel cell stacks	-	Reliability and weight of fuel cell subsystem	0 to 2
N	FN	Total number of increments into which the difference between the maximum and minimum positive power is divided	-	Portion of load assigned to batteries	2 to 25
$\Delta \alpha$	DALFA	Increment in the value of the depth of discharge	-	Depth of discharge	0.01 to 0.25

Equations	Computer Program	Definition	Units	Used For	Typical Value
-	SP4	Spare location	-	Future use	-
-	VMAXC	Maximum fuel cell stack voltage	volts	Operating characteristics of fuel cell subsystem	30
-	VMINC	Minimum fuel cell stack voltage	volts	Operating characteristics of fuel cell subsystem	26
V_{MAXB}	VMAXB	Maximum rechargeable battery voltage per cell	volts	Weight of voltage regulator	1.55 for Ag-Cd batteries
V_{BMIN}	VBMIN	Minimum battery voltage for all cells	volts	Discharge current, no. of battery cells, and weight of voltage regulator	20 to 28
-	SP5	Spare location	-	Future use	-
-	SP6	Spare location	-	Future use	-
-	SP7	Spare location	-	Future use	-
A_H	TKH	$\frac{\text{Weight of hydrogen + tankage}}{\text{Weight of hydrogen}}$	lbs/lb	Weight of reactant supply and storage package	2.5
A_O	TKO	$\frac{\text{Weight of oxygen + tankage}}{\text{Weight of oxygen}}$	lbs/lb	Weight of reactant supply and storage package	1.5

Equations	Computer Program	Definition	Units	Used For	Typical Value
e	EMISS	Emissivity of radiator material	-	Weight of radiator	0.9
T_S	TS	Radiator sink temperature	°R	Weight of radiator	430
K_R	CONKR	$\frac{\text{Weight of radiator}}{\text{sq. ft. of fin area}}$	lbs/sq. ft.	Weight of radiator	0.5

3.1.4 List of Control Characters

NPP-
- 0- All the output pages will be printed.
- 1- Output page five and six will not be printed.

LBT-
- 0- Only consider fuel cells.
- 1- Consider fuel cell-rechargeable battery combination.
- 2- Consider fuel cell-primary battery combination.
- 3- Consider both fuel cell-rechargeable battery and fuel cell-primary battery combinations.

LFL-
- 0- Calculate weight of reactants only.
- 1- Calculate weight of reactants together with the weight of supercritical storage and supply system.
- 2- Calculate weight of reactants together with the weight of subcritical storage and supply system.
- 3- Calculate weight of reactants and tankage using an empirical method.

LRD-
- 0- Do not consider a heat sink subsystem in the optimization.
- 1- Calculate the weight of heat sink subsystem using a flat radiator and not considering heat input from the environment.
- 2- Calculate the weight of heat sink subsystem using a cylindrical radiator, and not considering heat input from the environment.
- 3- Calculate the weight of heat sink subsystem using an empirical relationship.
- 4- Calculate the weight of heat sink subsystem using a flat radiator and considering heat input from the environment.

IBAT-
- 1- Consider Ni-Cd rechargeable batteries
- 2- Consider Ag-Cd rechargeable batteries
- 3- Consider Ag-Zn rechargeable batteries

LV 1- Effect of very small change in cell voltage due to modification of power profile is considered. Total system weight might change by less than 0.5 percent.

0- Effect of very small change in cell is not considered. This reduces the computer time by approximately 50 percent.

LSPI- Spare location

QW- 1100- System weight when water is not collected.

0- System weight when entire amount of generated water is collected.

110- System weight when ninety percent of the generated water is collected.

3.2 Terms Used on Output Page TWO

This page presents the input power profile.

3.3 Terms Used on Output Page THREE

Stage: The number of increments of power supplied by batteries.

0- All the power supplied by fuel cells.

1- Portion of power equal to ΔP is supplied by the batteries.

2- Portion of power equal to $2 \Delta P$ is supplied by the batteries.

N- Portion of power equal to $N (\Delta P)$ is supplied by the batteries.

VOPT- Optimum cell voltage for the fuel cell system corresponding to the maximum power supplied by fuel cells, volt.

WT TOTAL Total system weight, pounds.

WT CELL Weight of fuel cell subsystem, pounds.

WT AUX Weight of auxiliaries, pounds.

WT FUEL Weight of reactants together with the weight of reactant storage and supply package, pounds.

WT RAD	Weight of heat sink subsystem, pounds
WT BAT	Weight of batteries, pounds
NO CELL	Number of individual cells in a fuel cell stack
CELL AREA (A)	Area of one cell, square feet
WT REG	Weight of voltage regulator, pounds.

3.4 Terms Used on Output Page FOUR

All the values presented on this page are for the optimum combination of rechargeable batteries and fuel cells. Explanation of some of the terms is given in input and output page Three. Rest of the terms are described below.

DISRAT-	Ratio of discharge current to the capacity of the battery, hr^{-1}
TX, PX-	These represent the modified power profile that is supplied by fuel cells. Power profile had to be modified to include the effect of recharging the batteries, TX is time in hours and PX is power in watts.
C-	Capacity of the batteries, ampere-hours
RD-	Energy density of the batteries, $\frac{\text{watt-hours}}{\text{pound}}$
BAT-	Number of individual batteries required.
VBMAX-	Maximum value of the total battery voltage.

3.5 Terms Used on Output Page FIVE

This page presents the system weight tabulation for twenty-five different values of individual fuel cell voltage between VAB and VOC when NPP is zero. No output will be presented on this page if NPP is one.

VIN-	Individual cell voltage corresponding to the maximum power supplied by the fuel cells, volts
V2N-	Individual cell voltage corresponding to the minimum positive power supplied by the fuel cells, volts.

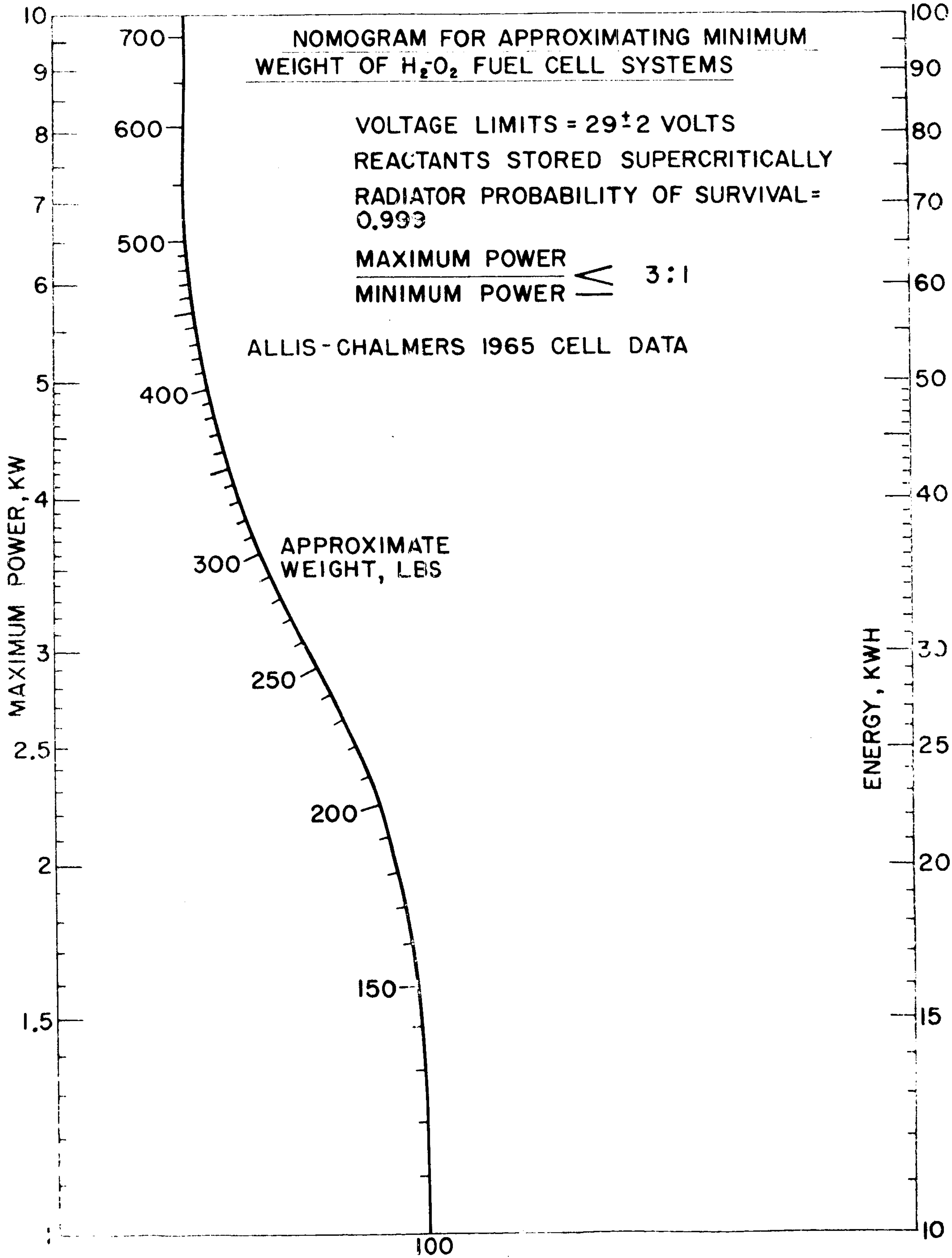
WT, WTC, WTAUX, WTF, WTR, WTRB, and WTREG have the same meaning as WT TOTAL, WT CELL, WT AUX, WT FUEL, WT RAD, WT BAT, and WT REG respectively of output page THREE.

3.6 Terms Used on Output Page SIX

This page will be printed only if NPP = 0

$$\text{Module weight} = \text{Weight of a single fuel cell module} = \frac{\text{weight of cells} + \text{weight of auxiliaries}}{\text{total number of modules}}$$

T	= Duration of power stage, hours
PFC	= Power supplied by the fuel cell system, watts
V MOD	= Stack voltage, volts
I/A	= J = current density, amperes per square foot
I	= Stack current, amperes
PW	= Waste heat to be removed from a stack, watts
WH_2	= Stoichiometric rate of hydrogen consumption for a stack, pounds per hour
WO_2	= Stoichiometric rate of oxygen consumption for a stack, pounds per hour
SUMT	= Total mission duration, hours
SUM PEC*T	= Energy supplied by the fuel cells, watt-hours
SUM PW*T	= Total waste heat removed from a stack, watt hours
SUM WH*T	= Total hydrogen consumed by a stack, pounds
SUM WO*T	= Total oxygen consumed by a stack, pounds.


NOMOGRAM FOR APPROXIMATING MINIMUM WEIGHT OF H_2-O_2 FUEL CELL SYSTEMS
VOLTAGE LIMITS = 29 ± 2 VOLTS
REACTANTS STORED SUPERCRITICALLY
RADIATOR PROBABILITY OF SURVIVAL= 0.993
MAXIMUM POWER / MINIMUM POWER ≤ 3:1
ALLIS-CHALMERS 1965 CELL DATA
APPROXIMATE WEIGHT, LBS
700
600
500
400
300
250
200
150
100
MAXIMUM POWER, KW
10
9
8
7
6
5
4
3
2.5
2
1.5
1
ENERGY, KWH
100
90
80
70
60
50
40
30
25
20
15
10

4.0 CONCLUSIONS

This program will calculate the minimum weight of fuel cell systems supplying power within set voltage limits. Nomograms on the following pages approximate the minimum system weight for various energy and power levels. The weights are determined on the basis of present Allis-Chalmers capabilities, a supercritical reactant storage, a radiator with a 0.999 probability of survival, and a voltage regulation requirement of 29 ± 2 volts.

Minimum system weight can be further reduced by using either primary or rechargeable batteries to supply a portion of peak power. The reduction in weight can be fifty percent or more if the peak power is four to five times the base load. Rechargeable batteries should be used if the peaks occur repeatedly. Percentage weight savings[12] that can be obtained under an ideal set of conditions by using rechargeable batteries are presented in Figures 7, 8, and 9. These ideal conditions are:

(1) A sufficient charging time is available during low level portions of the load profile.

(2) The power supplied by the fuel cells during any interval of time plus the power required to recharge batteries is always less than or equal to the maximum power supplied by fuel cells.

(3) Battery weight is 0.04 pounds per watt hour.

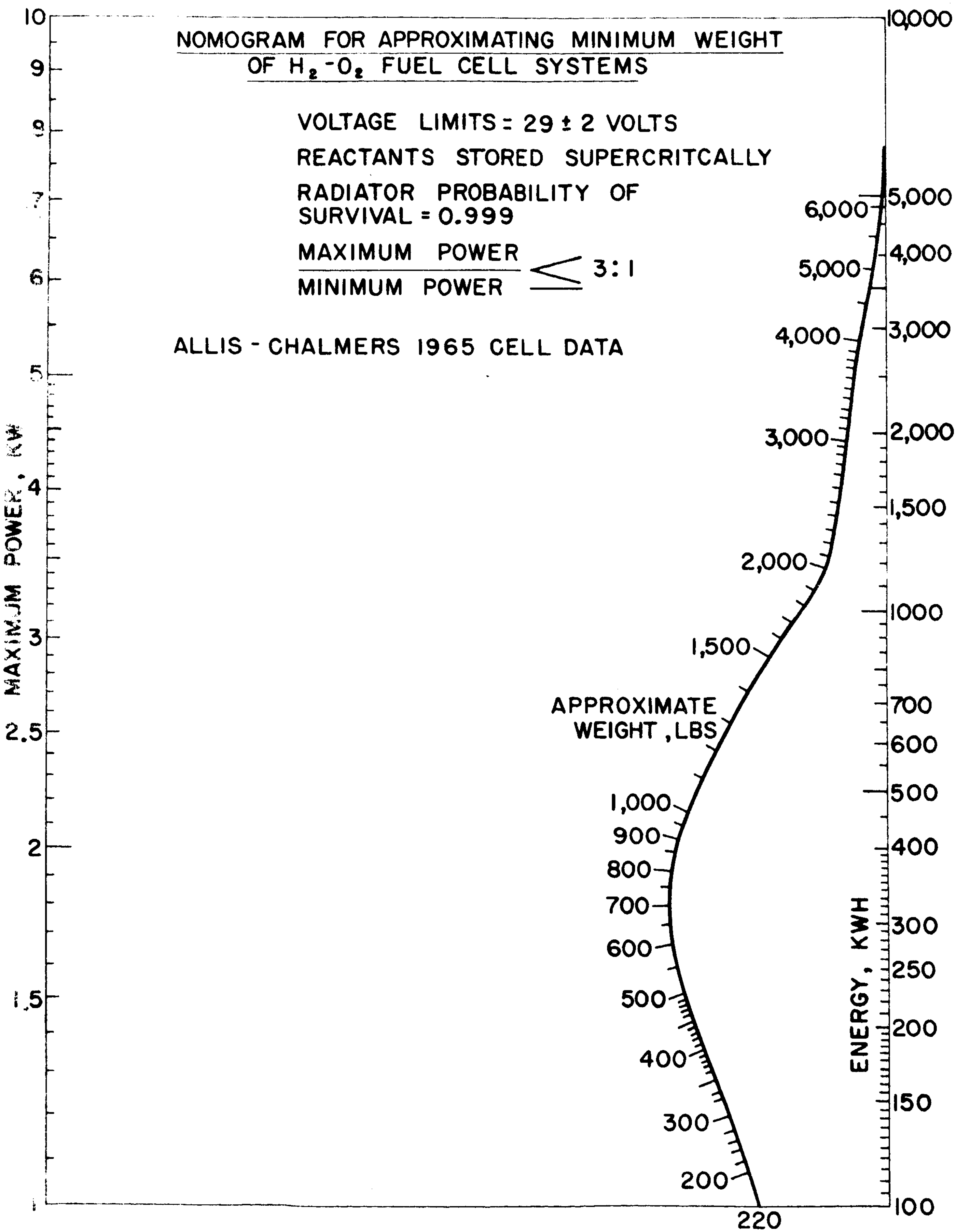
(4) Required charging current is less than maximum specified charging current.

(5) Charging and discharging efficiencies are equal to one.

(6) Weight of the voltage regulator is zero.

(7) The system will always stay within the voltage regulation limits regardless of the depth of discharge.

(8) Fuel cells must be capable of recharging batteries.


NOMOGRAM FOR APPROXIMATING MINIMUM WEIGHT OF H_2-O_2 FUEL CELL SYSTEMS
VOLTAGE LIMITS = 29 ± 2 VOLTS
REACTANTS STORED SUPERCRITCALLY
RADIATOR PROBABILITY OF SURVIVAL = 0.999
$\frac{\text{MAXIMUM POWER}}{\text{MINIMUM POWER}} \leq 3:1$
ALLIS - CHALMERS 1965 CELL DATA
MAXIMUM POWER, KW
APPROXIMATE WEIGHT, LBS
ENERGY, KWH
10
9
6
5
4
3
2.5
2
1.5
10,000
5,000
4,000
3,000
2,000
1,500
1000
700
600
500
400
300
250
200
150
100
6,000
5,000
4,000
3,000
2,000
1,500
1,000
900
800
700
600
500
400
300
200
220

5.0 REFERENCES

1. The Cryhocycle, Sundstrand Aviation - Denver, A Division of Sundstrand Corporation.

2. Private Communication

3. Investigation of a 3 KW Stirling Cycle Solar Power System, Volume VII, WADD-TR-61-122, Flight Accessories Laboratory, Wright-Patterson Air Force Base, Ohio, March 1962.

4. Optimization of a Non-Condensing Cylindrical Radiator (With Modified Penetration Criteria). Report H-81. Prepared by Harrell Stovall of Allison Division of General Motors Corporation, Indianapolis, Indiana, February 20, 1963.

5. Private Communication

6. Digital Programs for Establishing Steady-State Space Radiator Performance, AST-TDR-63-722, Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, October 1963.

7. Research and Development of Open Cycle Fuel Cells, NAS 8-5392-QPR-003, Third Quarterly Report, Research Division, Allis-Chalmers Manufacturing Company, June 15, 1965.

8. Eagle-Picher Company, Chemical and Metal Division, Personal Communication, November 18, 1964.

9. Direct Energy Conversion Operation, 63 DE 16, Quarterly Report Number Five of Contract NO_W 62-0984-D, General Electric Company, August 30, 1963.

10. Gulton Industries Incorporated, Alkaline Battery Division, personal communication, September 10, 1964.

11. Yardney Electric Corporation, personal communication, November 19, 1964.

12. Research and Development of Open Cycle Fuel Cells, NAS 8-5392-QPR-002, Second Quarterly Report, Research Division, Allis-Chalmers Manufacturing Company, March 15, 1965.

6.0 APPENDIX A

Included in this appendix are a flow diagram, a listing of the main program, sub-routines, and a table identifying error messages for the program.

6.1 Flow Diagram

Read Input Data

↓

Print Input Data (Page 1 and 2)

↓

Calculate the weight of the system when all of power is supplied by the fuel cells. (Subroutine S BQ)

Total Weight = weight of cell + weight of auxiliaries + weight of fuel storage + weight of radiator.

↓

Print Results on Line one of output page three

↓

Calculate the increment of Power (DP)

$$DP = \frac{\text{Max. power} - \text{min power}}{F\ N}$$

↓

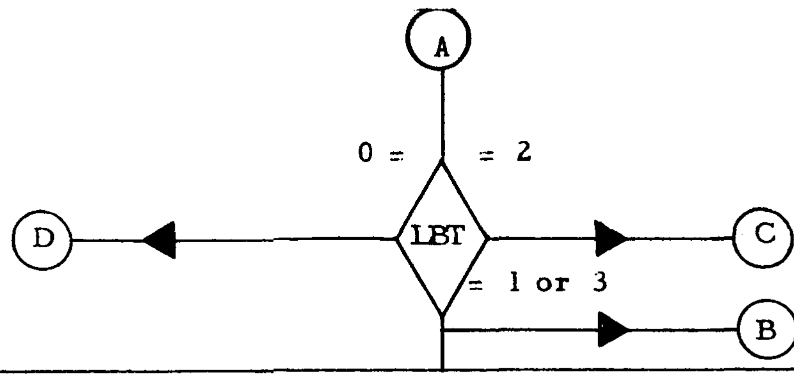
Calculate PFCMX

PFCMX = Maximum power - DP

All the power less than PFCMX will be supplied by the fuel cell. All power greater than PFCMX will be supplied by the batteries.

↓

(A)



Using PFCMX calculate weight of battery, weight of regulator, and new power profile.

1. Determine first peak where battery power will be needed. (Subroutine SUBB)

2. Determine next peak where battery power will be needed. (Subroutine SUBB)

3. Determine charging time available for the section of the power profile being considered. (Subroutine SUBC)

4. Determine capacity of battery, Ratio 1 and Ratio 2 for the section of the power profile being considered. (Subroutine SUB A)

5. Is charging time sufficient to recharge battery? If not, combine peaks and go back to Step 2; otherwise continue.

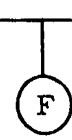
6. Store the capacity of the battery needed for this section of the power profile.

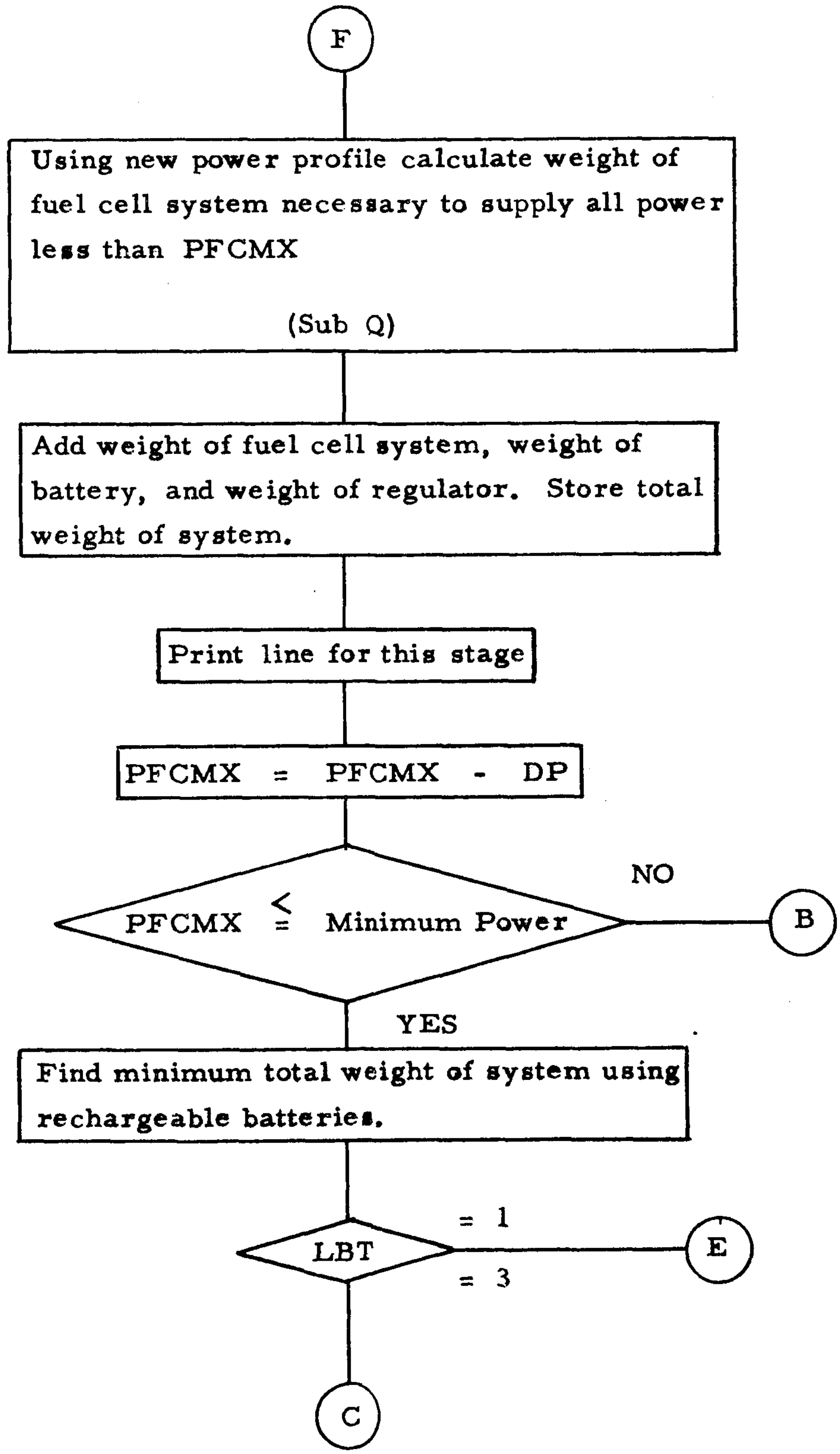
7. Have all peaks been considered? If not, go back to Step 2; otherwise continue.

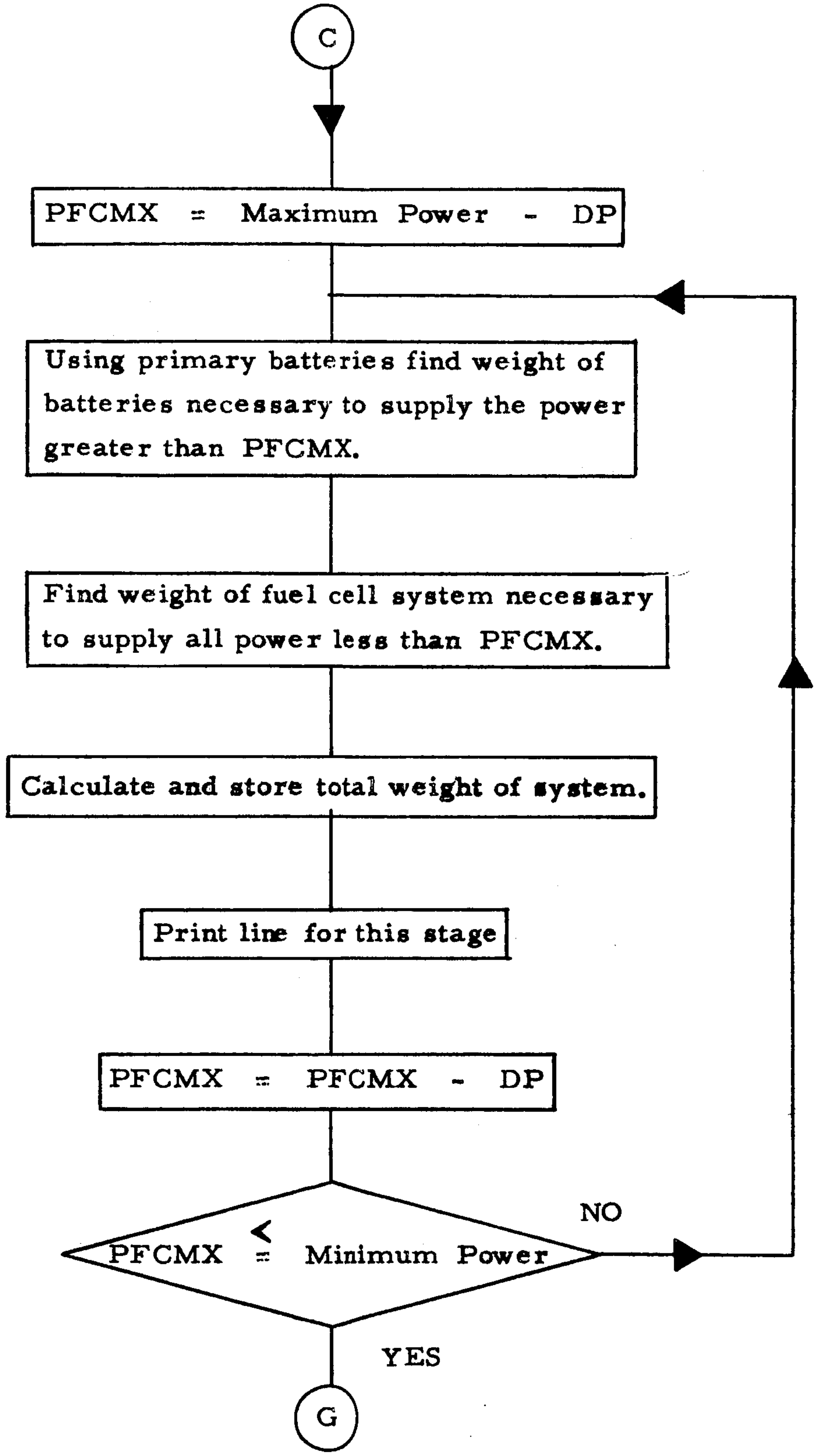
8. Find maximum capacity.

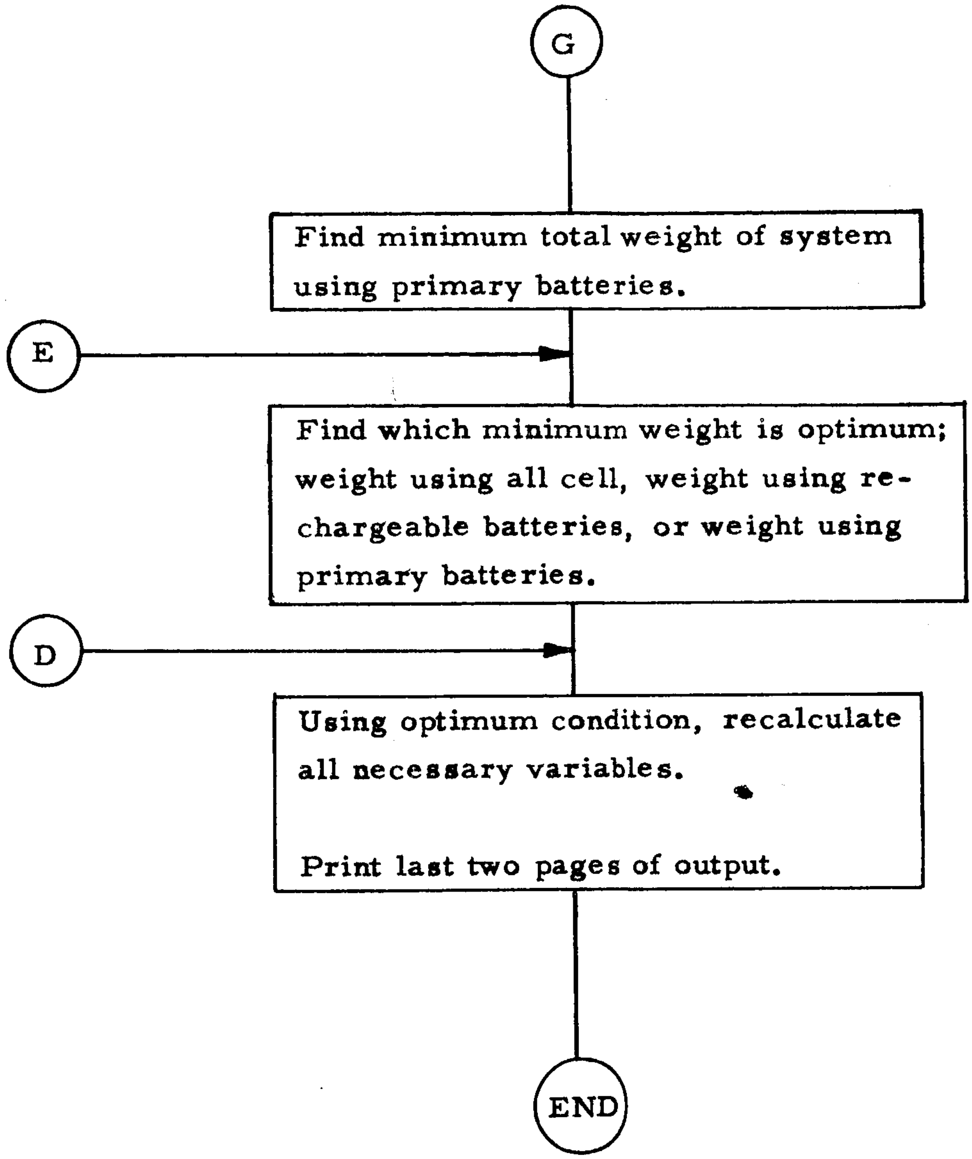
9. Using maximum capacity find corresponding VMINB; also find new power profile which includes charging power for battery. (Subroutines SUBA1, SUBE, and SUBD)

10. Find weight of battery and regulator.




F
Using new power profile calculate weight of fuel cell system necessary to supply all power less than PFCMX
(Sub Q)
Add weight of fuel cell system, weight of battery, and weight of regulator. Store total weight of system.
Print line for this stage
PFCMX = PFCMX - DP
PFCMX ≤ Minimum Power
NO
B
YES
Find minimum total weight of system using rechargeable batteries.
LBT
= 1
= 3
E
C


C
PFCMX = Maximum Power - DP
Using primary batteries find weight of batteries necessary to supply the power greater than PFCMX.
Find weight of fuel cell system necessary to supply all power less than PFCMX.
Calculate and store total weight of system.
Print line for this stage
PFCMX = PFCMX - DP
PFCMX ≤ Minimum Power
NO
YES
G


G
Find minimum total weight of system using primary batteries.
E
Find which minimum weight is optimum; weight using all cell, weight using re-chargeable batteries, or weight using primary batteries.
D
Using optimum condition, recalculate all necessary variables.
Print last two pages of output.
END

6.2 Listing and Subroutines Of The Program

```
C       PAUL CALLEN  DEPT. 3258   PROGRAM NO. 3258-734 MAIN
C
C          IBM 704 PROGRAM WRITTEN IN FORTRAN II
C          CARGE NO.......02-4800-00008
C          FOR DEPT NO....3341
C          JOB NO.........3258-734
C
C          THIS PROGRAM DETERMINES THE COMBINATION OF FUEL CELL AND
C                      BATTERY FOR WHICH TOTAL SYSTEM WEIGHT IS MINIMUM.
C          THE POWER PROFILE AND TYPE OF BATTERY TO BE USED ARE SPECIFIED
C
C      MAIN PROGRAM
C
C
      DIMENSION PABT(55),TABT(55)
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBC(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      DIMENSION WTCELL(25),AAREA(25)
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      COMMON    NVJ   ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P     ,T     ,
     1TA     ,  PA    ,TX     ,PX     ,V      ,AMP   ,VJ    ,NOPROF,NPROFA,
     2NPROFX,   TRD   ,NIP    ,REJECT,WTC     ,WTA   ,WTF   ,WTR   ,WREG  ,
     3WRB    ,  WTOPT ,WTOLD  ,WTNEW  ,DP     ,PFCMX ,SC    ,SAP   ,CON   ,
     4VOC    ,  VAB   ,PPC    ,PPV    ,ADD    ,BATT  ,TC    ,QW    ,SP2   ,
     5ALFMX  ,  ALFMN ,BCMIN  ,DBC    ,BCMAX  ,EC    ,ERD   ,ERC   ,EK2   ,
     6XNAM   ,  XNRM  ,FR     ,RPS    ,FN     ,DALFA ,EX3   ,VMAXC ,VMINC ,
     7VMAXB  ,  VBMIN ,EX4    ,EX5    ,EX6    ,NPP   ,LBT   ,LFL   ,LRD   ,
     8IBAT   ,  ICOMB ,LSP1   ,TKH    ,TKO    ,EMISS ,TS    ,CONKR ,NPF1  ,
     9NPF2   ,  IPX   ,IP     ,C      ,RATIO1,RATIO2,T1    ,T2    ,AREA
      COMMON    TT    ,NN     ,VCOR   ,NWT    ,PARA  ,TR    ,PR    ,VJCOR ,
     1SWH    ,  SWO   ,WT     ,DPCH1  ,ZZ     ,VCORI ,VOP1  ,VJOP1 ,TCH   ,
     2M1     ,M2      ,CODE   ,ALPHA  ,TD     ,COMB  ,FIBD  ,FJBC1 ,FEBC1 ,
     3CRIT   ,ALFAC   ,VJBC1  ,TCC    ,DISRAT,VMINB
C
      CALL EFM
C
C          READ FIXED TABLES OF DATA
C
      DO 15  K=1,4
   15 READ 5,(TRD(K,I),I=1,4)
      DO 16  K=1,11
   16 READ 5,(TCD1(K,I),I=1,2)
      DO 17  K=1,9
   17 READ 5,(TCD2(K,I),I=1,2)
      READ 5,(TIBD(I),I=1,7)
      READ 5,(TALPHA(I),I=1,5)
      READ 5,(TALPHA(I),I=6,10)
      DO 18 K=1,7
   18 READ 6,(TVMINB(I,K),I=1,10)
    6 FORMAT (10F7.0)
    5 FORMAT(7F10.0)
      NIP=3
   20 TRY=0.
```

```
      VOPOLD=0.0
      REJECT=0.
      CALL INPUT
C          READ INPUT DATA AND PRINT IT.
      CALL ARANGE (T,P,NOPROF,TA,PA,NPROFA,PMAX,PMIN)
C          ARRANGE THE POWER PROFILE IN DESCENDING ORDER OF POWER AND TO
C                 DETERMINE THE MAXIMUM AND MINIMUM POWER VALUES.
      WRITE OUTPUT TAPE 2,201
  201 FORMAT (14H1POWER PROFILE)
      WRITE OUTPUT TAPE 2,203
  203 FORMAT(1H0,7X,1HT,11X,1HP)
      DO 205 I=1,NOPROF
  205 WRITE OUTPUT TAPE 2,207,T(I),P(I)
  207 FORMAT (1H 2F12.3)
      PMAXXX=PMAX
      PMINX=PMIN
      CALL SUBQ
C          COMPUTE THE WEIGHT OF CELL,AUXILLIARY,FUEL AND RADIATOR FOR
C                 ALL CELL OPERATION OF THE SYSTEM.
      WTOLD=WTC(1)+WTA+WTF(1)+WTR(1)
C
      WTAC=WTOLD
      ISTAGE=0
      IZ=ZZ
      WRITE OUTPUT TAPE 2,105
  105 FORMAT (1H1)
      WRB=0.0
      WREG=0.0
      IF (LBT-2)1500,1510,1500
 1500 WRITE OUTPUT TAPE 2,1501
 1501 FORMAT (1H 5X,21HRECHARGABLE BATTERIES)
      GO TO 1550
 1510 WRITE OUTPUT TAPE 2,1301
 1550 WRITE OUTPUT TAPE 2,101
  101 FORMAT (1H 7X,11HSTAGE  VOPT,4X,7HWTTOTAL,4X,6HWTCELL,4X,5HWTAUX,
     14X,6HWTFUEL,4X,4HWRAD,5X,5HWTBAT,4X,7HNO CELL,3X,9HCELL AREA,5X,
     25HWTREG)
      WRITE OUTPUT TAPE 2,102,ISTAGE,VOP1,WTOLD,WTC(1),WTA,WTF(1),WTR(1)
     1,WRB,IZ,AREA,WREG
      WRITE OUTPUT TAPE 2,103
  103 FORMAT (1H+,10HALL CELL =)
      IF (FN-1.0)300,300,40
   40 DP=(PMAX-PMIN)/FN
      IF (LBT-1)300,45,44
   44 IF (LBT-2)45,1100,45
   45 PFCMX=PMAX-DP
      COUNT=0.0
      I=0
      IF (NOPROF-1)300,300,80
   80 CALL SUBP
      IF (CODE-1.0)82,800,20
C          COMPUTE THE WEIGHT OF RECHARGABLE BATTERY AND REGULATOR FOR
C                 THE SPECIFIED TYPE OF BATTERY AND THE MAXIMUM LEVEL OF
C                 POWER SUPPLIED BY FUEL CELL.
```

```
   82 CALL ARANGE(TX,PX,NPROFX,TA,PA,NPROFA,PMAX,PMIN)
C          ARRANGE THE POWER PROFILE AFTER RECHARGING THE BATTERIES IN
C                  ORDER TO DETERMINE NEW WEIGHT OF THE SYSTEM
      CALL SUBQ
      IF (ICOMB)83,83,599
  599 IF (COUNT-10.0)600,700,700
  600 IF (ABSF(VOP1-VOPOLD)-.0005)83,83,650
  650 VOPOLD=VOP1
      COUNT=COUNT+1.0
      GO TO 80
  700 WRITE OUTPUT TAPE 2,501
  501 FORMAT (34HOOPTIMUM VOLTAGE WILL NOT CONVERGE)
   83 I=I+1
      WTCELL(I)=WTC(1)+WTA+WTF(1)+WTR(1)+WRB+WREG
      VOPOLD=0.0
      IZ=ZZ
      ISTAGE=ISTAGE+1
      WRITE OUTPUT TAPE 2,102,ISTAGE,VOP1,WTCELL(I),WTC(1),WTA,WTF(1),
     1WTR(1),WRB,IZ,AREA,WREG
  102 FORMAT (10X,I2,F7.3,6F10.3,I7,3X,2F10.3)
      COUNT=0.0
      AAREA(I)=AREA
      PFCMX=PFCMX-DP
      IF(PMINX-PFCMX+.01)84,800,800
   84 TRY=1.0
      AREA=(PFCMX+PARA)/VJOP1/ZZ/XNAM
      GO TO 80
  800 WTEMP=WTCELL(1)
      TAREA=AAREA(1)
      JSAVE=1
  805 DO 840 J=1,I
      IF (WTEMP-WTCELL(J))840,840,810
  810 WTEMP=WTCELL(J)
      TAREA=AAREA(J)
      JSAVE=J
  840 CONTINUE
      IF (LBT-2)910,1100,1100
 1100 PFCMX=PMAXXX
      IF (LBT-2)1302,1303,1302
 1302 WRITE OUTPUT TAPE 2,1301
      WRITE OUTPUT TAPE 2,101
 1301 FORMAT (1H0,5X,17HPRIMARY BATTERIES)
 1303 IWT=0
 1110 IWT=IWT+1
      PFCMX=PFCMX-DP
      CALL ARANGE (T,P,NOPROF,TA,PA,NPROFA,PMAX,PMIN)
      IYY=0
      DO 1130 I=1,NPROFA
      PABT(I)=PA(I)-PFCMX
      TABT(I)=TA(I)
      IF (PABT(I))1150,1150,1120
 1120 IYY=IYY+1
 1130 CONTINUE
 1150 PTSUM=0.0
```

```
      DO 1160 I=1,IYY
 1160 PTSUM=PTSUM+PABT(I)*TABT(I)
      WTPRB=PTSUM*BATT
      DO 1190 I=1,NPROFA
      IF (PA(I)-PFCMX)1170,1170,1180
 1170 PX(I)=PA(I)
      TX(I)=TA(I)
      GO TO 1190
 1180 PX(I)=PFCMX
      TX(I)=TA(I)
 1190 CONTINUE
      CALL ARANGE (TX,PX,NPROFA,TA,PA,NPROFA,PMAX,PMIN)
      CALL SUBQ
      AAREA(IWT)=WTPRB
      WTCELL(IWT)=WTC(1)+WTA+WTF(1)+WTR(1)+WTPRB
      IZ=ZZ
      WRITE OUTPUT TAPE 2,102,IWT,VOP1,WTCELL(IWT),WTC(1),WTA,WTF(1),
     1WTR(1),WTPRB,IZ,AREA
      IF(PMINX-PFCMX+DP+.01)1110,1200,1200
 1200 IPSTG=1
      WTPRB=AAREA(1)
      WPRIM=WTCELL(1)
      DO 1260 I=1,IWT
      IF (WPRIM-WTCELL(I))1260,1260,1210
 1210 IPSTG=I
      WTPRB=AAREA(I)
      WPRIM=WTCELL(I)
 1260 CONTINUE
      XTEM=IPSTG
      IF (LBT-2)20,1270,1400
 1270 IF (WPRIM-WTAC)1280,300,300
 1280 PFCMX=PMAXXX-XTEM*DP
      DO 1350 I=1,NOPROF
      IF (P(I)-PFCMX)1300,1300,1310
 1300 PX(I)=P(I)
      TX(I)=T(I)
      GO TO 1350
 1310 PX(I)=PFCMX
      TX(I)=T(I)
 1350 CONTINUE
      CALL ARANGE (TX,PX,NOPROF,TA,PA,NPROFA,PMAX,PMIN)
      WRITE OUTPUT TAPE 2,1351,IPSTG
 1351 FORMAT (1H0,5X,26HTHE OPTIMUM CASE IS STAGE ,I2,25H USING PRIMARY
     1 BATTERIES)
      CALL SUBQ
      WREG=0.0
      WRB=WTPRB
      GO TO 500
 1400 IF (WTAC-WPRIM)1410,1410,1420
 1410 IF (WTAC-WTEMP)300,300,400
 1420 IF (WPRIM-WTEMP)1280,1280,400
  910 IF (WTEMP-WTAC)400,300,300
  300 CALL ARANGE(T,P,NOPROF,TA,PA,NPROFA,PMAX,PMIN)
      CALL SUBQ
```

```
      WTOPT=WTC(1)+WTA+WTF(1)+WTR(1)
      WREG=0.0
      WRB=0.0
      WRITE OUTPUT TAPE 2,104
  104 FORMAT (1H0,10X,28HTHE OPTIMUM CASE IS ALL CELL)
      GO TO 500
  400 XTEM=JSAVE
      PFCMX=PMAXXX-DP*XTEM
      AREA=TAREA
      CALL SUBP
      IF (CODE-2.0)410,20,20
  410 CALL ARANGE (TX,PX,NPROFX,TA,PA,NPROFA,PMAX,PMIN)
      CALL SUBQ
      WTOPT=WTC(1)+WTA+WTF(1)+WTR(1)+WREG+WRB
      WRITE OUTPUT TAPE 2,106
  106 FORMAT (1H1,5X,40HOPTIMUM CASE USING RECHARGABLE BATTERIES)
      WRITE OUTPUT TAPE 2,107
  107 FORMAT (1H0)
      WRITE OUTPUT TAPE 2,101
      J=JSAVE
      ISTAGE=JSAVE
      WRITE OUTPUT TAPE 2,102,ISTAGE,VOP1,WTOPT     ,WTC(1),WTA,WTF(1),
     1WTR(1),WRB,IZ,AREA,WREG
      WRITE OUTPUT TAPE 2,107
      WRITE OUTPUT TAPE 2,108,VMINB,ALPHA,IBAT,DISRAT
  108 FORMAT (1H0,10X,7HVMINB =,F7.3,3X,7HALPHA =,F7.3,3X,6HIBAT =,I3,
     15X,8HDISRAT =,F7.3)
      WRITE OUTPUT TAPE 2,111
  111 FORMAT (1H0,15X,2HTX,11X,2HPX)
      DO 113 I=1,NPROFX
  113 WRITE OUTPUT TAPE 2,112,TX(I),PX(I)
  112 FORMAT (1H ,11X,F8.3,5X,F8.3)
      EX3=C*VBMIN*ERD/WRB
      WRITE OUTPUT TAPE 2,114,C,EX3
  114 FORMAT (1H0,15X,3HC =,F8.3,6X,4HRD =,F8.3)
      WRITE OUTPUT TAPE 2,115,EX2,REJECT
  115 FORMAT (1H0,13X,5HBAT =,F8.3,3X,7HVBMAX =,F8.3)
  845 DO 900 J=1,25
      WTCELL(J)=0.0
  900 AAREA(J)=0.0
      IF (NPP-1)500,20,500
  500 CALL SUBR
      GO TO 20
      END(0,1,0,1,0)
```

```
C         JAYESH DALAL  D-3258  3258-734M    INPUT
C
      SUBROUTINE INPUT
C READ  CONTROL CARD
C
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      COMMON    NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P      ,T      ,
     1TA     ,  PA     ,TX     ,PX     ,V      ,AMP    ,VJ     ,NOPROF,NPROFA,
     2NPROFX,   TRD    ,NIP    ,REJECT,WTC    ,WTA    ,WTF    ,WTR    ,WREG   ,
     3WRB    ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX  ,SC     ,SAP    ,CON    ,
     4VOC    ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT   ,TC     ,QW     ,SP2    ,
     5ALFMX  ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC     ,ERD    ,ERC    ,EX2    ,
     6XNAM   ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA  ,EX3    ,VMAXC  ,VMINC  ,
     7VMAXB  ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP    ,LBT    ,LFL    ,LRD    ,
     8IBAT   ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS  ,TS     ,CONKR  ,NPF1   ,
     9NPF2   ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2     ,AREA
      COMMON    TT     ,NN     ,VCOR   ,NWT    ,PARA   ,TR     ,PR     ,VJCOR  ,
     1SWH    ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI  ,VOP1   ,VJOP1  ,TCH    ,
     2M1     ,M2       ,CODE   ,ALPHA  ,TD     ,COMB   ,FIBD   ,FJBC1  ,FIBC1  ,
     3CRIT   ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      DIMENSION TITLE(10)
  425 READ 12,I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,(TITLE(I),I=1,10)
      IF(I1-1) 600,475,415
  475 READ 20,NOPROF
      READ 25,(T(I),P(I),I=1,NOPROF)
      N=NOPROF-1
      TT=T(NOPROF)
      DO 595 I=1,N
  595 T(I)=T(I+1)-T(I)
      NOPROF=NOPROF-1
  600 IF(I2) 800,800,625
  625 READ 20,NXP
      READ 25,(V(I),AMP(I),I=1,NXP)
      DO 700 I=1,NXP
  700 VJ(I)=V(I)*AMP(I)
  800 IF(I3) 900,900,825
  825 READ 5,SC,SAP,CON,VOC,VAB,PPC,PPV
  900 IF(I4) 1000,1000,925
  925 READ 5,ADD,BATT,TC,QW,SP2,ALFMX,ALFMN
 1000 IF(I5) 1100,1100,1025
 1025 READ 5,BCMIN,DBC,BCMAX,EC,ERD,ERC,SP3
 1100 IF(I6) 1200,1200,1125
 1125 READ 5,XNAM,XNRM,FR,RPS,FN,DALFA,SP4
 1200 IF(I7) 1300,1300,1225
 1225 READ 5,VMAXC,VMINC,VMAXB,VBMIN,SP5,SP6,SP7
 1300 IF(I8)1350,1350,1325
 1325 READ 5,TKH,TKO,EMISS,TS,CONKR
 1350 IF(I9) 1400,1400,1375
 1375 READ 30,NPP,LBT,LFL,LRD,IBAT,ICOMB,LSP1
C
C  PRINT OUT INPUT DATA
```

```
C
 1400 PRINT 55,(TITLE(I),I=1,10)
      PRINT 60,NXP
      PRINT 65,(V(I),AMP(I),VJ(I),I=1,NXP)
      PRINT 70
      PRINT 68,SC,SAP,CON,VOC,VAB,PPC,PPV
      PRINT 80
      PRINT 68,ADD,BATT,TC,QW,SP2,ALFMX,ALFMN
      PRINT 90
      PRINT 68,BCMIN,DBC,BCMAX,EC,ERD,ERC,SP3
      PRINT 100
      PRINT 68,XNAM,XNRM,FR,RPS,FN,DALFA,SP4
      PRINT 110
      PRINT 68,VMAXC,VMINC,VMAXB,VBMIN,SP5,SP6,SP7
      PRINT 130
      PRINT 68,TKH,TKO,EMISS,TS,CONKR
      PRINT 120
      PRINT128,NPP,LBT,LFL,LRD,IBAT,ICOMB,LSP1
      RETURN
    5 FORMAT(7F10.0)
   12 FORMAT(10I1,10A6)
   20 FORMAT(I2)
   25 FORMAT(6F10.0)
   30 FORMAT(7I1)
   55 FORMAT(1H120X,10A6//1X)
   60 FORMAT(28H NO OF POINTS ON V-J CURVE =I3//6X,1HV10X,1HJ12X,2HVJ/)
   68 FORMAT(1XF10.5,6(2XF10.5))
   65 FORMAT(1XF10.5,2XF10.5,2XF10.5)
   70 FORMAT(1H0,4X2HSC10X3HSAP9X3HCON9X3HVOC9X3HVAB9X3HPPC9X3HPPV)
   80 FORMAT(1H0,3X3HADD8X4HBATT9X,2HTC10X2HQW10X3HSP27X5HALFMX9X,
     15HALFMN)
   90 FORMAT(1H0,1X5HBCMIN9X3HDBC6X5HBCMAX10X2HEC10X3HERD9X3HERC9X3HSP3)
  100 FORMAT(1H0,2X,4HXNAM8X4HXNRM9X2HFR9X3HRPS10X2HFN8X5HDALFA9X3HSP4)
  110 FORMAT(1H0,1X5HVMAXC7X5HVMINC6X5HVMAXB7X5HVBMIN9X3HSP510X3HSP6,
     19X3HSP7)
  120 FORMAT(1H0,3X3HNPP9X3HLBT8X3HLFL9X3HLRD8X4HIBAT8X5HLV    8X4HLSP1)
  128 FORMAT(1H0,3X,7(I1,11X))
  130 FORMAT(1H0,3X,3HTKH,9X,3HTKO,7X,5HEMISS,9X,2HTS,8X,5HCONKR)
  415 PAUSE 111
      GO TO 425
      END (0,1,0,1,0)
```

```
C          JAYESH G. DALAL      DEPT-3258 X-3362
C          SUBROUTINE TO REARRANGE THE POWER PROFILE IN DESCENDING ORDER
      SUBROUTINE ARANGE(T,P,NOPROF,TA,PA,NPROFA,PMAX,PMIN)
      DIMENSION T(1),P(1),TA(1),PA(1)
      DO 10 I=1,NOPROF
      TA(I)=T(I)
   10 PA(I)=P(I)
C     PA AND TA CONTAIN POWER PROFILE ARRANGED IN DESCENDING
C          ORDER OF POWER
C
      IF (NOPROF-1)100,100,20
   20 K1=NOPROF
      M= NOPROF
      K2=K1+1
      DO 77 K=1,K1
      DO 76 I=2,M
      IF(PA(I-1)-PA(I))75,76,76
   75 TEM1=PA(I-1)
      TEM2=TA(I-1)
      PA(I-1)=PA(I)
      TA(I-1)=TA(I)
      PA(I)=TEM1
      TA(I)=TEM2
   76 CONTINUE
      M=M-1
   77 CONTINUE
      PMAX=PA(1)
      PMIN=PA(NOPROF)
C          COMBINE  EQUAL POWER VALUES
C
   79 I=2
   81 IF(PA(I))300,300,80
   80 IF (ABSF(PA(I)-PA(I-1))-.01)200,200,90
   90 I=I+1
      GO TO 81
  100 PMAX=PA(1)
      PMIN=PA(1)
      NPROFA=1
      GO TO 320
  200 TA(I-1)=TA(I-1)+TA(I)
      K2=K2-1
      DO 210 J=I,K2
      PA(J)=PA(J+1)
  210 TA(J)=TA(J+1)
      GO TO 79
  300 NPROFA=K2-1
  320 IF (SENSE SWITCH 4)350,500
  350 PRINT 400,PMAX,PMIN,NPROFA,(PA(I),TA(I),I=1,NPROFA)
  400 FORMAT(  8HOARRANGE/5X,5HPMAX=,F10.4,5HPMIN=,F10.4,7HNPROFA=,
     1   I3/1H ,10X,2HPA,10X,2HTA/(1H ,2F12.4))
  500 RETURN
      END(0,1,0,1,0)
```

```
C     PAUL CALLEN  DEPT. 3258
      SUBROUTINE WTFUEL
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      COMMON   NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P      ,T      ,
     1TA     ,  PA     ,TX     ,PX     ,V      ,AMP    ,VJ     ,NOPROF,NPROFA,
     2NPROFX,  TRD    ,NIP    ,REJECT,WTC    ,WTA    ,WTF    ,WTR    ,WREG   ,
     3WRB    ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX  ,SC     ,SAP    ,CON    ,
     4VOC    ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT   ,TC     ,QW     ,SP2    ,
     5ALFMX  ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC     ,ERD    ,ERC    ,EX2    ,
     6XNAM   ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA  ,EX3    ,VMAXC  ,VMINC  ,
     7VMAXB  ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP    ,LBT    ,LFL    ,LRD    ,
     8IBAT   ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS  ,TS     ,CONKR  ,NPF1   ,
     9NPF2   ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2     ,AREA
      COMMON   TT     ,NN     ,VCOR   ,NWT    ,PARA   ,TR     ,PR     ,VJCOR  ,
     1SWH    ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI  ,VOP1   ,VJOP1  ,TCH    ,
     2M1     ,M2       ,CODE   ,ALPHA  ,TO     ,COMB   ,FIBD   ,FJBC1  ,FIBC1  ,
     3CRIT   ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
      CALL ACFLAG (VCOR,VJCOR,NXP,NIP,V,VJ)
      SUM=TR(1)/VCOR
      N1=NPROFA-NN
      IF (N1-1)205,205,100
  100 DO 200 I=2,N1
      VJCORI=PR(I)*VJCOR
      CALL ACFLAG (VJCORI,VCORI,NXP,NIP,VJ,V)
  200 SUM=SUM+PR(I)*TR(I)/VCORI
  205 AH=SUM*(PA(NN+1)+PARA)*TT
      SWH=(AH/12100.0)*(1.0+ADD)
      SWO=7.95*SWH
      IF (LFL-1)201,202,210
  210 IF (LFL-2)203,203,212
  212 FSS=TKH*SWH+TKO*SWO
      GO TO 204
  201 FSS=SWH+SWO
      GO TO 204
  202 FSS=30.29+11.3*SWH+(.00345*TT)*SWH**.666667
      GO TO 204
  203 FSS=30.29+9.7*SWH+(.00345*TT)*SWH**.666667
  204 WTF(NWT)=FSS
      TEMP  =((PA(NN+1)+PARA)/VJCOR)*SC*((XNAM+XNRM)/XNAM)
      WTC(NWT)=TEMP
      RETURN
       END (0,1,0,1,0)
```

```
C                  SUBROUTINE TO CALCULATE RADIATOR
      SUBROUTINE RADWT
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      COMMON    NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P      ,T      ,
     1TA    ,   PA     ,TX     ,PX     ,V      ,AMP   ,VJ    ,NOPROF,NPROFA,
     2NPROFX,   TRD    ,NIP    ,REJECT,WTC    ,WTA   ,WTF   ,WTR   ,WREG   ,
     3WRB   ,   WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX ,SC    ,SAP   ,CON    ,
     4VOC   ,   VAB    ,PPC    ,PPV    ,ADD    ,BATT  ,TC    ,QW    ,SP2    ,
     5ALFMX ,   ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC    ,ERD   ,ERC   ,EX2    ,
     6XNAM  ,   XNRM   ,FR     ,RPS    ,FN     ,DALFA ,EX3   ,VMAXC ,VMINC  ,
     7VMAXB ,   VBMIN  ,EX4    ,EX5    ,EX6    ,NPP   ,LBT   ,LFL   ,LRD    ,
     8IBAT  ,   ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS ,TS    ,CONKR ,NPF1   ,
     9NPF2  ,   IPX    ,IP     ,C      ,RATIO1,RATIO2,T1    ,T2    ,AREA
      COMMON    TT     ,NN     ,VCOR   ,NWT    ,PARA  ,TR    ,PR    ,VJCOR  ,
     1SWH   ,   SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI ,VOP1  ,VJOP1 ,TCH    ,
     2M1    ,M2        ,CODE   ,ALPHA  ,TD     ,COMB  ,FIBD  ,FJBC1 ,FIBC1  ,
     3CRIT  ,ALFAC     ,VJBC1  ,TCC    ,DISRAT,VMINB
      PPR=0.0
      IF (NPROFA-NN)15,15,10
   10 PPR1=((1.0-.67*VCOR)*PA(NN+1)+PARA)/(.67*VCOR)
      PPR=PPR1-(.0002165*PA(NN+1)*QW/VCOR)
      PPR=PPR+.175*(PA(1)-PA(NN+1))
   30 IF (LRD-1)21,22,24
   24 IF (LRD-3)23,40,50
   50 RPS1=1.0-RPS
      C1=0.70935
      C2=1.56+PPR*2.15E-6+2.0E-6/RPS1+TT*1.667E-5
      C3=0.208*(0.01/RPS1)**(.20808-4.08E-6/RPS1)+TT*2.083E-5
      C4=0.2088+0.000521*(0.01/RPS1)**1.04
      C5=-31.6+8.6E-5/RPS1+TT*2.917E-5+29389.5/TC+PPR*1.29E-4
      WTRAD=C1*((.0043*PPR)**C2)*((TT/24.0)**C3)*((.01/RPS1)**C4)*
     1((559.8/TC)**C5)
      GO TO 25
   40 WTRAD=PPR*3.415*CONKR/(EMISS*0.173((TC/100.)**4-(TS/100.)**4))
      GO TO 25
   21 WTRAD=0.0
      GO TO 25
   15 PPR=.175*PA(1)
      GO TO 30
   22 WTRAD1=55.6*PPR**1.533*TT**0.5
      WTRAD=WTRAD1/(1.0-RPS)**0.5/(TC-220.0)**3.57
      GO TO 25
   23 W1=0.906*(.0833333*TT)**(0.015*(0.0001138*PPR)**0.1974)
      WT1=(0.0001138*PPR)**W1
      WT2=(27.3+(0.0833333*TT)**0.3065)*((0.04166666*TT)**0.0314)
      W3=(0.434294*(LOGF(RPS)-LOGF(.99))/2.82)**1.07-34.6
      WT3=W3*(0.0001141*TT)**.2467*(0.00003412*PPR)**1.227
      WTRAD=WT1*WT2+WT3
   25 WTR(NWT)=WTRAD
      RETURN
```

```
END(0,1,0,1,0)
```

```
C          JAYESH DALAL  D-3258  JOB-734M  ACFLAG
C       3324-493 (DP-303) DUFRESNE
C       X=INDEPENDENT VARIABLE
C       NXP=NO OF X POINTS
C       NIP=NO OF INTERPOLATION POINTS
C       XP=X POINTS IN TABLE
C       YP=Y POINTS IN TABLE
C
C
        SUBROUTINE ACFLAG(X,Y,NXP,NIP,XP,YP)
        DIMENSION XP(1),YP(1)
C
C
        TEST=0.
        IF(XP(1)-XP(NXP)) 4,1,1
1       TEST=1.
        N=NXP/2
        M=NXP
        DO 3 I=1,N
        HOLD=XP(I)
        XP(I)=XP(M)
        XP(M)=HOLD
        HOLD=YP(I)
        YP(I)=YP(M)
        YP(M)=HOLD
        M=M-1
3       CONTINUE
4       NIPA=NIP
        VAR=X
        IF(VAR-XP(1)) 5,15,15
5       ANS=-1.
        GO TO 100
15      DO 20 I=1,NXP
        IF(XP(I)-VAR)20,25,30
20      CONTINUE
        ANS=-1.
        GO TO 100
25      ANS=YP(I)
        GO TO 100
C       TEST IF NO OF INTERPOLATION POINTS IS EVEN
30      IF(NIPA-(NIPA/2)*2)44,40,44
40      NQ=NIPA/2
        GO TO 55
44      IF (ABSF(XP(I)-VAR)-ABSF(VAR-XP(I-1))) 45,45,50
45      NQ=(NIPA-1)/2
        GO TO 55
50      NQ=(NIPA+1)/2
55      IF(I-NQ) 60,60,65
60      JJ=1
        GO TO 76
C       I-NQ IS THE POINT TO START INTERPOLATING WITH
C       NXP , THE NO OF POINTS MUST NOT EXCEED THE STARTING INTERPOLATION
C       POINT PLUS THE NO OF POINTS TO INTERPOLATE WITH
65      IF (NXP-(I-NQ+NIPA)) 70,75,75
```

```
70      JJ=NXP+1-NIPA
        GO TO 76
75      JJ=I-NO
76      ANS=0.
        J=JJ
        DO 90 L=1,NIPA
        SAVE=YP(J)
        K=JJ
        DO 88 M=1,NIPA
        HOLD=XP(J)-XP(K)
        IF(HOLD) 80,85,80
80      SAVE=(VAR-XP(K))/HOLD*SAVE
85      K=JJ+M
88      CONTINUE
        ANS=ANS+SAVE
        J=JJ+L
90      CONTINUE
100     Y=ANS
        IF(TEST) 101,110,101
101     M=NXP
        DO 103 I=1,N
        HOLD=XP(I)
        XP(I)=XP(M)
        XP(M)=HOLD
        HOLD=YP(I)
        YP(I)=YP(M)
        YP(M)=HOLD
        M=M-1
103     CONTINUE
110     RETURN
        END(0,1,0,1,1)
```

```
C     PAUL CALLEN  DEPT. 3258
      SUBROUTINE SUBQ
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      COMMON   NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P     ,T     ,
     1TA    ,  PA     ,TX     ,PX     ,V      ,AMP    ,VJ    ,NOPROF,NPROFA,
     2NPROFX,  TRD    ,NIP    ,REJECT,WTC     ,WTA    ,WTF   ,WTR   ,WREG  ,
     3WRB   ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX  ,SC    ,SAP   ,CON   ,
     4VOC   ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT   ,TC    ,QW    ,SP2   ,
     5ALFMX ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC     ,ERD   ,ERC   ,EX2   ,
     6XNAM  ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA  ,EX3   ,VMAXC ,VMINC ,
     7VMAXB ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP    ,LBT   ,LFL   ,LRD   ,
     8IBAT  ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS  ,TS    ,CONKR ,NPF1  ,
     9NPF2  ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2    ,AREA
      COMMON   TT     ,NN     ,VCOR   ,NWT    ,PARA   ,TR    ,PR    ,VJCOR ,
     1SWH   ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI  ,VOP1  ,VJOP1 ,TCH   ,
     2M1    ,M2       ,CODE   ,ALPHA  ,TD     ,COMB   ,FIBD  ,FJBC1 ,FIBC1 ,
     3CRIT  ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
      NN=0
      NIP=3
      DELTAV=(VOC-VAB)/50.0
  222 VCOR=VAB
      AMKR=0.0
      NJUMP=200
      NPG3=0
      NWT=1
      N5=0
      NCNT2=0
      NCNT3=0
   20 PARA=PPC*XNAM+PPV*PA(NN+1)
      KAT=NPROFA-NN
      DO 21 I=1,KAT
      I1=I+NN
   21 PR(I)=(PA(I1)+PARA)/(PA(NN+1)+PARA)
      TSUM=0.0
      K=NN+1
      DO 22 I=1,K
   22 TSUM=TSUM+TA(I)
      TR(1)=TSUM/TT
      DO 23 I=2,KAT
      I1=I+NN
   23 TR(I)=TA(I1)/TT
      IF (NPG3)62,24,62
   24 WTA=((PA(NN+1)+PARA)*SAP/XNAM+CON)*(XNAM+XNRM)
  333 CALL WTFUEL
      CALL RADWT
      WT(NWT)=WTC(NWT)+WTA+WTF(NWT)+WTR(NWT)
      IF(N5)30,31,30
   30 VOP1=VCOR
      GO TO 32
   31 IF(NCNT2-1)34,35,36
   34 VCOR=VCOR+DELTAV
```

```
      NWT=2
      NCNT2=1
      GO TO 333
   35 IF(WT(1)-WT(2))37,37,136
  136 NWT=1
      VCOR=VAB
   36 CALL TERP (AMKR,22,DELTAV,VCOR,WT(1))
      IF(AMKR)38,39,38
   38 NCNT2=2
      GO TO 333
   39 VOP1=VCOR
      GO TO 33
   37 VOP1=VAB
      NWT=1
      VCOR=VAB
   33 CALL WTFUEL
      CALL RADWT
      WTT    =WTC(NWT)+WTA+WTF(NWT)+WTR(NWT)
   32 IF(NJUMP-250)40,41,42
   40 CALL ACFLAG (VOP1,VJOP1,NXP,NIP,V,VJ)
      VJOP2=VJOP1*PR(KAT)
      CALL ACFLAG (VJOP2,VOP2,NXP,NIP,VJ,V)
      IF(VMIN)43,44,43
   43 ZZ=INTF(VMIN/VOP1+.999999)
      GO TO 45
   44 ZZ=INTF(VMAX/VOP2)
   45 IF(VMAX-ZZ*VOP2)47,46,46
   46 ZZ=MAX1F(ZZ,INTF(VMAX/VOP2))
      GO TO 555
   47 VNOP2=VMAX/ZZ
      ZZMOP=ZZ
      NWT=1
      CALL ACFLAG (VNOP2,VJNOP2,NXP,NIP,V,VJ)
      VJNOP1=VJNOP2/PR(KAT)
      CALL ACFLAG (VJNOP1,VNOP1,NXP,NIP,VJ,V)
      IF(VNOP1)57,57,58
   57 VNOP1=VAB
      GO TO 49
   58 IF(VMIN-ZZ*VNOP1)50,50,49
   41 NWT=2
   49 ZZ=ZZ-1.
      VNOP1=VMIN/ZZ
      CALL ACFLAG (VNOP1,VJNOP1,NXP,NIP,V,VJ)
      VJNOP2=VJNOP1*PR(KAT)
      CALL ACFLAG (VJNOP2,VNOP2,NXP,NIP,VJ,V)
      IF(VMAX-VNOP2*ZZ)49,51,51
   51 VCOR=VNOP1
      NJUMP=300
   52 N5=1
      GO TO 333
   50 VCOR=VNOP1
      VTEMP=VNOP1
      NJUMP=250
      GO TO 52
```

```
 42 IF (NWT-1)53,56,53
 53 IF(WT(2)-WT(1))54,54,55
 54 WT(1)=WT(2)
    WTR(1)=WTR(2)
    WTC(1)=WTC(2)
    WTF(1)=WTF(2)
    GO TO 56
 55 VOP1=VTEMP
    ZZ=ZZMOP
 56 WTT=WT(1)
555 WTMOD=(WTC(1)+WTA)/(XNAM+XNRM)
    CALL ACFLAG (VOP1,VJOP1,NXP,NIP,V,VJ)
    AREA=(PA(NN+1)+PARA)/VJOP1/ZZ/XNAM
    IF (SENSE SWITCH 4)600,62
600 PRINT 110,NN,VOP1,WTT,WTC(1),WTA,WTF(1),WTR(1),ZZ,AREA
110 FORMAT(5HOSUBQ/9H      NN= I3,7X,8H  VOP1= F10.5,8H   WTT= F10.3,
   18H    WTC= F10.3,8H   WTA= F10.3/9H    WTF= F10.3,8H   WTR= F10.3,
   28H    ZZ= F10.3,8H  AREA= F10.5)
 62 RETURN
    END(0,1,0,1,0)
```

```
C          JAYESH DALAL  D-3258  3258-734M  SUBP.
C
C          THIS SUBROUTINE DETERMINES WT OF REGULATOR AND RECHARGABLE
C          BATTERY FOR A SPECIFIED POWER LEVEL OF FUEL CELL OPERATION.
C          IT ALSO DETERMINES CAPACITY OF BATTERY,ALPHA AND MODIFIED
C          POWER PROFILE AFTER CHARGING BATTERY.
C
C
      SUBROUTINE SUBP
C
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      COMMON   NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P      ,T      ,
     1TA     ,  PA     ,TX     ,PX     ,V      ,AMP    ,VJ     ,NOPROF,NPROFA,
     2NPROFX,  TRD    ,NIP    ,REJECT,WTC    ,WTA    ,WTF    ,WTR    ,WREG   ,
     3WRB    ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX  ,SC     ,SAP    ,CON    ,
     4VOC    ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT   ,TC     ,QW     ,SP2    ,
     5ALFMX  ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC     ,ERD    ,ERC    ,EX2    ,
     6XNAM   ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA  ,EX3    ,VMAXC  ,VMINC  ,
     7VMAXB  ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP    ,LBT    ,LFL    ,LRD    ,
     8IBAT   ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS  ,TS     ,CONKR  ,NPF1   ,
     9NPF2   ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2     ,AREA
      COMMON   TT     ,NN     ,VCOR   ,NWT    ,PARA   ,TR     ,PR     ,VJCOR  ,
     1SWH    ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI  ,VOP1   ,VJOP1  ,TCH    ,
     2M1     ,M2       ,CODE   ,ALPHA  ,TD     ,COMB   ,FIBD   ,FJBC1  ,FIBC1  ,
     3CRIT   ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
C
      DIMENSION ST01(30),ST02(30),          ST04(30),ST05(30),ST06(30)
      IXX=0
      NPK=1
      NP=0
      ALPHA=ALFMX
      RATIO1=BCMIN
      RATIO2=0.
      COMB=0.
      CODE=0.
      CALL SUBB(P,NOPROF,PFCMX,NP,NP1)
C          SCAN THE INPUT POWER PROFILE TO DETERMINE A POINT WHERE THE
C          POWER REQUIREMENT EXCEEDS THE MAXIMUM LIMIT FOR FUEL CELL.
      NPF1=NP1
      NP=NP1
      TD=T(NPF1)
      DPBAT=P(NPF1)-PFCMX
      ED=TD*DPBAT
      EX5=ED
      FIBD=DPBAT/(VBMIN*ERD)
      C=FIBD*TD/ALPHA
      CALL SUBB(P,NOPROF,PFCMX,NP,NP1)
      IF(NP1)100,100,300
C          100...THERE IS ONLY ONE PEAK IN THE POWER PROFILE HIGHER THAN
C                PFCMX.HENCE RECHARGING OF BATTERY IS NOT NECESSARY.
C          300...THERE IS ONE MORE HIGHER POINT ON THE PROFILE SO
```

```
C                 RECHARGING IS REQUIRED.
  100 DO 110 I=1,NOPROF
      PX(I)=P(I)
  110 TX(I)=T(I)
      PX(NPF1)=PFCMX
      NPROFX=NOPROF
      DISRAT=FIBD/C
      CALL SUBH(TRD,IBAT,C,RD)
      CALL SUBE
C         DETERMINE MINIMUM BATTERY VOLTAGE.
      BAT=INTF(VBMIN/VMINB+0.99)
      EX2=BAT
      VMAXBT=BAT*VMAXB
      REJECT=VMAXBT
      WREG=FIBC1*(VMAXBT-VBMIN)/200.
      WRB=ED/(ALPHA*RD)
      IF (SENSE SWITCH 4)149,160
  149 PRINT 150,WREG,WRB,BAT,C,ALPHA,RATIO1,WTOLD
  150 FORMAT( 5HOSUBP/9H    WREG=F10.5,8H   WRB= F10.5,8H   BAT= F10.5,
     18H     C= F10.5,8H ALPHA= F10.5/9H RATIO1= F10.5,8H WTOLD= F10.5)
  160 RETURN
  300 NPF2=NP1
      CODE=0.0
      M1=NPF1+1
      M2=NPF2-1
      FIBC1=C*RATIO1
      FJBC1=FIBC1/AREA
      CALL SUBC
C         DETERMINE CHARGING TIME AVAILABLE
      CALL SUBG (IBAT,RATIO1,CRIT,ALFAC,ALFMX,BCMAX)
C         DETERMINE THE CRITICAL VALUES OF RATIO1 AND ALPHA
      CALL SUBA
C         DETERMINE THE CAPACITY OF BATTERY AND RATIO1,RATIO2 FOR THE
C         SECTION OF POWER PROFILE BETWEEN NPF1 AND NPF2
      IF(CODE)310,310,500
C         500...CHARGING TIME IS NOT ENOUGH BETWEEN NPF1 AND NPF2.
C                COMBINE MORE PEAKS AND TRY AGAIN.
  310 STO1(NPK)=NPF1
      STO2(NPK)=C
      STO5(NPK)=NPF2
      IF (IXX)311,311,312
  312 STO4(NPK)=-ED
      STO6(NPK)=FIBD
      GO TO 313
  311 STO6(NPK)=DPBAT
      STO4(NPK)=TD
  313 NPK=NPK+1
      IXX=0
      NPF1=NPF2
      NP=NPF2
      ALPHA=ALFMX
      RATIO1=BCMIN
      RATIO2=0.
      TD=T(NPF1)
```

```
      DPBAT=P(NPF1)-PFCMX
      ED=TD*DPBAT
      EX5=ED
      FIBD=DPBAT/(VBMIN*ERD)
      C=FIBD*TD/ALPHA
  320 CALL SUBB(P,NOPROF,PFCMX,NP,NP1)
      IF(NP1)400,400,300
C          400...THERE  IS NO HIGHER PEAK IN THE POWER PROFILE BEYOND
C                 NPF2.COMPUTE THE CAPACITY OF BATTERY REQUIRED FOR PEAK
C                 AT NPF1.
  400 STO1(NPK)=NPF1
      IF (CODE)1400,1400,1000
 1400 STO2(NPK)=C
      STO4(NPK)=TD
      STO5(NPK)=NPF2
      STO6(NPK)=DPBAT
      GO TO 600
C          600... BATTERY CAPACITIES ARE DETERMINED FOR EACH PEAK GREATER
C                 THAN PFCMX.DETERMINE THE MAXIMUM CAPACITY OF BATTERY
C                 REQUIRED AND HENCE THE WTS. OF BATTERY AND REGULATOR
  500 NP=NPF2
      ALPHA=ALFMX
      RATIO1=BCMIN
      RATIO2=0.
      IXX=1
      ED=ED+(P(NPF2)-PFCMX)*T(NPF2)
      EX5=ED
      C=ED/(VBMIN*ERD*ALPHA)
      PNPF1=P(NPF1)
      DO 520 JJ=NPF1,NPF2
      IF(PNPF1-P(JJ))510,520,520
  510 PNPF1=P(JJ)
  520 CONTINUE
      FIBD=(PNPF1-PFCMX)/(VBMIN*ERD)
      GO TO 320
  600 CMAX=0.
      DO 620  I=1,NPK
      IF(CMAX-STO2(I))610,620,620
  610 CMAX=STO2(I)
  620 CONTINUE
C          DETERMINE THE WEIGHTS OF REGULATOR AND BATTERY FOR THE MAXIMUM
C          VALUE OF C.
C
      C=CMAX
  650 IP=0
      IPX=0
      I=1
  660 NPF1=STO1(I)
      NPF2=STO5(I)
      IF (STO4(I))670,680,680
  670 ED=-STO4(I)
      FIBD=STO6(I)
      GO TO 690
  680 TD=STO4(I)
```

```
      DPBAT=STO6(I)
      ED=TD*DPBAT
      FIBD=DPBAT/(VBMIN*ERD)
  690 ALPHA=ED/(C*VBMIN*ERD)
      RATIO1=BCMIN
      RATIO2=0.
      DISRAT=FIBD/C
      M1=NPF1+1
      M2=NPF2-1
      FIBC1=C*RATIO1
      FJBC1=FIBC1/AREA
      CALL SUBC
      CALL SUBE
      STO2(I)=VMINB
      IF(I-NPK)700,800,800
  700 CALL SUBG(IBAT,RATIO1,CRIT,ALFAC,ALFMX,BCMAX)
      CALL SUBA1
      IF (CODE-2.0)720,1000,720
  720 CALL SUBD
      I=I+1
      GO TO 660
  800 IP=-1
      CALL SUBD
      VMINB=STO2(1)
      DO 900 I=2,NPK
      IF(VMINB-STO2(I))900,900,810
  810 VMINB=STO2(I)
  900 CONTINUE
      CALL SUBH(TRD,IBAT,CMAX,RD)
      BAT=INTF(VBMIN/VMINB+0.99)
      EX2=BAT
      VMAXBT=BAT*VMAXB
      REJECT=VMAXBT
      WREG=FIBC1*(VMAXBT-VBMIN)/200.
      WRB=C*VBMIN*ERD/RD
      IF (SENSE SWITCH 4)950,1000
  950 PRINT 150,WREG,WRB,BAT,C,ALPHA,RATIO1,WTOLD
C
 1000 RETURN
      END(0,1,0,1,0)
```

```
C          JAYESH DALAL  D-3258  3258-734M  SUBA.
C
C          THIS SUBROUTINE COMPUTES THE VALUE OF RATIO1 AND RATIO2 AND
C      AT THE SAME TIME CHECKS IF THERE IS SUFFICIENT CHARGING TIME.
C          TIME
C
C
      SUBROUTINE SUBA
C
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      COMMON    NVJ   ,TCD1  ,TCD2  ,TIBD  ,TALPHA,TVMINB,P     ,T     ,
     1TA    ,   PA    ,TX    ,PX    ,V     ,AMP   ,VJ    ,NOPROF,NPROFA,
     2NPROFX,   TRD   ,NIP   ,REJECT,WTC   ,WTA   ,WTF   ,WTR   ,WREG  ,
     3WRB   ,   WTOPT ,WTOLD ,WTNEW ,DP    ,PFCMX ,SC    ,SAP   ,CON   ,
     4VOC   ,   VAB   ,PPC   ,PPV   ,ADD   ,BATT  ,TC    ,QW    ,SP2   ,
     5ALFMX ,   ALFMN ,BCMIN ,DBC   ,BCMAX ,EC    ,ERD   ,ERC   ,EX2   ,
     6XNAM  ,   XNRM  ,FR    ,RPS   ,FN    ,DALFA ,EX3   ,VMAXC ,VMINC ,
     7VMAXB ,   VBMIN ,EX4   ,EX5   ,EX6   ,NPP   ,LBT   ,LFL   ,LRD   ,
     8IBAT  ,   ICOMB ,LSP1  ,TKH   ,TKO   ,EMISS ,TS    ,CONKR ,NPF1  ,
     9NPF2  ,   IPX   ,IP    ,C     ,RATIO1,RATIO2,T1    ,T2    ,AREA
      COMMON    TT    ,NN    ,VCOR  ,NWT   ,PARA  ,TR    ,PR    ,VJCOR ,
     1SWH   ,   SWO   ,WT    ,DPCH1 ,ZZ    ,VCORI ,VOP1  ,VJOP1 ,TCH   ,
     2M1    ,M2      ,CODE  ,ALPHA ,TD    ,COMB  ,FIBD  ,FJBC1 ,FIBC1 ,
     3CRIT  ,ALFAC   ,VJBC1 ,TCC   ,DISRAT,VMINB
C
      CODE=0.
C     COMPARE THE REQUIRED CHARGING TIME WITH THE AVAILABLE TIME-TCH.
      IF (TCH)400,400,10
   10 IF(RATIO1-CRIT)20,20,100
   20 TCC=ALPHA/(ERC*EC*RATIO1)
C          CHECK FOR CRITICAL VALUE OF CHARGING TIME-TCH
      IF(TCC-TCH)30,30,200
   30 IF (SENSE SWITCH 4)35,50
   35 PRINT 40,TCC,ALPHA,RATIO1,RATIO2,C,TCH,NPF1,NPF2,CODE
   40 FORMAT( 5H0SUBA/ 9H    TCC= F10.5,8H ALPHA= F10.5,8HRATIO1= F10.5,
     18HRATIO2= F10.5,8H     C= F10.5/9H    TCH= F10.5,8H  NPF1= I2,8X ,
     28H  NPF2= I2,8X,8H  CODE= F10.5)
   50 RETURN
C          CHECK FOR CRITICAL VALUE OF ALPHA
  100 TCC=TCH
      IF(ALPHA-ALFAC)150,150,110
  110 TEMP=EC*RATIO1*TCH*ERC-ALPHA
      RATIO2=RATIO1*(ALFAC-TEMP)/(TEMP+ALFAC)
  111 IF(RATIO2)200,200,120
  120 IF(RATIO2-RATIO1)30,30,200
  150 RATIO2=2.*ALPHA/(TCH*EC*ERC)-RATIO1
      GO TO 111
  200 RATIO1=RATIO1+DBC
      IF(RATIO1-BCMAX)210,210,300
  210 FIBC1=C*RATIO1
      FJBC1=FIBC1/AREA
```

```
      CALL  SUBC
      CALL  SUBG (IBAT,RATIO1,CRIT,ALFAC,ALFMX,BCMAX)
      GO TO 10
  300 RATIO1=BCMAX
      ALPHA=ALPHA-DALFA
      IF(ALPHA-ALFMN)400,310,310
  310 C=EX5/(VBMIN*ERD*ALPHA)
      GO TO 210
  400 CODE=1.0
      PRINT 410,NPF1,NPF2
  410 FORMAT (10X,6HPEAKS ,I2,6H THRU ,I2,19H HAVE BEEN COMBINED)
      GO TO 30
      END(0,1,0,1,0)
```

```
C          JAYESH DALAL  D-3258  3258-734M  SUBA1
C
C          THIS SUBROUTINE COMPUTES THE VALUE OF RATIO1 AND RATIO2
C          CORRESPONDING TO CMAX.
C
C
      SUBROUTINE SUBA1
C
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      COMMON    NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P      ,T      ,
     1TA     ,  PA     ,TX     ,PX     ,V      ,AMP    ,VJ     ,NOPROF,NPROFA,
     2NPROFX,   TRD    ,NIP    ,REJECT,WTC    ,WTA    ,WTF    ,WTR    ,WREG   ,
     3WRB    ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX  ,SC     ,SAP    ,CON    ,
     4VOC    ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT   ,TC     ,QW     ,SP2    ,
     5ALFMX  ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC     ,ERD    ,ERC    ,EX2    ,
     6XNAM   ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA  ,EX3    ,VMAXC  ,VMINC  ,
     7VMAXB  ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP    ,LBT    ,LFL    ,LRD    ,
     8IBAT   ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS  ,TS     ,CONKR  ,NPF1   ,
     9NPF2   ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2     ,AREA
      COMMON    TT     ,NN     ,VCOR   ,NWT    ,PARA   ,TR     ,PR     ,VJCOR  ,
     1SWH    ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI  ,VOP1   ,VJOP1  ,TCH    ,
     2M1     ,M2       ,CODE   ,ALPHA  ,TD     ,COMB   ,FIBD   ,FJBC1  ,FIBC1  ,
     3CRIT   ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
C
   10 IF(RATIO1-CRIT)20,20,100
   20 TCC=ALPHA/(ERC*EC*RATIO1)
      IF(TCC-TCH)30,30,200
   30 T1=TCH
      T2=0.
   31 IF (SENSE SWITCH 4)35,50
   35 PRINT 40,TCC,ALPHA,RATIO1,RATIO2,C,TCH,NPF1,NPF2,CODE
   40 FORMAT(6H0SUBA1/ 9H    TCC= F10.5,8H ALPHA= F10.5,8HRATIO1= F10.5,
     18HRATIO2= F10.5,8H      C= F10.5/9H    TCH= F10.5,8H  NPF1= I2,8X ,
     28H  NPF2= I2,8X,8H  CODE= F10.5)
   50 RETURN
  100 TCC=TCH
      IF(ALPHA-ALFAC)150,150,110
  110 TEMP=EC*RATIO1*TCH*ERC-ALPHA
      RATIO2=RATIO1*(ALFAC-TEMP)/(TEMP+ALFAC)
      T1=(ALPHA-ALFAC)/(EC*ERC*RATIO1)
      T2=TCH-T1
  111 IF(RATIO2)200,200,120
  120 IF(RATIO2-RATIO1)31,31,200
  150 RATIO2=2.*ALPHA/(TCH*EC*ERC)-RATIO1
      T1=0.
      T2=TCH
      GO TO 111
  200 RATIO1=RATIO1+DBC
      IF(RATIO1-BCMAX)210,210,300
  210 FIBC1=C*RATIO1
      FJBC1=FIBC1/AREA
```

```
      CALL SUBC
      CALL SUBG (IBAT,RATIOL,CRIT,ALFAC,ALFMX,BCMAX)
      GO TO 10
  300 PRINT 310
  310 FORMAT(6HOSUBA1/105H ERROR IN COMPUTING CMAX.FURTHER COMPUTATIONS
     1TERMINATED.PRESS START TO PROCEED WITH THE NEXT SET OF DATA)
      ERROR=1.0
      PAUSE 22222
      CODE=2.0
      RETURN
      END(0,1,0,1,0)
```

```
C  RETURN TO CARPENTER          DEPT 3258
C
      SUBROUTINE SUBB(P,NOPROF,PFCMX,NP,NP1)
C
C
      DIMENSION P(1)
      K=NP+1
      J=NOPROF
C IS THE PROFILE POINT  GREATER THAN PFCMX(MAXIMUM POWER LEVEL AT
C     WHICH FUEL CELL OPERATES)
   50 IF(P(K)-PFCMX)60,60,100
C PROFILE POINT LESS THAN PFCMX
   60 K=K+1
      IF(K-J)50,50,70
C NO PROFILE POINT GREATER THAN PFCMX
   70 NP1=0
      GO TO 110
C PROFILE POINT GREATER THAN PFCMX
  100 NP1=K
  110 IF (SENSE SWITCH 4)150,300
  150 PRINT  200,NP1,PFCMX
  200 FORMAT(1H0,22HSUBROUTINE SUBB   NP1=,I3,    6HPFCMX=,F10.4)
  300 RETURN
      END(0,1,0,1,0)
```

```
C          PAUL CALLEN  DEPT. 3258          X-2507
C DETERMINES THE AVAILABLE CHARGING TIME FOR A SECTION OF POWER
C     PROFILE
      SUBROUTINE SUBC
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      COMMON    NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P     ,T     ,
     1TA    ,  PA     ,TX     ,PX     ,V      ,AMP   ,VJ    ,NOPROF,NPROFA,
     2NPROFX,  TRD    ,NIP    ,REJECT,WTC     ,WTA   ,WTF   ,WTR   ,WREG  ,
     3WRB   ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX ,SC    ,SAP   ,CON   ,
     4VOC   ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT  ,TC    ,QW    ,SP2   ,
     5ALFMX ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC    ,ERD   ,ERC   ,EX2   ,
     6XNAM  ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA ,EX3   ,VMAXC ,VMINC ,
     7VMAXB ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP   ,LBT   ,LFL   ,LRD   ,
     8IBAT  ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS ,TS    ,CONKR ,NPF1  ,
     9NPF2  ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2    ,AREA
      COMMON    TT     ,NN     ,VCOR   ,NWT    ,PARA  ,TR    ,PR    ,VJCOR ,
     1SWH   ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI ,VOP1  ,VJOP1 ,TCH   ,
     2M1    ,M2       ,CODE   ,ALPHA  ,TD     ,COMB  ,FIBD  ,FJBC1 ,FIBC1 ,
     3CRIT  ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
      TCH=0
      I=M1
   10 PXXX=P(I)/AREA/ZZ
      CALL ACFLAG (PXXX,FXXX,NVJ,NIP,VJ,AMP)
      IF (FXXX)60,15,15
   15 FTOT1=FXXX+FJBC1
      CALL ACFLAG (FTOT1,PXX1,NVJ,NIP,AMP,VJ)
      IF (PXX1)60,20,20
   20 PI=PXX1*AREA*ZZ
C   IS POWER VALUE ON POWER PROFILE PLUS CHARGING POWER FOR BATTERY
C                              LESS THAN PFCMX
      IF(PI-PFCMX) 40,40,60
   40 TCH=TCH+T(I)
   60 I=I+1
C IS THIS THE END POINT ON THE PROFILE
      IF(I-M2)10,10,70
   70 IF(SENSE SWITCH 2)80,90
   80 PRINT 200,TCH,M1,M2,PFCMX
  200 FORMAT(1H0,21HSUBROUTINE SUBC  TCH=,F10.4,5X,3HM1=I3,5X,
     13HM2=I3,     5X,6HPFCMX=,F10.4)
   90 RETURN
      END(0,1,0,1,0)
```

```
C     PAUL CALLEN DEPT. 3258    SUBROUTINE SUBD
C
C     THIS SUBROUTINE MODIFIES THE POWER PROFILE TO COMPENSATE  FOR
C     THE POWER REQUIRED TO RECHARGE THE BATTERIES
      SUBROUTINE SUBD
C
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      COMMON   NVJ   ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P     ,T     ,
     1TA    ,  PA    ,TX     ,PX     ,V      ,AMP   ,VJ    ,NOPROF,NPROFA,
     2NPROFX,  TRD   ,NIP    ,REJECT,WTC    ,WTA    ,WTF   ,WTR   ,WREG  ,
     3WRB   ,  WTOPT ,WTOLD  ,WTNEW  ,DP     ,PFCMX ,SC    ,SAP   ,CON   ,
     4VOC   ,  VAB   ,PPC    ,PPV    ,ADD    ,BATT  ,TC    ,QW    ,SP2   ,
     5ALFMX ,  ALFMN ,BCMIN  ,DBC    ,BCMAX  ,EC    ,ERD   ,ERC   ,EX2   ,
     6XNAM  ,  XNRM  ,FR     ,RPS    ,FN     ,DALFA ,EX3   ,VMAXC ,VMINC ,
     7VMAXB ,  VBMIN ,EX4    ,EX5    ,EX6    ,NPP   ,LBT   ,LFL   ,LRD   ,
     8IBAT  ,  ICOMB ,LSP1   ,TKH    ,TKO    ,EMISS ,TS    ,CONKR ,NPF1  ,
     9NPF2  ,  IPX   ,IP     ,C      ,RATIO1,RATIO2,T1    ,T2    ,AREA
      COMMON   TT    ,NN     ,VCOR   ,NWT    ,PARA  ,TR    ,PR    ,VJCOR ,
     1SWH   ,  SWO   ,WT     ,DPCH1  ,ZZ     ,VCORI ,VOP1  ,VJOP1 ,TCH   ,
     2M1    ,M2      ,CODE   ,ALPHA  ,TD     ,COMB  ,FIBD  ,FJBC1 ,FIBC1 ,
     3CRIT  ,ALFAC   ,VJBC1  ,TCC    ,DISRAT,VMINB
C     IP IS A CODE USED TO INDICATE WHICH PART OF THE POWER PROFILE IS
C     BEING MODIFIED
      M1=NPF1+1
      IF (IP)10,30,50
   10 IF (NPF1-NOPROF)11,210,210
   11 DO 20 I=M1,NOPROF
      IPX=IPX+1
      TX(IPX)=T(I)
   20 PX(IPX)=P(I)
      GO TO 210
   30 DO 40 I=1,NPF1
      PX(I)=P(I)
   40 TX(I)=T(I)
      IP=1
      PX(NPF1)=PFCMX
      IPX=NPF1
   50 FIBC1=RATIO1*C
      FIBC2=RATIO2*C
      FJBC1=FIBC1/AREA
      FJBC2=FIBC2/AREA
      TSUM1=0.0
      DO 200 I=M1,NPF2
      IPX=IPX+1
      IF (P(I)-PFCMX)60,140,140
   60 PXXX=P(I)/AREA/ZZ
      CALL ACFLAG (PXXX,FXXX,NVJ,NIP,VJ,AMP)
      FTOT1=FXXX+FJBC1
      FTOT2=FXXX+FJBC2
      CALL ACFLAG (FTOT1,PXX1,NVJ,NIP,AMP,VJ)
      CALL ACFLAG (FTOT2,PXX2,NVJ,NIP,AMP,VJ)
```

```
      DPCH1=PXX1*AREA*ZZ-P(I)
      DELP2=PXX2*AREA*ZZ-P(I)
      DELP2=(DELP2+DPCH1)/2.0
      IF (T1-TSUM1)120,120,70
   70 PTEM=P(I)+DPCH1
      IF (PTEM-PFCMX)80,80,150
   80 TSUM1=TSUM1+T(I)
      IF(T1-TSUM1)100,90,90
   90 TX(IPX)=T(I)
      PX(IPX)=P(I)+DPCH1
      GO TO 200
  100 TX(IPX)=T1-TSUM1+T(I)
      PX(IPX)=P(I)+DPCH1
      IPX=IPX+1
      PX(IPX)=P(I)+DELP2
      TX(IPX)=T(I)-TX(IPX-1)
      GO TO 200
  120 PTEM=P(I)+DELP2
      IF (PTEM-PFCMX)130,130,150
  130 TX(IPX)=T(I)
      PX(IPX)=P(I)+DELP2
      GO TO 200
  140 PX(IPX)=PFCMX
      TX(IPX)=T(I)
      GO TO 200
  150 PX(IPX)=P(I)
      TX(IPX)=T(I)
  200 CONTINUE
  210 NPROFX=IPX
      IF (SENSE SWITCH 4)300,600
  300 WRITE OUTPUT TAPE 2,500
      WRITE OUTPUT TAPE 2,510
      WRITE OUTPUT TAPE 2,520,NPROFX,FIBC1,FIBC2
      WRITE OUTPUT TAPE 2,530
      WRITE OUTPUT TAPE 2,540,(TX(I),PX(I),I=1,IPX)
  500 FORMAT(1H0,15X,15HSUBROUTINE SUBD)
  510 FORMAT(1H0,3X,6HNPROFX,4X,5HFIBC1,4X,5HFIBC2)
  520 FORMAT (1H I7,2F11.3)
  530 FORMAT(1H0,4X,2HTX,10X,2HPX)
  540 FORMAT(1H ,2F10.3)
  600 RETURN
      END(0,1,0,1,0)
```

```
C      PAUL CALLEN  DEPT. 3258
       SUBROUTINE SUBE
       DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
      1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
      2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
       COMMON    NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P      ,T      ,
      1TA     ,  PA     ,TX     ,PX     ,V      ,AMP    ,VJ     ,NOPROF,NPROFA,
      2NPROFX,  TRD    ,NIP    ,REJECT,WTC    ,WTA    ,WTF    ,WTR    ,WREG   ,
      3WRB    ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX  ,SC     ,SAP    ,CON    ,
      4VOC    ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT   ,TC     ,QW     ,SP2    ,
      5ALFMX  ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC     ,ERD    ,ERC    ,EX2    ,
      6XNAM   ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA  ,EX3    ,VMAXC  ,VMINC  ,
      7VMAXB  ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP    ,LBT    ,LFL    ,LRD    ,
      8IBAT   ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS  ,TS     ,CONKR  ,NPF1   ,
      9NPF2   ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2     ,AREA
       COMMON    TT     ,NN     ,VCOR   ,NWT    ,PARA   ,TR     ,PR     ,VJCOR  ,
      1SWH    ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI  ,VOP1   ,VJOP1  ,TCH    ,
      2M1     ,M2       ,CODE   ,ALPHA  ,TD     ,COMB   ,FIBD   ,FJBC1  ,FIBC1  ,
      3CRIT   ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
       EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
       NSAVE=NXP
       NIP=2
C   IF IBAT=1 - NICKEL CADMIUM BATTERY    IBAT=2 - SILVER CADMIUM
C      IBAT=3 - SILVER-ZINC
       IF(IBAT-2) 50,100,300
C    NICKEL CADMIUM BATTERY
   50 NXP=11
       CALL ACFLAG(ALPHA,VMINB,NXP,NIP,TCD1(1,2),TCD1(1,1))
       IF(DISRAT-1.)600,600,75
   75 VMINB=VMINB-0.0225*(DISRAT-1.)
       GO TO 600
C SILVER CADMIUM BATTERY
  100 NXP=9
       CALL ACFLAG(ALPHA,VMINB,NXP,NIP,TCD2(1,2),TCD2(1,1))
       IF(ALPHA-0.1) 110,110, 150
  110 VMINB=VMINB-0.0032*(0.2-ALPHA)*(DISRAT-1.)
       GO TO 165
  150 VMINB=VMINB-0.032*(DISRAT-1.)
  165 IF(DISRAT-5.55) 600,600,180
  180 IF(ALPHA-0.5) 200,200, 275
  200 VMINB=VMINB-0.03*(DISRAT-5.55)
       GO TO 600
  275 VMINB=VMINB-0.03*((ALPHA/0.5)**1.75)*(DISRAT-5.55)
       GO TO 600
C SILVER ZINC BATTERY
  300 NXP=10
       I=1
       IF(DISRAT-TIBD(I))  350,350,310
  310 DO 380 I=2,7
       IF(DISRAT-TIBD(I))  375,350,380
  350 J=I
       GO TO 390
  375 J1=I
       J2=I-1
```

```
      GO TO  500
  380 CONTINUE
      J=7
  390 CALL ACFLAG(ALPHA,VMINB,NXP,NIP,TALPHA,TVMINB(1,J))
      GO TO 600
  500 CALL ACFLAG(ALPHA,VMINB1,NXP,NIP,TALPHA,TVMINB(1,J1))
      CALL ACFLAG(ALPHA,VMINB2,NXP,NIP,TALPHA,TVMINB(1,J2))
      VMINB=VMINB1+(VMINB2-VMINB1)*(TIBD(J1)-DISRAT)/(TIBD(J1)-TIBD(J2))
  600 IF (SENSE SWITCH 4)650,800
  650 PRINT 700,VMINB,ALPHA,IBAT,DISRAT
  700 FORMAT(1H0, 4HSUBE/1H ,6HVMINB=,F10.4, 6HALPHA=,F10.4, 5HIBAT=,
     1I3,7HDISRAT=,F10.4)
  800 NXP=NSAVE
      NIP=3
      RETURN
      END(0,1,0,1,0)
```

```
C          JAYESH DALAL  D-3258  JOB-734M   SUBG.
C          SUBROUTINE TO DETERMINE ALFAC AND CRIT FROM THE CHARGE TABLES
C          FOR A SPECIFIC TYPE OF RECHARGABLE BATTERY.
C
C
      SUBROUTINE SUBG (IBAT,RATIO1,CRIT,ALFAC,ALFMX,BCMAX)
C
C
      ALFAC=ALFMX
      CRIT=BCMAX
      IF(IBAT-2 )30,20,10
   10 CRIT=0.12
      GO TO 21
   20 CRIT=0.25
   21 ALFAC=RATIO1-CRIT
   30 IF(SENSE SWITCH 2)80,90
   80 PRINT 100,IBAT,RATIO1,CRIT,ALFAC
  100 FORMAT(5H0SUBG/7H0IBAT= I2,4X,8HRATIO1= F8.4,4X,6HCRIT= F8.4,4X,
     17HALFAC= F8.4)
   90 RETURN
      END(0,1,0,1,0)
```

```
C         PAUL CALLEN       DEPT. 3258        X-3362
C            SUBROUTINE TO DETERMINE RD USING TABLE TRD FOR THE
C            SPECIFIED CAPACITY AND TYPE OF BATTERY
C
      SUBROUTINE SUBH(TRD,IBAT,C,RD)
C
C
      DIMENSION TRD(4,4)
C
      I=IBAT+1
      IF(TRD(1,1)-C)20,10,10
   10 K=1
      GO TO 200
   20 IF(TRD(4,1)-C)30,30,40
   30 K=4
      GO TO 200
   40 DO 100 J=2,4
      IF(C-TRD(J,1))60,50,100
   50 K=J
      GO TO 200
   60 K2=J
      K1=J-1
      GO TO 110
  100 CONTINUE
  110 C1=TRD(K1,1)
      C2=TRD(K2,1)
      RD1=TRD(K1,I)
      RD2=TRD(K2,I)
C
      RD=RD1+(RD2-RD1)*(C-C1)/(C2-C1)
      GO TO 300
C
  200 RD=TRD(K,I)
C
  300 IF (SENSE SWITCH 4)500,600
  500 PRINT 400,IBAT,C,RD
  400 FORMAT(1H0,28HSUBROUTINE SUBH      ...IBAT= I2,5X,3HC= ,F6.2,5X,
     14HRD= ,F6.2)
  600 RETURN
      END(0,1,0,1,0)
```

```
C     PAUL CALLEN  DEPT. 3258
      SUBROUTINE SUBR
      EQUIVALENCE (NXP,NVJ),(VMAX,VMAXC),(VMIN,VMINC)
      DIMENSION TRD(4,4),TCD1(11,2),TCD2(9,2),TIBD(7),TALPHA(10),
     1TVMINB(10,7),P(55),T(55),TA(75),PA(75),TX(75),PX(75),V(30),
     2AMP(30),VJ(30),TR(75),PR(75),WTF(2),WTC(2),WTR(2),WT(2)
      COMMON    NVJ    ,TCD1   ,TCD2   ,TIBD   ,TALPHA,TVMINB,P      ,T      ,
     1TA     ,  PA     ,TX     ,PX     ,V      ,AMP    ,VJ     ,NOPROF,NPROFA,
     2NPROFX,   TRD    ,NIP    ,REJECT,WTC    ,WTA    ,WTF    ,WTR    ,WREG   ,
     3WRB    ,  WTOPT  ,WTOLD  ,WTNEW  ,DP     ,PFCMX  ,SC     ,SAP    ,CON    ,
     4VOC    ,  VAB    ,PPC    ,PPV    ,ADD    ,BATT   ,TC     ,QW     ,SP2    ,
     5ALFMX  ,  ALFMN  ,BCMIN  ,DBC    ,BCMAX  ,EC     ,ERD    ,ERC    ,EX2    ,
     6XNAM   ,  XNRM   ,FR     ,RPS    ,FN     ,DALFA  ,EX3    ,VMAXC  ,VMINC  ,
     7VMAXB  ,  VBMIN  ,EX4    ,EX5    ,EX6    ,NPP    ,LBT    ,LFL    ,LRD    ,
     8IBAT   ,  ICOMB  ,LSP1   ,TKH    ,TKO    ,EMISS  ,TS     ,CONKR  ,NPF1   ,
     9NPF2   ,  IPX    ,IP     ,C      ,RATIO1,RATIO2,T1     ,T2     ,AREA
      COMMON    TT     ,NN     ,VCOR   ,NWT    ,PARA   ,TR     ,PR     ,VJCOR  ,
     1SWH    ,  SWO    ,WT     ,DPCH1  ,ZZ     ,VCORI  ,VOP1   ,VJOP1  ,TCH    ,
     2M1     ,M2       ,CODE   ,ALPHA  ,TD     ,COMB   ,FIBD   ,FJBC1  ,FIBC1  ,
     3CRIT   ,ALFAC    ,VJBC1  ,TCC    ,DISRAT,VMINB
      WRITE OUTPUT TAPE 2,108
  108 FORMAT (1H120X36HTABULATION OF TOTAL WT OVER USABLE V,/1H0,6X,
     13HVIN 6X,3HV2N 7X, 2HWT 8X, 3HWTC 6X, 5HWTAUX 6X, 3HWTF 8X,
     23HWTR 5X,4HWTRB,6X,5HWTREG)
      ICODE=0
      WTMOD1=(WTC(1)+WTA)/(XNAM+XNRM)
      VCOR=VAB
      DELTAB=(VOC-VAB)/25.0
      DO 81 I=1,25
      CALL WTFUEL
      CALL RADWT
      WTPG4=WTC(1)+WTA+WTF(1)+WTR(1)+WRB+WREG
      WRITE OUTPUT TAPE 2,109,VCOR,VCORI,WTPG4,WTC(1),WTA,WTF(1),WTR(1),
     1WRB,WREG
  109 FORMAT (1H ,9F10.3)
   81 VCOR=VCOR+DELTAB
   80 NTM=XNAM+XNRM
      ROM=EXPF(-FR*TT)
      IF (XNRM)82,82,83
   82 REST=ROM**NTM
      GO TO 85
   83 REST=ROM**NTM
      NRM=XNRM
      TERM=ROM**NTM
      DO 84 I=1,NRM
      Y=(NTM-I+1)/I
      TERM=TERM*Y*(1.0-ROM)/ROM
   84 REST=REST+TERM
   85 PARM=PARA/XNAM
      WRITE OUTPUT TAPE 2,150,XNAM,XNRM,REST,WTMOD1,PARM
  150 FORMAT (1H17X, 35HFUEL CELL SUBSYSTEM DESIGN BASED ON F5.0, 21H  A
     1CTIVE MODULES AND ,F5.0, 20H  REDUNDANT MODULES./1H07X, 42HFUEL CE
     2LL SUBSYSTEM RELIABILITY ESTIMATE = ,F8.5/1H07X, 15HMODULE WEIGHT
     3= ,F10.3,/1H07X, 24HMODULE PARASITIC POWER = ,F10.3/1H0)
```

```
      WRITE OUTPUT TAPE 2,151
  151 FORMAT (1H038X, 32HMODULE OPERATING CHARACTERISTICS)
      WRITE OUTPUT TAPE 2,152
  152 FORMAT (1H07X,1HT10X,1HP10X,3HPFC9X,4HVMOD10X,3HI/A8X,1HI10X,
     12HPW9X,3HWH28X,3HWO26X,4HPMOD)
      NN=NN+1
      VX=VOP1
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
      SUM5=0.0
      SUM6=0.0
      VJX=VJOP1
      J=1
      DO 95 I=1,NPROFA
      IF (I-NN)90,90,91
   90 PFC=PA(NN)
      VMOD=ZZ*VOP1
      GO TO 96
   91 ITT=I+1-NN
      VJX=VJOP1*PR(ITT)
      CALL ACFLAG (VJX,VX,NXP,NIP,VJ,V)
      VMOD=ZZ*VX
      PFC=PA(I)
   96 PMOD=PFC/XNAM
      CUR=PMOD/VMOD
      CURD=VJX/VX
      PW=((1.0-.67*VX)*PMOD+PARM)/(.67*VX)-.0002165*QW*(PMOD+PARM)/VX
      WH2=((PMOD+PARM)/VMOD)*ZZ/12100.0
      WO2=7.95*WH2
      SUM1=SUM1+TA(I)
      SUM3=SUM3+PFC*TA(I)
      SUM4=SUM4+PW*TA(I)
      SUM5=SUM5+WH2*TA(I)
      SUM6=SUM6+WO2*TA(I)
      WRITE OUTPUT TAPE 2,160,TA(I),       PFC,VMOD,CURD,CUR,PW,WH2,WO2,
     1PMOD
   95 CONTINUE
      WRITE OUTPUT TAPE 2,161
  160 FORMAT (F12.3,12X,3F12.3,5F11.3)
  161 FORMAT (1H06X,5HSUM T6X,          10X,9HSUM PFC*T36X,8HSUM PW*T4X,
     18HSUM WH*T5X,8HSUM WO*T)
      WRITE OUTPUT TAPE 2,162,SUM1,      SUM3,SUM4,SUM5,SUM6
  162 FORMAT (F12.3,12X,F12.3,35X,3F11.3)
      RETURN
      END(0,1,0,1,0)
```

```
       REM INPL3 MODIFIED FOR FORTRAN
TERP   REM THIS ROUTINE WORKS ONLY IN THOSE PROGRAMS WHICH
       REM   ITERATE ON ONE VARIABLE AT A TIME.
       FUL
       MZE 0,0,4
       PZE
       PZE END,0,1
       PZE
       BCD 1TERP
       PZE TERP
       REL
F.F.F. EQU 18
       ORG 0
SQRT   BCD 1SQRT
TERP   SXD COMMON+7,4
       SXD TE30,2
       LXA TE30,2
       CLA 1,4
       STA TE15                 TO RESTORE MKR
       CLA 4,4
       STA TE20                 TO RESTORE X
TE3    CLA 1,4
       STA *+1
       CLA **
       TNX TE5,2,1
       STO TE10+4,2
       TXI TE3,4,-1
TE5    TSX INPL3,4
TE10   BSS 10
       TNZ *+2
       STZ TE10          ACCURACY OK
       LDQ TE10
TE15   STQ **                   MKR
       LDQ TE10+3
TE20   STQ **                   X
       LXD TE30,2
       LXD COMMON+7,4
       TRA 6,4
TE30   PZE 5,0,*
COMMON EQU 8150
       REM 3 POINT INTERPOLATION, USING ABSOLUTE VALUES OF Y AND
       REM SEARCHING FOR MINIMUM, OR USING SIGNED VALUES OF Y AND
       REM SEARCHING FOR ZERO
       REM TSX INPL3,4
       REM +1 MKR   MAKE ZERO WHEN STARTING ON NEW ROOT
       REM +2 NUMBER OF BITS ACCURACY DESIRED, MAKE FX PT 0 TO 27
       REM +3  DELTA
       REM +4  X
       REM +5 TO +10 RESERVE FOR ROUTINE TO USE FOR
       REM SAVING  X(RIGHT),Y(R),X(MID),Y(M),X(LEFT),Y(L)
       REM +11 EXIT, IF AC=0 ACCURACY OK, IF AC=NZ MORE ITERATIONS NEEDED
INPL3  TZE IN97
       ARS 2       MAKE ROOM FOR COUNT
       ALS 2
```

```
        SXD  IN14,1
        SXD  IN31,2
        SXD  IN19,4
        STO  COMMON                    Y(I)
        CLA  1,4                       MKR
        TNZ  IN15
        LXA  IN26,2        6
IN5     STZ  10,4
        TXI  IN7,4,1
IN7     TIX  IN5,2,1
        LXD  IN19,4                    RESTORE
        TSX  INA,1
        CLA  FL1
IN8     STO  1,4
IN9     LDQ  1,4                       MKR
        FMP  3,4                       X DELTA
        FAD  4,4                       X(I-1)
        STO  4,4                       X(I)
IN14    TXL  IN90,0,**                 TO EXIT
IN15    TMI  IN40                      TR IF COMING DOWN
        TSX  INA,1
        LDQ  8,4
        MPY  6,4
        TMI  IN20         CROSSED AXIS
        CLA  8,4
        SSP
        SBM  6,4
        TPL  IN20                      GETTING CLOSER TO AXIS
        LDQ  INB2                      GETTING FARTHER AWAY
        FMP  1,4
IN19    TXL  IN8,0,*
IN20    CLS  .25
        STO  1,4
        CLA  10,4
        TNZ  IN70
IN25    CLA  8,4                       USE 2 PT
IN26    FSB  6,4
        STO  COMMON                    Y
        CLA  5,4
        FSB  7,4
        FDH  COMMON
        FMP  8,4
        FAD  7,4
IN28    STO  COMMON                    X FROM 2 PT
        LDQ  FL3
        FMP  3,4
        FAD  4,4                       X+3DELTA
        LDQ  COMMON
        STQ  4,4
        TLQ  IN90                      TO EXIT
        STO  4,4                       NEW X
IN31    TXL  IN90,0,**                 TO EXIT
IN40    ADD  FL1
        TZE  IN48
```

```
        CLA 9,4
        TNZ IN41     THIRD PT FOUND
        LDQ 6,4        NO THIRD PT
        MPY 8,4
        TPL IN41
        CLS FL1
        STO 1,4         BOUNDED
        TXL IN49,0
IN41    CLA 4,4          NEW X
        SUB 5,4                  OLD X
        TMI IN44        X BACKED UP
        TSX INA,1
        LDQ 6,4         Y(I)
        MPY 10,4       Y(I-2)
        TMI IN42         CROSSED
        CLA 8,4        Y(I-1)
        SSP
        SBM COMMON
        TPL IN70          X NOT YET BOUNDED
IN42    CLS FL1
        STO 1,4
        TXL IN70,,
IN44    CLS FL1
        STO 1,4
IN48    CLA COMMON
        SSP
        SBM 8,4
        TPL IN50                 NEW PR FARTHER AWAY THAN MIDDLE PT
IN49    CLA 7,4
        STO COMMON+1
        LDQ 8,4
        CLA 4,4
        STO 7,4
        CLA COMMON
        STO 8,4
        CLA COMMON+1
        TXL IN53,0
IN50    CLA 4,4
        LDQ COMMON
IN53    CAS 7,4
        TXI IN55,4,4
        HTR
IN55    STO 9,4
        STQ 10,4
        LXD IN19,4
        LXD IN63,1
IN60    CAL 6,4                  Y
        ACL FX1
        SLW 6,4
        ANA FX3
        TZE IN62                 FORCE THIS PT OUT
        TNX IN64,1,1
        TXI IN60,4,-4
IN62    CLA 5,4
```

```
        LXD IN19,4
        FSB 7,4
        FDH INB3
        STQ COMMON
        CLA 7,4
        FAD COMMON
        STO 4,4
IN63    TXL IN90,0,2
IN64    LXD IN19,4
        REM  THREE POIUT INTERPOLATION
IN70    CLA 5,4                    X SUB 1
        FSB 9,4
        STO COMMON                 X(1)-X(3)
        CLA 5,4
        FSB 7,4
        STO COMMON+1               X(1)-X(2)
        TZE IN96
        CLA 6,4
        FSB 8,4
        FDH COMMON+1
        STQ COMMON+2               FRAC 2
        CLA 7,4
        FSB 9,4
        STO COMMON+3           X(2)-X(3)
        TZE IN96
        CLA 10,4
        FSB 8,4
        FDH COMMON+3
        STQ COMMON+3
        CLA COMMON+3
        FAD COMMON+2
        FDH COMMON
        STQ COMMON+5               A
        FMP COMMON+1
        FSB COMMON+2
        LDQ COMMON+5
        TQP *+2
        CHS     CHANGE SIGNS OF A,B,C
        STO COMMON+6     -B
        CLA COMMON+5
        SLW COMMON+5           SSP
        FDH .25               X4
        FMP 8,4
        STO COMMON
        LDQ COMMON+6
        FMP COMMON+6
        FSB COMMON
        TMI IN80        FIND MIN
        TSX SQRT,4
        NOP   PROVIDE FOR RETURN FROM SAP OR FORTRAN
        STO COMMON+1               DISCRIM
        SSM
IN77    FAD COMMON+6               -B
IN78    FDH COMMON+5
```

```
        FMP FL.5
        LXD IN19,4
        FAD 7,4
        STO COMMON
        SUB 9,4
        TPL IN79
        CLA COMMON+1           DISCRIM
        TXL IN77,0
IN79    CLA 1,4
        ADD .25
        TNZ IN28+1
        LDQ FL.5
        FMP 3,4
        FAD 4,4
        LDQ COMMON
        TLQ IN28
        TXL IN28+1
IN80    CLA COMMON+6
        TXL IN78,0
IN90    LXA FX3,2
        LXD IN19,1
        CLA 2,4
        ARS F.F.F.          F=18 FOR FORTRAN, F=0 FOR SAP
        STA IN95
IN91    CLA 4,4
        UFS 5,1
        LRS 27
        CLM
IN95    LLS *
        TZE IN96
        TXI *+1,1,-2
        TIX IN91,2,1
IN96    LXD IN14,1
        LXD IN31,2
        LXD IN19,4
        TNZ 11,4            NOT FINAL EXIT
IN97    STZ 1,4         RESET MKR
        TRA 11,4        FINAL EXIT
        REM MOVE ALL POINTS BACK
INA     LXA INA10,2
INA2    LDQ 8,4
        STQ 10,4
        TXI INA5,4,1
INA5    TIX INA2,2,1
        LXD IN19,4
INA10   CLA 4,4
        STO 5,4
        CLA COMMON
        STO 6,4
        TRA 1,1
INB2    DEC 1.25               TO MODIFY DELTA
INB3    DEC 6.                 CONSTANT TO FORCE OUT PERSISTENT POINT
FX1     DEC 1
FX3     DEC 3
```

```
.25     DEC .25
FL.5    DEC .5
FL1     DEC 1.
FL3     DEC 3.
END     BSS 0
        END
```

6.2.1 Explanation of Subroutine TERP - A 3-Point Interpolation Routine

Purpose

Many problems can be represented by the equation f (X) = Y. Often it is desired to find the value of X to make Y = 0, and this X is found by repeated evaluation of f (X). The purpose of this routine is to aid in estimating new values of X by saving the three best values and interpolating between them. The routine will attempt to find the X such that f (X) = 0 if the curve actually crosses the X axis, or it will find the X such that $\frac{d\,f(X)}{dX} = 0$ if the curve does not cross the axis.

Use

(1) In SAP programs, the routine is entered with the accumulator containing the value of X which is associated with the current value of X. The calling sequence is:

```
TSX     INPL3, 3
PZE     AMKR
PZE     ACC
PZE     DELTA
PZE     X
PZE     X(R)
PZE     Y(R)
PZE     X(M)
PZE     Y(M)
PZE     X(L)
PZE     Y(L)
        NORMAL RETURN
```

These quantities are defined to be:

AMKR	-	A marker which must be set to zero for each new function which will be evaluated.
ACC	-	The number of bits of accuracy desired for an acceptable solution--it must be a fixed point number between 0 and 27.
DELTA	-	The increment to be added to the initial X to get the second X.
X	-	The current value of X.

These four quantities need to be set before the first entry to the subroutine. The routine will modify them after that, and the new value of X will always be left in X . The next six locations contain the points which are being saved and are probably of no value to the programmer. On exiting from the routine, the accumulator and AMKR will be zero if the desired accuracy has been reached, and they will be non-zero if the desired accuracy has not been reached.

(2) In FORTRAN programs, the call statement is:

CALL TERP (AMKR, ACC, DELTA, X, Y)

6.2.2 EFM

EFM puts the program in a floating trap mode. Under this condition, a message is printed for each underflow or overflow. An adjustment is then made for this condition.

6.3 <u>Table of Error Messages</u>

(1) Computer halt

Computer halts displaying 22222; this means that RATIO 1 has exceeded BCMAX, and therefore CMAX cannot be calculated. Press start to proceed with the next set of data.

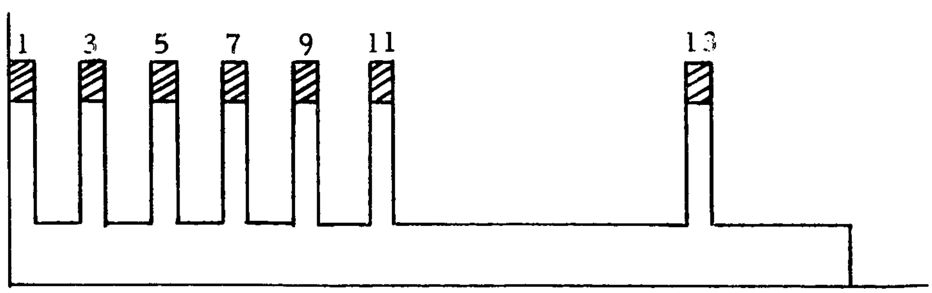
(2) Error Messages

A. "OPTIMUM VOLTAGE WILL NOT CONVERGE"

This message will be printed out only if LV is 1 and the optimum voltage does not converge after 10 iterations.

B. "PEAKS 1 THROUGH 3 HAVE BEEN COMBINED
PEAKS 1 THROUGH 5 HAVE BEEN COMBINED
PEAKS 1 THROUGH 7 HAVE BEEN COMBINED
PEAKS 1 THROUGH 9 HAVE BEEN COMBINED
PEAKS 1 THROUGH 11 HAVE BEEN COMBINED
PEAKS 13 THROUGH 15 HAVE BEEN COMBINED
PEAKS 13 THROUGH 17 HAVE BEEN COMBINED"

This message can be explained by the Figure given below.



Batteries after discharging at peak 1 could not be recharged during the period between peaks 1 and 3. An attempt was then made to see if the batteries could be recharged by combining the charging periods between peaks 1 and 3 and peaks 3 and 5. Batteries could not be recharged during this period. They could be charged, however, when all the charging times up to peak 13 were combined.

NOTE: Subroutine ACFLAG uses Lagrange method to interpolate between values in a table. If the independent variable exceeds the limits of the table being considered, the dependent variable is assigned the value of -1.0; e.g., if V = 0.6, then J will be -1.0.

7.0 APPENDIX B

A sample program is presented to demonstrate the capabilities and limitations of the program. It also explains the steps necessary in the program, shows a sample of input-output-data, and illustrates how the output data might be used.

7.1 Given

A combined fuel cell battery system is proposed as a power supply. The power profile for the mission is shown in Figure 3. Sixteen points on the voltage-current density graph, see Figure 4, were selected. These are tabulated on page 93 . Water generated in the fuel cell is collected. Reactants are stored supercritically. A flat radiator is used, with environmental heat input. Consideration should be given to both primary and rechargeable batteries.

PPC	=	Constant parasitic power	=	0
PPV	=	Variable parasitic power	=	0
ADD	=	Additional fuel for safety	=	0.12 pound/ pound
BATT	=	Weight constant of primary batteries	=	0.02 pound/ watt hour
TC	=	Temperature of coolant used in radiator	=	625° R
ALFMX	=	Maximum depth of discharge	=	0.75
ALFMN	=	Minimum depth of discharge	=	0.01

BCMIN	=	Minimum ratio of charging current to the capacity of the batteries	=	0.06/hr
BCMAX	=	Maximum ratio of charging current to the capacity of the batteries	=	0.50/hr
DBC	=	Increment in the above ratio	=	0.04/hr
EC	=	Charging efficiency	=	0.90
ERD	=	Regulator efficiency during discharge	=	0.90
ERC	=	Regulator efficiency during charge	=	0.90
XNAM	=	Number of operating fuel cell stacks	=	1
XNRM	=	Number of redundant fuel cell stacks	=	0
FR	=	Failure rate of fuel cells	=	0
RPS	=	Radiator probability of survival	=	0.999
FN	=	Number of increments between the maximum and minimum power	=	4
DALFA	=	Increment in the value of depth of discharge	=	0.10
VMAXC	=	Maximum fuel cell stack voltage	=	30 volts

VMINC	=	Minimum fuel cell stack voltage	=	26 volts
VMAXB	=	Maximum voltage per cell of the rechargeable battery	=	1.55 volts
VBMIN	=	Minimum total voltage for all cells of the battery	=	26

7.2 Required

Using the optimizing program establish the following parameters;

(1) Minimum weight

(2) Optimum voltage

(3) Weights of subsystems

(4) Cell area

(5) Number of cells

(6) Current and voltage for each power level

(7) Proportion of load assigned to primary or rechargeable batteries

(8) Rate of reactant consumption

(9) Total reactants consumed

(10) Total heat generated

(11) Table of subsystem and total weight for several individual cell voltages.

7.3 Additional Data Used

The following constants and tables were used in designing the system

SC	Cell Constant	=	2.95 pounds/square feet
SAP	Auxiliary Constant	=	0.00548 pounds/watts
K	Auxiliary Constant	=	14.49 pounds
VAB	Minimum limit of cell voltage	=	0.75 volts
TKH *	$\frac{\text{Weight of hydrogen + tankage}}{\text{Weight of hydrogen}}$	=	2.5 pounds/pound
TKO *	$\frac{\text{Weight of oxygen + tankage}}{\text{Weight of oxygen}}$	=	1.5 pounds/pound
EMISS *	Emissivity	=	0.85
TS *	Radiator sink temperature	=	430° R
CONKR *	$\frac{\text{Weight of radiator}}{\text{Square feet of fin area}}$	=	0.5

The table presented in Figure 5 was also used in designing the system.

* Values not used in the sample problem.

7.4 Sample Input Data Sheets

Data sheets for the problem are presented in Figure 5.

7.5 Output Data

The program solves the problem and prints data as shown in Figure 6. A reproduction of input data is printed out along with the calculated results.

7.6 Comments

From output page three, it is evident that a fuel cell-rechargeable battery combination would result in the lightest system. For such a system, maximum power supplied by fuel cells equals 1,625 watts. More refined results could be obtained by increasing the number of increments (FN), and by reducing DALFA and DBC. The refinement in the results would, of course, be obtained at the cost of longer machine time.

FUEL CELL POWER SYSTEM

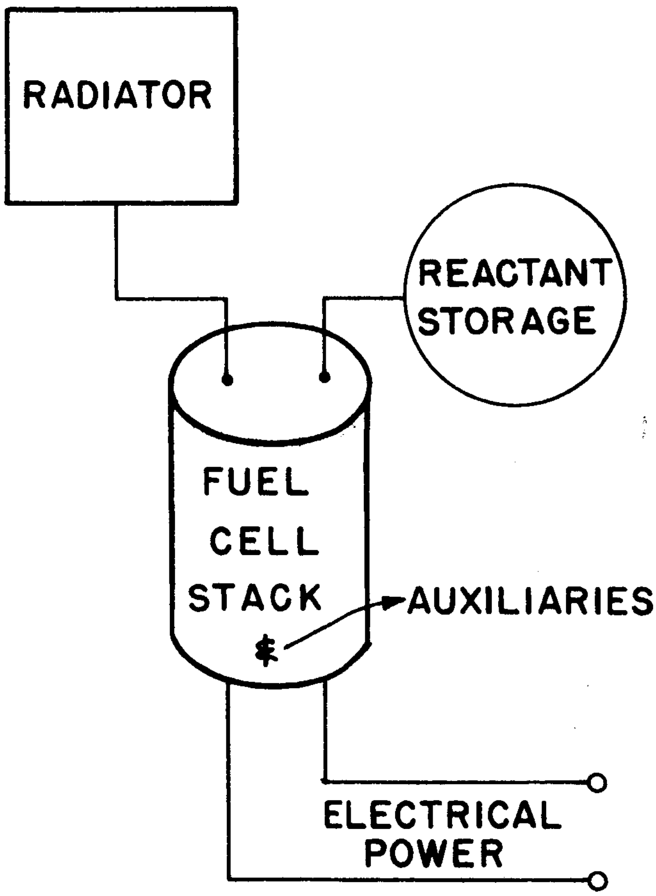
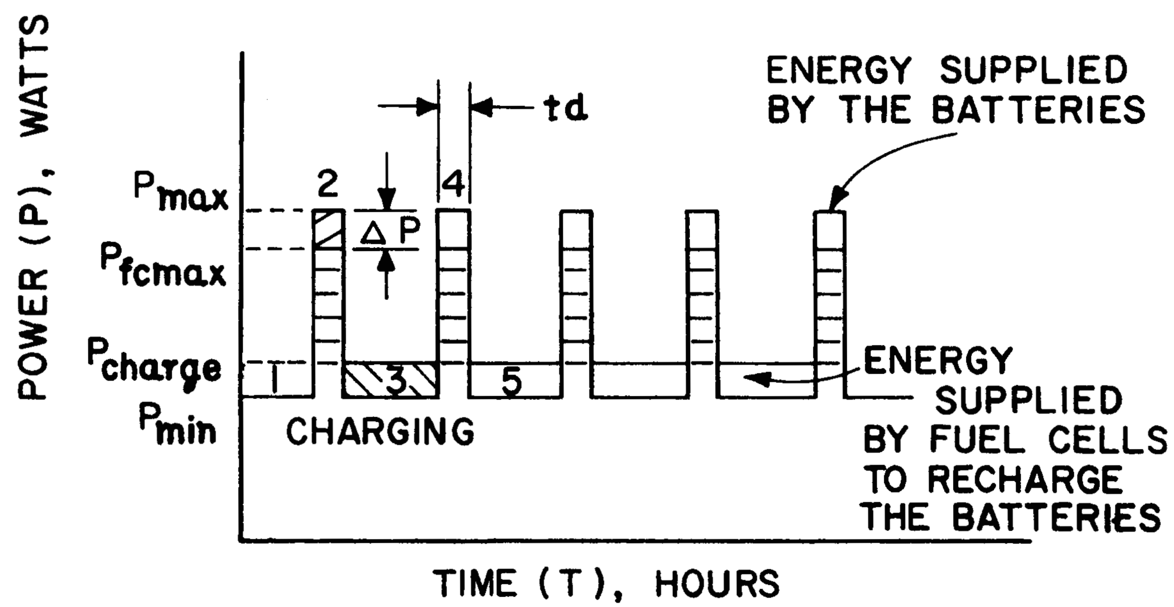


FIGURE 1

TWO STEP POWER PROFILE



NOMENCLATURE

P_{max} = MAXIMUM POWER LEVEL

P_{fcmax} = MAXIMUM POWER SUPPLIED BY THE FUEL CELLS

P_{charge} = POWER LEVEL AT WHICH THE BATTERIES ARE RECHARGED

P_{min} = MINIMUM POSITIVE POWER

FIGURE 2

POWER PROFILE FOR THE SAMPLE PROBLEM

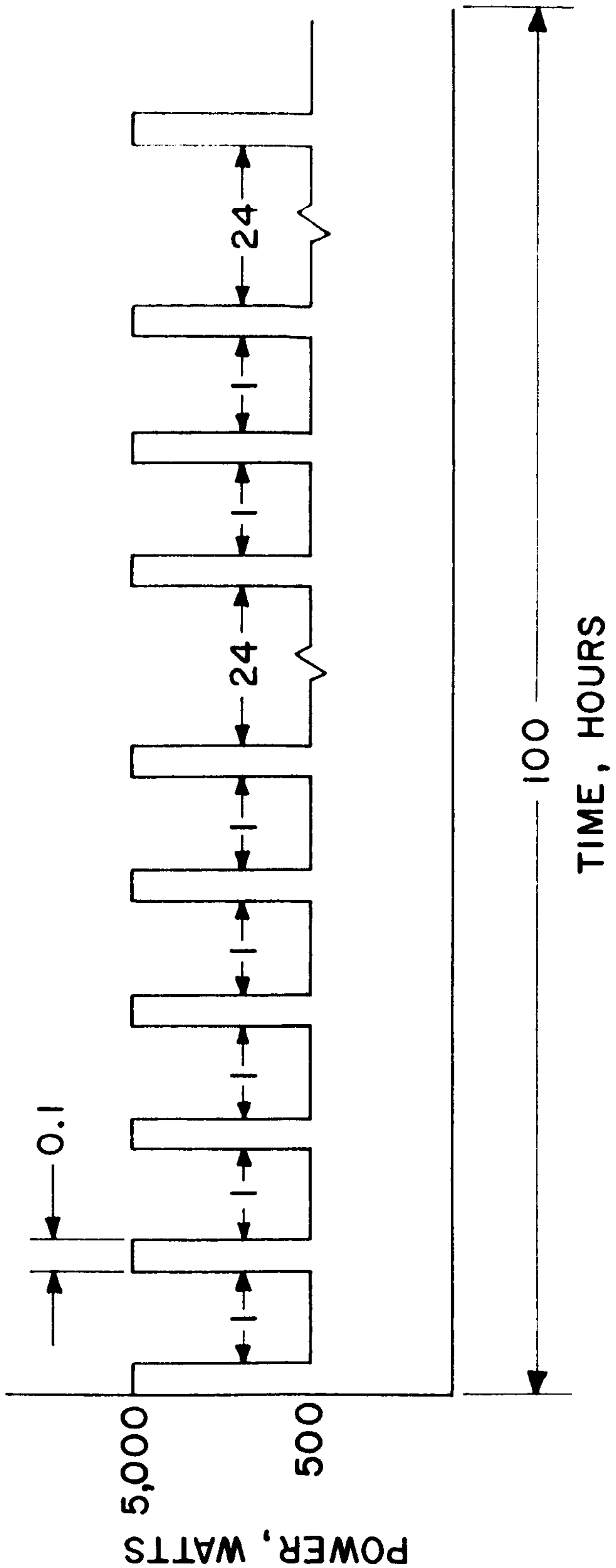


FIGURE 3

V-J CURVE OF A FUEL CELL

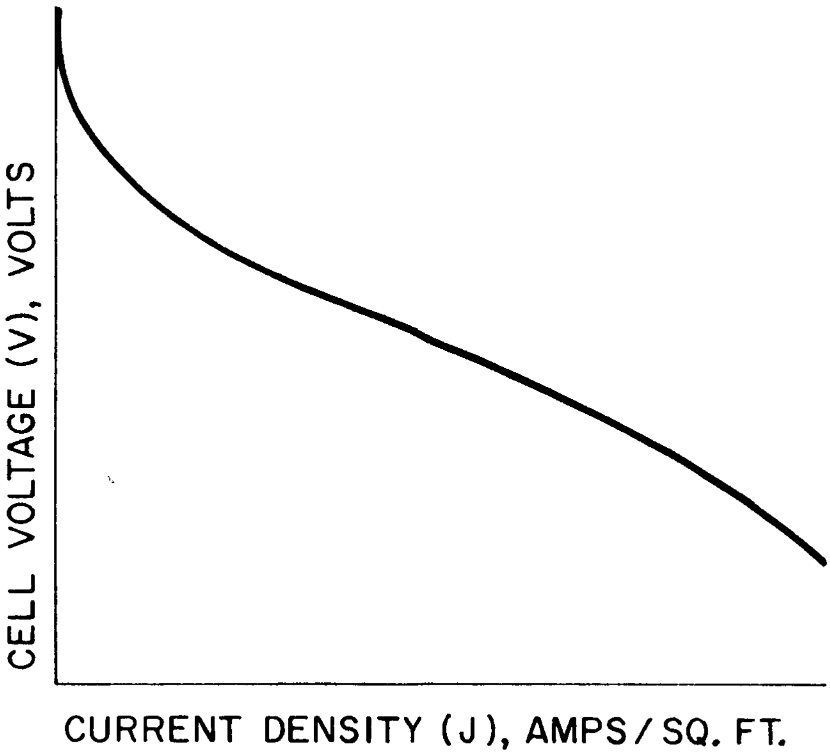


FIGURE 4

TYPICAL INPUT DATA

Control Card:

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	Title
	1	1	1	1	1	1	1	1	1	1	P_{max} = 5,000; T=100 hrs; Ag-Cd
COLS	1	2	3	4	5	6	7	8	9	10	11 … 70

I1 = 0 - Do not read set #1

= 1 - Read Set #1

= 2 - End of Job

I2-I10 = 0 - Set i absent

= 1 - Set i present

Title - Data Identification (60 characters maximum)

FIGURE 5

1. Set #1: Power Profile

(a) NOPROF - (I2): No. of values on power profile card columns 1-2

Cols 1 2

1	2
2	1

(b) TIME AND POWER VALUES FOR THE POWER PROFILE

	T (cols 1-10)	P (cols 11-20)	T (cols 21-30)	P (cols 31-40)	T (cols 41-50)	P (cols 51-60)
CARD#1	0.	5000.	.1	500.	1.1	5000.
#2	1.2	500.	2.2	5000.	2.3	500.
#3	3.3	5000.	3.4	500.	4.4	5000.
#4	4.5	500.	5.5	5000.	5.6	500.
#5	29.6	5000.	29.7	500.	30.7	5000.
#6	30.8	500.	31.8	5000.	31.9	500.
#7	55.9	5000.	56.	500.	100.	0.
#8						
#9						
#10						
#11						
#12						
#13						
#14						
#15						
#16						
#17						

FIGURE 5

2. Set #2: V-J Curve for Fuel-cell

(a) NXP-(I2): Number of values on V-J curve card columns 1-2

Cols	1	2
	1	6

(b) VOLTAGE AND CURRENT VALUES FOR V-J CURVE

	V (cols 1–10)	AMP/Sq.Ft. (cols 11–20)	V (cols 21–30)	AMP (cols 31–40)	V (cols 41–50)	AMP (cols 51–60)
CARD #1	1.1	0.	1.08	4.	1.06	11.
#2	1.04	24.	1.02	44.	1.00	70.
#3	.975	110.	.95	156.	.925	209.
#4	.900	269.	.875	334.	.850	404.
#5	.825	.475	.800	550.	.775	628.
#6	.750	712.				
#7						
#8						
#9						
#10						

FIGURE 5

3. Set #3

VARIABLE	SC	SAP	CON	VOC	VAB	PPC	PPV
CARD COL	1-10	11-20	21-30	31-40	41-50	51-60	61-70
	2.95	.00548	14.49	1.10	.75	0	0

4. Set #4

VARIABLE	ADD	BATT	TC	QW	SP2	ALFMX	ALFMN
CARD COL	1-10	11-20	21-30	31-40	41-50	51-60	61-70
	.12	.02	625.	0.	0.	0.75	0.01

5. Set #5

VARIABLE	BCMIN	DBC	BCMAX	EC	ERD	ERC	SP3
CARD COL	1-10	11-20	21-30	31-40	41-50	51-60	61-70
	.0625	0.04	0.50	.9	.9	.9	0.

6. Set #6

VARIABLE	XNAM	XNRM	FR	RPS	FN	DALFA	SP4
CARD COL	1-10	11-20	21-30	31-40	41-50	51-60	61-70
	1.	0.	0.	.999	4.	0.1	0.

7. Set #7

VARIABLE	VMAXC	VMINC	VMAXB	VBMIN	SP5	SP6	SP7
CARD COL	1-10	11-20	21-30	31-40	41-50	51-60	61-70
	30	26	1.55	26.	0.	0.	0.

8. Set #8

VARIABLE	TKH	TKO	EMISS	TS	CONKR
CARD COL	1-10	11-20	21-30	31-40	41-50
	2.5	1.5	0.85	430.0	0.5

9. Set #9

VARIABLE	NPP	LBT	LFL	LRD	IBAT	LV	LSP1
CARD COL	1-10	11-20	21-30	31-40	41-50	51-60	61-70
	0	3	1	4	2	0	0

FIGURE 5

FORMAT FOR TABLES

1. Table of d: TRD

   The values are read in row at a time with four values per card. FORMAT (4F10.0)

2. Nickel-Cadmium Cell Discharge Model: TCD1

   The values are read in row at a time with two values per card. FORMAT (2F10.0)

3. Silver-Cadmium Cell Discharge Model: TCD2

   The values are read in row at a time with two values per card. FORMAT (2F10.0)

4. Silver-Zinc Cell Discharge Model

   TIBD:

   All the values of TIBD are read in on one card. FORMAT (7F10.0)

   TALPHA:

   The values of TALPHA are read in on two cards with five values per card. FORMAT (5F10.0)

   TVMINB:

   The values of TVMINB are read in column at a time on seven cards with 10 values per card. FORMAT (10F7.0)

FIGURE 5

TABLES

1. Table of d: TRD (Reference 6)

Capacity Amp-hr	ρd - Ni-Cd	Watt-hr / lb Ag-Cd	Ag-Zn
1.	8.	12.	30.
25.	12.	21.	50.
100.	17.	32.	70.
300.	22.	41.	90.

$IBD/_C = 1$

2. Nickel-Cadmium Cell Discharge Model: TCD1 (References 7 and 8)

No.	Vminb	α
1	1.290	0.00
2	1.250	0.10
3	1.225	0.20
4	1.220	0.30
5	1.215	0.40
6	1.210	0.50
7	1.205	0.60
8	1.200	0.70
9	1.195	0.80
10	1.170	0.90
11	1.100	1.00

$IBD/_C = 1$

FIGURE 5

3. Silver-Cadmium Cell Discharge Model: TCD2 (References 7 and 8)

No.	Vminb	α
1	1.35	0.0000
2	1.14	0.0555
3	1.06	0.11
4	1.06	0.7200
5	1.04	0.7770
6	1.00	0.8330
7	0.95	0.8880
8	0.84	0.9420
9	0.60	1.0000

4. Silver-Zinc Cell Discharge Model (References 7 and 9)

a. Table of Values for IBD/C: TIBD

No.	IBD/C
1	0.0208
2	0.1000
3	0.3333
4	1.0000
5	2.0000
6	3.0000
7	6.0000

b. Table of Values for: TALPHA

No.	α	No.	α
1	0.000	6	0.175
2	0.050	7	0.250
3	0.100	8	0.300
4	0.1250	9	0.750
5	0.150	10	1.000

FIGURE 5

c. Table of Values for Vminb: TVMINB (Reference 7 and 8)

IBD/C \ α	0.0208	0.1	0.333	1.0	2.0	3.0	6.0
0.000	1.85	1.8	1.73	1.7	1.66	1.62	1.49
0.050	1.8475	1.79	1.715	1.69	1.62	1.5	1.37
0.100	1.845	1.78	1.7	1.68	1.58	1.42	1.30
0.125	1.845	1.765	1.68	1.64	1.54	1.41	1.295
0.150	1.83	1.751	1.66	1.60	1.50	1.4	1.29
0.175	1.80	1.72	1.64	1.575	1.48	1.4	1.31
0.250	1.60	1.60	1.58	1.50	1.45	1.4	1.33
0.300	1.58	1.54	1.52	1.50	1.45	1.4	1.33
0.750	1.58	1.54	1.52	1.50	1.45	1.4	1.33
1.000	1.58	1.54	1.52	1.50	1.45	1.33	1.2

FIGURE 5

NO. OF POINTS ON V-J CURVE 16

V	J	VJ
1.10000	0.	0.
1.08000	4.00000	4.32000
1.06000	11.00000	11.66000
1.04000	24.00000	24.96000
1.02000	44.00000	44.88000
1.00000	70.00000	70.00000
0.97500	110.00000	107.25000
0.95000	156.00000	148.20000
0.92500	209.00000	193.32500
0.90000	269.00000	242.10000
0.87500	334.00000	292.25000
0.85000	404.00000	343.39999
0.82500	475.00000	391.87500
0.80000	550.00000	440.00000
0.77500	628.00000	486.70000
0.75000	712.00000	534.00000

SC	SAP	CON	VOC	VAB	PPC	PPV
2.95000	0.00548	14.49000	1.10000	0.75000	0.	0.
ADD	BATT	TC	QW	SP2	ALFMX	ALFMN
0.12000	0.02000	625.00000	0.	0.	0.75000	0.01000
BCMIN	DBC	BCMAX	EC	ERD	ERC	SP3
0.06000	0.04000	0.50000	0.90000	0.90000	0.90000	0.
XNAM	XNRM	FR	RPS	FN	DALFA	SP4
1.00000	0.	0.	0.99900	4.00000	0.10000	0.
VMAXC	VMINC	VMAXB	VBMIN	SP5	SP6	SP7
30.00000	26.00000	1.55000	26.00000	0.	0.	0.
TKH	TKO	EMISS	TS	CONKR		
2.50000	1.50000	0.85000	430.00000	0.50000		
NPP	LBT	LFL	LRD	IBAT	LV	LSP1
0	3	1	4	2	0	0

FIGURE 6

POWER PROFILE

T	P
0.100	5000.000
1.000	500.000
0.100	5000.000
1.000	500.000
0.100	5000.000
1.000	500.000
0.100	5000.000
1.000	500.000
0.100	5000.000
1.000	500.000
0.100	5000.000
24.000	500.000
0.100	5000.000
1.000	500.000
0.100	5000.000
1.000	500.000
0.100	5000.000
24.000	500.000
0.100	5000.000
44.000	500.000

FIGURE 6

RECHARGABLE BATTERIES

	STAGE	VOPT	WTTOTAL	WTCELL	WTAUX	WTFUEL
ALL CELL	0	0.929	225.559	79.023	41.890	86.278
	1	0.897	203.570	45.921	35.725	88.455
	2	0.897	190.989	32.589	29.560	90.239
	3	0.867	178.141	15.504	23.395	93.586

WRAD	WTBAT	NO CELL	CELL AREA	WTREG
18.368	0.	28	0.957	0.
14.244	19.160	29	0.537	0.065
8.377	30.093	29	0.381	0.131
4.211	41.249	30	0.175	0.196

PRIMARY BATTERIES

STAGE	VOPT	WTTOTAL	WTCELL	WTAUX	WTFUEL
1	0.897	204.385	45.921	35.725	85.995
2	0.897	200.780	32.589	29.560	85.253
3	0.867	196.523	15.504	23.395	85.913

WRAD	WTBAT	NO CELL	CELL AREA	WTREG
14.244	22.500	29	0.537	
8.377	45.000	29	0.381	
4.211	67.500	30	0.175	

FIGURE 6

OPTIMUM CASE USING RECHARGABLE BATTERIES

STAGE	VOPT	WTTOTAL	WTCELL	WTAUX	WTFUEL	WRAD	WTBAT	NO CELL	CELL AREA	WTREG
3	0.867	178.194	15.504	23.395	93.639	4.211	41.249	30	0.175	0.196

VMINB 0.980 ALPHA = 0.350 IBAT 2 DISRAT = 3.500

TX	PX
0.100	1625.000
0.376	998.512
0.624	951.918
0.100	1625.000
0.376	998.512
0.624	951.918
0.100	1625.000
0.376	998.512
0.624	951.918
0.100	1625.000
0.376	998.512
0.624	951.918
0.100	1625.000
0.376	998.512
0.624	951.918
0.100	1625.000
24.000	568.039
0.100	1625.000
0.376	998.512
0.624	951.918
0.100	1625.000
0.376	998.512
0.624	951.919
0.100	1625.000
24.000	568.039
0.100	1625.000
44.000	500.000

C = 41.209 RD = 23.377
BAT = 27.000 VBMAX = 41.850

FIGURE 6

TABULATION OF TOTAL WT OVER USABLE V

VIN	V2N	WT	WTC	WTAUX	WTF	WTR	WTRB	WTREG
0.750	0.941	177.766	8.977	23.395	97.077	6.872	41.249	0.196
0.764	0.945	177.442	9.447	23.395	96.672	6.483	41.249	0.196
0.778	0.950	177.194	9.965	23.395	96.273	6.116	41.249	0.196
0.792	0.955	177.018	10.533	23.395	95.875	5.770	41.249	0.196
0.806	0.960	176.937	11.185	23.395	95.470	5.442	41.249	0.196
0.820	0.965	176.967	11.939	23.395	95.058	5.131	41.249	0.196
0.834	0.970	177.121	12.802	23.395	94.643	4.837	41.249	0.196
0.848	0.975	177.428	13.800	23.395	94.229	4.559	41.249	0.196
0.862	0.981	177.948	15.019	23.295	93.794	4.296	41.249	0.196
0.876	0.987	178.748	16.517	23.395	93.345	4.046	41.249	0.196
0.890	0.992	179.857	18.297	23.395	92.911	3.809	41.249	0.196
0.904	0.998	181.370	20.468	23.395	92.477	3.584	41.249	0.196
0.918	1.005	183.433	23.201	23.395	92.021	3.371	41.249	0.196
0.932	1.011	186.174	26.584	23.395	91.581	3.169	41.249	0.196
0.946	1.017	189.860	30.900	23.395	91.144	2.977	41.249	0.196
0.960	1.024	194.836	36.505	23.395	90.697	2.794	41.249	0.196
0.974	1.030	201.783	44.053	23.395	90.268	2.621	41.249	0.196
0.988	1.038	212.173	55.057	23.395	89.819	2.457	41.249	0.196
1.002	1.046	227.685	71.229	23.395	89.316	2.301	41.249	0.196
1.016	1.053	252.755	96.867	23.395	88.896	2.152	41.249	0.196
1.030	1.063	295.050	139.882	23.395	88.317	2.011	41.249	0.196
1.044	1.072	374.710	220.196	23.395	87.797	1.878	41.249	0.196
1.058	1.082	530.635	376.814	23.395	87.232	1.750	41.249	0.196
1.072	1.089	848.631	695.390	23.395	86.771	1.630	41.249	0.196
1.086	1.096	1923.679	1770.932	23.395	86.392	1.515	41.249	0.196

NOTE: Even though a value of cell voltage equal to 0.806 volt gives the minimum system weight, it cannot be used because of its failure to meet the voltage regulation limits of 28 $\pm$ 2 volts. Cell voltage equal to 0.867 volt will meet the voltage regulation limits. The purpose of the output on this page is to indicate the possibility of weight reduction by relaxing the voltage regulation limits.

FIGURE 6

FUEL CELL SUBSYSTEM DESIGN BASED ON 1. ACTIVE MODULES AND 0. REDUNDANT MODULES.

FUEL CELL SUBSYSTEM RELIABILITY ESTIMATE 1.00000

MODULE WEIGHT 38.899

MODULE PARASITIC POWER 0.

MODULE OPERATING CHARACTERISTICS

T	P	PFC	VMOD	I//	I	PW	WH2	WO2	PMOD
1.000		1625.000	26.000	356.756	62.500	1173.508	0.155	1.232	1625.000
2.630		998.512	27.804	204.995	35.913	609.533	0.089	0.708	998.512
4.370		951.919	27.948	194.424	34.061	573.199	0.084	0.671	951.919
48.000		568.039	29.234	110.913	19.431	301.995	0.048	0.383	568.039
44.000		500.000	29.487	96.791	16.957	259.256	0.042	0.334	500.000
SUM T		SUM PFC*T				SUM PW*T	SUM WH*T	SUM WO*T	
100.000		57676.876				31184.508	4.920	39.117	

FIGURE 6

PERCENTAGE WEIGHT SAVING VERSUS DISCHARGE TIME

For Ideal Set of Conditions

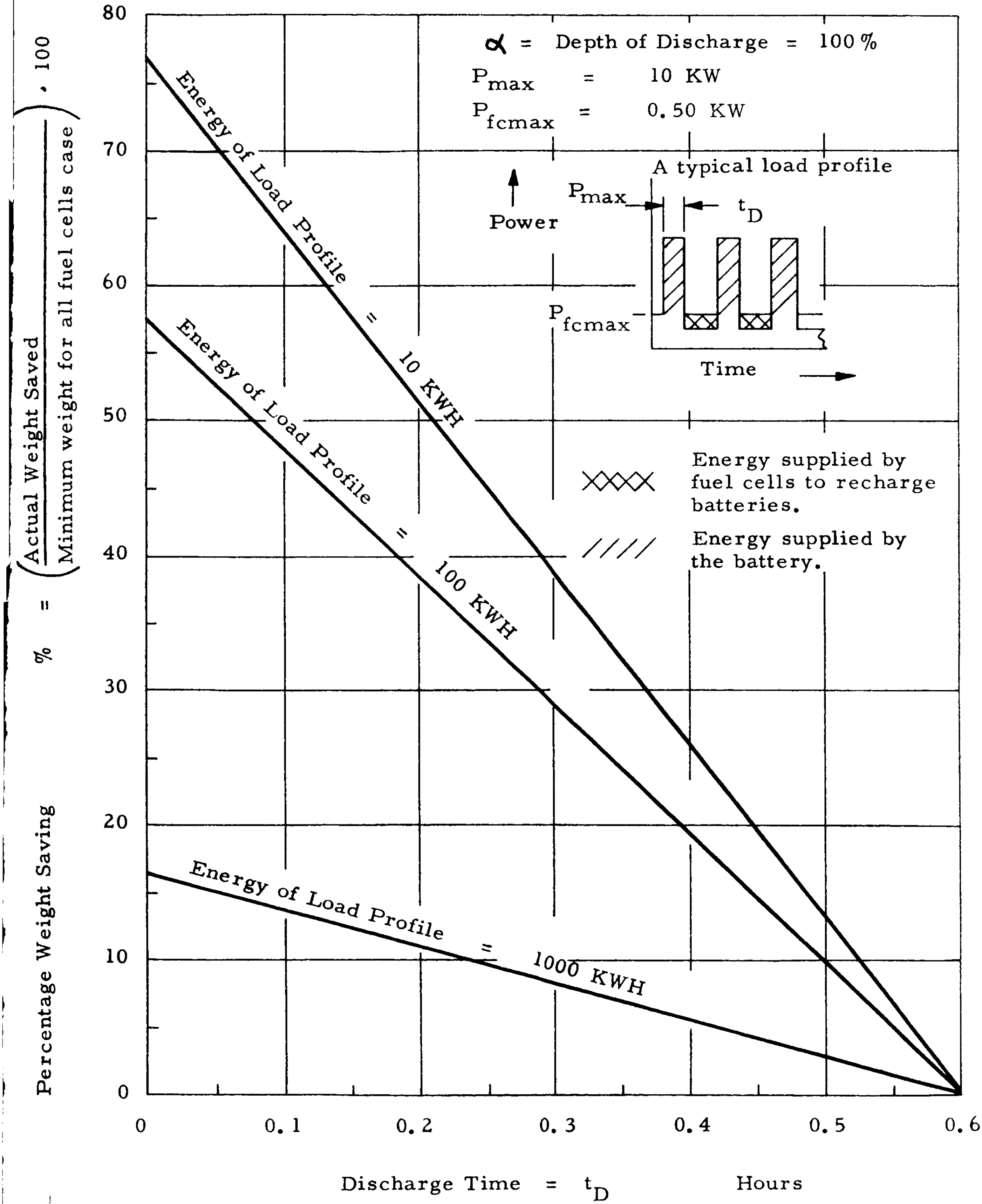


FIGURE 7

PERCENTAGE WEIGHT SAVING VERSUS DISCHARGE TIME

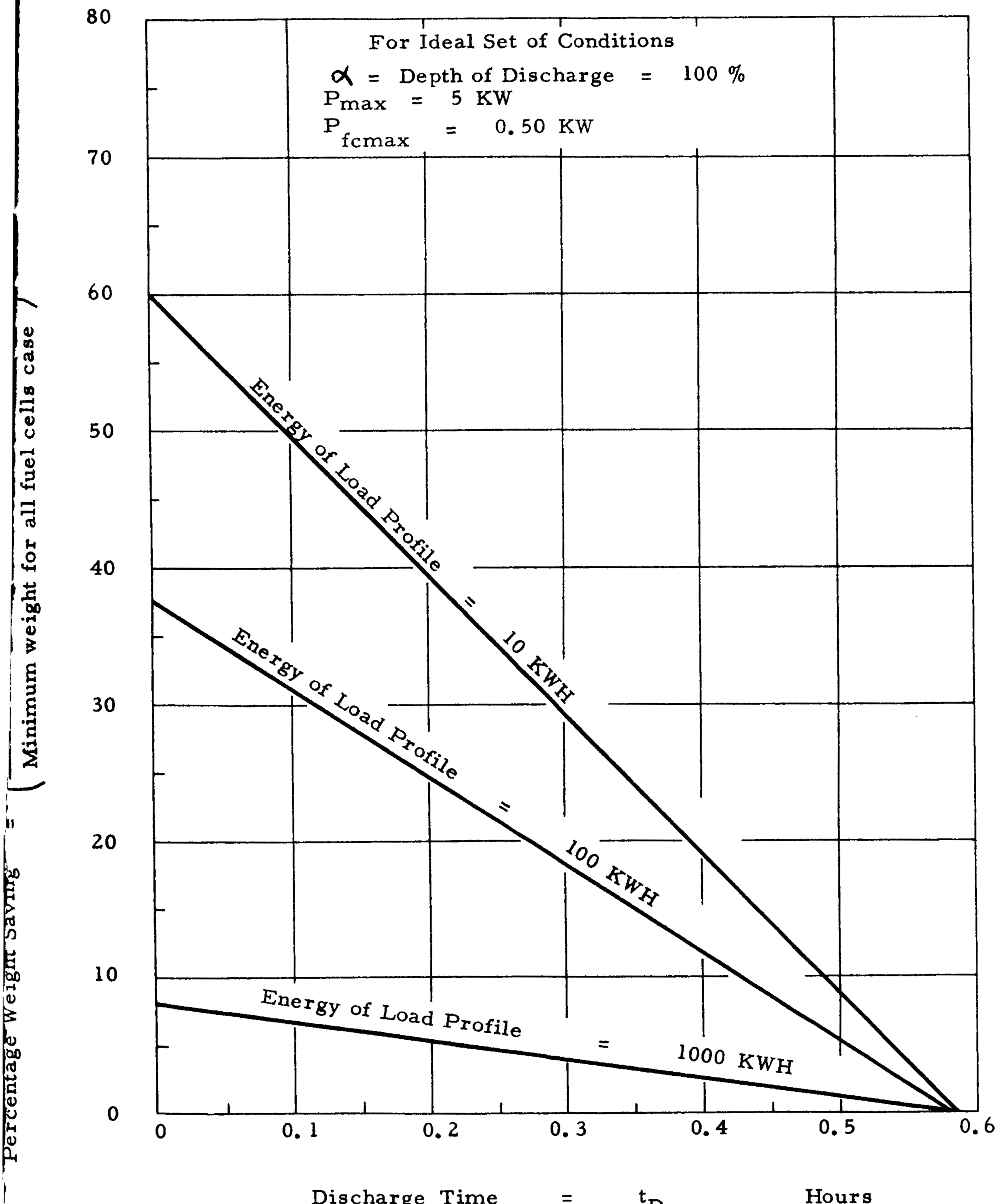


FIGURE 8

PERCENTAGE WEIGHT SAVING VERSUS DISCHARGE TIME

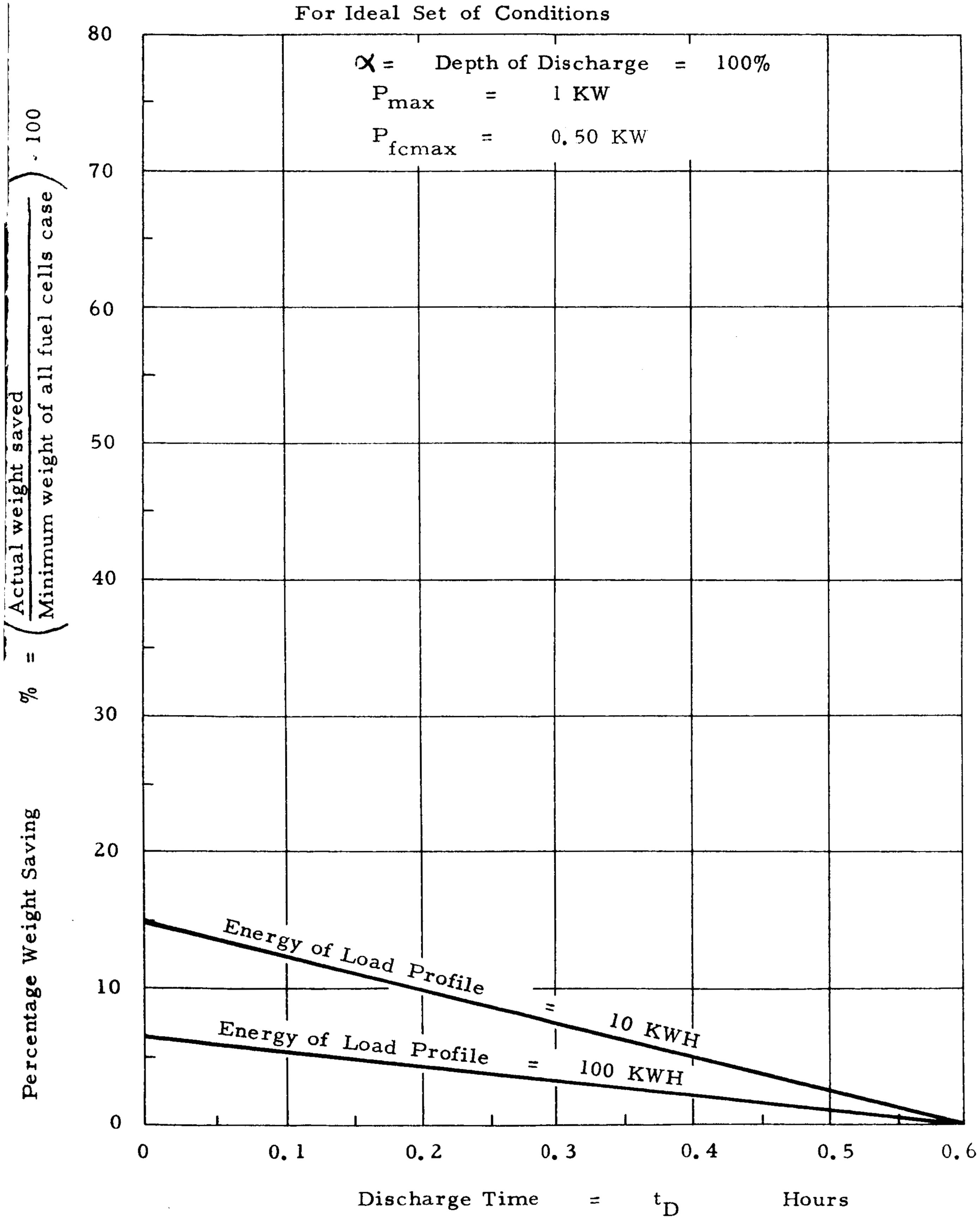


FIGURE 9