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THE NIMBUS ENERGY BALANCE COMPUTER PROGRAM

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FEBRUARY 1970

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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February 1970

*Formerly of RCA Astro-Electronics Division, where the computer program development was performed under GSFC Contracts NAS 5-10158 and NAS 5-11549.

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ABSTRACT

The lengthy and laborious hand calculations now associated with the design and analysis of satellite power systems can be greatly reduced through the use of the Nimbus Energy Balance Computer Program. By combining the known electrical characteristics of the power supply components, this program will simulate the operation of three general types of power systems – Nimbus, Series Maximum Power Point Tracker and Parallel Maximum Power Point Tracker – as the spacecraft passes through a complete orbital cycle. The effect of load changes, battery failure or changes in operating characteristics, solar array degradation or partial failure, and changes in electrical component characteristics on power system energy balance can be easily obtained; energy balance is defined as the condition where sufficient power exists to supply the spacecraft loads and completely recharge the batteries during a given orbit.

The output of the program is a summary of the operating condition of the various system components at user-specified time increments during an orbit: solar array maximum available power, actual array power

supplied, solar array current, battery current and voltage, the relative battery state-of-charge and number of ampere-minutes of capacity remaining in battery, total regulated bus current, peak load current and shunt dissipator current. The average power dissipation in the batteries, the battery ampere-minute charge-to-discharge ratio achieved during the orbit and the battery depth-of-discharge are also calculated and printed out.

THE NIMBUS ENERGY BALANCE

COMPUTER PROGRAM

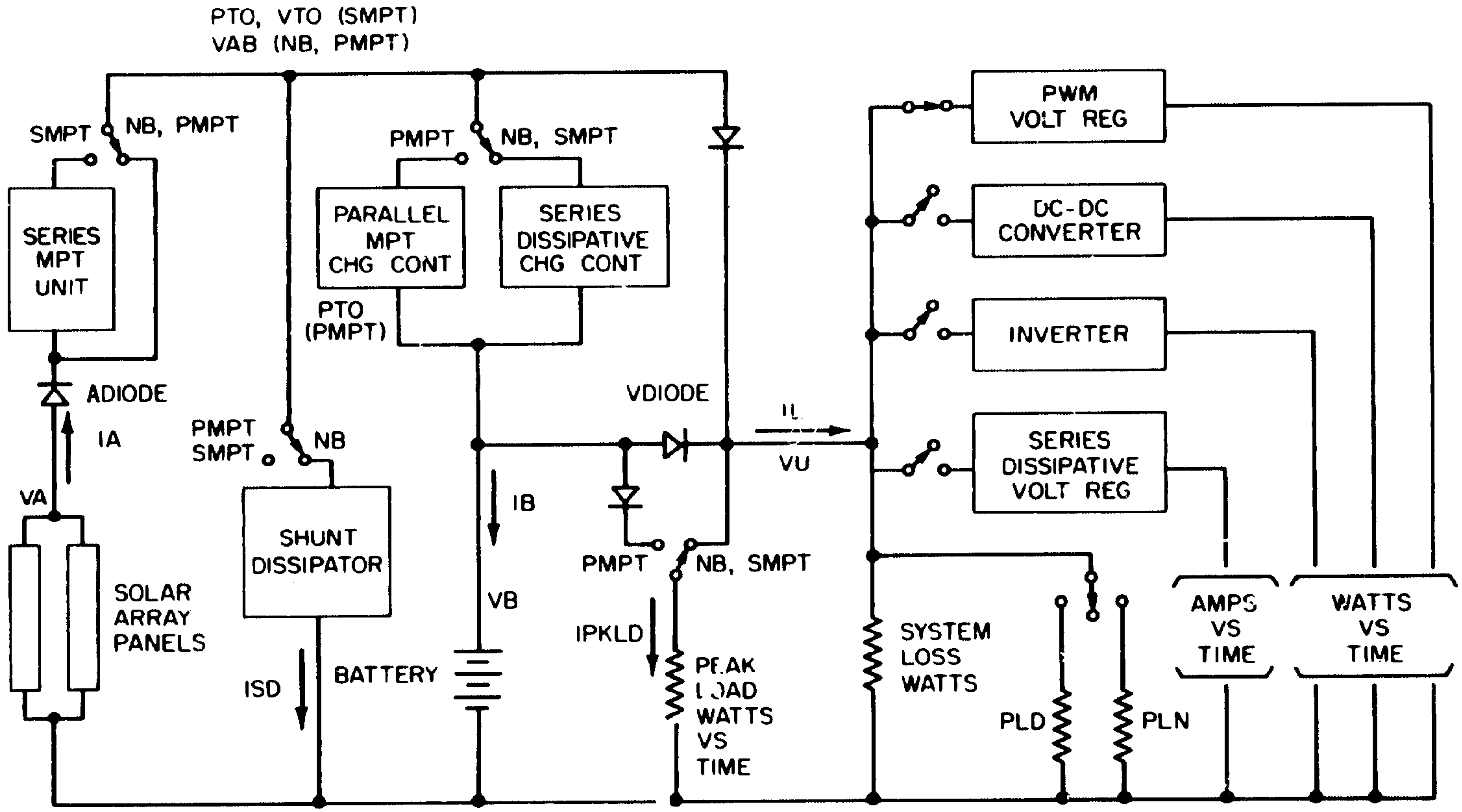
I. Introduction

The design and analysis of satellite power systems is greatly enhanced by the capability to simulate the power system's orbital performance. The laborious hand calculations usually associated with this simulation can be significantly reduced through the use of the Nimbus Energy Balance Computer Program. The determination of the various system component operating parameters is accomplished by combining the known electrical characteristics of the solar array, battery, source control devices, load power conditioning devices, charge controller, system power losses and spacecraft load profiles. A running tally of the various power system operating parameters is provided throughout the simulated orbit; these parameters are printed out at equal user-specified time increments during the orbit.

This program accommodates an energy balance analysis of three general types of power systems:

1. The Nimbus B series regulator type system (NB),
2. A parallel maximum power tracker system (PMPT), and
3. A series maximum power tracker system (SMPT).

Figure 1 presents a block diagram of the computer model of the three power system configurations. By supplying a particular "System Key" input data card,



SYSTEM KEY NB = NIMBUS B
PMPT = PARALLEL MAXIMUM POWER TRACKER
SMPT = SERIES MAXIMUM POWER TRACKER

Figure 1. Computer Model of Three Power System Configurations

the program user specifies which system configuration he wishes to simulate, and the computer "switches" shown in Figure 1 are positioned appropriately. All input data and computer instructions are supplied by the program user in a "data deck" consisting of 50 NCODE cards defining various power system parameters, 30 STINT tables containing solar cell, battery, temperature and load profile information, and up to 25 Panel Description Cards defining the solar array configuration to be simulated.

Because of the numerous power system components and functions that must be considered when simulating orbital performance, the energy balance program is divided into a main routine, called MAIN, and the following subroutines: STASH, STINT, DRAIN, AMPS and PRINT. All five subroutines are used when simulating either the NB, PMPT or SMPT system configurations and perform identical functions for all systems. Briefly, the functions of the subroutines are:

MAIN - Perform energy balance iterations

STASH - Supply solar cell information

STINT - Store input data tables

DRAIN - Determine value of load current

AMPS - Determine available solar array current

PRINT - Present output data in proper formats

A more complete description of each subroutine is contained in Section III.

II. Power System Components

The following paragraphs describe the characteristics of each of the components comprising the computer model of the three types of power systems shown in Figure 1.

1. Solar Array and Isolation Diode

The solar array may contain fron one to twenty-five solar cell panels connected electrically in parallel. Each panel may have its own number of series and parallel cells, its own solar incidence angle (which must remain constant throughout an orbit) and its own temperature-vs-time profile. All panels use the same solar cell as the basic building block, and pass current through the isolation diode ADIODE. The value of ADIODE (if applicable) includes the diode and slipring voltage drop. Total solar array output current, IA, is the sum of the individual panel currents at the solar array operating voltage VA.

The array current-voltage (I-V) curve values are determined by the computer multiplying the solar cell I-V points by the number of series cells for voltage, and by the number of parallel cells for current on each panel. The charged-particle-degraded solar cell I-V curve is supplied by the user as an input table of I-V pairs along the curve. Temperature coefficients and voltage and current degradation factors are also supplied as an input by the user; subroutine STASH manipulates the tabulated cell I-V curve to account for the various design factors and temperature effects.

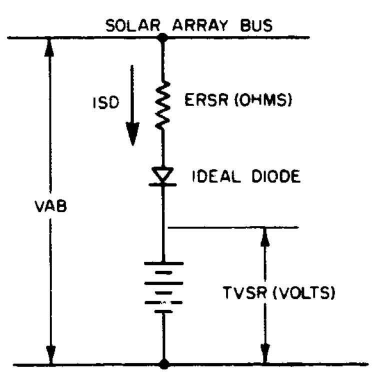
2. Series MPT Unit and Solar Array Bus

If the program user has elected to simulate the SMPT system, the switches in Figure 1 are placed in the SMPT position by the computer and the Series MPT Unit is connected in series with the output of the solar array. The component transfers solar array power (VA-ADIODE) × IA to the series tracker unit output with an efficiency, PTEFF, specified by the user. The power tracker output, PTO, is then defined by the relationship PTO = (VA-ADIODE) × IA × PTEFF, in watts. PTEFF retains a constant value during an orbit, and a minimum drop of 1.0 volt is maintained across the series tracker unit at all times. The series tracker unit output voltage is designated VTO.

When either a NB or PMPT system is to be simulated, the switches in Figure 1 are automatically positioned accordingly; the series tracker unit is shorted out, and the voltage on the solar array bus (VAB) is defined as VAB = VA - ADIODE.

3. Shunt Dissipator

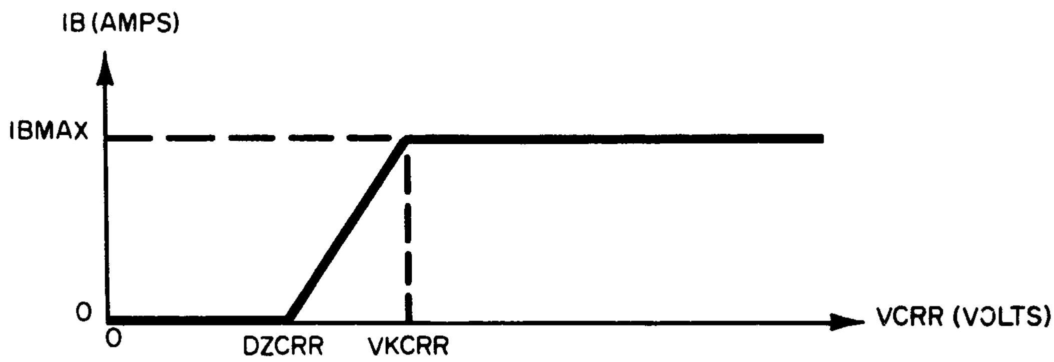
The shunt dissipator is employed in the NB system only, and is represented by the equivalent circuit shown below.



Whenever the solar array bus voltage (VAB) exceeds the shunt dissipator threshold voltage (TVSR), shunt dissipator current (ISD) will exist, as determined by the effective shunt dissipator resistance (ERSR). The values of TVSR and ERSR are specified by the user on input NCODE cards.

4. Charge Controller

The NB and SMPT systems use the same charge controller model, shown in the figure below.



When the voltage drop across the charge controller (VCRR) exceeds the dead zone voltage (DZCRR), battery charge current (IB) will increase linearly to the point where the maximum permissible charge current (IBMAX) occurs at the charge controller knee voltage (VKCRR); further increases in VCRR will maintain a constant IB value. If the value of battery charge voltage reaches the maximum permissible value (VBMAX), the computer will reduce the charge current to a value such that VBMAX is not exceeded, just as in actual voltage limiting circuit operation (tapered charge operation).

Values of DZCRR, VKCRR, IBMAX and VBMAX are specified by the user on input NCODE cards.

When a PMPT system is being simulated, the series dissipative charge controller previously described is disconnected and replaced by the parallel maximum power tracker unit, which transfers power from the solar array bus to the tracker output with a user-specified efficiency PTEFF. The tracker output power, PTO, is normally used to charge the battery, but can also deliver power to the peak load and/or the main load regulator if necessary.

The parallel tracker unit also contains the current-limiting (IBMAX) and voltage-limiting (VBMAX) circuits which control battery charge current just as in the other two system configurations. In addition, the parallel tracker unit continuously compares the total amp-minutes into the battery with the total amp-minutes taken out of the battery during the orbit being simulated. When the ratio of these parameters reaches the value specified by the program user as the C/D ratio (CTOD), battery charge current is automatically reduced to a nominally low (0.6A) value. This simulates the actual operation of an ampere-hour counter charge control method. If the program user does not wish to take advantage of this ampere-hour charge control program feature, a high value for CTOD (e.g. 100.0) should be specified in the NCODES.

5. Battery

The computer model assumes that all batteries connected in parallel in the power system have the same electrical characteristics and can therefore be lumped together into one equivalent battery having the combined capacities, the sum of the maximum charge currents and the same voltage as the individual batteries.

The voltage of the computer model of the battery depends upon its state of charge (SOC) and the value of current (IB) going into or out of the battery. The full capacity of the battery BAMMAX (Battery Amp-Minutes MAXimum) is defined by the user as an input and the state of charge (SOC) is calculated by the computer to be the amp-minutes in the battery at any given time (ACCUM), divided by BAMMAX. Storage cell data is read into the computer from an input data table which tabulates cell voltages as a function of SOC and charge or discharge current, IB. The computer multiplies the cell voltage by the number of series-connected cells in the battery (FUDGE) to obtain the battery voltage VB at a given SOC and a given value of IB. One battery is assumed in the computer system, having the combined capacity of all the storage modules, and charging or discharging at the total value of current. An example of how storage cell data is tabulated for computer input is presented later in the report.

Values of BAMMAX and FUDGE are specified by the user as an input to define the fully-charged system storage capacity in ampere minutes and the number of series connected cells in the battery. (NOTE: the variable NBAT is also used in the program to signify the number of series-connected cells in the battery).

6. Discharge Diode, Unregulated Bus and Peak Load

In all three system configurations, the battery discharges through an isolation diode in the battery discharge path between the battery and the unregulated bus. The voltage drop across this diode is called VDIODE, and is user-specified. Current exists through this diode only during battery discharge, providing a definition for unregulated bus voltage, VU, during satellite nighttime: VU = VB - VDIODE.

Note that VU can be much greater than VB during solar array illumination, since the battery discharge diode is then normally reverse-biased. During satellite night, the spacecraft load demand (except for peak load) is determined by the computer in subroutine drain to be ILT amperes demand at the unregulated bus voltage (VU), while ILT is defined at the array bus voltage (VAB) during satellite day.

The peak load is a user-supplied input data table which defines peak load power in watts as a function of time in minutes during an orbit. The table is prepared in the same format for all three systems, and in fact can define any type of unregulated bus power profile from a minimum duration of one minute up to an entire orbit duration load. As seen in Figure 1, the peak load in the NB and SMPT systems is supplied from the unregulated bus. The battery will discharge if the solar array bus cannot supply enough power at VU to satisfy ILT and the peak load current (IPKLD).

When the PMPT system is selected, the peak load is supplied from a peak load bus which is isolated from the unregulated bus by the battery discharge diode VDIODE. This permits the solar array to operate at its maximum-power voltage at all times with the PMPT system; the peak load current is supplied by the parallel tracker unit up to the limit of IBMAX - any additional current requirement is supplied by battery discharge to the peak load bus. The value VDIODE is applied to the voltage drop across the diode between the battery and peak load bus in the PMPT system.

7. Load Power Conditioning Devices

Figure 1 shows four types of power conditioning devices which derive unregulated DC power from the unregulated bus and supply the spacecraft loads with the desired type of voltage. Any or all of the four devices may be used with any of the three systems - the user defines which STINT table location (explained in Section IV of this report) contains the load vs time profile of a device which is to be employed in the system. The characteristics of each load power conditioning device are described below.

(a) PWM Voltage Regulator. - This device is a down-converting, switching regulator that basically transfers power at a relatively constant percentage efficiency. The input current can be less than the output current in this relatively efficient device. PWM regulator losses (transfer efficiency losses) are included along with other system losses in a separate stored table, as a function of regulated load power. The load profile for this device is tabulated as spacecraft load watts, at the regulated output voltage, versus time; calculation of losses is automatically made.

(b) DC-DC Converter. - This device supplies regulated DC power at an output voltage which can be higher than the input (unregulated) voltage. The load profile is prepared as regulated output power versus time; losses are calculated as a power transfer inefficiency with a user-supplied value of converter efficiency EFFCNV. The computer does not need the value of output voltage for its calculations; the user must define the appropriate constant value of EFFCNV, in percent, for the particular device he is simulating.

(c) Inverter. - This device supplies an A-C output voltage to the load profile which is tabulated as required watts versus time. A constant percentage power transfer efficiency EFFINV is supplied by the user as an input. Values of output voltage, frequency or power factor are not required by the computer; the user must supply an appropriate power transfer efficiency EFFINV, in percent, for the particular inverter he is simulating.

(d) Series Dissipative Voltage Regulator. - This device supplies current to the spacecraft load at a constant regulated DC output voltage which is less than the input voltage, similar to the PWM regulator. However, in the dissipative device, the input current is assumed to be equal to the output current. The product of this current times the voltage drop across the regulator is the power lost in supplying the loads with this device. The load profile for the series dissipative regulator is tabulated as amperes demand (at regulated voltage) versus time. Values of shunt power loss in the series dissipative regulator can be accounted for in the system power loss table, explained below.

8. System Power Losses and Fixed Losses

The system loss watts (SL) shown in the block diagram of Figure 1 are values of watts, stored in a table in the computer, that represent the measured PWM voltage regulator losses, telemetry and standby circuitry losses, solar array bus-to-unregulated bus diode losses and regulated power required by the eight charge controllers in the Nimbus B flight power subsystem. These are collectively called system power losses and are strongly dependent on both the unregulated bus voltage and the total spacecraft load demand on the power subsystem. Figure 2 presents the measured system power losses as a function of regulated bus output power for conditions of satellite nighttime (battery discharge, low unregulated voltage), solar array illumination (middle-range unregulated voltage) and shunt dissipator ON (highest unregulated voltage) for a typical Nimbus power subsystem.

When a PWM regulator is specified, the total value of system loss is obtained from the table which contains the Figure 2 data. If a PWM regulator is not used in a system, the losses are calculated as described in 7b, c, and d, and in addition the system loss (watts) at 0 watts PWM load is obtained to account for such losses as are caused by telemetry, standby circuitry and other power losses associated with the system.

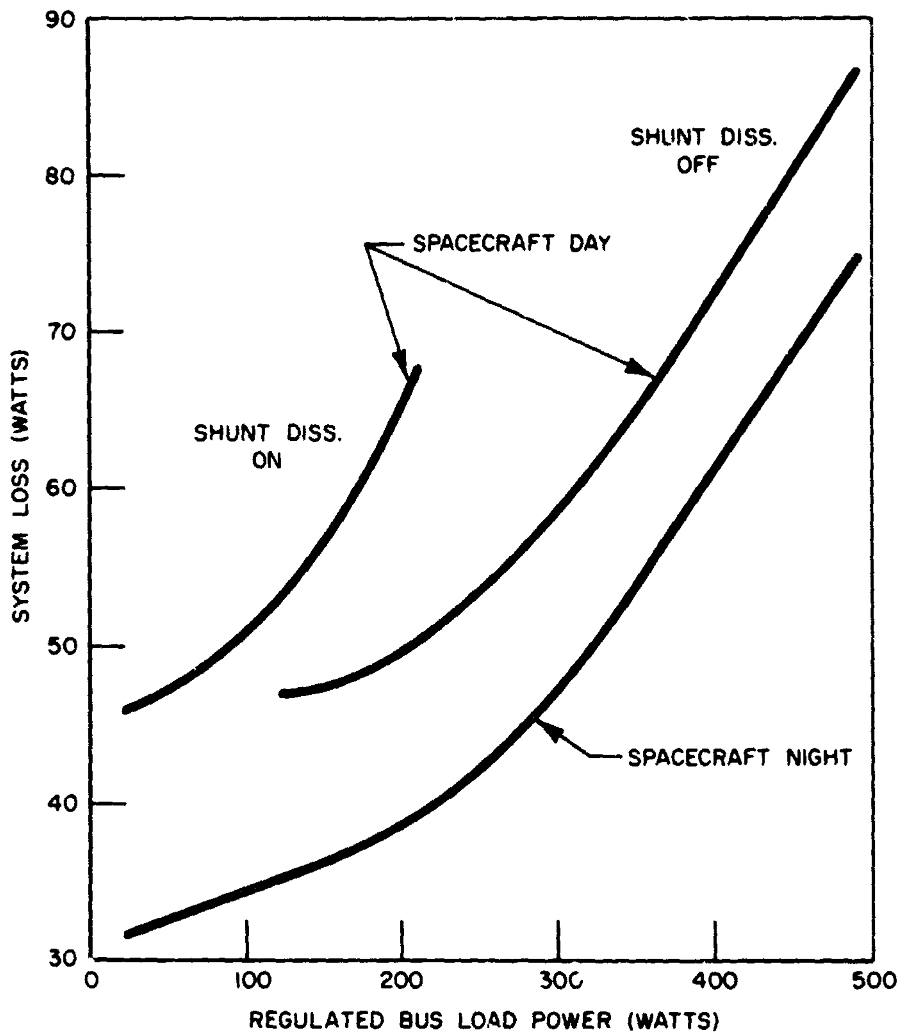


Figure 2. Typical Nimbus System Power Loss Versus Regulated Bus Load Power

Figure 1 also shows a computer "switch" which can be positioned to place a "power loss, night" (PLN), or "power loss, day" (PLD) load on the unregulated bus. The user can specify this constant value of power loss in addition to all other loads and losses by supplying the value of watts for daytime and/or nighttime system operation on an input data card. An example of the use of PLD is a

15-watt fixed loss in the series tracker unit of the SMPT system. This fixed loss is in addition to the loss caused by the power transfer efficiency of the series tracker unit, PTEFF.

III. Program Description

This section presents a functional description of the subroutines in the energy balance program (MAIN, STASH, STINT, DRAIN, AMPS and PRINT). A basic functional block diagram of the computer program is shown in Figure 3, which summarizes the important features of each subroutine.

A. MAIN - Computer Program Control

The purpose of MAIN is to load input data, initialize power system parameters, select the proper set of energy balance calculations for a particular system, perform a clock function during the orbit, call on the five subroutines for data as required and maintain and update values of the system parameters throughout the orbit. MAIN employs iterative processes to determine the various system voltages and solve for the various branch currents in the power system such that the Ohm and Kirchoff criteria are satisfied to within an arbitrarily small error. In addition to the various system voltages and currents, MAIN keeps track of battery relative state of charge (SOC), depth of discharge (DOD), accumulated ampere-minutes (ACCUM), net power dissipation in the battery on an orbit-average basis, ampere-minute C/D ratio achieved during the orbit, solar array maximum power and power at the actual operating point, and solar array temperature. MAIN also ensures that the maximum values of battery charge current and battery voltage are not exceeded.

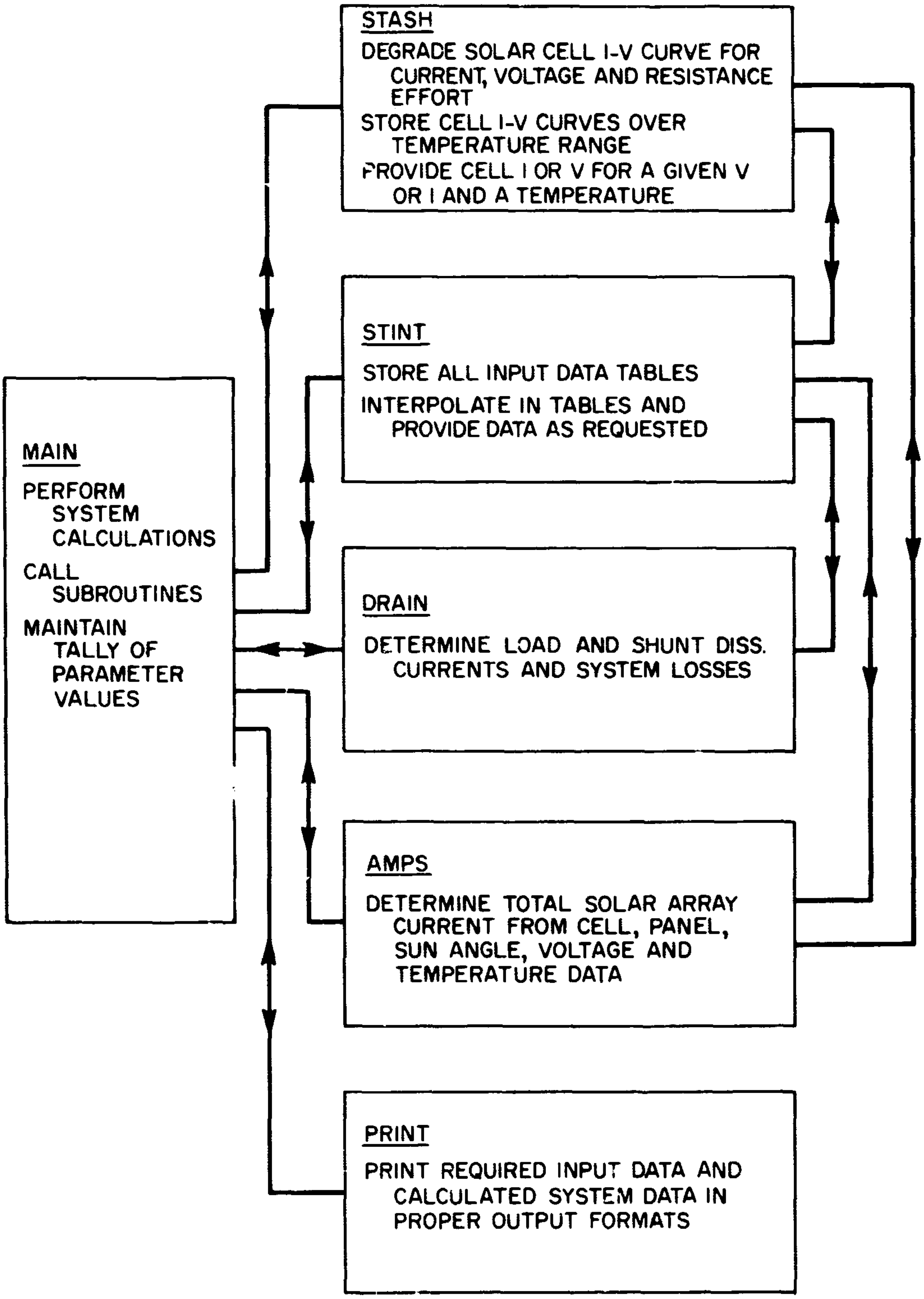


Figure 3. Subroutine Functions in Energy Balance Program

B. Subroutine STASH - Solar cell degradation and temperature effects

The purpose of subroutine STASH is to account for all factors, with the exception of charged particle irradiation degradation, which effect an individual solar cell's I-V curve. Illumination intensity change, coverglass transmission loss, current and voltage measurement uncertainty, ultraviolet effects on coverglass adhesive transmission and standard solar cell accuracy uncertainty are examples of factors which are accommodated by translating the solar cell I-V characteristic parallel to its voltage and current axes. STASH changes the cell I-V curve shape to account for external series resistance and operating temperature effects.

The input to this subroutine is an irradiation-degraded I-V curve*, specification of percentage degradation factors, and the solar cell temperature coefficients.

After applying the degradation factors to the input solar cell I-V curve, subroutine stash expands the degraded cell curve into a family of 15 I-V curves spanning the user-specified temperature range of interest for the ensuing energy-balance analysis. The 15 I-V curves are held in memory, supplying current or voltage data when interrogated during program execution.

A detailed technical discussion of the techniques employed in the solar cell I-V curve manipulation by subroutine STASH is contained in Reference 2.

*A solar cell I-V curve, accounting for charged particle irradiation effects, can be obtained by employing techniques described in Reference 1.

C. Subroutine STINT - Data Storage and Retrival

Subroutine STINT stores in tables, and then supplies on demand, the values of variables which are functions of one, two or three arguments. The first use of STINT loads the tabular data into the computer. Subsequent STINT calls will ask for a linear interpolation to be performed which corresponds to the supplied argument values.

One and two argument functions may be stored in single tables - Tables 1 and 6 are examples of one and two argument functions, respectively. Three argument functions must be stored in consecutive two argument tables; the number of two argument tables must be equal to the number of $argument_3$ values.

Subroutine STINT is called by means of a statement with the following format:

CALL STINT (ARG 1, ARG 2, ARG 3, FCT, KEY, NGRIPE, MINTBL, MAXTBL)

The first three dummy variables are the three arguments; zeroes must be substituted for unused arguments. FCT is the variable value to be calculated, and KEY tells the computer what kind of operation is to be performed (data loading or data interpolation). A value of -1 indicates the table loading mode, while a + 1 calls for a linear interpolation to be performed. NGRIPE is an error flag, advising the user of improperly prepared input data, MINTBL and MAXTBL are the number of the STINT tables used; both tables are the same if the variable is a function of one or two arguments. MINTBL is set equal to the table number which contains the lowest value of argument_3 values and MAXTBL is set to the table which contains the highest argument_3 values if the variable is a function of three arguments.

D. Subroutine DRAIN - Total Load Current Calculation

Subroutine DRAIN determines the total load current demand at the system operating voltage for each time increment during the orbital cycle. The subroutine obtains the value of load power (or current in the case of a series dissipative regulator load) from the profile table for each of the power conditioning devices specified by the user. By adding the system losses and resulting inefficiencies to either PLN or PLD, the subroutine computes the total load current. For example, during satellite night:

$$\text{ILT} = \frac{\text{PWM} + \text{SL}}{\text{VU}} + \frac{\frac{\text{PCONV}}{\text{EFFCONV}}}{\text{VU}} + \frac{\frac{\text{PINV}}{\text{EFFINV}}}{\text{VU}} + \frac{\text{PLN}}{\text{VU}} + \text{ISER}$$

where

ILT	= total load current demand @ VU
VU	= system unregulated bus voltage
PWM	= PWM regulator load demand, watts
SL	= system losses, watts
PCONV	= converter load power, watts
PINV	= inverter load power, watts
PLN	= fixed nighttime power loss
ISER	= series dissipative regulator current demand

EFFINV = power transfer efficiency of inverter

EFFCONV= power transfer efficiency of converter

In addition, DRAIN compares the operating voltage with the shunt dissipator threshold voltage (TVSR) and calculates the shunt dissipator current (ISD) if TVSR has been exceeded.

E. Subroutine AMPS - Solar Array Current Determination

Subroutine AMPS determines the total solar array current available at the solar array output voltage (VA), accounting for the series-parallel arrangements, sun angles, panel temperatures and blocking diodes associated with up to 25 solar-cell panels.

F. Subroutine PRINT - Output Data Presentation

Subroutine PRINT receives the user-specified input data and various calculated system parameters from MAIN and writes the output tape, preparing the data in the proper formats and column headings.

IV. Program Usage

The following describes the mechanics of using the program in "non-programmer" language. A complete Fortran IV program listing including the MAIN routine and subroutines can be found in the Appendix A; Appendix B illustrates a typical data deck set-up.

The assembly of the complete program as it is submitted to the computer is shown in Figure 4. This assembly basically consists of two parts - a program deck and a data deck. The program deck, which can be used in either Fortran

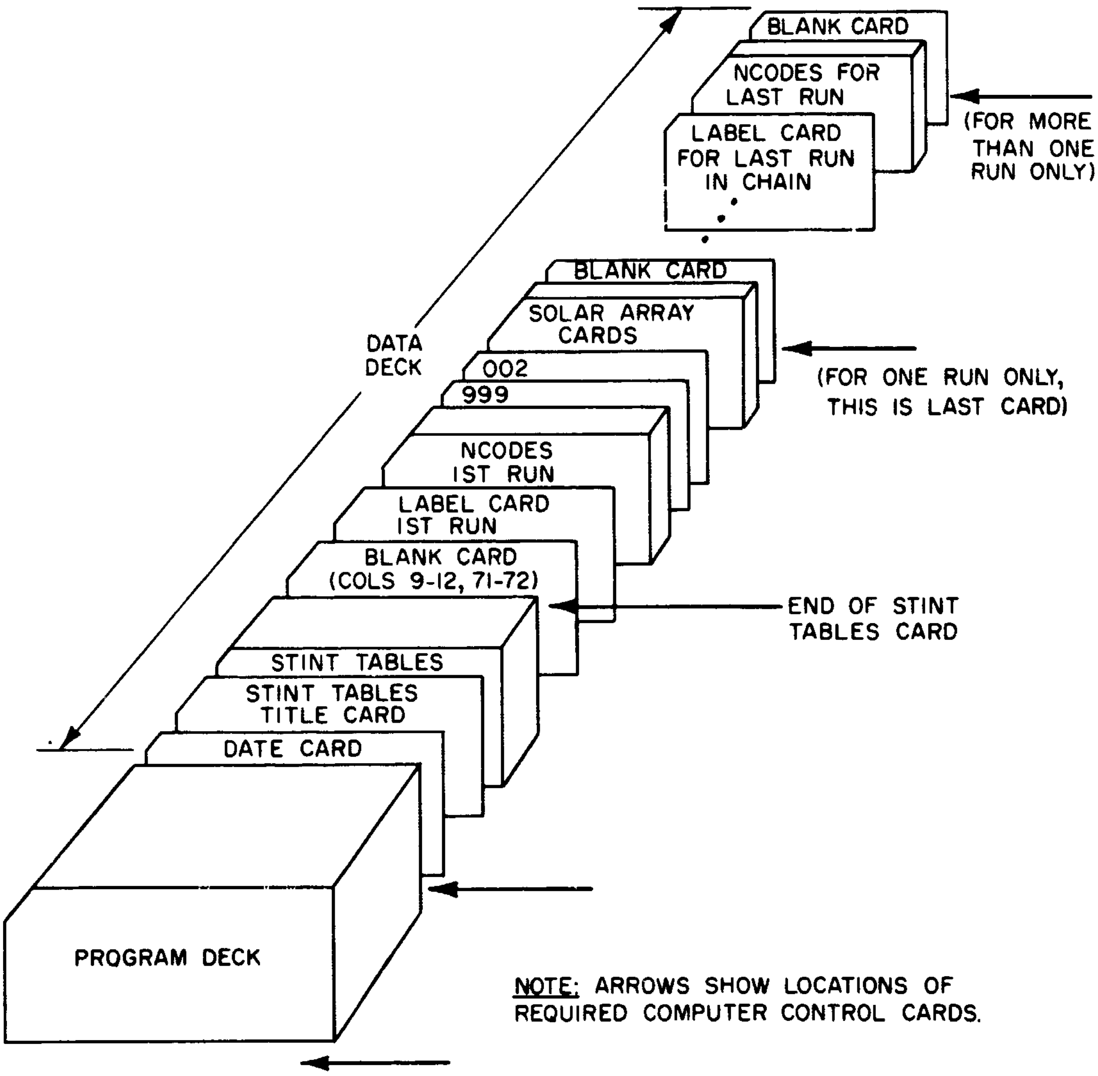


Figure 4. Assembly of Complete Energy Balance Program and Input Data

IV or binary form, is always used and is placed first in the assembly. It contains the MAIN routine and the five subroutines used in the program (DRAIN, PRINT, STASH, STINT, AMPS) and does not require any card change from run to run to perform its function.

The data deck contains all the numerical information the program requires for computation and defines the user-selected options for each run. Consequently, the data deck must be prepared specifically for each run, or series of chained runs, to be made. Cards and tables in the data deck must be positioned in the order shown in the program assembly in Figure 4. The input data deck description and format are presented below in the proper assembly sequence.

Date Card

Col. 1 - 2 Number of month

Col. 3 - 4 Number of day

Col. 5 - 6 Number of year

STINT Table Title Card

Col. 1	Blank
Col. 2-72	Any alpha-numeric information, such as "DATA TABLES FOR NIMBUS D POWER SYSTEM ENERGY BALANCE"

STINT Tables

The STINT tables are stacked one behind the other in the data deck in ascending numerical order. The tables listed below are present in the data deck in the order shown, for a typical NIMBUS energy balance analysis.

Table No.	Contents
1	2.0 amp series regulator load
2	System power loss data
3	ETA vs. Bat. Temp. Nimbus-B
4	Relative solar cell current vs. incidence angle
5	11.4 CRL I-V Curve Unglassed 28 Dec. C AMO

Table No.	Contents
26	PWM Reg Load 230W No XMTR
27	PWM Reg Load 240W No XMTR
28	PWM Reg Load 250W No XMTR
29	PWM Reg Load 260W No XMTR
30	PWM Reg Load 270W No XMTR

The maximum number of STINT tables that the program can presently accommodate is thirty. It is not necessary to fill all 30 table locations in STINT if the data is not needed.

The first card of each STINT table is a header card, which must be prepared in the following format:

Cols. 1-8: Any alpha-numeric characters can be used for a date.

Cols. 9-12: Table number. Cannot be zero. Fixed point and right-justified.

Cols. 13-14: Number of argument_1 values. Cannot be zero. Fixed point and right-justified.

Cols. 15-16: Number of argument_2 values. Cannot be zero, is 1 for a function of one argument. Fixed point and right-justified.

Cols. 17-19: Not used.

Cols. 10-70: Any alpha-numeric characters desired. Usually used for table title.

Cols. 71-72: 00

After the header card, each card in the table uses 10 fields of 7 columns each for the argument values and the function values. The first card contains the first nine $argument_1$ values in fields 2 through 10. In the following cards, field 1 contains an $argument_2$ value, and fields 2 through 10 contain corresponding function values. After all the $argument_2$ values have been spanned, the whole series of $argument_1$ cards followed by $argument_2$ cards can repeat until all the function values are used. If there is an $argument_3$ value for the table, it goes into field 1 of the $argument_1$ card. Columns 71 and 72 on each card must contain a sequence number, starting with 01 for the first card. Figure 5 shows a typical STINT table coding sheet for a single argument (solar cell current as a function of voltage) STINT table. Figure 6 shows a typical two-argument STINT table format.

After the last STINT table in the data deck, there is a card labled END OF STINT TABLES, starting in Col. 21. Cols 9-12 and 71-72 must be left blank on this card.

Run Label Card

Following the END OF STINT TABLES card is a card containing any desired alpha-numeric information in Cols. 2-72, which usually describes the first run to be made, such as: RUN NO. 1, NIMBUS D, 1 YR IN ORBIT, 25 DEG C BATTERY, CONSTANT 150W REG BUS LOAD.

NCODE

Following the Run Label Card are the 50 NCODE cards. The card number, or NCODE, is right justified against Col. 3. The numerical value of the NCODE variable is left-justified against Col. 5 and must have a decimal point. Table 1

FORTRAN TABLES FORMAT

PUNCH 1 CARD AS FOLLOWS

HEADER CARD

COLS 1-8 07-30-67 (TBL DATE)   COLS 9-12 0005 (TBL NO)   COLS 13-14 27 (L1)   COLS 15-16 01 (L2)

COL 20 NB I-V CURVE, BOL, 30 DEG C, AMO

COLS 71-72 00 (SN)   COLS 73-77 (TBL NAME)   COLS 78-80 (PDN)

FIELD 1 ±INTEGER ±EXP	FIELD 2 ±INTEGER ±EXP	FIELD 3 ±INTEGER ±EXP	FIELD 4 ±INTEGER ±EXP	FIELD 5 ±INTEGER ±EXP	FIELD 6 ±INTEGER ±EXP	FIELD 7 ±INTEGER ±EXP	FIELD 8 ±INTEGER ±EXP	FIELD 9 ±INTEGER ±EXP	FIELD 10 ±INTEGER ±EXP	SEQ NO	PROGRAM DECK NO
1 2 3 4 5 6 7	8 9 10 11 12 13 14	15 16 17 18 19 20 21	22 23 24 25 26 27 28	29 30 31 32 33 34 35	36 37 38 39 40 41 42	43 44 45 46 47 48 49	50 51 52 53 54 55 56	57 58 59 60 61 62 63	64 65 66 67 68 69 70	71 72	78 79 80
VOLTS →	0.0	0.225	0.275	0.295	0.315	0.335	0.350	0.365	0.380	01	
CURRENT →	0.1257	0.1245	0.1241	0.124	0.1237	0.1231	0.1229	0.1222	0.1213	02	
	0.390	0.400	0.410	0.420	0.430	0.440	0.450	0.460	0.470	03	
	0.1204	0.1194	0.1180	0.1167	0.1149	0.1129	0.1101	0.1066	0.1025	04	
	0.480	0.490	0.500	0.510	0.520	0.551	0.577	0.603	1.0	05	
	0.0974	0.0917	0.0850	0.0765	0.0655	0.030	0.0	-0.030	-0.030	06	

Figure 5. Format for a Typical Single-Argument Stint Table and Header Card

FORTRAN TABLES FORMAT

PUNCH 1 CARD AS FOLLOWS

HEADER CARD

COLS 1-8 1 0 - 2 4 - 6 8 (TBL DATE) COLS 9-12 0 0 1 5 (TBL NO) COLS 13-14 0 9 (L1) COLS 15-16 1 1 (L2) COL 20 : STORAGE C[illegible]L VOLTS VS AMPS VS SOC 35 DEG. C, BOL COLS 71-72 0 0 (SN)

FIELD 1 ±INTEGER ±EXP	FIELD 2 ±INTEGER ±EXP	FIELD 3 ±INTEGER ±EXP	FIELD 4 ±INTEGER ±EXP	FIELD 5 ±INTEGER ±EXP	FIELD 6 ±INTEGER ±EXP	FIELD 7 ±INTEGER ±EXP	FIELD 8 ±INTEGER ±EXP	FIELD 9 ±INTEGER ±EXP	FIELD 10 ±INTEGER ±EXP	SEQ NO	PRO-GRAM DECK NO
1 2 3 4 5 6 7	8 9 10 11 12 13 14	15 16 17 18 19 20 21	22 23 24 25 26 27 28	29 30 31 32 33 34 35	36 37 38 39 40 41 42	43 44 45 46 47 48 49	50 51 52 53 54 55 56	57 58 59 60 61 62 63	64 65 66 67 68 69 70	71 72	78 79 80
SOC →	0.10	0.80	0.825	0.85	0.90	0.95	1.0	1.05	1.80	01	
-100.0	1.1	1.217	1.218	1.220	1.234	1.259	1.330	1.330	1.330	02	
-16.0	1.1	1.217	1.218	1.220	1.234	1.259	1.330	1.330	1.330	03	
-8.0	1.13	1.235	1.237	1.239	1.253	1.281	1.360	1.360	1.360	04	
-0.001	1.13	1.235	1.237	1.239	1.253	1.281	1.360	1.360	1.360	05	
0 0	1.15	1.237	1.240	1.250	1.270	1.30	1.361	1.361	1.361	06	
0.001	1.18	1.238	1.250	1.270	1.300	1.315	1.362	1.362	1.362	07	
0.300	1.2	1.240	1.270	1.293	1.327	1.345	1.364	1.364	1.364	08	
4.0	1.21	1.245	1.283	1.309	1.344	1.373	1.40	1.425	1.425	09	
8.[illegible]	1.215	1.250	1.306	1.329	1.370	1.403	1.429	1.450	1.450	10	
[illegible] 0	1.22	1.255	1.325	1.350	1.387	1.420	1.455	1.480	1.480	11	
100.0	1.22	1.255	1.325	1.350	1.387	1.420	1.455	1.480	1.480	12	

CURRENT

Figure 6. Format for a Typical Two-Argument Stint Table and Header Card

Table 1
NCODE Names, Numbers, Typical Values and Description (Sheet 1 of 2)

NO.	NCODE NAME	NCODE NO.	TYPICAL VALUE		RUN COMMENTS OR VARIABLE DESCRIPTION
	TN	1	35.0		NIGHT TIME (MINUTES)
	TO	2	108.0		ORBIT TIME (MINUTES)
	ΔT	3	1.0		DELTA TIME (MINUTES) BETWEEN CALCULATIONS
	VBMAX	4	33.5		MAXIMUM BATTERY VOLTAGE (VOLTS)
	IBMAX	5	8.8		MAXIMUM BATTERY CURRENT (AMPS)
	DZCRR	6	0.95		DEAD ZONE IN CHARGE RATE REGULATOR (VOLTS)
	VKCRR	7	1.4		KNEE VOLTAGE, CHARGE RATE REGULATOR (VOLTS)
	CTOD	8	1.11		CHARGE TO DISCHARGE RATIO
	TVSR	9	38.0		TRIGGER VOLTAGE, SHUNT REGULATOR (VOLTS)
	ERSR	10	0.012		EQUIVALENT RESISTANCE OF SHUNT REG. (OHMS)
	PLN	11	0.0		CONSTANT NIGHT LOAD (WATTS)
	PLD	12	0.0		CONSTANT DAY LOAD (WATTS)
	VDIODE	13	0.5		BATTERY DIODE DROP (VOLTS)
	BAMMAX	14	2160.0		BATTERY MAX. AMP. MINUTE CAPACITY (A-M)
	ETA	15	0.0		PANEL NORMAL TO SUN VECTOR ANGLE
	NSLT	16	2.0		NO. OF SYSTEM POWER LOSS TABLE
	NBMINT	17	12.0		NO. OF BATTERY TABLE, MIN. TEMP.
	NBMAXT	18	12.0		NO. OF BATTERY TABLE, MAX. TEMP.
	NCELLT	19	5.0		NO. OF TABLE WITH SOLAR CELL DATA
	NPKLD	20	10.0		NO. OF TABLE WITH PEAK LOAD POWER PROFILE
	NPWM	21	25.0		NO. OF TABLE WITH PWM REGULATOR LOAD
	NINV	22	29.0		NO. OF INVERTER LOAD TABLE
	NCNV	23	30.0		NO. OF CONVERTER LOAD TABLE
	NSER	24	1.0		NO. OF SERIES REGULATOR LOAD TABLE
	SYSTEM KEY	25	0.0		SYSTEM KEY (-1.0=SMPT, 0.0=NB, 1.0=PMPT)

Table 1 (Continued)
NCODE Names, Numbers, Typical Values and Description (Sheet 2 of 2)

NO	NCODE NAME	NCODE NO.	TYPICAL VALUE		RUN COMMENTS OR VARIABLE DESCRIPTION
	NPRINT	26	2.0		INCREMENT BETWEEN CALC. WHICH OUTPUT IS PRINTED
	NEND	27	1.0		END OF RUNS KEY (1.0 OR 0.0)
	EFFINV	28	85.0		POWER TRANSFER EFF. OF THE INVERTER (%)
	EFFCNV	29	90.0		POWER TRANSFER EFF. OF THE CONVERTER (%)
	NBTEMP	30	3.0		NO. OF TABLE WITH BATTERY TEMP.
	NDGRAD	31	1.0		AUTOMATIC DEGRADATION OF ARRAY
	SIGISC	32	0.00007		AMP./DEG.C. TEMP. DEGRADATION OF CELL CURVE
	SIGVOC	33	0.0022		VOLTS/DEG.C. TEMP. DEGRADATION OF CELL CURVE
	DI1	34	95.0		CURRENT DEGRADATION (%)
	DI2	35	96.5		CURRENT DEGRADATION (%)
	DI3	36	97.0		CURRENT DEGRADATION (%)
	DI4	37	100.0		CURRENT DEGRADATION (%)
	DV1	38	99.0		VOLTAGE DEGRADATION (%)
	DV2	39	100.0		VOLTAGE DEGRADATION (%)
	AVPMO	40	0.47		MAX.PWR.POINT VOLTAGE (UNDEGRADED CELL) (VOLTS)
	AIPMO	41	0.1289		MAX.PWR.POINT CURRENT (UNDEGRADED CELL) (AMPS)
	AVOCO	42	0.59		OPEN CIRCUIT VOLTAGE OF UNDEGRADED CELL (VOLTS)
	THETA	43	100.0		VOLTAGE MEASUREMENT TOLERANCE (%)
	TNOT	44	28.0		CELL DATA TEST TEMP (DEG.C)
	NO. OF CELLS/BATT.	45	23.0		NUMBER OF CELLS PER BATTERY
	ADIODE	46	1.8		ARRAY DIODE DROP
	PTEFF	47	92.0		POWER TRANSFER EFF. OF TRACKER UNITS (%)
	DELTT	48	10.0		Δ TEMP. BETWEEN STEPS IN STASH ROUTINE
	ADDT	49	32.0		Δ TEMP. BETWEEN TNCT AND MAX. TEMP. OF INTEREST
	DENFAC	50	0.065		0.065 FOR 1 OHM-CM, 0.0 FOR 10 OHM-CM

shows the NCODE names, the NCODE numbers, the NCODE values and a brief description of each NCODE for a sample computer run. Only the NCODE number and its numerical value are punched on the NCODE cards; the other data in Table I is for information only. All 50 of the NCODES are initially loaded into memory, thus a single run or the first of a series of chained runs must contain all the NCODES in the data deck. The 50 NCODE cards used in the data deck are described below:

1. TN is the total orbit nighttime in minutes.
2. TO is the total orbit period in minutes.
3. ΔT is the time increment between energy balance calculations in minutes.
4. VBMAX is the maximum battery voltage permitted during power system operation.
5. IBMAX is the maximum allowable battery charge current.
6. DZCRR is the dead zone voltage of the battery charge controller. No battery charge current will flow unless the voltage across the charge controller exceeds this value.
7. VKCRR is the battery charger controller knee voltage. The maximum allowable charge current will flow into the battery when the voltage across the charge controller meets or exceeds this value.
8. CTOD is the battery ampere-minute charge-to-discharge ratio (C/D). The NCODE is needed only when simulating operation of an ampere-hour controlled PMPT System, and reduces the battery charge current to 0.6 amperes when the prescribed C/D ratio has been achieved.

9. TVSR is the shunt dissipator turn-on voltage (volts).

10. ERSR is the equivalent resistance of the shunt dissipator (ohms).

11. PLN is a constant nighttime loss, watts.

12. PLD is a constant daytime loss, watts.

13. VDIODE is the battery discharge diode voltage drop (volts).

14. BAMMAX is the ampere-minute capacity of the fully charged battery.

15. ETA is the panel normal to sun vector angle. A value of 0.0 must always be inputed for this NCODE (accounting for panel angle is explained later).

16. NSLT is the number of the STINT table which includes the power system losses.

17. NBMINT is the STINT table number with the minimum battery temperature information.

18. NBMAXT is the STINT table number with the maximum battery temperature information.

19. NCELLT is the number of the STINT table which contains the input solar cell I-V curve.

20. NPKLD is the number of the STINT table with the peak load power profile.

21. NPWM is the number of the STINT table with the PWM regulator load power profile.

22. NINV is the number of the STINT table with the inverter load power profile.

23. NCNV is the number of the STINT table with the converter load power profile.

24. NSER is the number of the STINT table with the series dissipative regulator load current profile.

25. SYSTEM KEY tells the computer to simulate a series maximum power tracker (-1.0), a Nimbus B system (0.0), or a parallel maximum power tracker (1.0). If this card is omitted from the data deck, the Nimbus B system will be simulated. The NCODE is called PMPT in the MAIN program listing.

26. NPRINT is the time increment in minutes between calculations at which output is printed.

27. NEND is an "end of runs" key. A value of 0.0 implies that additional computer runs are to follow, while a 1.0 signifies that this is the last run to be made.

28. EFFINV is the power transfer efficiency of the inverter, in percent.

29. EFFCNV is the power transfer efficiency of the converter, in percent.

30. NBTEMP gives the number of the STINT table with the battery temperature. A value of 3.0 must be inputed for this NCODE.

31. NDGRAD must be set to 1.0 in the first run. This causes the machine to automatically degrade the solar cell and expand it for temperature in Subroutine STASH as specified by the degradation and temperature parameters in the NCODES. When chaining additional runs, if the solar

cell degradations are not changed, NDGRAD should be set to 0.0 in the second run. By setting NDGRAD to 0.0, needless repetitive computations in the solar cell subroutine are eliminated.

32. SIGISC is the solar cell short circuit current temperature coefficient, (AMPS/°C).

33. SIGVOC is the solar cell open-circuit voltage temperature coefficient and is punched on the card as a positive number; the program later gives it the proper negative sign (volts/°C).

34. DI1 is the first short circuit current degradation factor; it usually refers to a standard cell error. (This parameter is given as a percentage of remaining current after correction is made).

35. DI2 is the second short circuit current degradation factor; it usually refers to a solar illumination intensity variation, (%).

36. DI3 is the third short circuit current degradation factor; it usually refers to an ultraviolet degradation (%).

37. DI4 is the fourth short circuit current degradation factor; it usually refers to a current measurement error (%).

38. DV1 is the first maximum power point voltage degradation factor; it usually refers to an external series wiring loss and is specified as a percentage of voltage remaining after correction is made.

39. DV2 is the second maximum power point voltage degradation factor; it usually refers to a thermal cycling degradation loss (%).

40. AVPMO is the maximum power point voltage of the undegraded solar cell in volts.

41. AIPMO is the maximum power point current of the undegraded solar cell in amperes.

42. AVOCO is the open circuit voltage of the undegraded solar cell in volts.

43. THETA is the open circuit voltage degradation factor, it usually refers to a voltage measurement error. This parameter is specified as a percentage of voltage remaining after correction is made.

44. TNOT is the input solar cell reference temperature in degrees centigrade.

45. NBAT is the number of series storage cells in the battery.

46. ADIODE is the array blocking diode voltage drop, specified by the user. A value of 0.0 is punched if no diode drop is desired.

47. PTEFF is the power transfer efficiency of the maximum power tracking unit, either series or parallel. This parameter is defined as a percentage.

48. DELTT is the temperature increment between the 15 stored solar cell I-V curve in STASH (°C).

49. ADDT is the temperature increment to be added to TNOT to determine the highest STASH temperature (°C).

50. DENFAC is a curve shape temperature correction factor for use in STASH. This factor should be specified as 0.065 for a 1 ohm-cm solar cell, and 0.0 for a 10 ohm-cm cell.

Array Signal Card

Immediately following NCODE 50 card must be a card containing 999 in columns 1-3. This card tells the computer that solar array information is to follow.

NPANEL Card

Following the Array Signal Card is the NPANEL card, which contains the number (NPANEL) of solar panels in the array (maximum number of panels is 25). This number must appear right-justified in columns 1-3; no decimal point is required.

Panel Description Cards

Following the NPANEL card is a panel description card for each solar panel in the array, up to a maximum of 25 panels. The number of these cards must agree with the value of NPANEL. Each card contains four fields of ten columns each, in floating point format (requires decimal point).

Columns	Variable	Typical Value
1-10	No. of Series Solar Cells per String	94.0
11-20	No. of Parallel Strings per Panel	36.0
21-30	Solar Incidence Angle (degrees)	0.0
31-40	Panel Temperature vs Time Table Location in STINT	11.0

Following the Panel Description Cards is a blank card. This tells the computer to stop reading in data and to start computing. If it is desired to chain an additional run, a new Run Label Card and only those NCODES and Panel Description Cards that contain changed or new information should be placed after the blank card. In addition, NCODE 27 must be set to 0.0 for all except the last run, when it must have a value of 1.0. As many runs as are desired can be chained in this manner, ensuring that each new run starts with a Run Label Card and ends with a blank card. Refer again to Figure 4 for the proper sequence of card positions for chained runs.

As indicated in Figure 4, computer control cards are required in front of the Program Deck, in front of the Date Card, and behind the last blank card at the end of the Data Deck. The particular control cards needed vary from computer to computer, and are sometimes different for identical machines at two separate facilities.

A complete listing of the input data deck, including typical control cards, 20 example STINT tables, and example run label cards and NCODES for two chained program checkout runs can be found in the attached Appendix B.

V. Program Output

The information that the computer equipment prints out after an energy balance run consists of the following items:

1. STINT Table Summary

The STINT table number, the date on the STINT table header card and the title of the tabulated data as it appears on the header card are listed for each table stored in STINT.

2. Input Data Page

- Run number and date
- Run comments (as specified on input card)
- Listing of NCODE numbers, names and values
- Solar Array description: panel number, number of series solar cells, number of parallel solar cell strings, solar illumination incidence angle and number of STINT table which contains the array temperature-time profile.

3. Subroutine STASH Printout

- Values of temperature for which the degraded solar cell I-V curve has been prepared are listed in a row across the page.
- Values of degraded solar-cell maximum-power voltage and current, open-circuit voltage and short-circuit current appear in columns under each temperature.
- Values of every other calculated current and voltage pair comprising the I-V curve and stored in the computer memory are listed in columns under each temperature.

4. Power Subsystem Data

The names of the calculated power system parameters are listed in a row across the top of the page: orbit time at which the calculation was made (TIME), number of ampere-minutes in the battery (ACCUM), relative state of charge of the battery (STATE), output voltage of the series tracker unit in the SMPT system (VTO), unregulated bus voltage during satellite nite or solar array bus voltage during satellite day (VU(Night), VAB(DAY)), solar array current (IA), solar array power at the operating point (PA), solar array maximum power (PMAX), battery voltage (VB), battery current (IB), load current including system losses (IL), shunt dissipator current (ISD), peak load current (IPKLD), and solar array temperature (TEMP).

5. Battery Data Summary

The depth of discharge, in percent of capacity at beginning of run, the ampere-minute C/D ratio actually achieved during the run, the charge energy into the battery during the run in watt-minutes, the discharge energy out of the battery during the run in watt-minutes, and the orbit-average power dissipated in the battery during the run, in watts, are presented.

If several runs are made at one time, the output data for each run is printed out in the same format as for the first run, except that only changed values of NCODES are printed out on the input data page, and subroutine STASH printout will not appear if the same solar cell I-V curve and degradation factors as in the previous run are used.

Figures 7, 8 and 9 show a typical energy balance computer run output. Figure 7 shows the NCODE and array description card listing. A portion of a typical STASH printout is shown in Figure 8, while Figure 9 shows the output of the power subsystem data.

```
    RUN NO.  1   ON THIS DATE OF 12-13-69

    TABLE COMMENTS.
     NIMBUS TABLES

    RUN COMMENTS.
RUN NO 1

    NEW OR CHANGED PARAMETERS


     1   TN(NIGHT TIME)..........................       25.0000
     2   TO(ORBIT TIME)..........................       80.0000
     3   DELTA T.................................        1.0000
     4   VBMAX (VOLTS)...........................       35.0000
     5   IBMAX (AMPS)............................        5.8000
     6   DZCRR (VOLTS)...........................        0.0500
     7   VKCRR (VOLTS)...........................        1.4000
     8   C/D RATIO...............................        1.1100
     9   TVSR  (VOLTS)...........................       38.0000
    10   ERSR  (OHMS)............................        0.0120
    11   PLN.....................................        0.0
    12   PLD.....................................        0.0
    13   VDIODE(VOLTS)...........................        0.5000
    14   RAMMAX (A-M)............................     2160.0000
    15   FTA-(DEG)...............................        0.0
    16   NSLT....................................        2
    17   NBMINT..................................       12
    18   NBMAXT..................................       12
    19   NCELLT..................................        5
    20   NPKLD...................................       10
    21   NPWM....................................       18
    22   NINV....................................       19
    23   NCNV....................................       20
    24   NSFR....................................        1
    25   SYSTEM KEY (-1.0=SMPT,0.0=NB,1.0=PMPT)          0.0
    26   NPRINT..................................        2
    28   EFFINV..................................       85.0000
    29   EFFCNV..................................       90.0000
    30   NBTEMP..................................        3
    31   NOGRAD..................................        1
    32   SIGISC (A/DEG C)........................        0.00014
    33   SIGVOC (V/DEG C)........................        0.00220
    34   DI1(PERCENT)............................       95.0000
    35   DI2(PERCENT)............................      100.0000
    36   DI3(PERCENT)............................      100.0000
    37   DI4(PERCENT)............................      100.0000
    38   DV1(PERCENT)............................       99.0000
    39   DV2(PERCENT)............................      100.0000
    40   AVEMO(VOLTS)............................        0.47000
    41   AIPMO(AMPS).............................        0.12890
    42   AVOCO(VOLTS)............................        0.59000
    43   THETA(PERCENT)..........................      100.0000
    44   TNOT(DEG C).............................       28.0000
    45   NO. OF CELLS/PATT.......................       24
    46   ADIODE(VOLT)............................        1.8000
    47   PTEFF...................................       92.0000
    48   DELTT(DEG C)............................       10.0000
    49   ADDT (DEG C)............................       32.0000
    50   DENFAC(1 OHM-CM=0.065,10 OHM-CM=0.0)..          0.0650

PANEL    1
CELLS = 102.0 STRINGS = 102.00 INCDN ANGLE =    0.0 TEMP TABLE = 1
```

Figure 7. Program Output–NCODE Listing and Solar Array Description

EDIT OF TEMPERATURE AND DEGRADATION CORRECTED SOLAR CELL I-V CURVES FOR ENERGY BALANCE PGM. IN AUTOMATIC MODE

TEMPERATURES	60.	50.	40.	30.	20.	10.	0.	-10.	-20.	-30.	-40.	-50.	-60.	-70.	-80.
I-MAX PWR	0.1241	0.1233	0.1226	0.1219	0.1212	0.1206	0.1201	0.1195	0.1190	0.1186	0.1181	0.1177	0.1173	0.1169	0.1165
V-MAX PWR	0.4012	0.4232	0.4452	0.467	0.4892	0.5112	0.5332	0.5552	0.5772	0.5992	0.6212	0.6432	0.6652	0.6872	0.7092
VOLTS OC	0.5218	0.5438	0.5658	0.5879	0.6098	0.6318	0.6538	0.6758	0.6978	0.7198	0.7418	0.7638	0.7858	0.8078	0.8298
AMPS SC	0.1392	0.1378	0.1365	0.1352	0.1338	0.1325	0.1312	0.1299	0.1285	0.1272	0.1259	0.1245	0.1232	0.1219	0.1205
I(1)	0.1392	0.1378	0.1365	0.1352	0.1339	0.1325	0.1312	0.1298	0.1285	0.1272	0.1259	0.1245	0.1232	0.1219	0.1205
V(1)	-0.0753	-0.0533	-0.0313	-0.0093	0.0127	0.0347	0.0567	0.0787	0.1007	0.1227	0.1447	0.1667	0.1887	0.2107	0.2327
I(3)	0.1392	0.1378	0.1365	0.1352	0.1338	0.1325	0.1312	0.1298	0.1285	0.1272	0.1259	0.1245	0.1232	0.1219	0.1206
V(3)	-0.0494	-0.0274	-0.0054	0.0166	0.0386	0.0606	0.0826	0.1046	0.1266	0.1486	0.1706	0.1926	0.2146	0.2366	0.2586
I(5)	0.1392	0.1378	0.1365	0.1352	0.1338	0.1325	0.1312	0.1298	0.1285	0.1272	0.1259	0.1245	0.1232	0.1219	0.1206
V(5)	-0.0294	-0.0074	0.0145	0.0366	0.0586	0.0806	0.1026	0.1246	0.1466	0.1686	0.1906	0.2126	0.2346	0.2566	0.2786
I(7)	0.1392	0.1378	0.1365	0.1352	0.1338	0.1325	0.1312	0.1299	0.1285	0.1272	0.1259	0.1245	0.1232	0.1219	0.1206
V(7)	-0.0094	0.0126	0.0345	0.0566	0.0786	0.1006	0.1226	0.1446	0.1666	0.1886	0.2106	0.2326	0.2546	0.2766	0.2986
I(9)	0.1392	0.1376	0.1365	0.1352	0.1338	0.1325	0.1312	0.1299	0.1285	0.1272	0.1259	0.1245	0.1232	0.1219	0.1206
V(9)	0.0106	0.0326	0.0545	0.0766	0.0986	0.1206	0.1426	0.1646	0.1866	0.2086	0.2306	0.2526	0.2746	0.2966	0.3186
I(11)	0.1392	0.1376	0.1355	[illegible]	0.1338	0.1325	0.1312	0.1298	0.1285	0.1272	0.1259	0.1246	0.1233	0.1219	0.1206
V(11)	0.0306	0.0526	0.0745	[illegible]	0.1186	0.1406	0.1626	0.1846	0.2066	0.2286	0.2506	0.2726	0.2946	0.3166	0.3386
I(13)	0.1392	0.1376	0.1365	0.1352	0.1338	0.1325	0.1312	0.1299	0.1285	0.1272	0.1259	0.1245	0.1233	0.1220	0.1207
V(13)	0.0506	0.0726	0.0945	0.1166	0.1386	0.1606	0.1826	0.2046	0.2266	0.2486	0.2706	0.2926	0.3146	0.3366	0.3586
I(15)	0.1392	0.1378	0.1365	0.1352	0.1338	0.1325	0.1312	0.1299	0.1285	0.1272	0.1259	0.1246	0.1233	0.1220	0.1207
V(15)	0.0706	0.0926	0.1145	0.1366	0.1586	0.1806	0.2026	0.2246	0.2466	0.2686	0.2906	0.3126	0.3346	0.3566	0.3786
I(17)	0.1392	0.1376	0.1365	0.1352	0.1338	0.1325	0.1312	0.1299	0.1286	0.1272	0.1259	0.1246	0.1234	0.1221	0.1208
V(17)	0.0906	0.1126	0.1345	0.1566	0.1786	0.2006	0.2226	0.2446	0.2666	0.2886	0.3106	0.3326	0.3546	0.3766	0.3986
I(19)	0.1392	0.1376	0.1365	0.1352	0.1339	0.1325	0.1312	0.1299	0.1286	0.1273	0.1260	0.1247	0.1234	0.1222	0.1209
V(19)	0.1106	0.1326	0.1545	0.1766	0.1986	0.2206	0.2426	0.2646	0.2866	0.3086	0.3306	0.3526	0.3746	0.3966	0.4186
I(21)	0.1392	0.1376	0.1355	0.1352	0.1338	0.1325	0.1312	0.1299	0.1286	0.1273	0.1260	0.1248	0.1235	0.1223	0.1210
V(21)	0.1306	0.1526	0.1745	0.1966	0.2186	0.2406	0.2626	0.2846	0.3066	0.3296	0.3506	0.3726	0.3946	0.4166	0.4386
I(23)	0.1392	0.1376	0.1365	0.1352	0.1338	0.1325	0.1312	0.1299	0.1286	0.1274	0.1261	0.1249	0.1236	0.1224	0.1212
V(23)	0.1506	0.1725	0.1945	0.2166	0.2386	0.2606	0.2826	0.3046	0.3266	0.3486	0.3706	0.3926	0.4146	0.4366	0.4586
I(25)	0.1391	0.1376	0.1355	0.1352	0.1338	0.1325	0.1312	0.1300	0.1287	0.1274	0.1262	0.1250	0.1238	0.1226	0.1214
V(25)	0.1706	0.1926	0.2146	0.2366	0.2586	0.2806	0.3026	0.3246	0.3466	0.3686	0.3906	0.4126	0.4346	0.4556	0.4786
I(27)	0.1390	0.1376	0.1353	0.1350	0.1337	0.1324	0.1311	0.1298	0.1286	0.1274	0.1261	0.1249	0.1238	0.1226	0.1215
V(27)	0.1906	0.2126	0.2345	0.2566	0.2786	0.3006	0.3226	0.3446	0.3666	0.3886	0.4106	0.4326	0.4546	0.4766	0.4986
I(29)	0.1386	0.1373	0.1359	0.1347	0.1334	0.1321	0.1308	0.1296	0.1284	0.1272	0.1260	0.1248	0.1237	0.1225	0.1215
V(29)	0.2106	0.2326	0.2546	0.2766	0.2986	0.3206	0.3426	0.3646	0.3866	0.4086	0.4306	0.4526	0.4746	0.4966	0.5186

Figure 8. Program Output—Subroutine STASH

TIME	ACCUM	STATE	VTO (STS ONLY)	VU(NIGHT) VA(DAY)	IA	PA	PMAX	VB	IB	IL	ISD	IPKLD	TEMP
0.0	2160.00	1.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	2146.52	0.994	0.0	32.282	0.0	0.0	0.0	32.782	-6.745	6.745	0.0	0.0	0.0
4.0	2133.00	0.987	0.0	32.177	0.0	0.0	0.0	32.677	-6.768	6.768	0.0	0.0	0.0
6.0	2119.43	0.981	0.0	32.067	0.0	0.0	0.0	32.563	-6.791	6.791	0.0	0.0	0.0
8.0	2105.81	0.975	0.0	31.953	0.0	0.0	0.0	32.453	-6.814	6.814	0.0	0.0	0.0
10.0	2092.14	0.969	0.0	31.834	0.0	0.0	0.0	32.334	-6.844	6.844	0.0	0.0	0.0
12.0	2078.40	0.962	0.0	31.647	0.0	0.0	0.0	32.147	-6.880	6.880	0.0	0.0	0.0
14.0	2064.58	0.956	0.0	31.478	0.0	0.0	0.0	31.970	-6.917	6.917	0.0	0.0	0.0
16.0	2050.69	0.949	0.0	31.309	0.0	0.0	0.0	31.809	-6.955	6.955	0.0	0.0	0.0
18.0	2036.72	0.943	0.0	31.138	0.0	0.0	0.0	31.670	-6.993	6.993	0.0	0.0	0.0
20.0	2022.68	0.936	0.0	30.965	0.0	0.0	0.0	31.469	-7.031	7.031	0.0	0.0	0.0
22.0	2008.56	0.930	0.0	30.795	0.0	0.0	0.0	31.295	-7.071	7.071	0.0	0.0	0.0
24.0	1994.36	0.923	0.0	30.622	0.0	0.0	0.0	31.122	-7.110	7.111	0.0	0.0	0.0
26.0	1992.81	0.923	0.0	33.937	13.670	652.675	707.133	32.660	5.034	6.730	0.0	0.0	-57.40
28.0	2004.98	0.928	0.0	34.160	12.806	441.731	765.003	32.936	6.136	6.490	0.0	0.0	-47.70
30.0	2017.54	0.934	0.0	34.330	12.970	446.[illegible]	743.176	33.066	6.333	6.456	0.0	0.0	-37.00
32.0	2030.39	0.940	0.0	34.536	13.098	475.156	710.103	33.226	6.454	6.574	0.0	0.0	-27.00
34.0	2043.51	0.946	0.0	34.660	13.178	480.530	600.021	33.383	6.585	6.537	0.0	0.0	-15.00
36.0	2056.82	0.952	0.0	34.837	13.247	485.736	681.006	33.507	6.695	6.562	0.0	0.0	-7.80
38.0	2070.34	0.958	0.0	34.306	13.309	490.606	667.861	33.702	6.777	6.531	0.0	0.0	-1.40
40.0	2084.05	0.965	0.0	35.166	13.385	496.315	650.630	33.866	6.886	6.800	0.0	0.0	5.00
42.0	2097.97	0.971	0.0	35.330	13.454	500.650	640.833	36.031	6.096	6.669	0.0	0.0	10.00
44.0	2112.09	0.978	0.0	35.511	13.531	505.476	605.300	34.196	7.088	6.374	0.0	0.0	15.60
46.0	2126.40	0.984	0.0	35.681	13.590	508.027	617.092	36.364	7.176	6.404	0.0	0.0	20.00
48.0	2140.84	0.991	0.0	35.847	7.612	512.442	603.477	36.527	7.236	6.776	0.0	0.0	24.00
50.0	2155.39	0.998	0.0	36.017	13.637	517.671	595.351	36.501	7.291	6.747	0.0	0.0	23.00
52.0	2170.01	1.005	0.0	36.170	13.648	512.323	587.673	36.858	7.321	6.317	0.0	0.0	31.20
54.0	2184.88	1.012	0.0	37.205	13.568	530.202	578.208	35.045	7.533	6.017	0.0	0.0	34.40
56.0	2197.75	1.017	0.0	38.017	13.574	578.833	571.627	36.000	6.131	6.756	0.087	0.0	37.60
58.0	2205.91	1.023	0.0	38.031	13.513	578.774	565.467	35.205	5.330	6.350	1.767	0.0	40.60
60.0	2219.66	1.027	0.0	38.035	13.458	574.005	560.677	35.000	4.717	6.354	2.787	0.0	43.60
62.0	2227.23	1.031	0.0	38.035	13.474	534.761	551.643	35.000	4.145	6.357	2.007	0.0	45.30
64.0	2235.15	1.035	0.0	38.037	13.303	533.677	547.457	35.000	3.962	6.357	3.031	0.0	47.10
66.0	2243.05	1.038	0.0	38.037	13.366	533.631	540.926	35.000	3.010	6.357	3.103	0.0	48.60
68.0	2250.80	1.042	0.0	38.038	13.343	531.530	543.969	35.000	3.855	6.357	3.136	0.0	50.00
70.0	2258.42	1.046	0.0	38.039	13.203	533.763	533.35[illegible]	34.005	3.770	6.357	3.167	0.0	51.00
72.0	2265.91	1.045	0.0	38.039	13.283	533.133	533.386	34.007	3.730	6.357	3.201	0.0	51.40
74.0	2273.32	1.052	0.0	38.030	13.265	528.873	535.030	34.005	3.[illegible]	6.357	3.227	0.0	51.80
76.0	2280.70	1.056	0.0	38.030	13.265	528.473	535.000	34.005	3.481	6.357	3.239	0.0	51.80
78.0	2288.09	1.059	0.0	38.030	13.243	520.125	517.736	36.000	3.407	6.357	3.273	0.0	51.40
80.0	2295.47	1.063	0.0	35.030	13.208	520.776	520.866	34.008	3.470	6.359	3.267	0.0	51.00

DEPTH OF DISCHARGE(PERCENT) -6.272

C/D RATIO 1.782

CHARGE ENERGY(WATT-MINUTES) 10585.045

DISCHARGE ENERGY(WATT-MINUTES) -5940.865

ORB AVG PWR DISSIPATED IN BATTERIES(WATTS) 53.264

Figure 9. Program Output–Power System Data

VI. Energy Balance Calculations

At the start of an energy balance computer run, the values of the NCODES and other internally-used system parameters are initialized. The data deck is then read in: STINT table data is stored in the computer memory, the NCODES for the new run are read in, updating the initialized values, and the solar array configuration, sun angles and temperature profile are defined from the panel description cards. This preliminary effort is done by MAIN, from the beginning of the routine through instruction 105 (Refer to Appendix A for listing of computer instructions).

A. Solar Cell Data

After the initialization described above, subroutine STASH obtains the user-supplied solar cell I-V curve from STINT and degrades the curve with the current, voltage and series resistance factors specified in the NCODES. This degraded I-V curve is then corrected for temperature effects and finally 15 I-V curves are stored in memory at 15 different temperature values, over the temperature range (TNOT + ADDT) to (TNOT + ADDT -15 DELTT), as specified by the NCODES. STASH will interpolate between the 15 stored I-V curves when called upon by MAIN or subroutine AMPS for particular solar cell data.

B. Spacecraft Nighttime Calculations

Energy balance calculations for spacecraft nighttime are made in MAIN, from instructions 106 through 3005. Since all three system configurations (NB, PMPT and SMPT) operate in the same manner during solar array eclipse periods, the same set of instructions in the computer is used for all three systems during the nighttime duration, TN.

Initialized parameters for the nighttime calculations are as follows:

(a) Orbit time is set equal to zero: T = 0.

(b) Total ampere minutes removed from battery is set equal to zero: TOTOUT = 0.

(c) The total energy, in watt-minutes, removed from battery is set equal to zero: EOUT = 0.

(d) The battery relative state-of-charge is set equal to 1.0: SOC = 1.0.

(e) The total ampere minutes presently in battery is set equal to the initial battery capacity, in ampere-minutes: ACCUM = BAMMAX.

The nighttime portion of the orbit (TN minutes duration) comes first, with the following computations being made at each DELTAT time increment.

(1) Increment T = T + DELTAT. If new T is greater than TN, nighttime calculations are completed; if not, continue with step (2).

(2) Assume a battery discharge current of 1 ma; determine storage cell discharge voltage: VBDCH @ SOC and IB = - 0.001A.

(3) The unregulated bus voltage during nighttime (VA) and battery voltage (VB) are calculated:

$$VB = VBDCH \times FUDGE$$

$$VA = VB - VDIODE$$

(4) The total load (ILT) and peak power currents (IPKLD) are calculated at VA:

$$ILT = \frac{PWM + SL}{VA} + \frac{\frac{PINV}{EFFINV}}{VA} + \frac{\frac{PCONV}{EFFCNV}}{VA} + \frac{PLN}{VA} + ISER$$

$$IPKLD = \frac{PKLD}{VA}$$

(5) The battery table is reentered at IB = - ILT - IPKLD and a new value of VBDCH is determined at SOC and IB. New values for VB and VA are calculated as in step (3).

(6) Step (4) is repeated at the new unregulated bus voltage. The sum of ILT and IPKLD are compared with IB from step (5).

(7) If the difference between the two values is less than 10 ma, go to step (8). If the difference is greater than 10 ma, return to step (5) to determine a new value for VBDCH at IB = - ILT - IPKLD.

(8) The ampere-minutes removed from battery during time interval DELTAT is computed:

$$\text{AMPMIN} = \text{IB} \times \text{DELTAT}$$

(9) The number of ampere-minutes remaining in battery is determined:

$$\text{ACCUM} = \text{ACCUM} + \text{AMPMIN}$$

(10) The new battery state-of-charge is calculated:

$$\text{SOC} = \frac{\text{ACCUM}}{\text{BAMMAX}}$$

(11) The total amper-minutes removed from the battery is computed:

$$\text{TOTOT} = \text{TOTOUT} - \text{AMPMIN}$$

(12) The energy, in watt-minutes, removed from battery is determined:

$$\text{EOUT} = \text{EOUT} + \text{AMPMIN} \times \text{VB}$$

(13) The time is compared with the total nighttime; if T < TN, go to (1). If T = TN, the battery depth of discharge is calculated:

$$\text{DEPTH} = (1.0 - \text{SOC}) \times 100$$

Return to step 1; if T and TN have different values, go to step 1.

When, in step 1, T is greater than TN the spacecraft has emerged into the sunlight. The solar array is illuminated and a much more complicated set of computations must be made at each time increment.

C. Spacecraft Daytime Calculations

Energy balance calculations for spacecraft daytime (solar array is illuminated and orbit time is greater than TN) are made in MAIN, with a different set of computer instructions used for each of the three system configurations.

Before the daytime calculations are begun, the value of equivalent charge controller resistance is calculated: RCRR = (VKCRR-DZCRR)/IBMAX. Instructions 130 through 806 are common to all three systems and are executed at each time increment during the daytime before the energy balance computations are started; the solar array maximum power PMAX at the orbit time T is calculated. The values of total ampere-minutes into the battery (TOTIN) and total energy into the battery (EIN) are set to 0.0 before the daytime computation begins.

1. Nimbus B (NB) Daytime Energy Balance Calcuations

The NB system uses the 900 series of instructions in MAIN for daytime energy balance calculations.

(1) The storage cell open-circuit voltage (VBO) is determined at SOC and IB = 0. The battery voltage (VB) is calculated:

$$VB = VBO \times FUDGE$$

(2) The total load (ILT) and peak load (IPKLD) currents are calculated at an array bus voltage (VAB) set equal to VB:

$$ILT = \frac{PWM + SL}{VAB} + \frac{\frac{PINV}{EFFINV}}{VAB} + \frac{\frac{PCONV}{EFFCNV}}{VAB} + \frac{PLD}{VAB} + ISER$$

$$IPKLD = \frac{PKLD}{VAB - VDIODE}$$

(3) Subroutine AMPS is entered at array voltage VA = VAB + ADIODE to determine the solar array current (IA) available at the array operating voltage, VA. The available battery charge current is calculated: IB = IA - ILT - IPKLD.

(a) If IB = 0, go to step (4)

(b) If IB < 0, go to step (5)

(c) If IB > 0, go to step (6).

(4) The solar array operating power (PA) is calculated: PA = IA x (VAB + ADIODE). The battery parameters are updated:

$$AMPMIN = IB \times DELTAT$$

$$ACCUM = ACCUM + AMPMIN$$

$$SOC = \frac{ACCUM}{BAMMAX}$$

$$EOUT = EOUT - AMPMIN \times VB$$

$$TOTOUT = TOTOUT - AMPMIN$$

Time is incremented (T = T + DELTAT), and program operation operation is returned to Step (1) to begin calculations at the next time increment in orbit.

(5) The storage cell discharge voltage, VBDCH, is located at SOC and IB and the battery voltage determined: VB = VBDCH x FUDGE. The array bus voltage is set equal to VB; ILT and IPKLD are

calculated as in step (2). The total array current is determined a.. VA = VAB + ADIODE and the actual value of battery discharge current is calculated: IB = IA - ILT - IPKLD. Go to step (4).

(6) The battery charge current is set equal to IBMAX and the storage cell voltage (VBM) is determined at IB and SOC. Battery voltage is calculated: VB = VBM x FUDGE, and array bus voltage is determined: VAB = VB + DZCRR + (RCRR x IBMAX). The total load and peak load currents are calculated as in (2). Subroutine AMPS is entered (at VAB + ADIODE) to determine the solar array current. The available battery current is calculated: IB = IA - ILT - IPKLD. If the available battery charge current is greater than IBMAX, go to (a); if IB < IBMAX, go to (b).

(a) A voltage increment is defined: DELTAV = 0.1 volt. The array bus voltage VAB is set equal to TVSR + DELTAV and the array current at VA = VAB + ADIODE is determined. Values for ILT and IPKLD are calculated as in (2). The available battery charge current is calculated: IB = IA - ILT - IPKLD. (Note that ILT now contains some value of shunt dissipator current ISD - defined as (VAB - TVSR)/ERSR. The new value of IB is again compared with IBMAX; if IB is still greater than IBMAX, set DELTAV = DELTAV/2.0. A new array bus voltage is calculated. (Note that VAB is now equal to

TVSR + 0.1 + 0.05). System currents are again evaluated, and a new DELTAV is added to VAB in order to further increase ISD and reduce IB if IB still exceeds IBMAX. A maximum of 10 iterations is allowed in this manner to zero-in on the values of system currents. Go to (7).

(b) If IB < IBMAX, the array bus voltage is calculated: VAB - VBO x FUDGE + DZCRR. ILT, IPKLD and IA are determined at VAB, VAB-VDIODE, and VAB + ADIODE respectively. The storage cell voltage VBM is located in STINT at SOC and IB = IA - ILT - IPKLD; the battery voltage is determined as VB = VBM x FUDGE. The array current is determined at VA = VB + DZCRR + IB x RCRR) + ADIODE; ILT and IPKLD are calculated at new VAB = VA - ADIODE. The new charge current (IBN) is determined; IBN = IA - ILT - IPKLD. If | IBN - IB | > 10 ma, a new value of storage cell voltage VB is located at IB = IBN; this interation is repeated until the difference between IBN and (IA - ILT - IPKLD) is less than 10 ma. When | IBN - IB | ≤ 10 ma, go to (7).

(7) The battery voltage is now compared with the maximum allowable voltage (VBMAX). If VB ≤ VBMAX, go to (8); if VB > VBMAX, the computer moves the system operating point out along the I-V curve just as in (6(a)). Less input power is

obtained at each new voltage point until both the currents and voltages are compatible with acceptable small errors and maximum limits; then proceed to step (8).

(8) The battery parameters are updated:

AMPMIN = IB x DELTAT

ACCUM = ACCUM + AMPMIN

EIN = EIN + AMPMIN x VB

SOC = ACCUM/BAMMAX

TOTIN = TOTIN + AMPMIN

The solar array operating power is defined:

PA = (VAB + ADIODE) x IA

The final value shunt dissipator current is determined:

$$ISD = \frac{VAB - TVSR}{ERSR}$$

(9) Orbit time in incremented: T = T + DELTAT. If T $\leq$ TO, go to (1); if T > TO, go to step (10).

(10) The ampere minute charge-to-discharge ratio is calculated: RATIO = TOTIN/TOTOUT. Orbital average power dissipated in the battery is determined:

$$PAVG = \frac{(EIN + EOUT)}{TO}$$

The energy balance run for NB is now complete.

2. Parallel Maximum Power Tracker (PMPT) Daytime Energy Balance Calculations

The PMPT system uses the 600 series of instructions in MAIN for daytime energy balance calculations. Another parameter is also used with this system and is computed at each time increment: RATIO = TOTIN/TOTOUT. TVSR is set to 1000 volts to avoid unintentional use of a shunt dissipator in this system, which can operate at a solar array bus voltage up to 80 volts or greater. Refer to Figure 1 for the PMPT system block diagram.

(1) The unregulated bus voltage is initially defined as the previously-calculated solar array maximum-power voltage minus the array diode drop, VU = AVMPSA - ADIODE, and the solar array current is set equal to the current found earlier at the maximum power point, IA = IAM. The total load current ILT is calculated at VU; ILT is compared with IA. If (IA - ILT) < 0, go to (2); if (IA - ILT) > 0, go to step (3).

(2) As the total load current is greater than the array current, battery discharge power is needed to support the load. Cell discharge voltage VBDCH is looked up by STINT at SOC and at IB = -1.0 ampere. Unregulated bus voltage is calculated VU = VBDCH x FUDGE - VDIODE. Solar array current IA is found at VU, as well as ILT and IPKLD. Total value of battery discharge is calculated: IB = IA - ILT - IPKLD, solar array operating power is determined, PA = (VU + ADIODE) x IA, and the battery parameters are updated just as in step (4) of the NB daytime calculations. Orbit time is incremented and step (1) above is repeated.

(3) If (IA - ILT) from (1) is positive, the value of RATIO is compared with the user-specified CTOD; if RATIO is greater, the battery has reached a full state of charge and a limit value of charge current is set: ILIM = 0.6A. If RATIO is less than CTOD, set ILIM = IBMAX.

(4) The parallel tracker unit output power is calculated: PTO = VU x (IA - ILT) x PTEFF. Battery open-circuit voltage at SOC and 0.0 amps is calculated and an initial value of charge current is found: IB = (PTO/VB) - PKLD/(VB-VDIODE). Note that this value of IB will high since a low VB (open-circuit voltage) was assumed. If IB $<$ 0, go to (5); if IB $>$ 0, go to (6).

(5) If IB from (4) is negative (this can only occur if a high peak load exists), storage cell discharge voltage VBDCH is located in STINT at SOC and IB = - 1.0 A. The battery voltage is defined (VB = VBDCH x FUDGE), and a final value of battery discharge current is determined: IB = PTO/VB - PKLD/(VB-VDIODE). The remaining system parameters are defined: VA = VU, PA = (VA + ADIODE) x IA. The battery parameters (SOC, AMPMIN, ACCUM, TOTOUT, and EOUT) are updated just as in step (4) of the NB daytime calculations. The time is incremented (T = T + DELTAT) and the calculations in step (1) are begun again.

(6) If IB from (4) is positive, it is compared with the value of ILIM. If IB is greater than ILIM, battery voltage VB is found at SOC and at

IB = ILIM and IB is redefined: IB = PTO/VB - PKLD/(VB-VDIODE).

If IB is still greater than ILIM, a new operating voltage is specified: VU = VU + 0.1. IA is found by AMPS at the new VU, DRAIN supplies the new value of ILT and step (3) is repeated. Eventually, the increasing value of VU will reduce the available IB below ILIM, as follows: Battery voltage is found at the new value of IB, and now another value of IB is obtained from VB: IB = PTO/VB - PKLD/(VB-VDIODE). This value of IB is now compared with ILIM; if IB is greater, VU is again incremented, further reducing IB. After sufficiently increasing the array operating voltage, IB will be equal to or just slightly less than ILIM, and the last value of VB is compared with VBMAX.

(7) If VB is greater than the maximum permissible VBMAX, VU is incremented to a higher value just as it was when IB was too great. Charge current is further reduced at the higher array operating voltage and eventually the reduced value of IB will result in the VBMAX limit not being exceeded. At this time the battery parameters (AMPMIN, RATIO, EIN, TOTIN, ACCUM and SOC) are updated, array operating power is calculated, the values of all system parameters sent to PRINT and orbit time is again incremented.

(8) If orbit time T is less than or equal to TO, step (1) is repeated; if time T is greater than orbit duration TO, the actual C/D ratio achieved is calculated: RATIO = TOTIN/TOTOUT, battery power dissipated as

heat is calculated: PD = (EIN + EOUT)/TO and the energy balance run is complete.

An additional feature of the PMPT coding instructions is that when a final system operating point has been determined from energy balance considerations, a check is made to see if the unregulated bus voltage VU is at least one volt greater than the battery voltage, during system charge. This check is necessary since an operating point is assumed at the maximum-power voltage, which conceivably could be even less than battery voltage for an unusual combination of high array temperature, low battery temperature and a severe solar array voltage degradation. If VU is too low, the computer will increment VU = VU + 0.1 until a satisfactory operating point is reached, and an error message will be printed out at the completion of the run.

3. Series Maximum Power Tracker (SMPT) Daytime Energy Balance Calcuations

The SMPT system uses the 700 series of instructions in MAIN for daytime energy balance calculations. As seen in the system block diagram of Figure 1, the operation of the SMPT system is identical to that of the NB system after the series tracker unit has processed the solar array power.

(1) The tracker output power is determined at the array maximum power point (IA = IAM and VAB = AVMPSA - ADIODE): PTO = IA x VAB x PTEFF. Assuming zero current into the battery, the storage cell voltage (VBO) is obtained from STINT, and the battery voltage is

defined: VB = VBO x FUDGE. The series tracker output voltage (VTO) is set equal to VB, and the total load current calculated:

$$ILT = \frac{PWM + SL}{VTO} + \frac{\frac{PINV}{EFFINV}}{VTO} + \frac{\frac{PCONV}{EFFCNV}}{VTO} + \frac{PLD}{VTO} + ISER.$$

A first value of battery charge current is defined:

IB = PTO/VB - PKLD/(VB-VDIODE) - ILT.

(2) If IB from (1) is negative, battery power is required to support the spacecraft load. Storage cell voltage (VBDCH) is determined at SOC and IB = - 1.0A and battery voltage is defined: VB = VBDCH x FUDGE. DRAIN is entered to determine the new ILT at the lower VB, and a refined value of IB is calculated as in (1). Battery parameters are updated, just as in step (4) of the NB daytime calculation, and calculation at the next time increment is begun in step (1) after the values of system parameters have been sent to PRINT.

(3) If IB from (1) is positive, IB is set equal to IBMAX. After storage cell voltage (VBM) is determined at IB and SOC, the battery voltage is calculated: VB = VBM x FUDGE. An initial value of tracker output voltage is defined as VTO = VB + VKCRR. A new value of ILT is calculated at this value of VTO, as in (1), and a value of IB is determined: IB = PTO/VTO - ILT - PKLD/(VTO - VDIODE).

(4) If the value of IB from (3) is greater than IBMAX, the system operating voltage on the array is incremented: VAB = VAB + 0.1, where

originally VAB = AVMPSA - ADIODE. A new value of IA is obtained from AMPS, and step (1) is executed again. This procedure is repeated until IB is less than or equal to IBMAX.

(5) After an IB which is less than or equal to IBMAX has been determined, either from (3) or after the last iteration of step (4), a maximum of 10 iterations are started to find the proper value of IB. The charge controller resistance is calculated as RCRR = (VKCRR - DZCRR)/IBMAX and the tracker output voltage is set equal to VB + DZCRR, where VB is defined as the battery open circuit voltage (VBO x FUDGE). A value of ILT is found at VTO as in (1) and a value of IB is calculated: IB = PTO/VTO - ILT - PKLD/(VTO-VDIODE). The storage cell voltage at the new value of IB is located in STINT and a new battery voltage calculated; VTO is redefined as VB + DZCRR + (IB x RCRR). ILT is recalculated at the new VTO, and a new value of IB is defined:

IBN = PTO/VTO - ILT - PKLD/(VTO-VDIODE)

(6) The new value of battery charge current is compared with the older value; if $|$ IBN - IB $|$ < 10 ma, the error is deemed small enough and program operation is shifted to step (7). If the difference is not within the allowable 10 ma tolerance. IB is set equal to IBN. The calculations of step (5) are repeated, up to a maximum of 10 times, each time replacing IB with IBN and allowing the system operating point to be determined with little error.

(7) After IB from (6) has been determined, the resulting battery voltage VB is compared with VBMAX. If VB is greater than the user-specified VBMAX, the array bus voltage is incremented VAB = VAB + 0.1, as in step (4), until the decreased available power at the higher VAB produces a low enough value of IB such that VBMAX is not exceeded.

(8) System operating voltage is checked, just as with the PMPT system, to ensure that VAB is greater than VB by at least 1.0 volt. When this criterion is satisfied, battery parameters (SOC, AMPMIN, TOTIN, EIN, ACCUM) are updated, solar array power is calculated: PA = IA x (VAB + ADIODE), and step (1) is repeated for the next time increment. If T > TO, RATIO and PD are calculated as with the other two systems, and the energy balance run is completed.

VII. Summary

A computer program has been described which will simulate the operation of three general types of satellite power supply configurations (Nimbus B, Parallel Maximum Power Tracker, and Series Maximum Power Tracker) as the spacecraft passes through a complete orbital cycle. The simulation is accomplished by combining the known electrical characteristics of the various system components. The system's operating condition (array power, load powers, battery voltage and current, etc.) is determined at each time increment during the orbit and printed out. The program will enable the user to quickly and easily ascertain the effect on the power supply operation of load changes, disconnecting one or more batteries, occurrance of a partial solar array failure or expected array degradation and differing component electrical characteristics. Power dissipation in the storage models under any conditions can be determined, as can the battery ampere-minute charge-to-discharge ratio achieved during the orbit. Excellent agreement has been demonstrated between the computer calculated power system operation and actual hardware measurements.

VIII. References

1. Obenschain, A. F. and Rasmussen, R., "The Solar Array Synthesis Computer Program," NASA-GSFC Document X-716-69-390, September 1969.

2. Harmon, H. and R. Rasmussen, "Temperature, Illumination Intensity and Degradation Factor Effects on Solar Cell Output Characteristics," presented at the IEEE Aerospace and Electronic Systems Conference, Seattle, Washington, July 1966.

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APPENDIX A

```
C**** NIMBUS POWER SUBSYSTEM ENERGY BALANCE PROGRAM
      DIMENSION NDATE(3)
      DIMENSION RS(25)
      DIMENSION XC(25),XS(25),NTEMPS(25),ANGL1(25),ANGLA(25),PTEMPS(25)
      LOGICAL NITE
      NITE=.TRUE.
      COMMON NPANEL
      COMMON  ATEMP,AVMP,AXIMP,KEYE
C     READ DATE
      JA=5
      JB=6
      KEYE=1
      READ  (JA,7000)NDATE(1),NDATE(2),NDATE(3)
      NRUN=1
      DO 6001 I=1,25
      XS(I)=0.0
      XC(I)=0.0
      NTEMPS(I)=0
      ANGL1(I)=0.0
      RS(I)=0.0
 6001 ANGLA(I)=0.0
      MODEL=0.0
      DI1=100.
      DI2=100.
      DI3=100.
      DI4=100.
      DV1=100.0
      DV2=100.0
      TN=0.0
      TO=0.0
      DELTAT=0.0
      XIBMAX=20.0
      DZCRR=0.95
      VKCRR=1.40
      CLSR=0.0
      TVSR=1000.
      ERSR=0.0
      PLN=0.0
      PLD=0.0
      VDIODE=0.0
      BAMMAX=0.0
      AMSTRT=100.
      NAUTO=1.0
      NDGRAD=0
      SIGISC=0.0
```

```
      SIGVOC=0.0                                                        01 00450
      TNOT=0.0                                                          01 00460
      NBAT=0                                                            01 00470
      NVBMAX=0                                                          01 00480
      VBMAX=0.0                                                         01 00490
      XICCL=0.0                                                         01 00500
      E=100.0                                                           01 00510
      PLRN=0.0                                                          01 00520
      PLRD=0.0                                                          01 00530
      NRLOAD=0                                                          01 00540
      ETA=0.0                                                           01 00550
      NLOAD=0                                                           01 00560
      NCHAIN=0                                                          01 00570
      NPRINT=1                                                          01 00580
      NEND=0                                                            01 00590
      NFLOAD=0                                                          01 00600
      BATEMP=0.0                                                        01 00610
      NBTEMP=0                                                          01 00620
      ADIODE=0.0                                                        01 00660
      DELANG=360.0                                                      01 00670
      TOTIN=0.0                                                         01 00680
      TOTOUT=0.01                                                       01 00690
      DEGTOT=1.0                                                        01 00700
      DENFAC=0.0750                                                     01 00710
      NSLT=0                                                            01 00720
      NPMM=0                                                            01 00730
      NINV=0                                                            01 00740
      NCNV=0                                                            01 00750
      NSER=0                                                            01 00760
      EFFINV=100.0                                                      01 00770
      EFFCNV=100.0                                                      01 00780
      XISD=0.0                                                          01 00790
      SYSKEY=0.0                                                        01 00800
      PTEFF=100.0                                                       01 00810
      CTOD=10.0                                                         01 00820
      NPKLD=0                                                           01 00830
      FLAG=0.0
      EIN=0.0
      EOUT=0.0
      PD=0.0
C     READ TABLES COMMENT CARD                                          01 00840
  100 READ  (JA,7001)                                                   01 00850
C     LOAD STINT TABLES                                                 01 00860
      CALL STINT (0.0,0.0,0.0,0.0,0.0,-1,NGRIPE,0,0)                    01 00870
      IF(NGRIPE)101,101,102                                             01 00880
```

```
  102 WRITE (JB,7001)
      WRITE (JB,7002)
      PRINT 7002
      CALL EXIT
C     READ RUN COMMENTS
  101 READ  (JA,7003)
C     PRINT HEADER
      WRITE (JB,7004)NRUN,(NDATE(J),J=1,3)
      WRITE (JB,7001)
      WRITE (JB,7005)
      WRITE (JB,7003)
      WRITE (JB,7006)
  103 READ  (JA,7007)NCODE,PARAM
      IF  (NCODE-999)  1103,99,1103
 1103 IF  (NCODE)   105,105,104
   99 READ  (JA,7007)NPANEL
      IF (NPANEL.GT.25) GO TO 400
      DO 6000  I=1,NPANEL
      READ  (JA,6600)P1,P2,P3,P5
 6600 FORMAT (10F10.5)
      XC(I)=P1
      XS(I)=P2
      ANGLA(I)=P3
      ANGLI(I)=P3
      NTEMPS(I)=P5+.01
 6000 WRITE (JB,6601)I,XC(I),XS(I),P3,NTEMPS(I)
 6601 FORMAT (7H0PANEL  I3/  9H CELLS = F5.1,11H STRINGS = F6.2,
     1                        15H INCON ANGLE = F5.1,
     2                        14H TEMP TABLE = I2)
      WRITE (JB,6602)
 6602 FORMAT (1H0  )
      GO TO 103
  104 GO TO  (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,
     123,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,
     243,44,45,46,47,48,49,50                                   ),NCODE
    1 TN=PARAM
      WRITE (JB,8001)NCODE,TN
      GO TO 103
    2 TO=PARAM
      WRITE (JB,8002)NCODE,TO
      GO TO 103
    3 DELTAT=PARAM
      WRITE (JB,8003)NCODE,DELTAT
      GO TO 103
    4 VBMAX=PARAM
```

```
      WRITE (JB,8004)NCODE,VBMAX
      IF (VBMAX) 6993,103,103
 6993 NVBMAX=-VBMAX+0.01
      GO TO 103
    5 XIBMAX=PARAM
      WRITE (JB,8005)NCODE,XIBMAX
      GO TO 103
    6 DZCRR=PARAM
      WRITE (JB,8006)NCODE,DZCRR
      GO TO 103
    7 VKCRR=PARAM
      WRITE (JB,8007)NCODE,VKCRR
      GO TO 103
    8 CTOD=PARAM
      WRITE (JB, 8008)NCODE,CTOD
      GO TO 103
    9 TVSR=PARAM
      WRITE (JB,8009)NCODE,TVSR
      GO TO 103
   10 ERSR=PARAM
      WRITE (JB,8010)NCODE,ERSR
      GO TO 103
   11 PLN=PARAM
      WRITE (JB,8011)NCODE,PLN
      GO TO 103
   12 PLD=PARAM
      WRITE (JB,8012)NCODE,PLD
      GO TO 103
   13 VDIODE=PARAM
      WRITE (JB,8013)NCODE,VDIODE
      GO TO 103
   14 BAMMAX=PARAM
      WRITE (JB,8014)NCODE,BAMMAX
      GO TO 103
   15 ETA=PARAM
      WRITE (JB,8015)NCODE,ETA
      GO TO 103
   16 NSLT=PARAM+.01
      WRITE (JB,8016)NCODE,NSLT
      GO TO 103
   17 NBMINT=PARAM+.01
      WRITE (JB,8017)NCODE,NBMINT
      GO TO 103
   18 NBMAXT=PARAM+.01
      WRITE (JB,8018)NCODE,NBMAXT
```

```
      GO TO 103
   19 NCELLT=PARAM+.01
      WRITE (JB,8019)NCODE,NCELLT
      GO TO 103
   20 NPKLD=PARAM+.01
      WRITE (JB,8020)NCODE,NPKLD
      GO TO 103
   21 NPWM=PARAM+.01
      WRITE (JB,8021)NCODE,NPWM
      GO TO 103
   22 NINV=PARAM+.01
      WRITE (JB,8022)NCODE,NINV
      GO TO 103
   23 NCNV=PARAM+.01
      WRITE (JB,8023)NCODE,NCNV
      GO TO 103
   24 NSER=PARAM+.01
      WRITE (JB,8024)NCODE,NSER
      GO TO 103
   25 SYSKEY=PARAM
      WRITE (JB,8025)NCODE,SYSKEY
      GO TO 103
   26 NPRINT=PARAM+.01
      WRITE (JB,8026)NCODE,NPRINT
      GO TO 103
   27 NEND=PARAM+.01
      WRITE (JB,8027)NCODE,NEND
      GO TO 103
   28 EFFINV=PARAM
      WRITE (JB,8028)NCODE,EFFINV
      GO TO 103
   29 EFFCNV=PARAM
      WRITE (JB,8029)NCODE,EFFCNV
      GO TO 103
   30 NBTEMP=PARAM+.01
      WRITE (JB,8030)NCODE,NBTEMP
      GO TO 103
   31 NDGRAD=PARAM+.01
      WRITE (JB,8031)NCODE,NDGRAD
      GO TO 103
   32 SIGISC=PARAM
      WRITE (JB,8032)NCODE,SIGISC
      GO TO 103
   33 SIGVOC=PARAM
      WRITE (JB,8033)NCODE,SIGVOC
```

```
      GO TO 103
   34 DI1=PARAM
      WRITE (JB,8034)NCODE,DI1
      GO TO 103
   35 DI2=PARAM
      WRITE (JB,8035)NCODE,DI2
      GO TO 103
   36 DI3=PARAM
      WRITE (JB,8036)NCODE,DI3
      GO TO 103
   37 DI4=PARAM
      WRITE (JB,8037)NCODE,DI4
      GO TO 103
   38 DV1=PARAM
      WRITE (JB,8038)NCODE,DV1
      GO TO 103
   39 DV2=PARAM
      WRITE (JB,8039)NCODE,DV2
      GO TO 103
   40 AVPMO=PARAM
      WRITE (JB,8040)NCODE,AVPMO
      GO TO 103
   41 AIPMO=PARAM
      WRITE (JB,8041)NCODE,AIPMO
      GO TO 103
   42 AVOCO=PARAM
      WRITE (JB,8042)NCODE,AVOCO
      VOCOI = AVOCO
      GO TO 103
   43 THETA=PARAM
      WRITE (JB,8043)NCODE,THETA
      THETA=THETA/100.0
      GO TO 103
   44 TNOT=PARAM
      WRITE (JB,8044)NCODE,TNOT
      GO TO 103
   45 NBAT=PARAM+0.01
      WRITE (JB,8045)NCODE,NBAT
      FUDGE=PARAM
      GO TO 103
   46 ADIODE=PARAM
      WRITE (JB,8046)NCODE,ADIODE
      GO TO 103
   47 PTEFF=PARAM
      WRITE (JB,8047)NCODE,PTEFF
```

```
      PTEFF=PTEFF/100.0
      GO TO 103
   48 DELTT=PARAM
      WRITE (JB,8048)NCODE,DELTT
      GO TO 103
   49 ADDT=PARAM
      WRITE (JB,8049)NCODE,ADDT
      GO TO 103
   50 DENFAC=PARAM
      WRITE (JB,8050)NCODE,DENFAC
      GO TO 103
C     END DATA LOADER
C     HOUSEKEEPING FOLLOWS
  105 IF(NDGRAD)501,501,500
  500 DISC=DI1/100.*DI2/100.*DI3/100.*DI4/100.
      DV=DV1/100.*DV2/100.
      NDGRAD=0
C     INITIAL ENTRY INTO SUBROUTINE STASH, INITIALIZATION
      CALL STASH(DISC,THETA,AVPMO,AIPMO,TNOT,-1,NGRIPE,NCELLT,VOCOI,
     1 ADDT,DELTT)
C     SECOND ENTRY INTO SUBROUTINE STASH, INITIALIZATION
      CALL STASH(DV,DISC,SIGISC,SIGVOC,TNOT,0,NGRIPE,NCELLT,DENFAC,ADDT,
     1DELTT)
      IF(NGRIPE)501,501,502
  502 WRITE (JB,8997)
      NGRIPE=7777
      GO TO 113
  501 OCH=0.0
      PMAX=0.0
      SLAM=0.0
      RCRR=(VKCRR-DZCRR)/XIBMAX
      IF (NCHAIN) 106,106,107
  107 IF (SOC - 1.0)  1107,1107,106
  106 SOC = AMSTRT/100.0
      ACCUM = BAMMAX*SOC
 1107 T=0.0
      IF (NBTEMP)   1109,1110,1109
 1109 CALL STINT (ETA,0.0,0.0,BATEMP,1,NGRIPE,NBTEMP,NBTEMP)
      IF (NGRIPE)   1110,1110,112
 1110 NTALLY=0
      NPAGE=50
      EFF=E/100.
      CALL PRINT (NPRINT,NPAGE,NTALLY,T,ACCUM,SOC,0.0,0.0,0.0,0.0,0.0,0.
     10,0.0,0.0,0.0,0.0,0.0,0.0)
  108 T=T+DELTAT
```

```
 6994 CONTINUE
      IF (VKCRR) 10113,10112,10113
10113 DELTAV=VKCRR
      ITER=20
      GO TO 10114
10112  DELTAV=0.4
      ITER=10
10114 CONTINUE
      PTEMPS(1)=0.0
      PTEMPS(2)=0.0
      IF(T-TN)109,109,110
  109 CALL STINT (SOC, 0.001,BATEMP,VBDCH,1,NGRIPE,NBMINT,NBMAXT)
      VTO=0.0
      VBDCH=VBDCH*FUDGE
      IF(NGRIPE)111,111,112
  112 NGRIPE=1
  113 WRITE (JB,7008)NGRIPE
      GO TO 200
  111 VA=VBDCH-VDIODE
      VB=VBDCH
      NGRIPE=NFLOAD
      CALL DRAIN (XIL,XILT,PLN,VA,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      CALL STINT (T,0.0,0.0,PKLD,1,NGRIPE,NPKLD,NPKLD)
      XIPKLD=PKLD/VA
  117 XIB=-XILT-XIPKLD
 3000 CALL STINT (SOC,XIB,BATEMP,VBDCH,1,NGRIPE,NBMINT,NBMAXT)
      IF (NGRIPE) 3001,3001,3002
 3002 NGRIPE = 20
      GO TO 113
 3001 VBDCH = VBDCH*FUDGE
      VA = VBDCH - VDIODE
      NGRIPE = NFLOAD
      VB = VBDCH
      CALL DRAIN (XIL,XILS,PLN,VA,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
 3003 IF(XILS+PKLD/VA+XIB-0.01) 3005,3005,3006
 3006 XIB=-XILS-PKLD/VA
      GO TO 3000
 3005 XILT = XILS
      TEMPT=0.0
      TEMPS=0.0
      VO = 0.0
      XIA=0.0
      PA=0.0
```

```
  121 IF (XIB) 123,123,126                                         01 03570
  123 AMPMIN=XIB*DELTAT                                            01 03580
      ACCUM=ACCUM+AMPMIN                                           01 03590
      SOC=ACCUM/BAMMAX                                             01 03600
      EOUT=EOUT+AMPMIN*VB
      IF(NPANEL-1) 10744,10744,10745                               01 03610
10744 TEMPT=PTEMPS(1)                                              01 03620
      GO TO 124                                                    01 03630
10745 TEMPT=PTEMPS(1)                                              01 03640
      TEMPS=PTEMPS(2)                                              01 03650
      GO TO 124                                                    01 03660
  126 AMPMIN=XIB*DELTAT*EFF                                        01 03670
      ACCUM=ACCUM+AMPMIN                                           01 03680
      SOC=ACCUM/BAMMAX                                             01 03690
      EIN=EIN+AMPMIN*VB
      IF(NPANEL-1) 10744,10744,10746                               01 03700
10746 TEMPT=PTEMPS(1)                                              01 03710
      TEMPS=PTEMPS(2)                                              01 03720
  124 CALL PRINT (NPRINT,NPAGE,NTALLY,T,ACCUM,SOC,VTO,VA,XIA,PA,VB,  01 03730
     1XIB,XIL,TEMPT,XISD,XIPKLD,TEMPS,PMAX)                        01 03740
      XISD = 0.0
      IF(.NOT.NITE.OR.T.LT.TN) GO TO 10124
      NITE = .FALSE.
10124 DEPTH = (1.0 - SOC)*100.0                                    01 03760
11124 IF (AMPMIN) 12124,108,13124                                  01 03770
12124 TOTOUT = TOTOUT-AMPMIN                                       01 03780
      GO TO 108                                                    01 03790
13124 TOTIN = TOTIN+AMPMIN                                         01 03800
      RATIO = TOTIN/TOTOUT                                         01 03810
      GO TO 108                                                    01 03820
  110 IF(T-TO)130,130,200                                          01 03830
  207 NRUN=NRUN+1                                                  01 03840
      IF(NEND)100,101,129                                          01 03850
  129 CALL EXIT                                                    01 03860
  130 DO 804 LRM=1,NPANEL
      D = T-TN                                                     01 03880
      KEYE=0                                                       01 03890
      IF (XC(LRM)) 801,802,801                                     01 03900
  801 CALL STINT (D,ETA,0.0,ATEMP,1,NGRIPE,NTEMPS(LRM),NTEMPS(LRM)  01 03910
     1)                                                            01 03920
      IF (NGRIPE) 804,804,803                                      01 03930
  803 NGRIPE=5                                                     01 03940
      GO TO 113                                                    01 03950
  804 CALL STASH (SIGISC,SIGVOC,DISC,DV,TNOT,KEY,NGRIPE,NCELLT,     01 03960
     1VOCOI,ADDT,DELTT)                                            01 03970
```

```
  802 CONTINUE
      KEYE=1
  805 AVMPSA=AVMP  * XC(1)
      CALL STASH (AXIMP,VKN1,AVMP,ATEMP,0.0,1,NGRIPE,NCELLT,VOCOI,ADDT
     1,DELTT)
      PAR=0.0
      DO 806 L=1,NPANEL
  806 PAR=PAR+XS(L)
      XIAM=AXIMP * PAR
      PMSAB= XIAM * (AVMPSA - ADIODE )
      PMAX = XIAM * AVMPSA
  800 IF (SYSKEY) 700,900,600
C**** NIMBUS B WITH PEAK LOAD REGULATOR STARTS
  900 VTO=0.0
      DO 911 L=1,NPANEL
      IF (XC(L)) 911,911,912
  912 CALL STINT (D,ETA,0.0,PTEMPS(L),1,NGRIPE,NTEMPS(L),NTEMPS(L))
  911 CONTINUE
      CALL STINT (SOC,0.0,BATEMP,VBO,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBO*FUDGE
      VAB=VB
      CALL DRAIN (XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      CALL STINT (T,0.0,0.0,PKLD,1,NGRIPE,NPKLD,NPKLD)
      CALL AMPS (XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)
      XIB=XIA-XILT-PKLD/(VAB-VDIODE)
      IF (XIB) 901,902,903
  901 CALL STINT (SOC,XIB,BATEMP,VBD,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBD*FUDGE
      VAB=VB
      CALL DRAIN (XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      CALL AMPS (XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)
      XIB=XIA-XILT-PKLD/(VAB-VDIODE)
      GO TO 904
  902 XIB=0.0
      GO TO 904
  903 XIB=XIBMAX
      CALL STINT (SOC,XIB,BATEMP,VBM,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBM*FUDGE
      VAB=VB+XIB*RCRR+DZCRR
      CALL DRAIN (XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
```

```
      CALL AMPS (XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,        01 04430
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)                     01 04440
      XIB=XIA-XILT-PKLD/(VAB-VDIODE)                                       01 04450
      IF(XIB-XIBMAX) 905,920,920
  905 VAB=VBO*FUDGE+DZCRR                                                  01 04470
      CALL DRAIN (XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,           01 04480
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)                                01 04490
      CALL AMPS (XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,        01 04500
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)                     01 04510
      XIB=XIA-XILT-PKLD/(VAB-VDIODE)                                       01 04520
  908 CALL STINT (SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)                01 04530
      VB=VB*FUDGE                                                          01 04540
      VAB=VB+DZCRR+XIB*RCRR                                                01 04550
      CALL DRAIN (XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,           01 04560
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)                                01 04570
      CALL AMPS (XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,        01 04580
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)                     01 04590
      XIBN=XIA-XILT-PKLD/(VAB-VDIODE)                                      01 04600
      IF (XIBN-XIB-.01)909,909,907                                         01 04610
  907 XIB=XIBN                                                             01 04620
      GO TO 908                                                            01 04630
  909 IF(VB-VBMAX) 904,904,920
  920 VL=VAB
      VAB=TVSR
      CALL DRAIN(XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      CALL AMPS(XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,
     1NCELLT,ADIODE,DELANG,RS,MODDEL.VOCOI,ADDT,DELTT)
      XIBT=XIA-XILT-PKLD/(VAB-VDIODE)
      IF(XIBT-XIB) 921,906,906
  921 IF(XIBT-XIBMAX) 922,906,906
  922 XIB=XIBT
      CALL STINT(SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)
      VB=VB*FUDGE
      IF(VB-VBMAX) 923,904,906
C****  ITERATION BEGINS TO FIND OPERATING POINT IN BATT V-T LIMIT MODE
  923 DELV=TVSR-VL
      JILT=0
  924 DELV=DELV/2.0
      JILT=JILT+1
      IF(JILT.GT.10) GO TO 904
      IF(VB.GT.VBMAX) GO TO 925
      VAB=VAB-DELV
      GO TO 926
  925 VAB=VAB+DELV
```

```
  926 CONTINUE
      CALL DRAIN(XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      CALL AMPS(XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)
      XIB=XIA-XILT-PKLD/(VAB-VDIODE)
      CALL STINT(SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)
      VB=VB*FUDGE
      GO TO 924
C**** ITERATION TO FIND SHUNT DISSIPATOR CURRENT FOLLOWS
  906 DELTAV=0.1
      ITER=0
      VAB=TVSR+DELTAV
  910 XISD=XILT-XIL
      ITER=ITER+1
      IF (ITER-10) 916,916,904
  916 CALL AMPS (XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)
      CALL DRAIN (XIL,XILT,PLD,VAB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      XIB=XIA-XILT-PKLD/(VAB-VDIODE)
      IF (XIB-XIBMAX) 914,914,913
  913 DELTAV=DELTAV/2.0
      VAB=VAB+DELTAV
      GO TO 910
  914 CALL STINT (SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)
      VB=VB*FUDGE
      IF (VB-VBMAX) 915,904,913
  915 DELTAV=DELTAV/2.0
      VAB=VAB-DELTAV
      GO TO 910
  904 VA=VAB
      PA=XIA*(VAB+ADIODE)
      XIPKLD=PKLD/(VAB-VDIODE)
      GO TO 121
C**** NB COMPUTATION COMPLETE FOR ONE TIME INCREMENT
  200 WRITE (JB,7009)DEPTH
      RATIO =TOTIN/TOTOUT
      WRITE (JB,7010)RATIO
      RATIO=0.0
      TOTIN=0.0
      TOTOUT=0.01
      PD=(EIN+EOUT)/TO
      WRITE(JB,7011)EIN
      WRITE(JB,7012)EOUT
```

```
      WRITE(JB,7013)PD
      EOUT=0.0
      EIN=0.0
      PD=0.0
      IF(FLAG.GT.0.0) WRITE(JB,8060)
      FLAG=0.0
      GO TO 207
C**** PARALLEL MAX PWR TRKR WITH A-H CTR AND PEAK LOAD REGULATOR STARTS
  600 TVSR=1000.0
      VTO=0.0
      VU=AVMPSA-ADIODE
      XIA=XIAM
      DO 611 LRM=1,NPANEL
      IF (XC(LRM)) 611,611,612
  612 CALL STINT (D,ETA,0.0,PTEMPS(LRM),1,NGRIPE,NTEMPS(LRM),NTEMPS(LRM)
     1)
  611 CONTINUE
  607 CALL DRAIN (XIL,XILT,PLD,VU,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      IF (XIA-XILT)601,602,603
  601 CALL STINT (SOC,-1.0,BATEMP,VBD,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBD*FUDGE
      VU=VB-VDIODE
      CALL AMPS (XIA,VU,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,NCELLT
     1,ADIODE,DELANG,RS,MODDEL,VOCOI,ADDT,DELTT)
      CALL DRAIN (XIL,XILT,PLD,VU,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      CALL STINT (T,0.0,0.0,PKLD,1,NGRIPE,NPKLD,NPKLD)
      XIB=XIA-(XILT+PKLD/VU)
      GO TO 604
  602 CALL STINT (T,0.0,0.0,PKLD,1,NGRIPE,NPKLD,NPKLD)
      IF (PKLD) 630,630,631
  630 XIB=0.0
      CALL STINT (SOC,XIB,BATEMP,VBO,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBO*FUDGE
      GO TO 604
  631 CALL STINT (SOC,-1.0,BATEMP,VBD,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBD * FUDGE
      XIB=PKLD/(VB-VDIODE)
      GO TO 604
  603 XILIM=XIBMAX
      IF (RATIO-CTOD) 622,621,621
  621 XILIM=0.6
  622 PTO=VU*(XIA-XILT)*PTEFF
      CALL STINT (SOC,0.0,BATEMP,VBO,1,NGRIPE,NBMINT,NBMAXT)
```

```
      VB=VBO * FUDGE                                                    01 05350
      CALL STINT (T,0.0,0.0,PKLD,1,NGRIPE,NPKLD,NPKLD)                  01 05360
      XIB= (PTO/VB) - (PKLD/(VB-VDIODE))                                01 05370
      IF (XIB) 617,616,615                                              01 05380
  615 IF (XIB-XILIM) 608,605,605                                        01 05390
  616 XIB=0.0                                                           01 05400
      GO TO 604                                                         01 05410
  617 CALL STINT (SOC,-1.0,BATEMP,VBD,1,NGRIPE,NBMINT,NBMAXT)           01 05420
      VB=VBD *FUDGE                                                     01 05430
      XIB=(PTO/VB)-(PKLD/(VB-VDIODE))                                   01 05440
      GO TO 604                                                         01 05450
  605 CALL STINT (SOC,XILIM,BATEMP,VBL,1,NGRIPE,NBMINT,NBMAXT)          01 05460
      VB=VBL * FUDGE                                                    01 05470
      XIB=(PTO/VB)-(PKLD/(VB-VDIODE))                                   01 05480
      IF(XIB-XILIM) 620,613,606                                         01 05490
  606 VU=VU+0.1                                                         01 05500
      CALL AMPS (XIA,VU,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,NCELLT01 05510
     1,ADIODE,DELANG,RS,MODDEL,VUCUI,ADDT,DELTT)                        01 05520
      GO TO 607                                                         01 05530
  608 CALL STINT (SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)             01 05540
      VB=VB*FUDGE                                                       01 05550
      XIBN= (PTO/VB)-(PKLD/(VB-VDIODE))                                 01 05560
      IF((XIBN/XIB)-0.99) 619,619,618                                   01 05570
  618 XIB=XIBN                                                          01 05580
      GO TO 613                                                         01 05590
  619 XIB=XIB-0.1                                                       01 05600
      GO TO 608                                                         01 05610
  613 IF(VBMAX-VB) 606,606,640
  620 CALL STINT (SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)             01 05630
      VB=VB*FUDGE                                                       01 05640
      XIB=(PTO/VB) - (PKLD/(VB-VDIODE))                                 01 05650
      IF (XILIM-XIB) 606,613,613                                        01 05660
  640 VC=VB+1.0
      IF(VU.LT.VC) GO TO 641
C**** PMPT COMPUTATION COMPLETE FOR ONE TIME INCREMENT                   01 05670
  604 VA=VU                                                             01 05680
      PA=(VA+ADIODE)*XIA                                                01 05690
      XIPKLD=PKLD/(VB-VDIODE)                                           01 05700
      GO TO 121                                                         01 05710
  641 FLAG=1.0
      GO TO 606
C**** SERIES MAX PWR TRACKER (SINGLE TRACKER UNIT) BEGINS               01 05720
  700 TVSR=1000.0                                                       01 05730
      VAB=AVMPSA-ADIODE                                                 01 05740
      XIA=XIAM                                                          01 05750
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```
      DO 711 LRM=1,NPANEL
      IF (XC(LRM))711,711,712
  712 CALL STINT (D,ETA,0.0,PTEMPS(LRM),1,NGRIPE,NTEMPS(LRM),NTEMPS(LRM)
     1)
  711 CONTINUE
      PTO=XIA*VAB*PTEFF
      CALL STINT (SOC,0.0,BATEMP,VBO,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBO*FUDGE
      VBO=VB
      CALL STINT (T,0.0,0.0,PKLD,1,NGRIPE,NPKLD,NPKLD)
      VTO=VB
      CALL DRAIN (XIL,XILT,PLD,VTO,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      XIB=PTO/VB-PKLD/(VB-VDIODE)-XILT
      IF (XIB)701,702,703
  701 CALL STINT (SOC,-1.0,BATEMP,VBD,1,NGRIPE,NBMINT,NBMAXT)
      VB=VBD*FUDGE
      CALL DRAIN (XIL,XILT,PLD,VB,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      XIB=PTO/VB-PKLD/(VB-VDIODE)-XILT
      VTO=VB
      XIPKLD=PKLD/(VB-VDIODE)
      GO TO 704
  702 XIB=0.0
      VTO=VB
      XIPKLD=PKLD/(VB-VDIODE)
      GO TO 704
  703 XIB=XIBMAX
      CALL STINT (SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)
      VB=VB*FUDGE
      VTO=VB+VKCRR
      CALL DRAIN (XIL,XILT,PLD,VTO,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
  708 XIB=PTO/VTO-XILT-PKLD/(VTO-VDIODE)
      IF (XIB-XIBMAX)707,706,705
  705 VAB=VAB+0.1
      CALL AMPS (XIA,VAB,PTEMPS,XS,XC,ETA,ANGLA,ANGLI,NGRIPE,NAUTO,
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCCI,ADDT,DELTT)
      PTO=XIA*VAB*PTEFF
      GO TO 708
  706 IF(VBMAX-VB) 705,705,740
C**** ITERATION BEGINS TO FIND PROPER BATTERY CHARGE CURRENT
  707 ITER=10
      RCRR=(VKCRR-DZCRR)/XIBMAX
      VTO=VBO+DZCRR
```

```
      CALL DRAIN (XIL,XILT,PLD,VTO,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      XIB=PTO/VTO-XILT-PKLD/(VTO-VDIODE)
  710 CALL STINT (SOC,XIB,BATEMP,VB,1,NGRIPE,NBMINT,NBMAXT)
      VB=VB*FUDGE
      VTO=VB+DZCRR+XIB*RCRR
      CALL DRAIN (XIL,XILT,PLD,VTO,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,
     1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)
      XIBN=PTO/VTO-XILT-PKLD/(VTO-VDIODE)
      IF (X.--XIBN-0.01)706,706,709
  709 XIB=XIBN
      ITER=ITER-1
      IF (ITER)706,706,710
  740 VC=VB+1.0
      IF(VAB.LT.VC) GO TO 741
  704 PA=XIA*(VAB+ADIODE)
      XIPKLD=PKLD/(VTO-VDIODE)
      VA=VAB
      GO TO 121
  741 FLAG=1.0
      GO TO 705
  400 WRITE (6,410) NPANEL
  410 FORMAT ( 1X,'NUMBER OF PANELS = ',I3,'EXCEEDS NUMBER ALLOWED')
      STOP
C**** STS COMPUTATION COMPLETE FOR ONE TIME INCREMENT
C     SATELLITE ENERGY BALANCE FORMATS
 7000 FORMAT (3I2)
 7001 FORMAT (72H
     1                    )
 7002 FORMAT (34H  UNABLE TO READ TABLES, ABORT RUN)
 7003 FORMAT (72H
     1                    )
 7004 FORMAT (12H1     RUN NO.I3,18H  ON THIS DATE OF I2,1H .2,1H I2,77H
     1  SATELLITE ELECTRICAL ENERGY BALANCE (C) P.J.HYLAND,R.RASMUSSEN P
     2ROGRAMMERS/20H0     TABLE COMMENTS.)
 7005 FORMAT (18H0     RUN COMMENTS.)
 7006 FORMAT (30H0     NEW OR CHANGED PARAMETERS/1H0)
 7007 FORMAT (I3,F12.0)
 7008 FORMAT (35H0    ERROR IN TABLE LOOKUP, NGRIPE =I4)
 7009 FORMAT (28H0DEPTH OF DISCHARGE(PERCENT)F7.3//)
 7010 FORMAT (10H C/D RATIOF6.3//)
 7011 FORMAT (43H CHARGE ENERGY(WATT-MINUTES)                F10.3//)
 7012 FORMAT (43H DISCHARGE ENERGY(WATT-MINUTES)             F10.3//)
 7013 FORMAT (43H ORB AVG PWR DISSIPATED IN BATTERIES(WATTS)F10.3//)
 8001 FORMAT (I7,40H  TN(NIGHT TIME).......................F12.4)
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8002 FORMAT (I7,40H  TO(ORBIT TIME)........................F12.4)       01 06560
8003 FORMAT (I7,40H  DELTA T...............................F12.4)       01 06570
8004 FORMAT (I7,40H  VBMAX (VOLTS).........................F12.4)       01 06580
8005 FORMAT (I7,40H  IBMAX (AMPS)..........................F12.4)       01 06590
8006 FORMAT (I7,40H  DZCRR (VOLTS).........................F12.4)       01 06600
8007 FORMAT (I7,40H  VKCRR (VOLTS).........................F12.4)       01 06610
8008 FORMAT (I7,40H  C/D RATIO.............................F12.4)       01 06620
8009 FORMAT (I7,40H  TVSR  (VOLTS).........................F12.4)       01 06630
8010 FORMAT (I7,40H  ERSR  (OHMS)..........................F12.4)       01 06640
8011 FORMAT (I7,40H  PLN...................................F12.4)       01 06650
8012 FORMAT (I7,40H  PLD...................................F12.4)       01 06660
8013 FORMAT (I7,40H  VDIODE(VOLTS).........................F12.4)       01 06670
8014 FORMAT (I7,40H  BAMMAX (A-M)..........................F12.4)       01 06680
8015 FORMAT (I7,40H  ETA-(DEG).............................F12.4)       01 06690
8016 FORMAT (I7,40H  NSLT..................................I8)          01 06700
8017 FORMAT (I7,40H  NBMINT................................I8)          01 06710
8018 FORMAT (I7,40H  NBMAXT................................I8)          01 06720
8019 FORMAT (I7,40H  NCELLT................................I8)          01 06730
8020 FORMAT (I7,40H  NPKLD.................................I8)          01 06740
8021 FORMAT (I7,40H  NPWM..................................I8)          01 06750
8022 FORMAT (I7,40H  NINV..................................I8)          01 06760
8023 FORMAT (I7,40H  NCNV..................................I8)          01 06770
8024 FORMAT (I7,40H  NSER..................................I8)          01 06780
8025 FORMAT (I7,40H  SYSTEM KEY (-1.0=SMPT,0.0=NB,1.0=PMPT)F12.4)       01 06790
8026 FORMAT (I7,40H  NPRINT................................I8)          01 06800
8027 FORMAT (I7,40H  NEND..................................I8)          01 06810
8028 FORMAT (I7,40H  EFFINV................................F12.4)       01 06820
8029 FORMAT (I7,40H  EFFCNV................................F12.4)       01 06830
8030 FORMAT (I7,40H  NBTEMP................................I8)          01 06840
8031 FORMAT (I7,40H  NDGRAD................................I8)          01 06850
8032 FORMAT (I7,40H  SIGISC (A/DEG C)......................F12.5)       01 06860
8033 FORMAT (I7,40H  SIGVOC (V/DEG C)......................F12.5)       01 06870
8034 FORMAT (I7,40H  DI1(PERCENT)..........................F12.4)       01 06880
8035 FORMAT (I7,40H  DI2(PERCENT)..........................F12.4)       01 06890
8036 FORMAT (I7,40H  DI3(PERCENT)..........................F12.4)       01 06900
8037 FORMAT (I7,40H  DI4(PERCENT)..........................F12.4)       01 06910
8038 FORMAT (I7,40H  DV1(PERCENT)..........................F12.4)       01 06920
8039 FORMAT (I7,40H  DV2(PERCENT)..........................F12.4)       01 06930
8040 FORMAT (I7,40H  AVPMO(VOLTS)..........................F12.5)       01 06940
8041 FORMAT (I7,40H  AIPMO(AMPS)...........................F12.5)       01 06950
8042 FORMAT (I7,40H  AVOCO(VOLTS)..........................F12.5)       01 06960
8043 FORMAT (I7,40H  THETA(PERCENT)........................F12.4)       01 06970
8044 FORMAT (I7,40H  TNOT(DEG C)...........................F12.4)       01 06980
8045 FORMAT (I7,40H  NO. OF CELLS/BATT.....................I8)          01 06990
8046 FORMAT (I7,40H  ADIODE(VOLT)..........................F12.4)       01 07000
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8047 FORMAT (I7,40H  PTEFF..................................F12.4)       01 07010
8048 FORMAT (I7,40H  DELTT(DEG C)...........................F12.4)       01 07020
8049 FORMAT (I7,40H  ADDT (DEG C)...........................F12.4)       01 07030
8050 FORMAT (I7,40H  DENFAC(1 OHM-CM=0.065,10 OHM-CM=0.0)..F12.4)       01 07040
8060 FORMAT(78H0  SOLAR ARRAY MAXIMUM-POWER VOLTAGE IS TOO LOW FOR EFFI
    1CIENT SYSTEM OPERATION )
8997 FORMAT ( 25H STASH DID NOT INITIALIZE )                            01 07050
     END                                                                01 07060
     SUBROUTINE DRAIN (XIL,XILT,P,VA,CLSR,TVSR,ERSR,T,NGRIPE,NSLT,      02 00010
    1NPWM,NINV,NCNV,NSER,EFFINV,EFFCNV,TN)                              02 00020
     NSW=NGRIPE                                                         02 00030
     NGRIPE=0                                                           02 00040
     XIPROF=0.0                                                         02 00050
     XIL=0.0                                                            02 00060
     BINV=0.0                                                           02 00070
     ACNV=0.0                                                           02 00080
     SER=0.0                                                            02 00090
     IF (NPWM-1) 37,37,2                                                02 00100
   2 CALL STINT (T,0.0,0.0,PWM,1,NGRIPE,NPWM,NPWM)                      02 00110
     GO TO 10                                                           02 00120
  37 PWM=0.0                                                            02 00130
  10 IF(T-TN)9,20,20                                                    02 00140
   9 BEYE=1                                                             02 00150
     GO TO 15                                                           02 00160
  20 IF(VA-TVSR)21,22,22                                                02 00170
  21 BEYE=2                                                             02 00180
     GO TO 15                                                           02 00190
  22 BEYE=3                                                             02 00200
  15 CALL STINT (PWM,BEYE,0.0,SL,1,NGRIPE,NSLT,NSLT)                    02 00210
     PWML=PWM+SL                                                        02 00220
     XIL=PWML                                                           02 00230
   1 IF (NINV-1) 3,3,4                                                  02 00240
   3 IF (NCNV-1) 5,5,6                                                  02 00250
   5 IF (NSER-1) 7,7,8                                                  02 00260
   4 CALL STINT (T,0.0,0.0,AINV,1,NGRIPE,NINV,NINV)                     02 00270
     BINV=AINV/EFFINV * 100.0                                           02 00280
     GO TO 3                                                            02 00290
   6 CALL STINT (T,0.0,0.0,CNV,1,NGRIPE,NCNV,NCNV)                      02 00300
     ACNV=CNV/EFFCNV  * 100.0                                           02 00310
     GO TO 5                                                            02 00320
   8 CALL STINT (T,0.0,0.0,SER,1,NGRIPE,NSER,NSER)                      02 00330
   7 XIPROF=(XIL+BINV+ACNV+P)/VA+SER                                    02 00340
     XIL=XIPROF                                                         02 00350
     DIFF=VA-TVSR                                                       02 00360
     IF(DIFF)34,34,35                                                   02 00370
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 34 XILT=XIL+CLSR                                                        02 00380
    RETURN                                                               02 00390
 35 IF(ERSR)36,34,36                                                     02 00400
 36 XILT=XIL+CLSR+DIFF/ERSR                                              02 00410
    RETURN                                                               02 00420
    END                                                                  02 00430
    SUBROUTINEPRINT(NPRINT,NPAGE,NTALLY,A,B,C,D,E,F,G,H,P,Q,R,S,T,U,V)03 00010
    JA=5                                                                 03 00020
    JB=6                                                                 03 00030
    IF(NTALLY)1,1,2                                                      03 00040
  1 IF(NPAGE-50)4,5,5                                                    03 00050
  5 WRITE (JB,6)                                                         03 00060
    WRITE (JB,9)                                                         03 00070
    NPAGE=0                                                              03 00080
  4 NPAGE=NPAGE +1                                                       03 00090
    WRITE (JB,7)A,B,C,D,E,F,G,V,H,P,Q,S,T,R                              03 00100
    NTALLY=NPRINT-1                                                      03 00110
    RETURN                                                               03 00120
  2 NTALLY=NTALLY-1                                                      03 00130
    RETURN                                                               03 00140
  7 FORMAT (F6.1,F8.2,10F9.3,2F8.2)                                      03 00150
  6 FORMAT (120H1TIME    ACCUM     STATE       VTO    VO(NIGHT)     IA   03 00160
   1  PA       PMAX      VB        IB      IL       ISD    IPKLD   TEMP 03 00170
   2/)                                                                   03 00180
  9 FORMAT (43H                          (STS ONLY) VAR(DAY)//)          03 00190
    END                                                                  03 00200
    FUNCTION ANGLE (Z)                                                   04 00010
 10 IF (Z-360.0)  2,2,1                                                  04 00020
  1 Z=Z-360.0                                                            04 00030
    GO TO 10                                                             04 00040
  2 CALL STINT (Z,0.0,0.0,A,1,NGRIPE,4,4)                                04 00050
    ANGLE=A                                                              04 00060
    RETURN                                                               04 00070
    END                                                                  04 00080
    SUBROUTINE STASH (SIGISC,SIGVOC,DISC,DV,TNOT,KEY,NGRIPE,NCELLT,      05 00010
   1VOCOT,ADDT,DELTT)                                                    05 00020
    DIMENSION VVEC(101),XIVEC(101),TEMP(15),VMAP(15,101),XIMAP(15,101)05 00030
    DIMENSION VOCT(15),XISCT(15),VMP(15),XIMP(15)                        05 00040
    COMMON NPANEL
    COMMON  ATEMP,AVMP,AXIMP,KEYE                                        05 00050
C   NEW SUBROUTINE STASH TO DEGRADE CURVES ACCORDING TO NEW PROCEEDURE05 00060
C   DECIDE IF INITIALIZATION OR COMPUTATION                              05 00070
    JA=5                                                                 05 00080
    JB=6                                                                 05 00090
    NGRIPE=0                                                             05 00100
```

```
      IF (KEYE)1,5000,1
    1 IF(KEY)2000,3000,1000
C     INITIALIZATION - OBTAIN I AND V INPUT VECTORS
C     ***************************************************************
C     IN FIRST ENTRY
C     SISISC IS DISC
C     SIGVOC IS THETA
C     DISC IS AVPMO
C     DV IS AIPMO
C     TNOT IS TNOT
C     KEY IS -1
C     NGRIPE IS NGRIPE
C     NCELLT IS NCELLT
C     VOCOI IS VOCOI
C     ADDT IS ADDT
C     DELTT IS DELTT
 2000 VVEC(1)=0.0
      XIVEC(1)=0.0
      DO 2001 I=2,101
      XIVEC(I)=0.0
 2001 VVEC(I) = VVEC(I-1) + 0.010
      DO 2002 I = 1,100
      CALL STINT (VVEC(I),0.0,0.0,XIVEC(I),1,NGRIPE,NCELLT,NCELLT)
      IF(NGRIPE)2002,2002,2003
 2002 CONTINUE
      GO TO 2005
 2003 IF (XIVEC(I-1))2005,2005,12003
12003 RETURN
C     EXTRAPOLATE INPUT CURVE
C     LOCATE FIRST ZERO ELEMENT IN XIVEC
 2005 DO 2107 I = 2,101
      N=I
      IF(XIVEC(I))2106,2106,2107
 2107 CONTINUE
 2106 SLOPE=(XIVEC(N-1)-XIVEC(N-2))/(VVEC(N-1)-VVEC(N-2))
C     LOCATE POINT OF ZERO CURRENT FOR UNDEGRADED CURVE
      PZCU = VVEC(I) - XIVEC(I)/SLOPE
      DO 2108 J = N,101
 2108 XIVEC(J)=XIVEC(N-1)+(VVEC(J)-VVEC(N-1))*SLOPE
C     DO CURRENT DEGRADATION WITH GAMMA,TNOT,THETA
      XISC=XIVEC(1)
      GAMMA=SIGISC
      DELTAI=(1.0-GAMMA)*XISC
      RECIP=1.0/GAMMA
      THETA=SIGVOC
```

```
      DELTAV=(TNOT+273.16)*0.8614E-04*ALOG  (RECIP)
      DELTAV = DELTAV + (1.0 - THETA)*VOCOI
      DO 2600 I = 1,101
      XIVEC(I) = XIVEC(I) - DELTAI
      IF (XIVEC(I)) 2703,2703,2600
 2703 KIX = I - 1
      LOU = I+ 1
      DO 2622 L = LOU,101
 2622 XIVEC(L) = XIVEC(L) - DELTAI
      GO TO 2006
 2600 CONTINUE
 2006 CONTINUE
C     LOCATE POINT OF ZERO CURRENT FOR DEGRADED CURVE
      SLOPE = (XIVEC(KIX) - XIVEC(KIX-1))/(VVEC(KIX) - VVEC(KIX-1))
      PZCD = VVEC(KIX) - XIVEC(KIX)/SLOPE
      DELTAV = (PZCU - PZCD) - DELTAV
      DO 2704 I = 2,101
 2704 VVEC(I) = VVEC(I) + DELTAV
C     CURRENT DEGRADATION IS NOW COMPLETE
C     GO ON TO DO SERIES RESISTANCE DEGRADATION
C     STORE AIPMO AND AVPMO AND FETCH NEW BATCH OF VARIABLES
      AIPMO=DV
      AVPMO=DISC
      RETURN
C*******************************************************************
C     IN SECOND CALL
C     SIGISC IS DV
C     SIGVOC IS DISC
C     DISC IS SIGISC
C     DV IS SIGVOC
C     TNOT IS TNOT
C     KEY IS 0
C     NGRIPE IS NGRIPE
C     NCELLT IS NCELLT
C     VOCOI IS DENFAC
C     ADDT IS ADDT
C     DELTT IS DELTT
 3000 ALFA=SIGISC
      DENFAC=VOCOI
      TKI=DISC
      TKV=DV
      RES=((1.0-ALFA)*AVPMO/AIPMO)
      DO 3001 I = 1,101
 3001 VVEC(I)=VVEC(I)-XIVEC(I)*RES
C     SERIES RESISTANCE DEGRADATION IS NOW COMPLETE
```

```
C     DETERMINE VOC - LOCATE FIRST NEGATIVE ELEMENT IN XIVEC
      DO 3007 I = 2,101
      N=I
      IF(XIVEC(I))3006,3006,3007
 3007 CONTINUE
 3006 VOC=VVEC(N-1)+XIVEC(N-1)*(VVEC(N)-VVEC(N-1))/(XIVEC(N-1)-XIVEC(N))
C     FILL TEMPERATURE VECTOR
      IF (DELTT) 3012,3012,3013
 3012 ADDT = 120.0
      DELTT = 20.0
 3013 CONTINUE
      TEMP(1) = TNOT + ADDT
      VOCT(1)= VOC-ADDT*TKV
      DO 3202 I=2,15
      TEMP(I) = TEMP(I-1) - DELTT
 3202 VOCT(I)=VOC-(TEMP(I)-TNOT)*TKV
C     EXPAND I-V CURVE INTO FAMILY OF CURVES FOR 15 TEMPERATURES
C     OUTER DO FOR EACH TEMPERATURE ON INDEX I
      DO 3040 I=1,15
C     FIRST INNER DO FOR VOLTAGES ON INDEX J
      T2T1=TEMP(I)-TNOT
      DELTAV=TKV*T2T1
      DO 3204 J = 1,101
 3204 VMAP(I,J)=VVEC(J)-DELTAV
      XKIT=TKI*T2T1*SIGVOC
      DENOM=VOC-DENFAC-TKV*T2T1
C     SECOND INNER DO FOR CURRENTS ON INDEX J
      DO 3205 J = 1,101
      Z=VMAP(I,J)/DENOM
      Z6=Z*Z*Z*Z*Z*Z
      UMZ6=1.0-Z6
      IF(UMZ6)3300,3205,3205
 3300 UMZ6=0.0
 3205 XIMAP(I,J)=XIVEC(J)+XKIT*UMZ6
 3040 CONTINUE
C     FIND V AND I AT MAXIMUM POWER POINT FOR EACH TEMPERATURE
      DO 4005 I=1,15
      N=1
      PWR= -1000000.0
 4000 PWRT=VMAP(I,N)*XIMAP(I,N)
      IF(PWRT-PWR) 4002,4004,4001
 4001 N=N+1
      PWR=PWRT
      GO TO 4000
 4004 VMP(I)=VMAP(I,N)
```

```
      XIMP(I)=XIMAP(I,N)                                                05 01460
      GO TO 4005                                                        05 01470
 4002 SLOPE=(XIMAP(I,N-1)-XIMAP(I,N))/(VMAP(I,N)-VMAP(I,N-1))           05 01480
 4003 VMP(I)=VMAP(I,N-1)+0.00015                                        05 01490
      XIMP(I)=XIMAP(I,N-1)-SLOPE*(VMP(I)-VMAP(I,N-1))                   05 01500
      PWRT=VMP(I)*XIMP(I)                                               05 01510
      IF (PWRT-PWR) 4005,4005,4008                                      05 01520
 4008 PWR=PWRT                                                          05 01530
      GO TO 4003                                                        05 01540
 4005 CONTINUE                                                          05 01550
 4006 DO 4007 I=1,15                                                    05 01560
 4007 XISCT(I)=XIMAP(I,1)                                               05 01570
C     EDIT RESULTS                                                      05 01580
      WRITE (JB,7000)                                                   05 01590
      WRITE (JB,7001)(TEMP(J),J=1,15)                                   05 01600
      WRITE (JB,7002)(XIMP(J),J=1,15)                                   05 01610
      WRITE (JB,7003)(VMP(J),J=1,15)                                    05 01620
      WRITE (JB,7006)(VOCT(I),I=1,15)                                   05 01630
      WRITE (JB,7007)(XISCT(I),I=1,15)                                  05 01640
      DO 2040 J=1,30,2                                                  05 01650
      WRITE (JB,7004)J,(XIMAP(I,J),I=1,15)                              05 01660
 2040 WRITE (JB,7005)J,(VMAP(I,J),I=1,15)                               05 01670
      WRITE (JB,7000)                                                   05 01680
      WRITE (JB,7001)(TEMP(J),J=1,15)                                   05 01690
      WRITE (JB,7002)(XIMP(J),J=1,15)                                   05 01700
      WRITE (JB,7003)(VMP(J),J=1,15)                                    05 01710
      WRITE (JB,7006)(VOCT(I),I=1,15)                                   05 01720
      WRITE (JB,7007)(XISCT(I),I=1,15)                                  05 01730
      DO 2041 J = 31,60,2                                               05 01740
      WRITE (JB,7004)J,(XIMAP(I,J),I=1,15)                              05 01750
 2041 WRITE (JB,7005)J,(VMAP(I,J),I=1,15)                               05 01760
      WRITE (JB,7000)                                                   05 01770
      WRITE (JB,7001)(TEMP(J),J=1,15)                                   05 01780
      WRITE (JB,7002)(XIMP(J),J=1,15)                                   05 01790
      WRITE (JB,7003)(VMP(J),J=1,15)                                    05 01800
      WRITE (JB,7006)(VOCT(I),I=1,15)                                   05 01810
      WRITE (JB,7007)(XISCT(I),I=1,15)                                  05 01820
      DO 2042 J = 61,90,2                                               05 01830
      WRITE (JB,7004)J,(XIMAP(I,J),I=1,15)                              05 01840
 2042 WRITE (JB,7005)J,(VMAP(I,J),I=1,15)                               05 01850
      WRITE (JB,7000)                                                   05 01860
      WRITE (JB,7001)(TEMP(J),J=1,15)                                   05 01870
      WRITE (JB,7002)(XIMP(J),J=1,15)                                   05 01880
      WRITE (JB,7003)(VMP(J),J=1,15)                                    05 01890
      WRITE (JB,7006)(VOCT(I),I=1,15)                                   05 01900
```

```
      WRITE (JB,7007)(XISCT(I),I=1,15)
      DO 2043 J = 91,99,2
      WRITE (JB,7004)J,(XIMAP(I,J),I=1,15)
 2043 WRITE (JB,7005)J,(VMAP(I,J),I=1,15)
      RETURN
C     EDIT FORMATS
 7000 FORMAT (117H1   EDIT OF TEMPERATURE AND DEGRADATION CORRECTED SOLAR
     1 CELL I-V CURVES FOR         ENERGY BALANCE PGM. IN AUTOMATIC MODE)
 7001 FORMAT (14H0 TEMPERATURES15F7.0)
 7002 FORMAT (14H0 I-MAX PWR   15F7.4)
 7003 FORMAT (14H  V-MAX PWR   15F7.4)
 7004 FORMAT (4H0 I(I2,8H)          15F7.4)
 7005 FORMAT (4H  V(I2,8H)          15F7.4)
 7006 FORMAT (14H  VOLTS OC     15F7.4)
 7007 FORMAT (14H  AMPS  SC     15F7.4)
C     LOOK UP CURRENT AND MAX PWR POINT GIVEN VCELL + TEMPERATURE
 1000 VCELL=DISC
      HELHOT=DV
      NK = (TEMP(1) - HELHOT)/DELTT
      NHI=NK+1
      NLO=NK+2
      IF (KEY - 989) 1334,1333,1334
C     FOR KEY = 989 INTO SIGISC PUT OPEN CIRCUIT VOLTAGE AT TEMPETATURE
 1333 SIGISC = VOCT(NLO)+((DV-TEMP(NLO))/DELTT)*(VOCT(NHI)-VOCT(NLO))
      RETURN
 1334 IF (KEY - 988) 1335,1336,1335
C     FOR KEY = 988 INTO SIGISC PUT VOLTAGE AT THE GIVEN CURRENT
 1336 DO 1402 J = 2,101
      N = J
      IF (VCELL- XIMAP(NLO,J))1402,1402,1403
 1402 CONTINUE
 1403 XILO = VMAP(NLO,N-1) + (VCELL - XIMAP(NLO,N-1))*  (VMAP(NLO,N) -
     1VMAP(NLO,N-1))/(XIMAP(NLO,N)-XIMAP(NLO,N-1))
      DO 1422 J = 2,101
      N = J
      IF (VCELL- XIMAP(NHI,J))1422,1422,1423
 1422 CONTINUE
 1423 CONTINUE
      XIHI = VMAP(NHI,N-1) + (VCELL - XIMAP(NHI,N-1))* (VMAP(NHI,N) -
     1VMAP(NHI,N-1))/(XIMAP(NHI,N) - XIMAP(NHI,N-1))
      GO TO 1210
 1335 CONTINUE
      IF(VCELL-VMAP(NLO,1))1100,1100,1001
 1100 XILO=XIMAP(NLO,1)
      GO TO 1010
```

```
 1001 DO 1002 J = 2,101
      N=J
      IF(VCELL-VMAP(NLO,J))1003,1003,1002
 1002 CONTINUE
 1003 XILO=XIMAP(NLO,N-1)+(VCELL-VMAP(NLO,N-1))*(XIMAP(NLO,N)-XIMAP(NLO,
     1N-1))/(VMAP(NLO,N)-VMAP(NLO,N-1))
 1010 IF(VCELL-VMAP(NHI,1))1200,1200,1020
 1200 XIHI=XIMAP(NHI,1)
      GO TO 1210
 1020 DO 1222 J = 2,101
      N=J
      IF(VCELL-VMAP(NHI,J))1023,1023,1222
 1222 CONTINUE
 1023 XIHI=XIMAP(NHI,N-1)+(VCELL-VMAP(NHI,N-1))*(XIMAP(NHI,N)-XIMAP(NHI,
     1N-1))/(VMAP(NHI,N)-VMAP(NHI,N-1))
 1210 FAKTOR=(HELHOT-TEMP(NLO))/(TEMP(NHI)-TEMP(NLO))
C     XICELL PUT INTO SIGISC
      SIGISC=XILO+(XIHI-XILO)*FAKTOR
      RETURN
 5000 DO 5500          J=1,15
      IF (TEMP(J)-ATEMP) 5001,5002,5500
 5500 CONTINUE
 5002 AVMP = VMP(J)
      RETURN
 5001 AVMP= VMP(J-1)+((TEMP(J-1)-ATEMP) /  (TEMP(J-1) - TEMP(J))) *
     1(VMP(J) - VMP(J-1))
      RETURN
      END
      SUBROUTINE AMPS(XIA,VA,PTEMPS,XS,XC,ETA,ANGLA,ANGL1,NGRIPE,NAUTO,
     1NCELLT,ADIODE,DELANG,RS,MODDEL,VOCO1,ADDT,DELTT)
      DIMENSION RS(25)
      DIMENSION PTEMPS(25),XS(25),XC(25),ANGLA(25),ANGL1(25)
      COMMON NPANEL
      XIA=0.0
      DO 100 LRM=1,NPANEL
      COG = 1.0
      IF (XC(LRM))  100,100,1
    1 ANG=COS    (ETA/57.2957795)*COS    (ANGLA(LRM)/57.2957795)+SIN    (
     1      ETA/57.2957795)*SIN    (ANGLA(LRM)/57.2957795)*COS    ((ANGL1(
     2LRM)      +DELANG)/57.2957795)
      IF (ANG) 100,100,2
    2 ARG1=(VA+ADIODE)/XC(LRM)
      IF (ABS    (ANG) - 1.0) 3,33,100
    3 ANG = ACS(ANG)
      EFFECT = ANGLE(ANG*57.2957795)
```

```
C       THIRD ENTRY AND LATER ENTRIES, TABLE LOOKUP
      4 CALL STASH(TLU,VKN1,0.0,PTEMPS(LRM),0.0,1,NGRIPE,NCELLT,VUCUI,ADDT
       1,DELTT)
   3010 DELI=TLU*(1.0-EFFECT*COG)
        PHIL=1.0/(EFFECT*COG)
        DELV=(0.026*(273.0+PTEMPS(LRM))/300.0)*ALOG  (PHIL)
        CALL STASH (UCV,VKNEE,0.0,PTEMPS(LRM),0.0,989,NGRIPE,NCELLT,VOCI,
       1ADDT,DELTT)
        CALL STASH (VAI,   VKN1,DELI,PTEMPS(LRM),0.0,988,NGRIPE,NCELLT,
       1VOCI,ADDT,DELTT)
        DELV = UCV - VAI - DELV
        ARG1=ARG1-DELV
        IF (NAUTO) 14,15,14
     33 DELI = 0.0
        IF (NAUTO)  14,15,14
     14 CALL STASH(FCT,VKNEE,ARG1,PTEMPS(LRM),0.0,1,NGRIPE,NCELLT,VOCOI,
       1ADDT,DELTT)
        GO TO 16
     15 GO TO 14
     16 DUM=XS(LRM)*(FCT-DELI)
        IF (DUM)  17,18,18
     17 DUM=0.0
     18 CONTINUE
    201 XIA = XIA + DUM
    100 CONTINUE
    101 RETURN
        END
        FUNCTION ACS (X)
        IF (X) 1,2,3
      2 A=1.5707963
        ACS = A
        RETURN
      3 IF (X-1.0) 6,4,4
      4 A=0.0
        ACS = A
        RETURN
      1 IF (X+1.0)5,5,7
      5 A=3.14159265
        ACS = A
        RETURN
      6 A=ATAN  (SQRT  (1.0-X*X)/(X))
        ACS = A
        RETURN
      7 A=3.14159265+ATAN  (SQRT  (1.0-X*X)/(X))
        ACS = A
```

```
      RETURN
      END
      SUBROUTINE STINT (ARG1,ARG2,ARG3,FCT,KEY,NGRIPE,MINTBL,MAXTBL)
      DIMENSIONNUMPTS(31),L1(30),L2(30),L3(30),STG(2000),DUMMY(30),AXE(2
     1)
      DIMENSION NAME(14), DATE(2)
      EQUIVALENCE (NAT,L3(1))
      JA=5
      JB=6
      NGRIPE=0
      IF(KEY) 1,1,70
    1 I=1
      NG=1
      NORMAL=1
      PRINT 1357
 1357 FORMAT(34H1  TABLE        DATE        CONTENTS   )
      GO TO 55
 2000 NG=2
      NORMAL=2
      PRINT 1257
 1257 FORMAT (1H1)
 3000 RETURN
  775 NGRIPE=1
      RETURN
  776 NGRIPE=2
      WRITE (JB,9000)ARG1,ARG2,ARG3,MINTBL,MAXTBL
      RETURN
 9000 FORMAT (20H0 ERROR IN TLU,ARG1=F12.5,6H ARG2=F12.5,6H ARG3=F12.5,
     18H MINTBL=I4,8H MAXTBL=I4)
C      GRUMMEN  AIRCRAFT ROUTINE FOLLOWS
C      BEGINNING OF STINT
   55 NUMTBL=1
      MANDAN=0
      NUMPTS(1)=0
   56 IF(I) 69,103,102
  102 READ  (JA,57)DATE,K,L1(NUMTBL),L2(NUMTBL),NAME,ISEQ
   57 FORMAT (2A4,I4,2I2,13A4,A2,I2)
      PRINT 1157,K,DATE,NAME
 1157 FORMAT (I8,5X,2A4,5X,13A4,A2)
  104 IF(ISEQ) 69,58,69
   58 IF (K)  99,99,1159
 1159 IF (K-30)    59, 59,1103
   59 L8=L1(NUMTBL)
      N1=(L8-1)/9+1
      DO 68 IS=1,N1
```

```
      NAT=(IS-1)*9+1
      IF (IS-N1) 60,61,60
   60 L4=NAT+8
      GO TO 62
   61 L4=L8
   62 L5=NUMPTS(NUMTBL)+1
      L6=L5+NAT
      L7=L5+L4
      JJ=0
      L9=L2(NUMTBL)
      LM=L5+L8
      LN=LM+L9
   63 IF(I) 69,106,105
  105 READ  (JA,64)(DUMMY(K),K=1,10),ISEQ
   64 FORMAT (10E7.0,I2)
  107 STG(L5)=DUMMY(1)
      K=2
      DO 65 J=L6,L7
      STG(J)=DUMMY(K)
   65 K=K+1
      IF (ISEQ-((IS-1)*(L9+1)+JJ+1)) 69,66,69
   66 L6=LN+NAT
      L7=LN+L4
      L5=LM+1+JJ
      IF (JJ-L9) 67,68,69
   67 JJ=JJ+1
      LN=LN+L8
      GO TO 63
   68 CONTINUE
      IF (MANDAN) 108,109,108
  109 LEE=NUMPTS(NUMTBL)+(L8+1)*(L9+1)
      IF (LEE-2000)  1100,1101,1101
 1100 IF (NUMTBL-30)  1102,108,1103
 1102 NUMPTS(NUMTBL+1)=LEE
  108 NUMTBL=NUMTBL+1
      GO TO 56
 1101 WRITE (JB,1111)LEE
      GO TO 775
 1103 WRITE (JB,1113)NUMTBL
      GO TO 775
 1111 FORMAT (17H TOO MANY POINTS  I8)
 1113 FORMAT (17H TOO MANY TABLES  I8)
   69 GO TO (775,776,776),NG
   70 IF (MINTBL-MAXTBL) 71,100,69
   71 DO 73 NAT=MINTBL,MAXTBL
```

```
      L4=NUMPTS(NAT)+1
      IF (ARG3-STG(L4)) 72,74,73
   72 IF(NAT-MINTBL)69,69,75
   73 CONTINUE
      GO TO 69
   75 L5=1
      L6=2
      L7=L4
  101 DO 97 L8=L5,L6
      L4=NUMPTS(NAT)+1
      L9=L1(NAT)
      LM=L9+L4
      DO 77 LN=1,L9
      JJ=L4+LN
 2626 IF (ARG1-STG(JJ)) 76,78,77
   76 IF (LN-1) 69,69,79
   77 CONTINUE
      GO TO 69
   78 N1=-1
      GO TO 80
   79 N1=+1
   80 K=L2(NAT)
      DO 82 I=1,K
      IDATE=LM+I
      IF (ARG2-STG(IDATE)) 81,83,82
   81 IF (I-1) 69,69,84
   82 CONTINUE
      GO TO 69
   83 IS=-1
      GO TO 85
   84 IS=+1
   85 ISEQ=LM+L2(NAT)+LN+(I-1)*L9
      J=ISEQ-L9
      K8=LM+(I-1)
      K9=L4+LN-1
      IF (N1+IS) 86,88,91
   86 IF (STG(ISEQ)-9999.E9) 87,69,69
   87 FCT=STG(ISEQ)
      GO TO 95
   88 IF (N1) 89,69,93
   89 IF (AMAX1 (STG(ISEQ),STG(J))-9999.E9) 90,69,69
   90 FCT=STG(ISEQ)-(STG(IDATE)-ARG2)*(STG(ISEQ)-STG(J))/(STG(IDATE)
     1-STG(K8))
      GO TO 95
   91 IF (AMAX1 (STG(ISEQ),STG(J),STG(ISEQ-1),STG(J-1))-9999.E9) 92,
```

```
     1 69,69                                                            06 01340
  92 FCT=((STG(IDATE)-ARG2)*((STG(JJ)-ARG1)*STG(J-1)-(STG(K9)-ARG1)    06 01350
     1*STG(J))-(STG(K8)-ARG2)*((STG(JJ)-ARG1)*STG(ISEQ-1)-(STG(K9)-    06 01360
     2ARG1)*STG(ISEQ)))/((STG(IDATE)-STG(K8))*(STG(JJ)-STG(K9)))       06 01370
     GO TO 95                                                           06 01380
  93 IF (AMAX1 (STG(ISEQ),STG(ISEQ-1))-9999.E9) 94,69,69               06 01390
  94 FCT=STG(ISEQ)-(STG(JJ)-ARG1)*(STG(ISEQ)-STG(ISEQ-1))/(STG(JJ)-    06 01400
     1STG(K9))                                                          06 01410
  95 GO TO (96,98,99),L8                                                06 01420
  96 DUMMY(1)=FCT                                                       06 01430
  97 NAT=NAT-1                                                          06 01440
  98 FCT=DUMMY(1)-(STG(L7)-ARG3)*(DUMMY(1)-FCT)/(STG(L7)-STG(L4))      06 01450
  99 GO TO (2000,3000),NORMAL                                           06 01460
 100 NAT=MINTBL                                                         06 01470
     IF (MINTBL.LT.1) GO TO 2
  74 L5=3                                                               06 01480
     L6=3                                                               06 01490
     GO TO 101                                                          06 01500
 103 READ 57,K,L1(NUMTBL),L2(NUMTBL),ISEQ                               06 01510
     GO TO 104                                                          06 01520
 106 READ 64,(DUMMY(K),K=1,10),ISEQ                                     06 01530
     GO TO 107                                                          06 01540
   2 FCT = 0.0
     RETURN
C    END STINT  TABLE LOOK-UP                                           06 01550
     END                                                                06 01560
```

APPENDIX B

```
121368
      NIMBUS TABLES
07-23-6800010201    ISER-LOAD                                                      00
        0.0     130.0                                                              01
        2.0     2.0                                                                02
07-09-6800022103    SYSTEM LOSS DATA                                               00
        0.0     20.0    30.0    40.0    50.0    70.0    85.0    100.0   115.0      01
1.0     31.0    31.5    32.0    32.3    32.5    33.4    33.9    34.5    35.0       02
2.0     47.0    47.0    47.0    47.0    47.0    47.0    47.0    47.0    47.0       03
3.0     45.5    45.5    46.0    46.5    47.0    48.5    49.4    50.6    52.2       04
        125.0   150.0   175.    200.0   210.0   250.0   300.0   350.0   400.0      05
1.0     35.5    36.3    37.5    38.7    39.5    42.3    47.2    53.8    61.0       06
2.0     47.0    47.4    48.3    49.6    50.2    53.4    58.4    64.5    72.0       07
3.0     53.3    56.6    60.7    65.3    67.5    67.5    67.5    67.5    67.5       08
        450.0   490.0   500.0                                                      09
1.0     68.4    74.2    74.2                                                       10
2.0     80.0    86.0    86.0                                                       11
3.0     67.5    67.5    67.5                                                       12
12-03-6500030101    ETA VS. BAT. TEMP. NIMBUS-B                                    00
        0.0                                                                        01
        25.0                                                                       02
21JAN64 00044001                                                                   00INCDNFCT
        0.0     5.0     10.0    15.0    20.0    25.0    30.0    35.0    40.0       01INCDNFCT
        1.0     0.99    0.98    0.965   0.94    0.905   0.86    0.815   0.76       02INCDNFCT
        45.0    50.0    55.0    60.0    65.0    70.0    75.0    80.0    85.0       03INCDNFCT
        0.69    0.63    0.555   0.48    0.385   0.30    0.20    0.12    0.06       04INCDNFCT
        90.0    90.001  269.001270.0    275.0   280.0   285.0   290.0   295.0      05INCDNFCT
        0.0     -1.0    -1.0    0.0     0.06    0.12    0.20    0.30    0.385      06INCDNFCT
        300.0   305.0   310.0   315.0   320.0   325.0   330.0   335.0   340.0      07INCDNFCT
        0.48    0.555   0.63    0.69    0.76    0.815   0.86    0.905   0.94       08INCDNFCT
        345.0   350.0   355.0   360.0                                              09INCDNFCT
        0.965   0.98    0.99    1.00                                               10INCDNFCT
11-15-6800052701    11.4 CRL I-V CURVE UNGLASSED 28 DEG.C AMD                      00
        0.0     0.25    0.30    0.35    0.37    0.39    0.40    0.41    0.42       01
        0.1420  0.1420  0.1412  0.1412  0.1409  0.1400  0.1397  0.1390  0.1380     02
        0.43    0.44    0.45    0.46    0.47    0.48    0.49    0.50    0.51       03
        0.1369  0.1355  0.1332  0.1312  0.1289  0.1256  0.1210  0.1161  0.1088     04
        0.52    0.53    0.54    0.55    0.56    0.57    0.590   0.600   1.0        05
        0.1005  0.0925  0.0825  0.0700  0.0550  0.0388  0.0     -0.0125-0.012506
12-05-6800062201    3 MOS I-V CURVE,FLUX IS 7.9 EXP 13                             00
        0.0     0.1249  0.2249  0.2649  0.2849  0.3049  0.3249  0.3449  0.3648     01
        0.1330  0.1330  0.1330  0.1325  0.1322  0.1322  0.1322  0.1321  0.1315     02
        0.3848  0.4048  0.4247  0.4446  0.4644  0.4841  0.5037  0.5232  0.5424     03
        0.1307  0.1290  0.1265  0.1222  0.1166  0.1071  0.0915  0.0735  0.0460     04
        0.5614  0.5665  0.6005  1.0                                                05
        0.0104  0.0     -.070   -.070                                              06
12-05-6800072301    6 MOS I-V CURVE, FLUX IS 1.58 EXP 14                           00
        0.0     0.1196  0.2196  0.2396  0.2596  0.2796  0.2996  0.3196  0.3396     01
        0.1296  0.1296  0.1296  0.1294  0.1291  0.1288  0.1288  0.1287  0.1286     02
        0.3596  0.3795  0.3994  0.4193  0.4391  0.4588  0.4784  0.4976  0.5168     03
        0.1280  0.1273  0.1256  0.1231  0.1188  0.1132  0.1037  0.0881  0.0701     04
        0.5355  0.5538  0.5570  0.592   1.0                                        05
        0.0426  0.0070  0.0     -0.075  -0.075                                     06
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11-15-6800082501    1 YR I-V CURVE PHI # 3.16 EXP14,T#28DEG.                    00
        0.0     0.25    0.30    0.32    0.34    0.35    0.36    0.37    0.38    01
        0.1249  0.1244  0.1241  0.124   0.1238  0.1237  0.1234  0.123   0.1222  02
        0.39    0.40    0.41    0.42    0.43    0.44    0.45    0.46    0.47    03
        0.1215  0.1205  0.1191  0.1173  0.115   0.1127  0.1098  0.106   0.101   04
        0.48    0.49    0.50    0.527   0.5466  0.5662  1.0                     05
        0.0942  0.0864  0.077   0.040   0.0     -0.04   -0.04                   06
11-15-6800092501    2YR I-V CURVE PHI#6.32 EXP14, T#28 DEG.                     00
        0.0     0.25    0.3     0.32    0.34    0.35    0.36    0.37    0.38    01
        0.1186  0.1182  0.118   0.1178  0.1175  0.1173  0.117   0.1164  0.1155  02
        0.39    0.40    0.41    0.42    0.43    0.44    0.45    0.46    0.47    03
        0.1145  0.1131  0.1116  0.1097  0.1074  0.1047  0.1008  0.0958  0.090   04
        0.48    0.49    0.50    0.52    0.536   0.552   1.0                     05
        0.083   0.074   0.063   0.03    0.0     -0.03   -0.03                   06
12-05-6800100601    400 WATT PKLD TABLE                                         00
        0.0     100.0   101.0   105.0   106.0   130.0                           01
        0.0     0.0     400.0   400.0   0.0     0.0                             02
08-04-6700111701    NB SA TEMP. VS TIME PROFILE,612 NM                          00
        0.0     5.0     10.0    15.0    20.0    25.0    30.0    35.0    40.0    01
0.0     -59.0   -31.0   -11.0   5.0     18.0    28.0    36.0    43.5    48.0    02
        45.0    50.0    55.0    60.0    65.0    70.0    73.0    130.0           03
0.0     51.0    52.0    51.0    48.5    46.0    44.0    43.0    43.0            04
10-09-6800120911    25 DEG.C, BOL                                               00
25.0    0.10    0.80    0.825   0.90    0.925   0.975   1.03    1.05    1.80    01
-100.0  1.10    1.245   1.246   1.264   1.274   1.335   1.367   1.367   1.367   02
-16.0   1.10    1.245   1.246   1.264   1.274   1.335   1.367   1.367   1.367   03
-8.0    1.10    1.260   1.265   1.284   1.295   1.350   1.390   1.390   1.390   04
-0.001  1.10    1.260   1.265   1.284   1.295   1.350   1.390   1.390   1.390   05
0.0     1.15    1.264   1.270   1.287   1.30    1.353   1.392   1.392   1.392   06
0.001   1.2     1.268   1.272   1.290   1.312   1.357   1.395   1.395   1.395   07
0.800   1.21    1.27    1.278   1.298   1.342   1.377   1.400   1.405   1.405   08
4.0     1.22    1.275   1.294   1.318   1.360   1.410   1.458   1.464   1.464   09
8.0     1.23    1.28    1.325   1.340   1.380   1.430   1.485   1.495   1.495   10
18.0    1.25    1.292   1.349   1.366   1.410   1.466   1.515   1.523   1.523   11
100.0   1.25    1.292   1.349   1.366   1.410   1.466   1.515   1.523   1.523   12
10-09-6800130911    25 DEG.C, 1YR. LIFE                                         00
25.0    0.10    .80     .825    .90     .95     1.0     1.03    1.05    1.8     01
-100.0  1.1     1.158   1.160   1.175   1.202   1.270   1.270   1.270   1.270   02
-16.0   1.1     1.158   1.160   1.175   1.202   1.270   1.270   1.270   1.270   03
-8.0    1.1     1.178   1.180   1.195   1.222   1.290   1.290   1.290   1.290   04
-0.001  1.1     1.178   1.180   1.195   1.222   1.290   1.290   1.290   1.290   05
0.0     1.15    1.183   1.20    1.22    1.24    1.30    1.33    1.335   1.335   06
0.001   1.180   1.195   1.225   1.300   1.339   1.37    1.38    1.387   1.387   07
0.800   1.190   1.205   1.255   1.330   1.369   1.40    1.41    1.417   1.417   08
4.0     1.2     1.215   1.276   1.345   1.390   1.435   1.457   1.466   1.466   09
8.0     1.21    1.230   1.30    1.370   1.410   1.460   1.485   1.490   1.490   10
18.0    1.22    1.240   1.325   1.390   1.430   1.478   1.506   1.517   1.517   11
100.0   1.22    1.240   1.325   1.390   1.430   1.478   1.506   1.517   1.517   12
10-09-6800140911    25 DEG.C,2YR. LIFE                                          00
25.0    0.10    .80     .825    .875    .925    1.0     1.03    1.05    1.8     01
-100.0  1.08    1.10    1.115   1.14    1.177   1.270   1.270   1.270   1.270   02
-16.0   1.08    1.10    1.115   1.14    1.177   1.270   1.270   1.270   1.270   03
-8.0    1.1     1.123   1.145   1.162   1.196   1.290   1.290   1.290   1.290   04
-0.001  1.1     1.123   1.145   1.162   1.196   1.290   1.290   1.290   1.290   05
0.0     1.15    1.17    1.20    1.260   1.285   1.30    1.30    1.310   1.310   06
0.001   1.17    1.185   1.22    1.280   1.325   1.37    1.385   1.40    1.40    07
```

0.800	1.18	1.205	1.25	1.310	1.355	1.400	1.418	1.423	1.423	08
4.0	1.2	1.210	1.27	1.327	1.375	1.429	1.455	1.465	1.465	09
8.0	1.2	1.22	1.289	1.346	1.393	1.45	1.476	1.485	1.485	10
18.0	1.2	1.225	1.31	1.368	1.416	1.47	1.495	1.505	1.505	11
100.0	1.2	1.225	1.31	1.368	1.416	1.47	1.495	1.505	1.505	12
10-24-6800150911	35 DEG.C, BOL									00
35.0	0.10	0.80	0.825	0.85	0.90	0.95	1.0	1.05	1.80	01
-100.0	1.1	1.217	1.218	1.220	1.234	1.259	1.330	1.330	1.330	02
-16.0	1.1	1.217	1.218	1.220	1.234	1.259	1.330	1.330	1.330	03
-8.0	1.13	1.235	1.237	1.239	1.253	1.281	1.360	1.360	1.360	04
-0.001	1.13	1.235	1.237	1.239	1.253	1.281	1.360	1.360	1.360	05
0.0	1.15	1.237	1.240	1.250	1.270	1.30	1.361	1.361	1.361	06
0.001	1.18	1.238	1.250	1.270	1.300	1.315	1.362	1.362	1.362	07
0.800	1.2	1.240	1.270	1.293	1.327	1.345	1.364	1.364	1.364	08
4.0	1.21	1.245	1.283	1.309	1.344	1.373	1.40	1.425	1.425	09
8.0	1.215	1.250	1.306	1.329	1.370	1.403	1.429	1.450	1.450	10
18.0	1.22	1.255	1.325	1.350	1.387	1.420	1.455	1.480	1.480	11
100.0	1.22	1.255	1.325	1.350	1.387	1.420	1.455	1.480	1.480	12
10-24-6800160911	35 DEG.C,1YR. LIFE									00
35.0	0.10	0.80	0.825	0.85	0.90	0.95	1.0	1.05	1.80	01
-100.0	1.1	1.13	1.132	1.135	1.150	1.180	1.250	1.250	1.250	02
-16.0	1.1	1.13	1.132	1.135	1.150	1.180	1.250	1.250	1.250	03
-8.0	1.12	1.15	1.152	1.158	1.173	1.200	1.270	1.270	1.270	04
-0.001	1.12	1.15	1.152	1.158	1.173	1.200	1.270	1.270	1.270	05
0.0	1.15	1.17	1.20	1.225	1.240	1.260	1.275	1.275	1.275	06
0.001	1.16	1.18	1.240	1.275	1.315	1.338	1.348	1.351	1.351	07
0.800	1.18	1.20	1.268	1.305	1.345	1.368	1.379	1.382	1.382	08
4.0	1.2	1.220	1.290	1.327	1.369	1.402	1.420	1.434	1.434	09
8.0	1.21	1.240	1.305	1.340	1.386	1.419	1.445	1.455	1.455	10
18.0	1.22	1.245	1.313	1.353	1.405	1.438	1.469	1.480	1.480	11
100.0	1.22	1.245	1.313	1.353	1.405	1.438	1.469	1.480	1.480	12
10-24-6800170911	35 DEG.C,2YR. LIFE									00
35.0	0.10	0.80	0.825	0.85	0.90	0.95	1.0	1.05	1.80	01
-100.0	1.05	1.07	1.084	1.098	1.132	1.179	1.249	1.249	1.249	02
-16.0	1.05	1.07	1.084	1.098	1.132	1.179	1.249	1.249	1.249	03
-8.0	1.07	1.09	1.106	1.12	1.156	1.20	1.270	1.270	1.270	04
-0.001	1.07	1.09	1.106	1.120	1.156	1.20	1.270	1.270	1.270	05
0.0	1.10	1.12	1.15	1.210	1.240	1.270	1.300	1.300	1.300	06
0.001	1.12	1.15	1.225	1.265	1.318	1.346	1.359	1.365	1.365	07
0.800	1.15	1.20	1.255	1.295	1.348	1.376	1.389	1.395	1.395	08
4.0	1.2	1.21	1.275	1.316	1.370	1.409	1.433	1.445	1.445	09
8.0	1.21	1.22	1.297	1.339	1.390	1.426	1.45	1.465	1.465	10
18.0	1.22	1.235	1.315	1.358	1.410	1.445	1.468	1.480	1.480	11
100.0	1.22	1.235	1.315	1.358	1.410	1.445	1.468	1.480	1.480	12
07-18-6900180201	180 WATT LOAD									00
	0.0	130.0								01
	180.0	180.0								02
09-18-6900190201	ZERO INVERTER LOAD									00
	0.0	130.0								01
	0.0	0.0								02
09-18-6900200201	ZERO CONVERTER LOAD									00
	0.0	130.0								01
	0.0	0.0								02

END OF STINT TABLES

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 RUN NO 1
001 25.0
002 80.0
  3 1.0
  4 35.0
005 8.8
  6 0.95
007 1.4
  8 1.11
  9 38.0
 10 .0120
 11 0.0
 12 0.0
 13 0.5
 14 2160.0
 15 0.0
 16 2.0
 17 12.0
 18 12.0
 19 5.0
 20 10.0
021 18.0
022 19.0
023 20.0
024 1.0
025 0.0
 26 2.0
 28 85.0
 29 90.0
 30 3.0
 31 1.0
032 0.000140
033 0.0022
 34 95.0
 35 100.0
 36 100.0
 37 100.0
 38 99.0
 39 100.0
 40 0.470
 41 0.1289
 42 0.590
 43 100.0
 44 28.0
 45 24.0
 46 1.8
 47 92.0
 48 10.0
 49 32.0
 50 0.065
999
  1
102.0     102.0     0.0      11.0

 RUN NO 2
001 35.0
027 1.0
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