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# Electrical Power Requirements Analysis

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## Single Failure Tolerant Entry

Mission Planning and Analysis Division

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NASA
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
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SHUTTLE PROGRAM

# ELECTRICAL POWER REQUIREMENTS ANALYSIS
# SINGLE FAILURE TOLERANT ENTRY

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## SYMBOLS

| | |
|---|---|
| APU | AUXILIARY POWER UNIT |
| DFI | DEVELOPMENT FLIGHT INSTRUMENTATION |
| ECLSS | ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM |
| EOM | END OF MISSION |
| EPS | ELECTRICAL POWER SYSTEM |
| FA | FLIGHT AFT (MDM) |
| FCP | FUEL CELL POWERPLANT |
| FCS | FLIGHT CONTROL SURFACE |
| FES | FLASH EVAPORATOR SYSTEM |
| FF | FLIGHT FORWARD (MDM) |
| FM | FREQUENCY MODULATION |
| GPC | GENERAL PURPOSE COMPUTER |
| GSE | GROUND SUPPORT EQUIPMENT |
| H2 | HYDROGEN |
| H20 | WATER |
| KW | KILOWATTS |
| NASA | NATIONAL AERONAUTICS AND SPACE ADMINISTRATION |
| N/A | NOT APPLICABLE |
| OA | OPERATIONAL FORWARD (MDM) |
| OMS | ORBITAL MANEUVERING SYSTEM |
| OV | ORBITER VEHICLE |
| 02 | OXYGEN |
| PL | PAYLOAD |
| PLB | PAYLOAD BAY |
| PSIA | POUNDS PER SQUARE INCH ABSOLUTE |
| RCS | REACTION CONTROL SYSTEM |
| RH | RIGHT HAND |
| RJD | REACTION JET DRIVER |
| RMS | REMOTE MANIPULATOR SYSTEM |
| SEPS | SHUTTLE ELECTRICAL POWER SYSTEM ANALYSIS COMPUTER PROGRAM |
| SFT | SINGLE FAILURE TOLERANT |
| SODB | SHUTTLE OPERATIONAL DATA BOOK |
| SOURCE | SHUTTLE ORBITER UNIFIED RECORDS FOR CONSUMABLES EVALUATION |
| [illegible] | STOPROLL |
| SSME | SPACE SHUTTLE MAIN ENGINE |
| TACAN | TACTICAL AIR NAVIGATION |
| TCS | THERMAL CONTROL SYSTEM |
| TV | TELEVISION |
| VDC | VOLTS DIRECT CURRENT |

# ELECTRICAL POWER REQUIREMENTS ANALYSIS

# SINGLE FAILURE TOLERANT ENTRY

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## 1.0 SUMMARY

This document presents the results of an analysis of the orbiter electrical power system for the case of a single failure tolerant (SFT) entry. The analysis was performed using the Shuttle Electrical Power System (SEPS) analysis computer program (Ref. 1). It was performed to permit assessment of the capability of the orbiter systems to support the proposed entry configuration and to provide the data necessary to identify potential constraints and limitations.

Three contingency modes have been identified which would require an SFT entry. This analysis addresses an SFT entry resulting from the loss of two fuel cell powerplants, while on orbit. The analysis is presented in three parts, as follows:

- o Electrical Power system configuration definition
- o Guidelines and Assumptions for the analysis
- o Discussion of the results of the analysis

The results of the analysis indicate that, even under near optimum conditions, the fuel cell power demand will exceed the tested operating capacity of 16 kw, and that various electrical components may experience voltages below 24 VDC. Insufficient data is available to assess the implications of these limit violations, or to perform a worst case analysis. Without this data and analysis, the SFT configuration cannot be shown to be safe for entry.

## 2.0 INTRODUCTION

Three failure modes have been postulated that require a minimum Orbiter power entry (Ref. 2). The failure modes are the loss of two fuel cells, the loss of one freon loop, and the loss of cabin pressure. Loss of two fuel cells limits the capability to provide electrical power to that available from a single fuel cell. Loss of a freon loop restricts power due to the resulting degradation in heat transport and heat rejection capabilities. With loss of cabin pressure, and the necessity to maintain an 8 psia environment, available power is limited by reduced air cooling and cryogenic oxygen flow rate constraints.

Two electrical equipment entry configurations have also been identified as possible means of dealing with these contingencies. The first of these, known as the single string configuration, provides the minimum guidance, flight control, and display electronics necessary to accomplish a safe entry and landing, but provides no hardware or software redundancy. This is the minimum power configuration for a safe entry and landing. The second configuration is the single failure tolerant (SFT) mode. This configuration provides limited redundancy in the areas of guidance and flight control, at the expense of increased power and heat rejection demands.

Heretofore, the single string configuration has been the design baseline. Due to concerns regarding the lack of failure tolerance in the critical flight control areas, however, the SFT configuration is being considered as a revised baseline. This analysis was performed to evaluate the capability of the electrical power generation system to support this configuration and to identify possible bus voltage limitations and constraints.

The analysis was performed with the SEPS computer program, using the basic avionics configuration of Reference 2, with equipment usage variations derived through a series of meetings with flight control division personnel.

## 3.0 SYSTEM DEFINITION DATA

The EPS, as modeled by the SEPS computer program, consists of the orbiter electrical power generation and distribution subsystems. The system generates required orbiter electrical power and delivers it to end item loads in accordance with a predefined equipment time line. The sections which follow define the EPS system characteristics and the system loads used in this analysis.

### 3.1 Fuel Cell Characteristics

The fuel cell performance characteristics, used in the analysis, are those illustrated in Figure 3.1-1. These characteristics were derived from powerplant performance predictions and test data, and include extrapolations beyond the operational capabilities of the powerplant. The portion of the curve lying between 2 and 12 kilowatts (kw) is based on predicted initial powerplant performance, as defined in the Shuttle Operational Data Book (Ref. 3). The portion of the curve ranging from 12 to 16 kw is predicated on the results of powerplant tests performed in support of SFT entry analyses. The portion of the curve above 16 kw is an extrapolation for purposes of analysis and may not be representative of actual powerplant performance.

### 3.2 Circuit Description

The SEPS circuit, used in the analysis, is described in Reference 4. This description is in conformance with Shuttle Operational Data Book (SODB) amendments 59 and P2-144 (Refs. 3 and 5). The guidelines and assumptions used in formulating the circuit are discussed, in detail, in Reference 6.

## 3.3 Inverter Characteristics

The inverter performance characteristics used in the analysis are shown in Figure 3.3-1.

## 3.4 Orbiter Electrical Loads

The orbiter electrical equipment list, utilized in the performance of this analysis, is that defined in Reference 7 for operational orbiters. This list corresponds to the OV-103 equipment list contained in SODB Amendment 5^ (Ref. 3).

## 3.5 Payload Electrical Loads

No discrete payload electrical equipment was utilized in the performance of this analysis. The maximum power allocation for maintaining a safe payload, however, was applied as a constant power load on auxiliary bus A, at station 693 (Ref. 8).

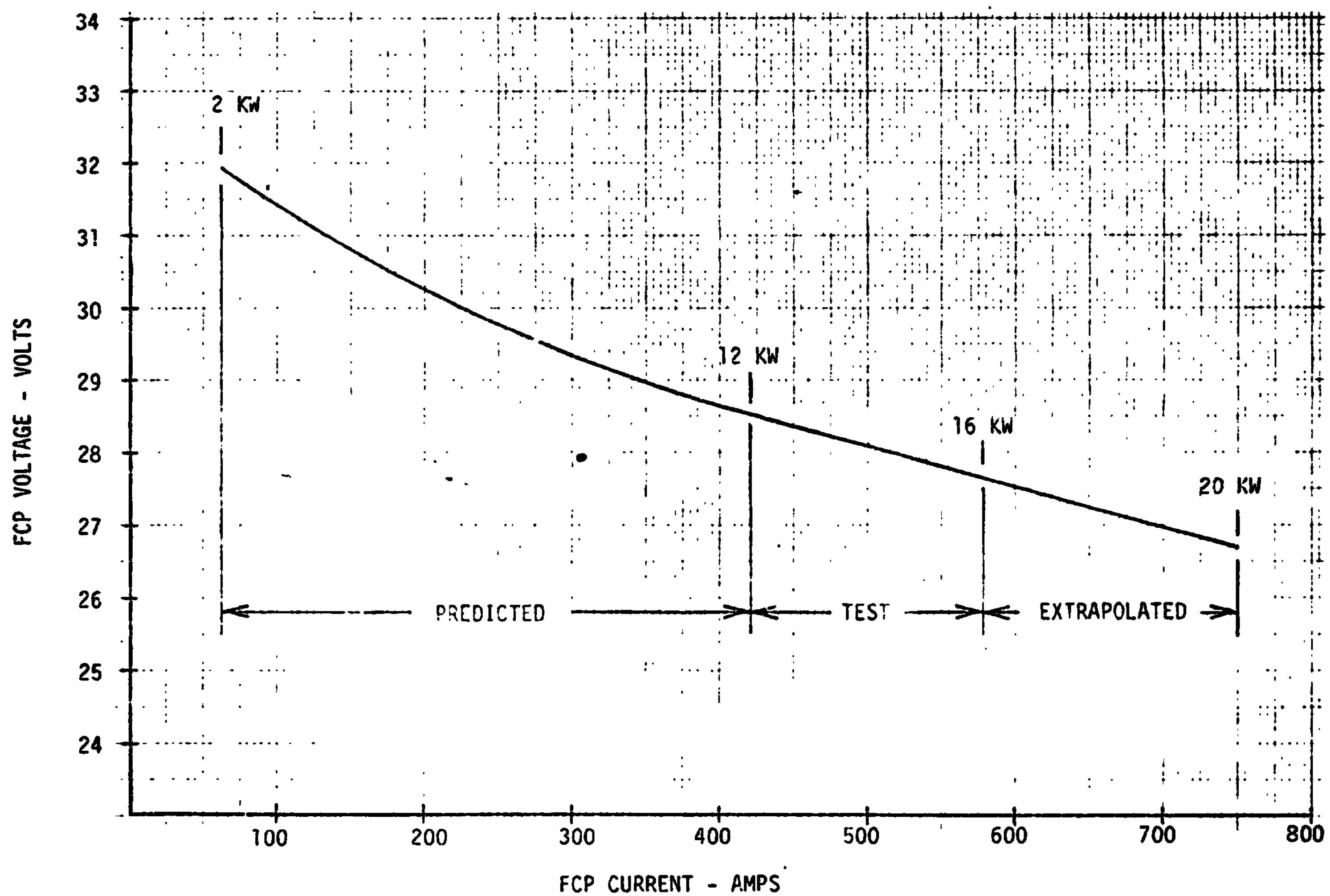


Figure 3.1-1. - Fuel cell performance characteristics - SEPS program

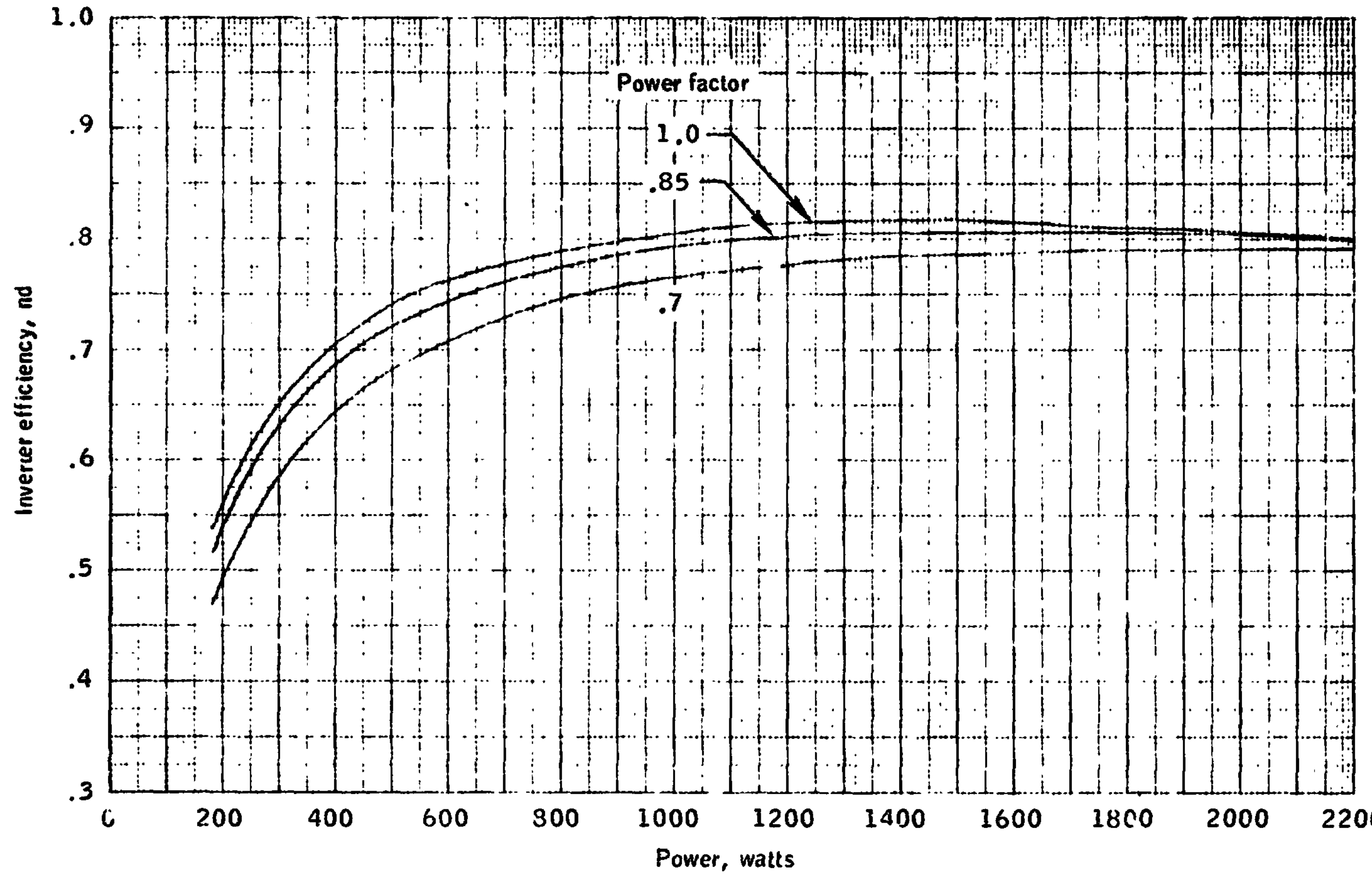


Figure 3.3-1. - Inverter characteristics - SEPS program

## 4.0 GUIDELINES AND ASSUMPTIONS

The guidelines followed and the assumptions made, in the formulation of the EPS analysis, are the subject of this section.

### 4.1 Guidelines

The guidelines used in formulating the single failure tolerant entry analysis were as follows:

a. The vehicle analyzed is an OV-103 configuration orbiter on an operational flight.

b. The single failure tolerant entry resulted from the loss of fuel cells 2 and 3.

c. The electrical power distribution subsystem is reconfigured such that fuel cells 2 and 3 are isolated, while fuel cell 1 is supplying power to main buses A, B, and C.

d. The analysis is initiated with fuel cells 2 and 3 deactivated and fuel cell 1 supplying all power.

e. The analysis covers the interval from three hours prior to deorbit until the orbiter is deactivated 4.56 hours later.

f. Critical avionics equipment is configured in accordance with Reference 2, including those changes identified therein as being requested by the NASA. The avionics configuration used is that presented in Table 4.1-I.

## 4.2 Assumptions

The following assumptions were made in formulating the single failure tolerant entry analysis:

a. Two hundred watts of payload safing power are applied as a constant power load on auxiliary bus A.

b. No OMS kit is installed.

c. Thermal conditioning of the orbiter is impractical due to thermal lag and the time available. Therefore, a nominal attitude and a 40 to 50 degree beta angle were used to define thermal control heater operation.

d. With fuel cell powerplants 2 and 3 off, their product water line heaters are assumed to cycle with 40% duty cycles.

e. No nose gear strut actuator heater is installed.

f. All communication requirements are satisfied using S-Band direct. Therefore, no Ku-Band equipment is required.

g. The following heaters were disabled in accordance with information obtained from flight control division personnel:

   (1) Forward RCS thruster heaters

   (2) Forward RCS line and tank heaters

   (3) Aft RCS vernier thruster heaters

   (4) FES port feedwater line heaters

   (5) Waste $H_2O$ dump line heaters

(6) Waste $H_2O$ dump nozzle heaters

(7) Potable $H_2O$ dump line heaters

(8) Potable $H_2O$ dump nozzle heaters

(9) $O_2/H_2$ purge line heaters

(10) RMS arm heaters

(11) SSME controller heaters

(12) Ku-band deployed assembly heaters

(13) Ku-band cable heaters

(14) PLB and RMS TV camera heaters

(15) PLB and RMS pan tilt assembly heaters

(16) Galley $H_2O$ heaters

(17) $O_2$ cryogenic heaters (one set)

(18) Air data probe heaters

h. Flight deck lighting was configured in accordance with information received from C. D. Wheelwright/EW5. The configuration used was as follows:

(1) Forward instrument lights - 40% of max power

(2) Glareshield floodlights - 20% of max power

(3) Forward numerics - 50% of max power

i. One hydraulic circulation pump was operated from the start of the analysis until the beginning of the pre-deorbit aerosurface deflection checks at deorbit minus 2:30:00. It was subsequently operated from deorbit minus 1:30:00 until the GPC's were configured for descent at deorbit minus 00:35:00.

j. The brake skid power units were activated five minutes prior to touchdown.

## TABLE 4.1-I
## AVIONICS CONFIGURATION FOR SFT ENTRY

| DESCRIPTION | NUMBER ACTIVE |
|---|---|
| CENTRAL PROCESSING UNITS-INPUT/OUTPUT PROCESSORS | 2 |
| MULTIPLEXER/DEMULTIPLEXERS - FF | 3 |
| MULTIPLEXER/DEMULTIPLEXERS - FA | 3 |
| MULTIPLEXER/DEMULTIPLEXER - PL | 1 |
| DISPLAY DRIVER UNITS | 2 |
| DISPLAY ELECTRONICS UNITS/CRT DISPLAY UNITS | 3 |
| MASS MEMORY UNITS | 0 |
| PCM MASTER UNITS | 1 |
| MULTIPLEXER/DEMULTIPLEXER - OF | 3 |
| MULTIPLEXER/DEMULTIPLEXER - OA | 3 |
| MULTIPLEXER/DEMULTIPLEXER - FLIGHT DECK | 1 |
| MAINTENANCE LOOP RECORDER | 0 |
| WIDEBAND SIGNAL CONDITIONERS | 0 |
| SIGNAL CONDITIONING UNITS | 13 |
| INERTIAL MEASUREMENT UNITS | 2 |
| AIR DATA TRANSDUCER ASSEMBLIES | 3 |
| RATE GYRO ASSEMBLIES | 3 |
| ACCELEROMETERS | 3 |
| ROTATIONAL HAND CONTROLLERS | 1 |
| RUDDER PEDAL TRANSDUCER ASSEMBLIES | 1 |
| SPEED BRAKE THRUST CONTROLLERS | 1 |
| AEROSURFACE SERVO AMPLIFIERS | 3 |
| REACTION CONTROL SYSTEM RJD'S | 4 |
| S-BAND FM TRANSMITTER | 0 |
| S-BAND POWER AMPLIFIER | 0 |
| S-BAND PRE-AMPLIFIER | 0 |
| S-BAND TRANSPONDER | 1 |
| S-BAND NETWORK SIGNAL PROCESSOR | 1 |
| TAC[illegible] | 2 |
| MICROWAVE SCAN BEAM LANDING SYSTEM | 2 |
| RADAR ALTIMETERS | 2 |
| AUDIO TERMINAL UNITS | 2 |
| ATTITUDE DIRECTOR INDICATORS - FORWARD | 2 |
| HORIZONTAL SITUATION INDICATORS | 2 |
| ALPHA MACH INDICATORS | 2 |
| ALTITUDE VERTICAL VELOCITY INDICATORS | 2 |
| FUEL CELL POWERPLANTS | 1 |
| APU/HYDRAULICS SYSTEMS | 3 |
| DFI SYSTEM | N/A |
| E[illegible]S | NORM |

## 5.0 SINGLE FAILURE TOLERANT ENTRY ANALYSIS

This EPS analysis was performed using the SEPS analysis computer program (Ref. 1), operating with input data derived from the SOURCE data base. The SEPS program models the orbiter electrical power generation and distribution subsystems and, working to a predefined electrical equipment time line, generates circuit analysis data based on a nodal solution technique. The SOURCE data base is a magnetic tape file containing a composite of all orbiter electrical equipment, along with activity blocks defining the nominal usage of that equipment. The data base provides the capability to select the equipment complement of any desired orbiter along with the nominal usage of that equipment as a function of specific flight parameters. In performing this analysis, it was necessary to modify the nominal usage data, contained within the SOURCE data base, in accordance with the requirements of this specific contingency situation.

### 5.1 Analysis Definition Data

The following definition data was used as input to this analysis:

a. SOURCE Data Base Input Data.

(1) Orbiter - OV-103 (Operational)

(2) Crew Size/Shift Description - 4/Single Shift

(3) Payload Support Equipment - N/A

(4) OMS Kits/RH Manipulator - N/A

(5) Payload Effects on Orbiter - None

b. Deviations from nominal SOURCE data base equipment usage were made as required to conform to the guidelines and assumptions of Section 4.

c. The time line used in this analysis of the SFT entry contingency is presented in Table 5.1-I.

## 5.2 Analysis Results

The results of the single failure tolerant entry analysis are as follows:

a. Figure 5.2-1 presents fuel cell 1 power, current, and voltage for the SFT entry contingency, as analyzed. A review of this figure indicates that fuel cell power can be expected to range from 11.92 kw to 16.90 kw, with an average value of 14.06 kw. Furthermore, the peak power point can be expected to occur after stoproll, when the three hydraulic circulation pumps are activated. The maximum power observed prior to touchdown was 16.14 kw. This level was achieved 1.33 hours prior to deorbit, while the payload bay doors were closing.

b. A further review of Figure 5.2-1 reveals that the fuel cell 1 voltage can be expected to range between 27.40 and 28.55 VDC, with the minimum occurring after stoproll, when the three hydraulic circulation pumps are activated. The minimum voltage experienced prior to touchdown was the 27.58 VDC value which corresponds to the pre-touchdown peak power point.

c. Figures 5.2-2 through 5.2-5 present voltage profiles for the forward, mid, aft, and essential buses, as analyzed. Figure 5.2-6 is a corresponding plot of the voltage levels experienced at circuit breaker panels 14, 15, and 16. For purposes of analysis, constraint limits were set on each of these parameters and the parameters were monitored for limit violations. The limits used, the lowest values experienced, and the numbers of constraint violations are tabulated in Table 5.2-I. It should be observed that, for the most part, the limits used represent the expected worst case voltage levels at the local buses. These are the levels which were used in selection of the wire sizes necessary to insure component interface voltages above 24 VDC, under worst case conditions. The single exception was the essential bus voltage limits, which were set to 27.0 VDC.

d. Tapes created in the performance of this analysis are itemized in Table 5.2-II.

## 5.3 Analysis Uncertainties

The following major analysis uncertainties should be considered when interpreting the results of this analysis:

a. The fuel cell curve utilized in this analysis is representative of a relatively new powerplant. Predictions are that an older powerplant will produce a somewhat lower voltage for any given power level. A review of existing data (Ref. 3) indicates that this decrease will be on the order of 0.65 VDC at 12 kw and that it may be greater at higher power levels. A supplementary analysis has been performed using powerplant characteristics thought to be more representative of a 5000 hour fuel cell but, since no supporting fuel cell test data is available, the results must be considered as tentative, at best. The results, however, are presented in Table 5.3-I for information.

b. Thermal control system (TCS) heaters were not cycled in this analysis, but were averaged over time. The peak power effects of multiple heaters being on concurrently, therefore, will not be apparent from this analysis. As a result, actual maximum power levels may be significantly higher than those indicated in Figure 5.2-1. For a discussion of the effects of concurrent heater power application, see Reference 9.

c. The heater usage factors used in this analysis were those of a nominal attitude within the beta angle range of 40 to 50 degrees. The effects of this contingency occurring at a worst case attitude and beta angle were not considered.

d. In general, the SEPS computer program does not model wiring to discrete electrical end-items below the local bus level. To acquire data below the local bus level, the component interface voltages must, therefore, be calculated from analysis local bus voltages, using actual wire lengths and sizes, and the corresponding load power values.

e. Fuel cell powerplant operating characteristics above 16 kw are indeterminate. The operating characteristics used above this level are based on extrapolations from test data and may not be representative of actual fuel cell operation.

f. The TCS heater usage factors used in this analysis are based on preliminary and partially complete thermal analysis data.

g. No TCS heaters were active in this analysis when below 400,000 feet.

## 6.0 CONCLUSIONS

The following conclusions may be drawn from this analysis:

a. Both fuel cell power and bus low voltage limits will be violated during an SFT entry, even under near optimum conditions.

b. Insufficient data is available to allow a worst case analysis or to permit an assessment of the impact of limit violations. The analysis indicates, however, that, during an SFT entry under nominal to cold thermal conditions, a catastrophic fuel cell failure may occur along with random component failures. In addition, the available information indicates that the magnitude of these failures will be a function of the specific thermal conditions and the accumulated operating time on the one remaining fuel cell.

c. To perform a more definitive analysis, the following actions are required:

   1. The characteristics of a near 5000 hour fuel cell must be determined from 12 KW to the maximum operating limit (fuel cell failure).

   2. Detailed heater duty cycles must be determined for the worst case attitude and beta angle.

   3. Critical items of electrical equipment must be identified and their low voltage operating limits must be determined.

4. Line resistances must be determined between all local buses and the end item equipment.

d. Without a worst case analysis based on the above data, the SFT configuration cannot be shown to be a safe mode of entry.

TABLE 5.1-I
SFT ENTRY ANALYSIS - TIME LINE

| TIME (HHMMSS) | EVENT | ACTIVITY BLOCKS NAME | ON | OFF |
|---|---|---|---|---|
| 000000 | BEGIN ANALYSIS | ORBIT COMMON (ORB-DEORB) | X | |
| | | RCS ATTITUDE CONTROL | X | |
| | | DEORBIT PREP 1 | X | |
| | | PLB DOORS OPEN | X | |
| | | NOMINAL HTRS BETA=40-50 | X | |
| | | SFT CRYO HEATERS | X | |
| | | MISSION COMMON (GSE-GSE) | X | |
| 003000 | FCS CHECKOUT | APU DESCENT | X | |
| 003500 | | APU DESCENT | | X |
| 013630 | CLOSE PLB DOORS | PLB DOORS OPEN | | X |
| | | PLB DOORS CLOSE | X | |
| 025000 | RCS MANEUVER | FWD RCS MANEUVER | X | |
| 025015 | | FWD RCS MANEUVER | | X |
| 030000 | DEORBIT | ORBIT COMMON (ORB-DEORB) | | X |
| | | DESCENT COMMON (DEORB-GSE) | X | |
| | | DESCENT COMMON (DEORB-SR) | X | |
| | | OMS MANEUVER | X | |
| | | RCS ATTITUDE CONTROL | | X |
| | | DEORBIT PREP 1 | | X |
| | | PLB DOORS CLOSE | | X |
| | | DESCENT (DEORB-400 KFT) | X | |
| 030641 | | OMS MANEUVER | | X |
| 033828 | APU SYSTEM ON | APU DESCENT | X | |
| 034328 | 400,000 FEET | DESCENT (DEORB-400 KFT) | | X |
| | | DESCENT (400 KFT-SR) | X | |
| | (TCS HEATERS OFF)[1] | NOMINAL HEATERS BETA=40-50 | | X |
| 041935 | TOUCHDOWN | DESCENT (LOW ALT OPS) | X | |
| 042035 | STOPROLL | DESCENT (DEORB-SR) | | X |
| | | DESCENT (400 KFT-SR) | | X |
| | | POSTLANDING (SR-GSE) | X | |
| 042135 | APU SYSTEM OFF | APU DESCENT | | X |
| 043335 | EOM | MISSION COMMON (GSE-GSE) | | X |
| | | DESCENT COMMON (DEORB-GSE) | | X |
| | | SFT CRYO HEATERS | | X |

[1] For purposes of analysis

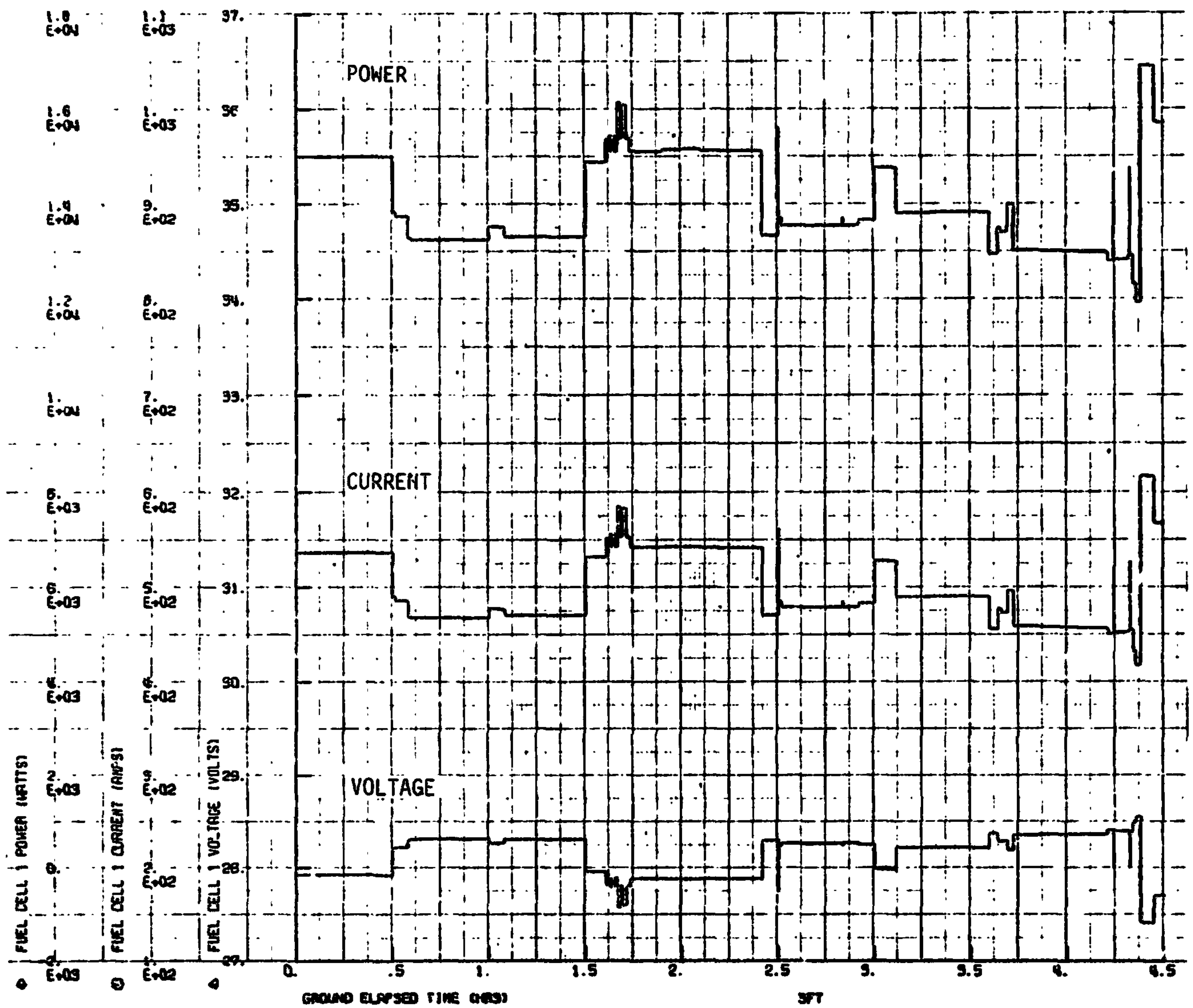


Figure 5.?-1. - Fuel cell 1 source power, current, and voltage

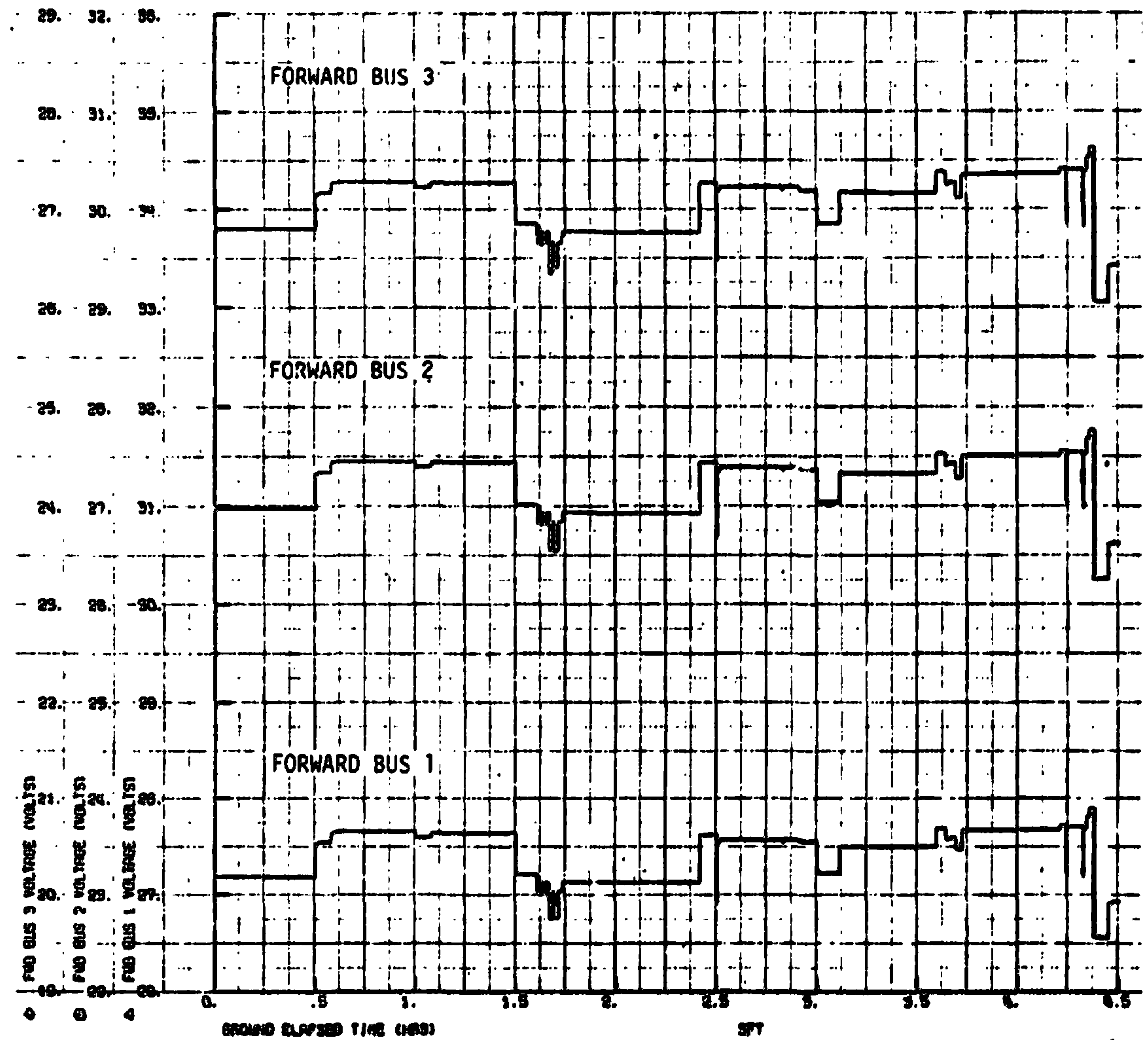


Figure 5.2-2. - Forward bus 1, 2, and 3 voltage profiles

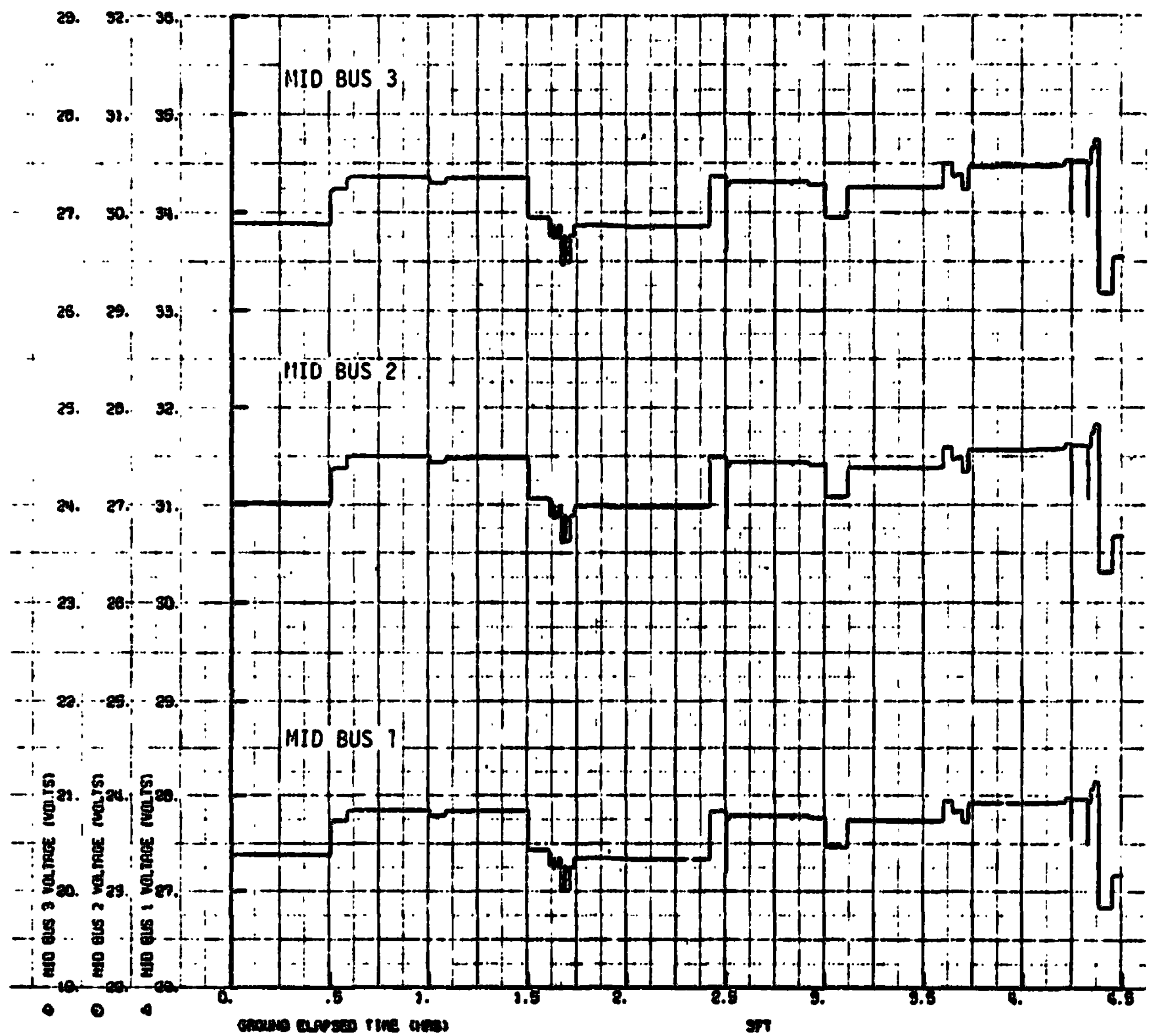


Figure 5.2-3. - Mid bus 1, 2, and 3 voltage profiles

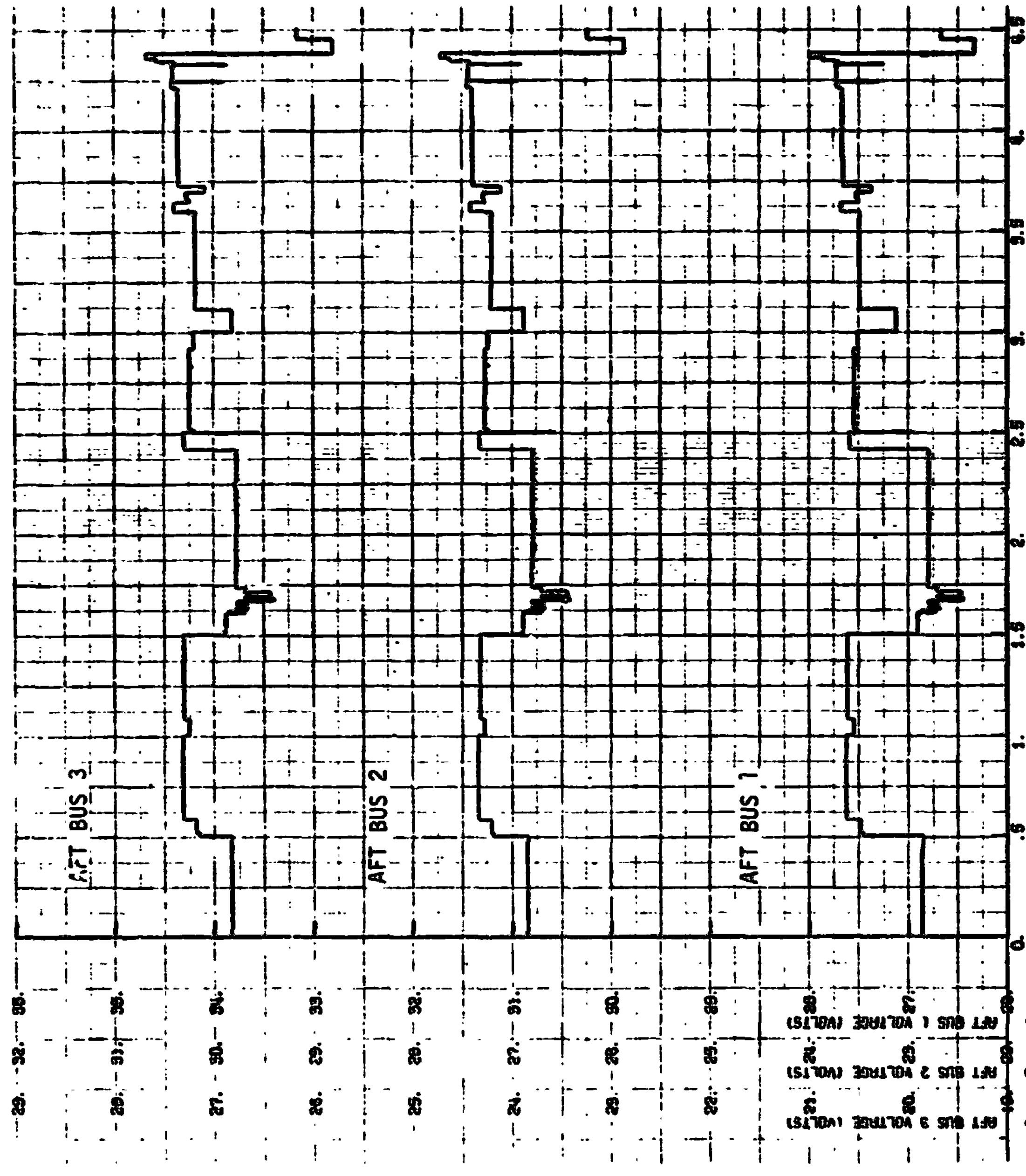


Figure 5.2-4. - Aft bus 1, 2, and 3 voltage profiles

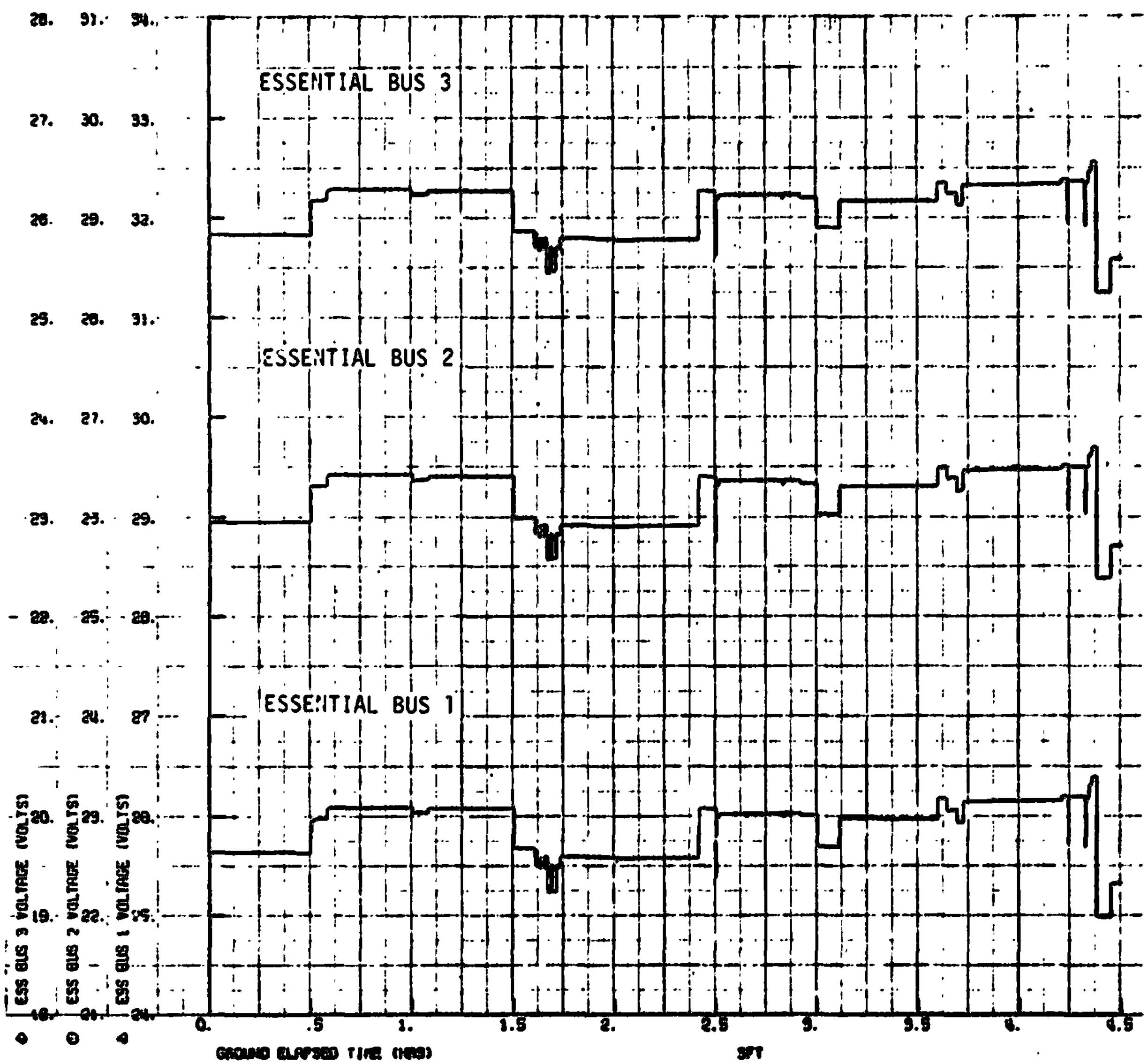


Figure 5.2-5. - Essential bus 1, 2, and 3 voltage profiles

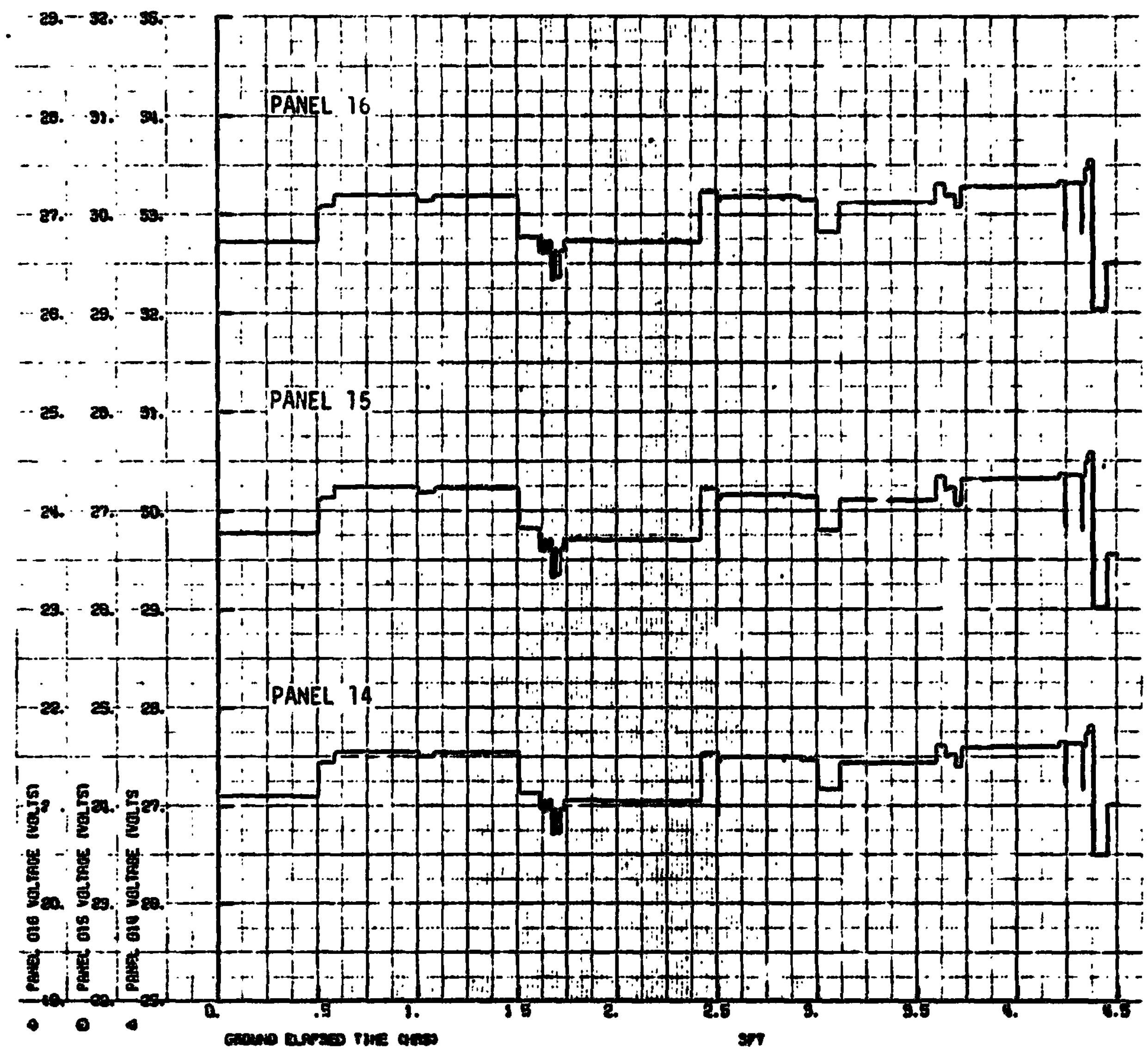


Figure 5.2-6. - Panel 14, 15, and 16 bus voltage prof''es

TABLE 5.2-I
LOW VOLTAGE LIMITS - SFT ANALYSIS USING NEW POWERPLANT

| LOCATION | SEPS PROGRAM | | MINIMUM VOLTAGE (VDC) | | | | LIMIT VIOLATIONS |
|---|---|---|---|---|---|---|---|
| | NODE NO. | LIMIT SENSED (VDC MIN) | PRE-DEORBIT | ABOVE 400,000 FT | 400,000 FT TO SR | SR-EOM | |
| FWD BUS 1 | 6 | 26.2 | - | - | - | - | 0 |
| MID BUS 1 | 10 | 27.0 | - | - | - | 26.83 | 1 |
| AFT BUS 1 | 11 | 26.1 | - | - | - | - | 0 |
| ESS BUS 1BC | 9 | 27.0 [1] | 25.23 | 25.94 | 25.69 | 24.98 | 71 [2] |
| PANEL 14 | 5 | 25.6 | - | - | - | - | 0 |
| FWD BUS 2 | 18 | 26.2 | - | - | - | - | 0 |
| MID BUS 2 | 22 | 27.0 | 26.63 | - | - | 26.31 | 26 |
| AFT BUS 2 | 23 | 26.1 | - | - | - | 25.87 | 1 |
| ESS BUS 2CA | 21 | 27.0 [1] | 25.57 | 26.27 | 26.04 | 25.33 | 71 [2] |
| PANEL 15 | 17 | 25.6 | - | - | - | - | 0 |
| FWD BUS 3 | 30 | 26.2 | - | - | - | 26.05 | 1 |
| MID BUS 3 | 35 | 27.0 | 26.47 | - | 26.97 | 26.18 | 32 |
| AFT BUS 3 | 36 | 26.1 | - | - | - | 25.81 | 1 |
| ESS BUS 3AB | 33 | 27.0 [1] | 25.45 | 26.14 | 25.91 | 25.25 | 71 [2] |
| PANEL 16 | 29 | 25.6 | - | - | - | - | 0 |

1 For purposes of analysis

2 All analysis time-points

TABLE 5.2-II

EPS ANALYSIS TAPE INFORMATION

| TAPE TYPE | TAPE NUMBER |
|---|---|
| DATA | X15227 |
| INTERFACE 1 | X15144 |
| INTERFACE 2 | X15175 |
| PLOTS | X15202 |

TABLE 5.3-I
LOW VOLTAGE LIMITS - SFT ANALYSIS USING 5000 HOUR POWERPLANT (INFORMATION ONLY)

| LOCATION | SEPS PROGRAM | | MINIMUM VOLTAGE (VDC) | | | | LIMIT VIOLATIONS |
|---|---|---|---|---|---|---|---|
| | NODE NO. | LIMIT SENSED (VDC MIN) | PRE-DEORBIT | ABOVE 400,000 FT | 400,000 TO SR | SR-EOM | |
| FWD BUS 1 | 6 | 26.2 | 26.07 | - | - | 25.90 | 4 |
| MID BUS 1 | 10 | 27.0 | 26.09 | 26.97 | 26.75 | 26.18 | 40 |
| AFT BUS 1 | 11 | 26.1 | 25.76 | - | - | 25.70 | 25 |
| ESS BUS 1BC | 9 | 27.0 [1] | 24.56 | 25.19 | 24.95 | 24.34 | 71 [2] |
| PANEL 14 | 5 | 25.6 | - | - | - | - | 0 |
| FWD BUS 2 | 18 | 26.2 | 25.87 | - | - | 25.61 | 17 |
| MID BUS 2 | 22 | 27.0 | 25.93 | 26.59 | 26.32 | 25.66 | 69 |
| AFT BUS 2 | 23 | 26.1 | 25.74 | - | - | 25.23 | 26 |
| ESS BUS 2CA | 21 | 27.0 [1] | 24.91 | 25.52 | 25.30 | 4.74 | 71 [2] |
| PANEL 15 | 17 | 25.5 | - | - | - | 25.38 | 1 |
| FWD BUS 3 | 30 | 26.2 | 25.65 | - | 26.06 | 25.41 | 32 |
| MID BUS 3 | 35 | 27.0 | 25.78 | 26.49 | 26.22 | 25.53 | 67 |
| AFT BUS 3 | 36 | 26.1 | 25.72 | - | - | 25.17 | 27 |
| ESS BUS 3A3 | 33 | 27.0 [1] | 24.77 | 25.40 | 25.18 | 24.62 | 71 [2] |
| PANEL 16 | 29 | 25.6 | - | - | - | 25.38 | 1 |

[1] For purposes of analysis

[2] All analysis time-points

## 7.0 REFERENCES


1. MDTSCO: User's Manual for the Shuttle Electrical Power System Analysis Computer Program - SEPS. (Unpublished) January 1976.

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