RELIABILITY ANALYSIS

SOUTHWEST RESEARCH INSTITUTE

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Department of Applied Electromagnetics

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RELIABILITY ANALYSIS REPORT

FOR THE

M074 SPECIMEN MASS MEASUREMENT DEVICE

AND THE

M172 BODY MASS MEASUREMENT DEVICE

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M172 BODY MASS MEASUREMENT DEVICE

U.S. Air Force Contract No. F41609-70-C-0029
SwRI Project 16-2837

APPROVALS

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1.0 ABSTRACT

The estimated reliability of the Specimen Mass Measurement Device (SMMD) for the Skylab mission is .99. The estimated reliability for the Body Mass Measurement Device (BMMD) is .99. Since there are two SMMD's and one BMMD aboard Skylab, the estimated reliability for the entire mass measurement device group is .9763. That is, the probability that all three devices survive for the entire mission is estimated to be .9763. However, if one spare Electronics Subsystem is available, the estimated reliability for the group is .9997. Thus, the addition of a spare Electronics Subsystem increases the reliability from .9763 to .9997.

2.0 INTRODUCTION

The reliability analysis for the Specimen Mass Measurement Device (SMMD) and the Body Mass Measurement Device (BMMD) was carried out considering all of the requirements of MSC-KA-D-68-1, the Apollo Applications Program Experimental Hardware General Requirements, and the SwRI End Item Specifications MSC-KW-E-69-10 and MSC-KW-E-69-11.

The results of the reliability analysis are used in the Single Failure Point Summary documents (SFPS-1 and SFPS-2) to show the reliability of each component.

The reliability figures of merit which are derived in this analysis encompass all of the failure modes shown in the Failure Mode and Effects Analysis (FMEA-601 and FMEA-602).

The reliability analysis for the electronics portion of the SMMD and BMMD was conducted based on the principles outlined in MIL-HDBK-217A, Section 5.0.

Since the ratio of the design strength to the expected load for each of the mechanical parts, in both the SMMD and BMMD, is in excess of 1.5, the risk of failure of any mechanical part was considered to be negligible. In effect, the system reliability is limited to the reliability of the electronics subsystem. Since the electronics subsystem is identical (and interchangeable) for both devices, the same reliability analysis covers both devices.

3.0 APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced here and other detail content of Sections 2.0, 4.0, 5.0 and 6.0, the detail content of Sections 2.0, 4.0, 5.0 and 6.0 shall be considered a superseding requirement.

3.1 Specifications

3.1.1 NASA

MSC-KA-D-68-1 Revision B 27 January 1970	Apollo Applications Program Experimental Hardware General Requirements

3.1.2 SwRI

MSC-KW-E-69-10 Revision B 12 October 1970	End Item Specifications Flight Hardware for Specimen Mass Measurement (Experiment M074)
MSC-KW-E-69-11 Revision B 12 October 1970	End Item Specification Flight Hardware for Body Mass Measurement (Experiment M174)

3.2 Standards

3.2.1 Federal

MIL-STD-756 Revision A 15 May 1963	Reliability Prediction

3.3 Drawings

3.3.1 SwRI

2837-001-01 30 October 1970	Top Assembly of Body Mass Measurement Device System
2837-002-01 30 October 1970	Top Assembly of Specimen Mass Measurement Device System

3.3.1 SwRI (Continued)

2837-100-01 30 October 1970	Body Mass Measurement Device Mechanical Subsystem
2837-400-01 23 October 1970	Specimen Mass Measurement Device Mechanical Subsystem
2837-700-01 30 October 1970	Mass Measurement Device Electronics Subsystem

3.4 Other Documents

3.4.1 Military

MIL-HDBK-217 Revision A 1 December 1965	Reliability Stress and Failure Rate Data for Electronic Equipment

3.4.2 SwRI

SFPS-1 Revision A 30 October 1970	Single Failure Point Summary for the M074 Specimen Mass Measurement Device
SFPS-2 Revision A 30 October 1970	Single Failure Point Summary for the M172 Body Mass Measurement Device
FMEA-601 Revision A 20 October 1970	Failure Mode and Effects Analysis for the M074 Specimen Mass Measurement Device
FMEA-602 Revision A 20 October 1970	Failure Mode and Effects Analysis for the M172 Body Mass Measurement Device

4.0 DESCRIPTION OF MASS MEASUREMENT DEVICES

4.1 Description of Specimen Mass Measurement Device

The top assembly drawing (SwRI Drawing number 2837-002-01) illustrates the features of the specimen mass measurement device (SMMD).

The specimen mass measurement device comprises a mechanical subsystem and an electronics subsystem. This device is completely self-contained with the exception of requiring a nominal 28 v dc power source and a plane, stable mounting surface.

To operate the device, the mass to be measured is placed on the specimen tray and secured with appropriate tie-downs. The "mass/off/temp" switch of the electronics subsystem is put in the "mass" position, and the digital display is cleared by actuating the reset switch. A control lever is then pulled forward to unlock the tray and release the sear, after which the tray begins to oscillate.

An electro-optical transducer sends a signal to the device's logic circuit each time the tray crosses the equivalent midpoint in its oscillating cycle. After two cycles have been completed, the total elapsed time for the next three cycles, in tens of microseconds, appears on the device's digital display. The device is shut down by actuating the control lever, which moves the tray to the offset position, latches the sear, and finally locks the tray. The period reading, shown on the digital display, is recorded. The "mass/off/temp" switch is put in the "temp" position, the reset switch is actuated, and the temperature, shown on the digital display, is recorded. The electronics is then deenergized. The recorded readings (i.e., temperature and period of oscillation) are used to obtain mass values by reference to a calibration curve, conversion chart, or equation.

4.1.1 Description of Mechanical Subsystem of Specimen Mass Measurement Device

The subsystem drawing (SwRI Drawing Number 2837-400-01) illustrates the features of the mechanical subsystem of the specimen mass measurement device.

The main components of the mechanical subsystem are the base, frame, springs, specimen tray, tray lock, tie-down, and sear mechanism.

The frame and base form the structure of the device, and the specimen tray is suspended from the frame by means of the springs. When the device is not in use, the tray is locked to the frame by the tray lock. Protection to the springs is provided in the locked configuration because the mass of the tray is no longer suspended on the springs, therefore forces accidentally applied to the tray are not transmitted to the springs.

The springs are plate-fulcra type, and consist of a pair of identical flat plates, one at each end of the frame. One end of each spring is rigidly attached to an end of the specimen tray. This arrangement suspends the tray from the frame on the springs, and allows relative motion between the tray and frame during the measurement cycle.

The tie-down is an elastomeric sheet permanently attached to one side of the specimen tray and designed to hook over the opposite edge. In preparing for a measurement, the specimen is placed on the tray and the tie-down is stretched over the specimen, then hooked over the tray edge. This couples the specimen to the tray, preventing relative motion during the measurement cycle.

The sear mechanism serves to hold the specimen tray an exact distance from its neutral position, in preparation for the measurement cycle. In this position the springs are also offset. When the sear is released by the control lever, (which first unlocks the tray), the restoring force of the springs causes the tray to oscillate. After the mass measurement is completed, the control lever is actuated in the reverse direction. This moves the tray and springs to the offset position, latches the sear, and locks the tray.

4.1.2 Description of Electronics Subsystem

The electronics subsystem (SwRI Drawing Number 2837-700-01) consists of five separate functional components. These components are the power regulator, the temperature sensor, the electro-optical transducer, the clock and digital logic, and the digital display. Figure 4.1.2-1 is a block diagram of the electronics subsystem.

The five components are encapsulated into a single module. The SMMD and BMMD electronics subsystems are identical. Following is a brief description of each component:

a. Power Regulator

Voltage regulation of the spacecraft-supplied power is accomplished by a "switching" regulator, which provides maximum efficiency in voltage regulation. Pulse current is supplied to a storage element as required to maintain the desired +5 volts dc output. A balanced filter is incorporated in the input section to reduce conducted EMI on the input lines and to provide protection against transients from the spacecraft source.

The power regulator supplies power necessary to operate the electronics subsystem and derives its power from the unregulated power supply of the spacecraft.

b. Electro-Optical Transducer

The electro-optical transducer component senses the passage of the specimen tray or seat through its equilibrium position. The first two periods of oscillation are ignored by the logic circuitry in order to allow any transients produced by the release mechanism to dissipate. The beginning of the third period signals a start count to the clock and digital logic component, and the beginning of the sixth period signals a stop count to the clock and digital logic component.

The optical source consists of a solid state light emitting diode in the 900 nanometer wavelength range, while the sensor consists of a solid state photosensitive device. The electro-optical transducer operates on power furnished by the power regulator.

c. Temperature Sensor

The temperature is sensed by a thermistor probe. The probe determines the "on time" of an integrated monostable multivibrator, which in turn controls the input to the clock and digital logic component. Temperature is displayed to the nearest degree by two of the six digits in the digital display. Accuracy is $\pm$ 1°F between 65°F and 80°F. The temperature is displayed continuously when the function switch is in the "Temp" position and may be updated by depressing the "Reset" switch. The temperature sensor operates on power furnished by the power regulator.

d. Clock and Digital Logic

The clock and digital logic component consists of a 1 MHz oscillator, seven integrated circuit up/down decade counters,

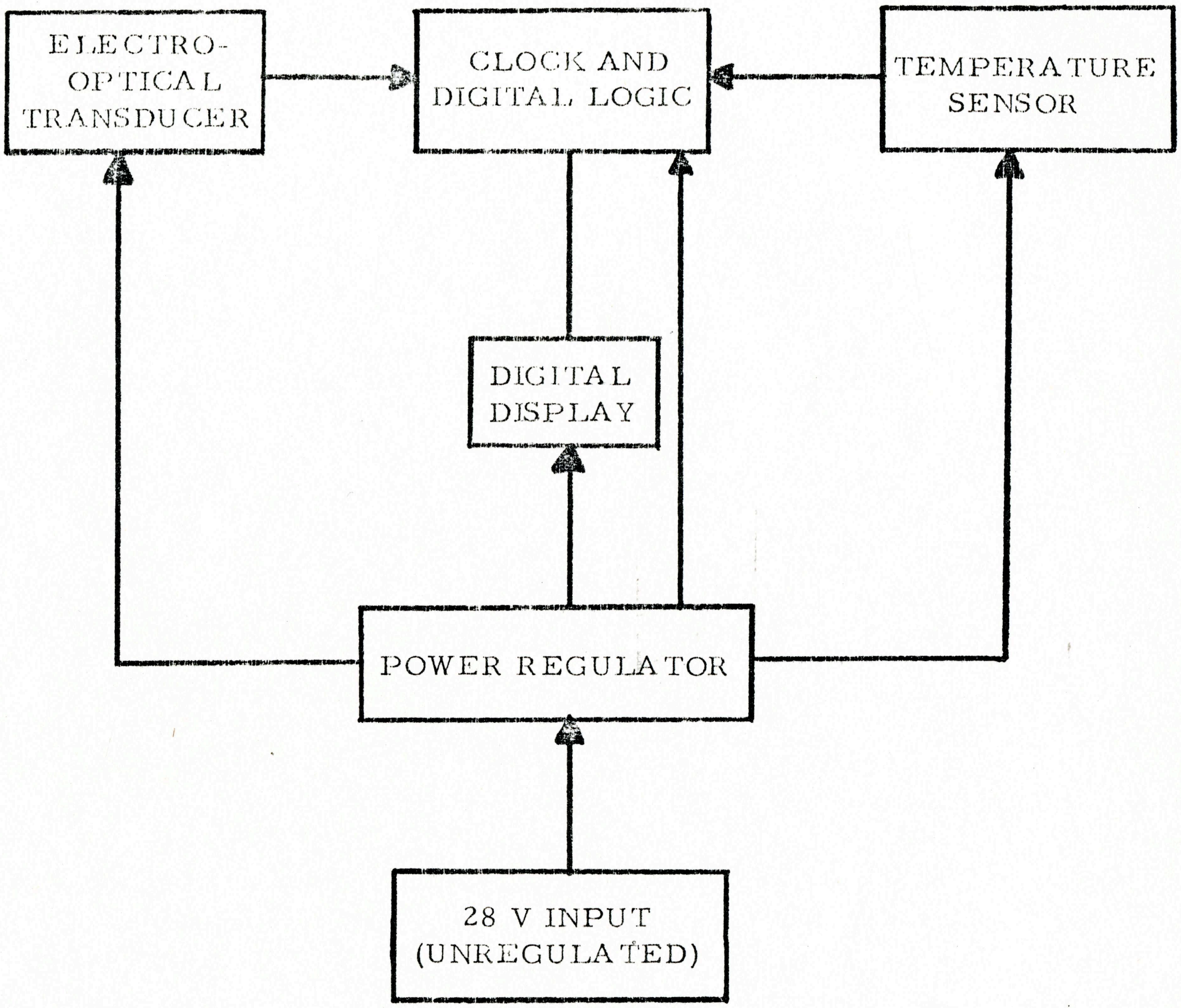


FIGURE 4.1.2-1- ELECTRONICS SUBSYSTEM BLOCK DIAGRAM

and six BCD to 7-Bar Converters. The control logic necessary to perform the functions for mass and temperature measurements is also contained in the clock and digital logic component.

When measuring mass, the counter will "count up", and the period of 3 specimen tray oscillations is displayed on the digital display component.

As the thermistor has a negative temperature coefficient, the counter will "count down" from a pre-set number when measuring temperature, and the temperature can be read directly from the digital display.

The clock and digital logic component operates on power furnished by the power regulator.

e. Digital Display

The digital display component is composed of six 7-bar light emitting diode numerical displays. The signals processed by the clock and digital logic component are displayed in digital form by the digital display component.

The digital display component operates on power provided by the power regulator.

4.2 Description of Body Mass Measurement Device

The top assembly drawing (SwRI drawing number 2837-001-01) illustrates the features of the body mass measurement device (BMMD).

The body mass measurement device comprises a mechanical subsystem and an electronics subsystem. This device is completely self contained with the exception of requiring a nominal 28 v dc power source and a plane, stable mounting surface.

To operate the device, the subject to be measured lowers himself into the seat and fastens the body restraint straps. The "mass/off/temp" switch of the electronics subsystem is put in the "mass" position, and the digital display is cleared by actuating the reset switch. A control lever is then pushed forward to unlock the seat. The subject tenses his muscles, holds his breath (breath will be held for about ten seconds) then releases a sear and the seat begins to oscillate.

An electro-optical transducer sends a signal to the device's logic circuit each time the seat crosses the equivalent midpoint in its oscillating cycle. After two cycles have been completed, the total elapsed time for the next three cycles, in tens of microseconds, appears on the device's digital display. The device is shut down by actuating the control lever, which moves the seat to the offset position, latches the sear, and finally locks the seat. The period reading, shown on the digital display, is recorded. The "mass/off/temp" switch is put in the "temp" position, the reset switch is actuated, and the temperature, shown on the digital display, is recorded. The electronics is then deenergized. The recorded readings (i.e. temperature and period of oscillation) are used to obtain mass values by reference to a calibration curve, conversion chart, or equation.

4.2.1 Description of Mechanical Subsystem of the Body Mass Measurement Device

The subsystem drawing (SwRI drawing number 2837-100-01) illustrates the features of the mechanical subsystem of the body mass measurement device.

The main components of the mechanical subsystem are the frame, springs, seat, seat lock, restraint system, and sear mechanism.

The frame forms the structure of the device, and the seat is suspended from the frame by means of springs. When the device is not in use, the seat is locked to the frame by the seat lock. Protection to the springs is provided in the locked configuration because the mass of the seat is no longer suspended on the springs, therefore forces accidentally applied to the seat are not transmitted to the springs.

The springs are plate-fulcra type, and consist of a pair of identical flat plates, one at each side of the frame. One end of each spring is rigidly attached to the frame, and the other end of each spring is rigidly attached to the seat, one at the front and the other at the rear. This arrangement suspends the seat from the frame on the springs, and allows relative motion between the seat and frame during the measurement cycle.

The restraint system consists of body restraint straps which couple the seat and the subject whose mass is to be measured. After the subject lowers himself into the seat, the restraint straps are fastened around his body and attached to the seat. This couples the subject to the seat, preventing relative motion during the measurement cycle.

The sear mechanism serves to hold the seat an exact distance from its neutral position, in preparation for the measurement cycle. In this position the springs are also offset. In operation, a control lever is first used to unlock the seat. When the subject is ready for mass measurement, he releases the sear, and the restoring force of the springs causes the seat to oscillate. After the mass measurement is completed, the control lever is actuated in the reverse direction. This moves the seat and springs to the offset position, latches the sear, and locks the seat.

4.2.2 Description of Electronics Subsystem

The Electronics Subsystem for the Body Mass Measurement Device is identical to that of the Specimen Mass Measurement Device (see Section 4.2.2).

5.0 RELIABILITY MODELS AND ANALYSIS

5.1 Mission Profile

There will be two SMMD's aboard Skylab, and one BMMD. One SMMD will be in the wardroom and will be used to measure the remaining mass of food packages whose contents have been wholly or partially eaten. The other SMMD will be in the waste management area and will be used to measure feces and vomitus. The BMMD will be floor mounted and will be used to measure mass of crew members.

5.1.1 Launch Environment Models

The launch environment is estimated to last about 20 minutes (1/3 hour), and although the mass measuring equipment will be in the stowed mode, it will still be subjected to shock and vibration. Therefore the "missile" environment, as shown in MIL-HDBK-217A, with the appropriate "k" factors is used for the calculation of failure rates to be used for the electronic piece parts in the Electronics Subsystem during the launch period.

The mechanical components which move during operation (Plate Fulcra Springs, Seat and Specimen Tray, Control Lever and Sear) are supported and locked during launch and while not in operation. Therefore the risk of abnormal stress on these parts is considered negligible. Since the ratio of the design strength to expected load is in excess of 1.5 for all the mechanical parts, the risk of failure of the mechanical parts is negligible throughout the mission.

5.1.2 Earth Orbit Environment Models

During the earth orbit phase, the environment which most closely resembles that of the cabin is the "ground" environment (as shown in MIL-HDBK-217A).

The SMMD in the wardroom is expected to see the most use. The "on" time for the Electronics Subsystem is estimated for the wardroom SMMD on the basis of 3 measurements per food package, 2 food packages per meal, 3 meals per day, 3 crew members, and 140 days, resulting in total measurements (t_m) of:

$$t_m = 3 \times 2 \times 3 \times 3 \times 140 = 7,560.$$

Each group of 3 measurements is expected to take 5 minutes. Rounding the total measurements off to 8,000, the number of hours (T_m) which the Electronics Subsystem will be expected to operate is:

$$T_m = (8000/3) \times (5/60) = 222 \text{ hours}.$$

To be on the conservative side, a mission time (T_m) for the Electronics Subsystem of 250 hours is used in all the reliability calculations for all three systems during the earth orbit phase.

5.2 Reliability Mathematical Model

Figure 5.2-1 is the Reliability Logic Block Diagram for the SMMD. Figure 5.2.2 is the Reliability Logic Block Diagram for the BMMD. The overall system reliability for both the SMMD and the BMMD is limited to the reliability of the Electronics Subsystem.

The Electronics Subsystem has been broken down into the five functional components, as shown in Figures 5.2-1 and 5.2-2. The failure rate tabulation for each of the components for the launch phase is shown in Section 6.1, and the failure rates for the earth orbit phase are shown in Section 6.2.

Component failure rates were computed based on stress factors and part population as outlined in Section 5.0 of MIL-HDBK-217A. Some of the stress factors were based on calculations, some on measurements, and the others were estimated based on good engineering design practices. The general assumptions listed in MIL-STD-756A, paragraph 5.5.4 apply.

The failure density function of each component is assumed to be exponential with the failure rates for the two environments as tabulated in Sections 6.1 and 6.2.

Since the failure of any component in the Electronics Subsystem would result in the failure of the Subsystem, the sum of the failure rates of the components is the failure rate of the Subsystem.

5.3 Reliability Analysis

The probability of survival for each component and for the entire Electronics Subsystem is shown in Table 7.0-1. The estimated reliability of an Electronics Subsystem is calculated to be .99. The estimated probability of survival of all three Electronic Subsystems is calculated in Section 7.1, and is .9763. If one spare Electronics Subsystem is available, the probability of at least three out of the four surviving is .9997 (see Section 7.1).

Thus, the addition of a spare Electronics Subsystem to the Skylab mission would increase the estimated reliability of the entire mass measurement devices from .9763 to .9997.

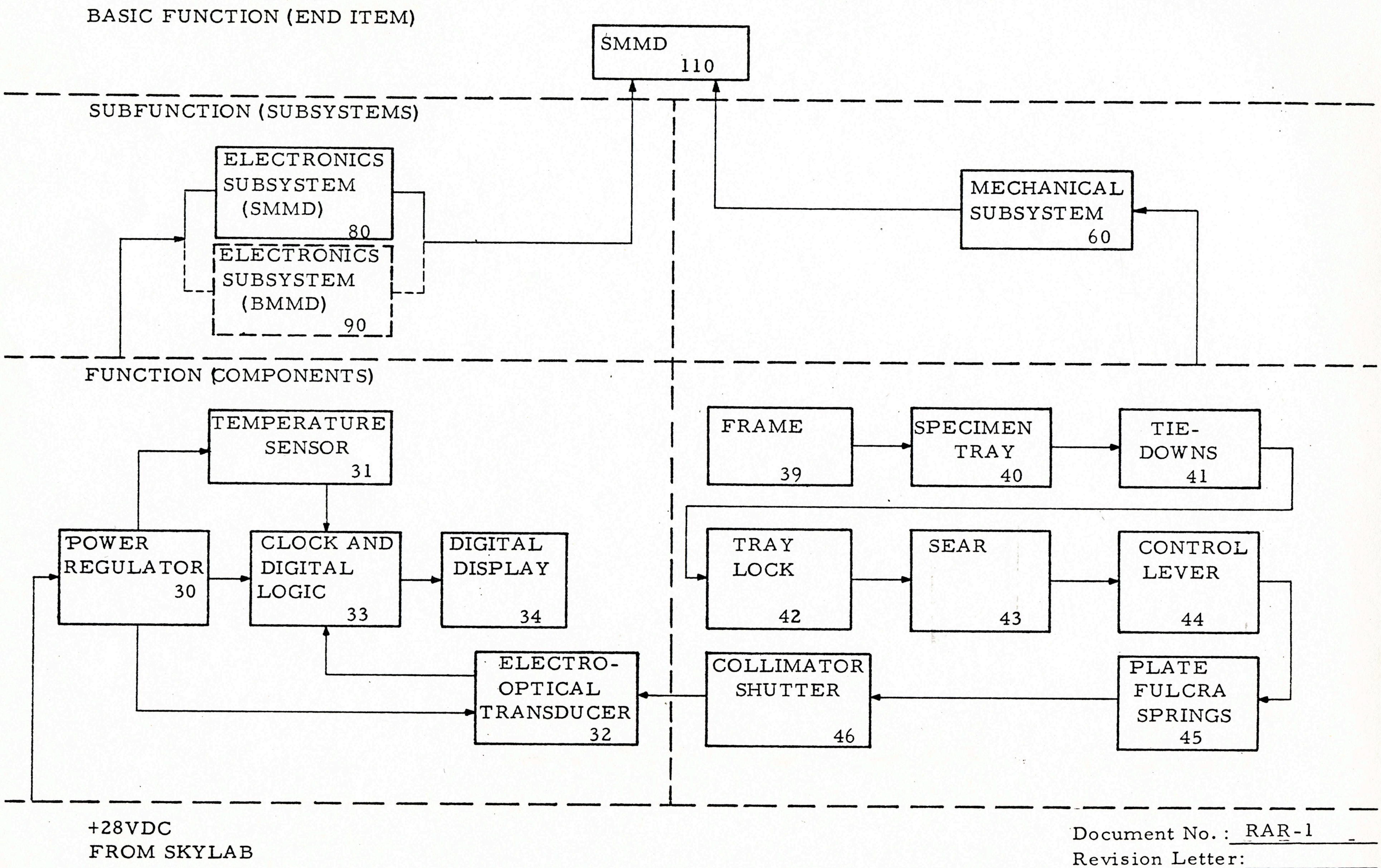
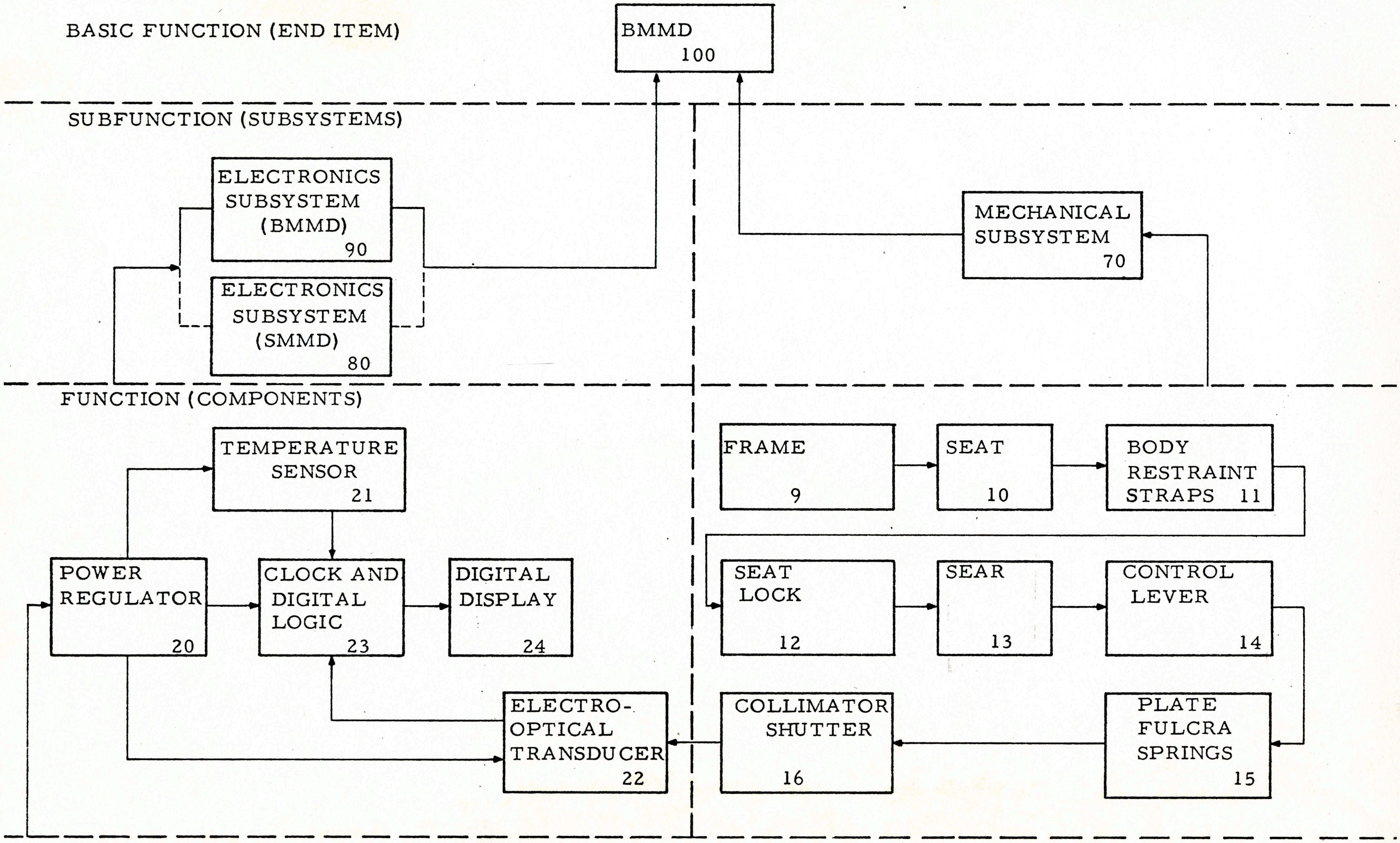


FIGURE 5.2-1. RELIABILITY BLOCK DIAGRAM OF THE SPECIMEN MASS MEASUREMENT DEVICE



+28VDC
FROM SKYLAB

FIGURE 5.2-2. RELIABILITY BLOCK DIAGRAM OF THE BODY MASS MEASUREMENT DEVICE

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6.0 COMPONENT FAILURE RATE COMPILATION

6.1 Component Failure Rate Compilation for Launch Environment

The following listings are the failure rate compilations for the Electronics Subsystem components for the launch environment.

7.0 MATHEMATICAL CALCULATIONS

In general, the reliability R(t), for a mission time, t, for a Component which follows an exponential failure density function with failure rate, λ , can be calculated by the following formula:

$$R(t) = \exp(-\lambda t).$$

If a mission time t is divided into two different environments, as in our case, launch (t_1) and earth orbit (t_2), where $t = t_1 + t_2$, and the corresponding failure rates for the two periods are λ_1, and λ_2, then:

$$R(t) = \exp(-\lambda_1 t_1 - \lambda_2 t_2)$$

The failure rate for the entire Electronics Subsystem is the sum of the failure rates of its components.

Where the product of λt is less than .01, a good approximation of,

$$R(t) = \exp(-\lambda t),$$

is,

$$R(t) = 1 - \lambda t.$$

Using the relationships described above, and the failure rates from Sections 6.1 and 6.2, Table 7.0-1, Component and Electronics Subsystem Reliability, was derived.

7.1 Calculation of Reliability for Combined Mass Measurement Devices Without and With a Spare Electronics Subsystem

The reliability for the combined mass measurement devices (Re(t)) that is the probability that both of the SMMD's and the BMMD survived for the entire mission is,

$$Re(t) = \exp(-3\ \lambda_1 t_1 - 3\ \lambda_2 t_2)$$

$$= \exp\ [-3\ (244.1 \times 10^{-6})\ (1/3) - 3\ (31.7 \times 10^{-6}) \times 250\ ]$$

$$= \exp\ (-(244.1 + 23775)\ (10^{-6}))$$

$$= \exp\ (-.024019) \approx .9763$$

If one spare Electronics Subsystem were available on Skylab, the probability that at least three out of the four Electronic Subsystems would survive the entire mission (Rp(t)) can be calculated considering all the possible outcomes that would result in at least three of the four subsystems surviving both the launch and the earth orbit mission phases. These outcomes can be enumerated as follows:

(1) 4 survive launch; 4 survive orbit

(2) 4 survive launch; 3 survive orbit

(3) 3 survive launch; 3 survive orbit

The first two outcomes can be combined into one, that is;

(1a) 4 survive launch, and at least 3 survive orbit.

The reliability for the condition ($R_1(t)$) can be calculated as follows:

$$R_1(t) = \exp\ [-4(244.1)(1/3)(10^{-6})]\quad \exp\ [-3(250)(31.7)(10^{-6})]\ [1+3(250)(31.7)(10^{-6})]$$

$$= [\exp\ (-.000325)]\ [\exp\ (.023775)\ (1.023775)]$$

$$\approx (.9997)\ (.9766)\ (1.0238)$$

$$\approx .9995$$

Now the probability of exactly 3 surviving launch, and 3 surviving orbit, $R_3(t)$, is:

$$R_3(t) = 4\ [\exp(-.000244)]\ [1-\exp(-.000081)]\ [1-\exp(-.023775)]$$

$$\approx 4\ (.99977)\ (.000081)\ (.9765)$$

$$\approx .0002$$

Now the reliability, $R_p(t)$ is:

$$R_p(t) = R_1(t) + R_3(t)$$

$$.9975 + .0002$$

$$.9997$$