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NASA TECHNICAL MEMORANDUM

NASA TM X-64853

RETENTION AND APPLICATION OF SKYLAB EXPERIENCES TO FUTURE PROGRAMS

Skylab Program Office

NASA

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George C. Marshall Space Flight Center
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16. ABSTRACT

This document has been prepared to summarize the problems encountered and special techniques and procedures developed on the Skylab program, and to summarize the experiences and practical benefits obtained for dissemination and use on future programs. A total of 2,250 discrepancy reports were reviewed to formulate this document.

The document is divided into three major sections: an electrical problem section, a mechanical problem section, and a special techniques section. Each problem section is prefaced by three indices:

1. Hardware Index — Classifies the problems by type of hardware such as valves, switches, etc.
2. Problem Index — Lists the problems with the hardware resulting from design, human error, maintenance, manufacturing, and procedure factors.
3. Condition Index — Denotes the physical condition of the hardware after problem occurrence.

Thirty special techniques and procedures are identified that were either developed or refined during the Skylab program. These techniques and procedures came from all manufacturing and test phases of the Skylab program and include both flight and GSE items from component level to sophisticated spaceflight systems.

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ABBREVIATIONS

ACE	Automatic Checkout Equipment
AMP or A	Ampere
A& PCS	Attitude & Pointing Control System
ATM	Apollo Telescope Mount
BPMD	Blood Pressure Measuring Device
CBRM	Charger, Battery Regulator Module
CDC	Control Data Corporation
CEI	Contract End Item
CFE	Contractor Furnished Equipment
CMG	Control Moment Gyro
CRT	Cathode Ray Tube
DC	Direct Current
DCS	Digital Command System
DIP	Dual Incline Packages
DVTU	Design Verification Test Unit
ECE	Electrical Checkout Equipment
EIDD	End Item Description Document
EMI	Electro Magnetic Interference
E. O.	Engineering Order
EPC	Experiment Pointing Control
F	Fahrenheit
FBU	Flight Backup Unit (ATM)
G	Gravity
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
H_2O	Water

ABBREVIATIONS (Concluded)

IC	Integrated Circuits
ICD	Interface Control Document
IP&CL	Instrumentation Program & Components Listing
IPS	Inches per Second
KSC	Kennedy Space Center
LED	Light Emitting Diode
MDA	Multiple Docking Adapter
MLU	Memory Loading Unit
MSFC	Marshall Space Flight Center
OWS	Orbital Work Shop
P.C.	Printed Circuit
PCM/DDAS	Pulse Code Modulation/Digital Data Acquisition System
PMC	Post Manufacturing Checkout
PSIA	Pounds per Square Inch Absolute
PPM	Parts per Million
PSI	Pounds per Square Inch
RF	Radio Frequency
RFI	Radio Frequency Interference
S/C	Space Craft
SEM	Scanning Electron Microscope
S_1O_2	Silicone Dioxide
VDC	Volts, Direct Current
VSWR	Voltage Standing Wave Ratio

TECHNICAL MEMORANDUM TM X-64853

RETENTION AND APPLICATION OF SKYLAB EXPERIENCES TO FUTURE PROGRAMS

SUMMARY

A total of 2,250 Skylab Discrepancy Reports were reviewed to formulate this document. All duplications, unverified failures, GSE problems, and minor defects were eliminated. Only functional failures and major defects reported from post-manufacturing checkout through launch were included. Of the resulting 216 problem entries, 150 or 69 percent were electrical problems, and 66 or 31 percent were mechanical problems. The problems in each section were collated and indexed by type of hardware. Electrical/electronic assemblies experienced the greatest number of problems in the electrical section and accounted for 41 percent of the reported problems, while capacitors, resistors, and pots, etc., were next with 13 percent. In the mechanical section, valves experienced the largest number of problems and accounted for 27 percent of the reported problems.

The problems were indexed into five major categories of problem orientation. Overall, 32 percent were design oriented problems, 10 percent were human error, 1 percent were maintenance, 44 percent were manufacturing, and 13 percent were procedural problems. In the electrical section, design accounted for 31 percent of the problems, human error 11 percent, maintenance 1 percent, manufacturing 49 percent, and procedures 8 percent. In the mechanical section, design accounted for 36 percent of the problems, human error 8 percent, maintenance 2 percent, manufacturing 33 percent, and procedures 21 percent.

The problems were also indexed according to the hardware physical condition. In the electrical section, the physical condition of inadequate/improper design accounted for 22 percent of the problems while improper assembly/installation accounted for 14 percent. Each of the other physical conditions in the electrical problem section accounted for 10 percent or less. In the mechanical section, inadequate/improper design accounted for 21 percent of the problems while improper assembly/ installation accounted for 14 percent. Each of the other physical conditions were 10 percent or less.

Thirty special techniques and procedures are identified that were either developed or refined during the Skylab program. These techniques and procedures came from all manufacturing and test phases of the Skylab program and include both flight and GSE items from component level to sophisticated spaceflight systems.

Similar data on Saturn Experiences have been published in NASA TM X-64574, Retention and Application of Saturn Experiences to Future Programs.

INTRODUCTION

This document has been prepared to summarize the problems encountered and special techniques and procedures developed on the Skylab program, and to summarize the experiences and practical benefits obtained for dissemination and use on future programs. A total of 2,250 discrepancy reports were reviewed to formulate this document.

The document is divided into three major sections: an electrical problem section, a mechanical problem section, and a special techniques section. Each problem section is prefaced by three indices:

1. Hardware Index — Classifies the problems by type of hardware such as valves, switches, etc.

2. Problem Index — Lists the problems with the hardware by the following types of problems:

Design	—	Problems resulting from inadequate design.
Human Error	—	Problems resulting from human error, workmanship, etc.
Maintenance	—	Problems resulting from the lack of maintenance/preventive maintenance and inadequate processing controls subsequent to manufacture.
Manufacturing	—	Problems resulting from the manufacturing process, excluding procedural and human error problems.
Procedures	—	Problems resulting from deficient procedures.

3. Condition Index — Denotes the physical condition of the hardware after problem occurrence.

Each individual entry in the electrical and mechanical problem summaries as referenced by the indices contains the following information:

Item Number	Problem Description	Problem Effect
Hardware Nomenclature	Problem Cause	Remarks/ Suggestions

All duplication has been eliminated in the document in that items with the same hardware nomenclature, problem, and cause appear only once; however, where the problem or cause is not the same, the item is again identified. The entries are collated into hardware families or similiar hardware families and it should be noted that the figures and numbers reflected on the hardware, problem and condition graphs relate only to the contents of this document.

Contained in section three of this document are thirty special techniques and procedures that were developed or refined during the Skylab program. These techniques and procedures came from all manufacturing and test phases of the Skylab program and include both flight and GSE items from component level to sophisticated space-flight systems.

CONCLUSIONS AND RECOMMENDATIONS

It is not the intent of this handbook to make conclusions and recommendations concerning design changes, procedural changes, etc.; however, it is recommended that these data be used in future programs to minimize occurrence of similar problems. This document can have broad application in future space activities — from the designer making a part selection for a specific application to the test engineer or technician in the identification of a particular failure cause. The new techniques identified in the document should prove invaluable for future programs requiring an end product as complex as that delivered under the Skylab program, since the use of these techniques will enhance product quality and reliability and decrease cost and manpower requirements. Use of the document will also allow greater management emphasis to be placed upon potential problem areas.

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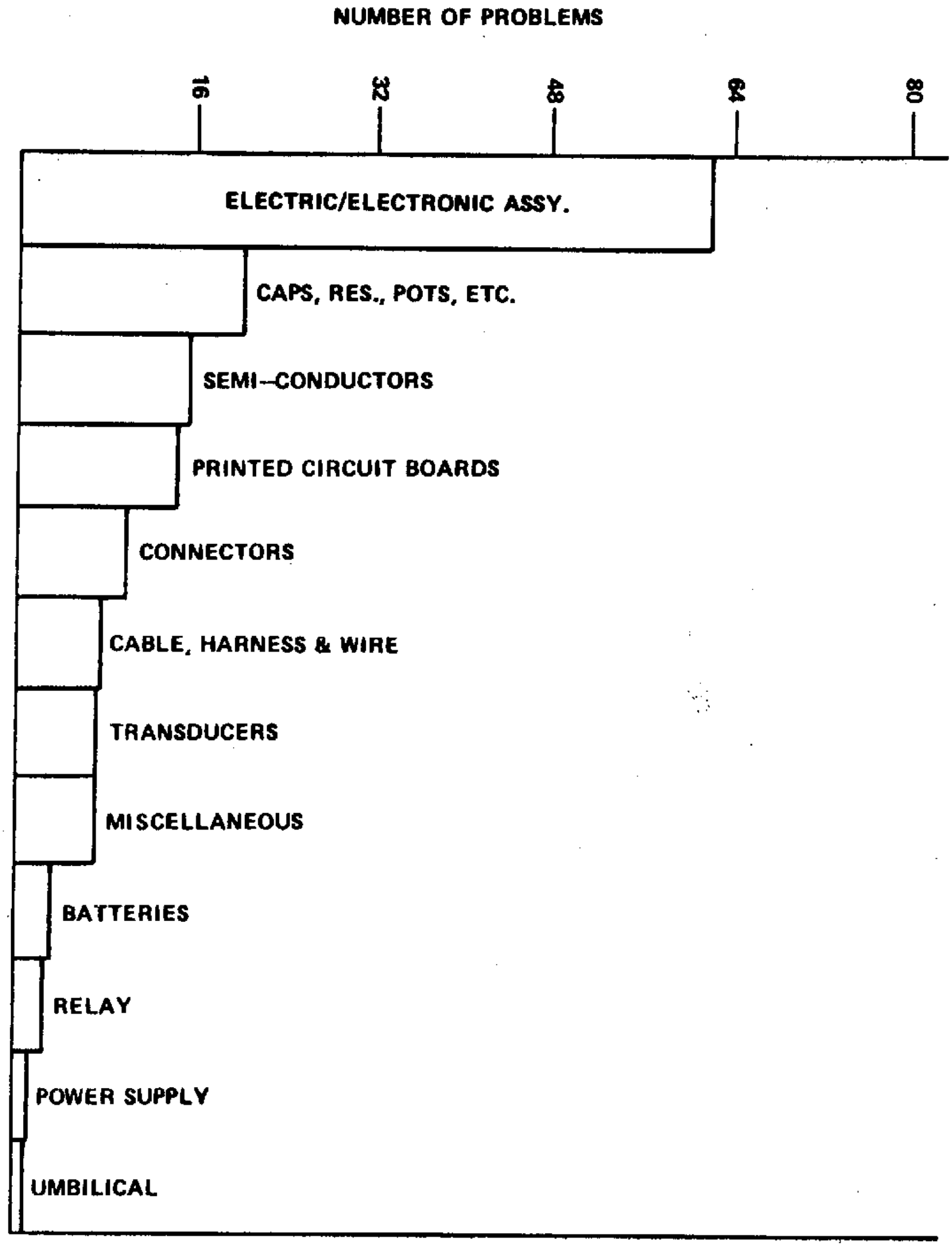

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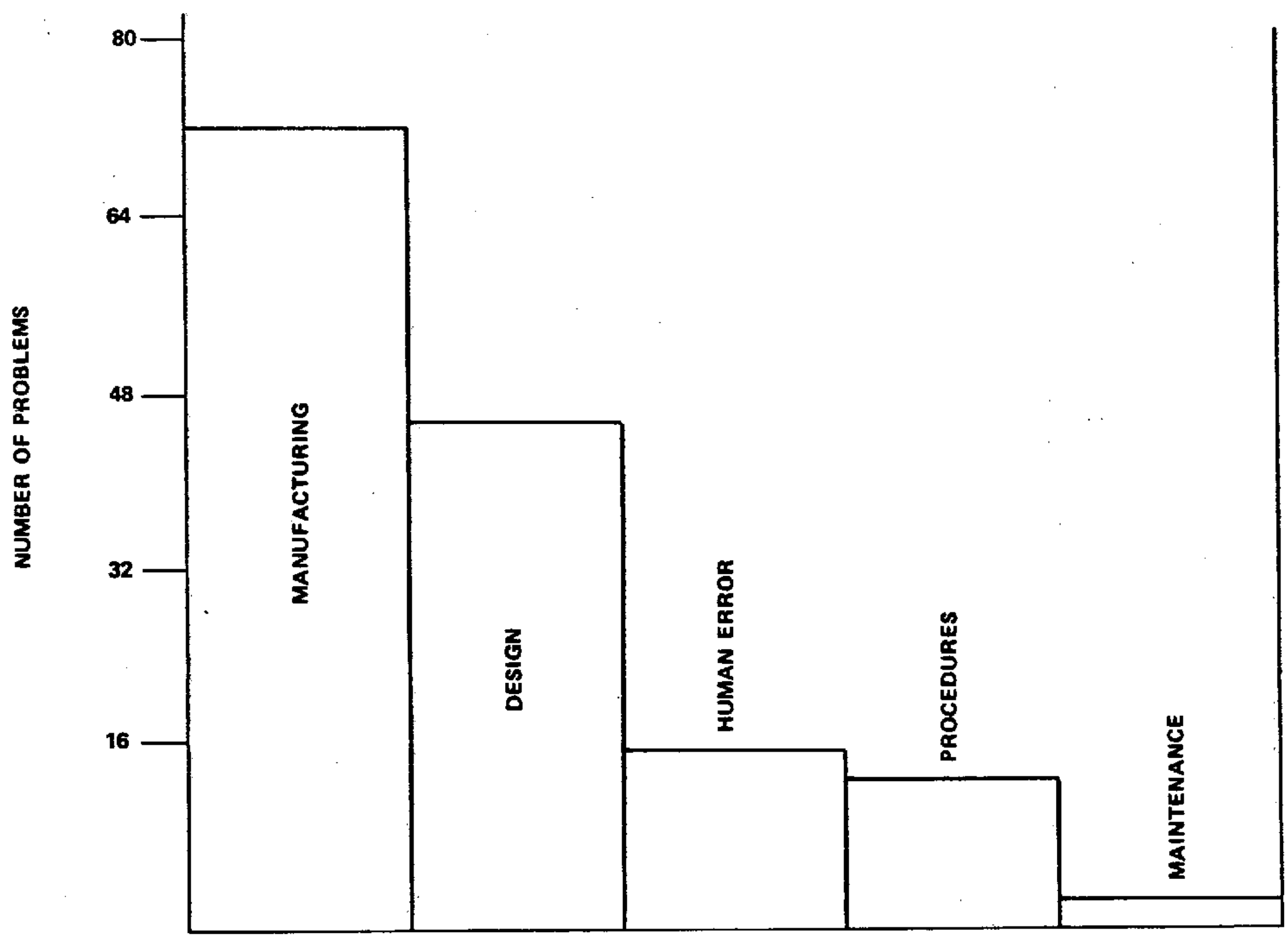

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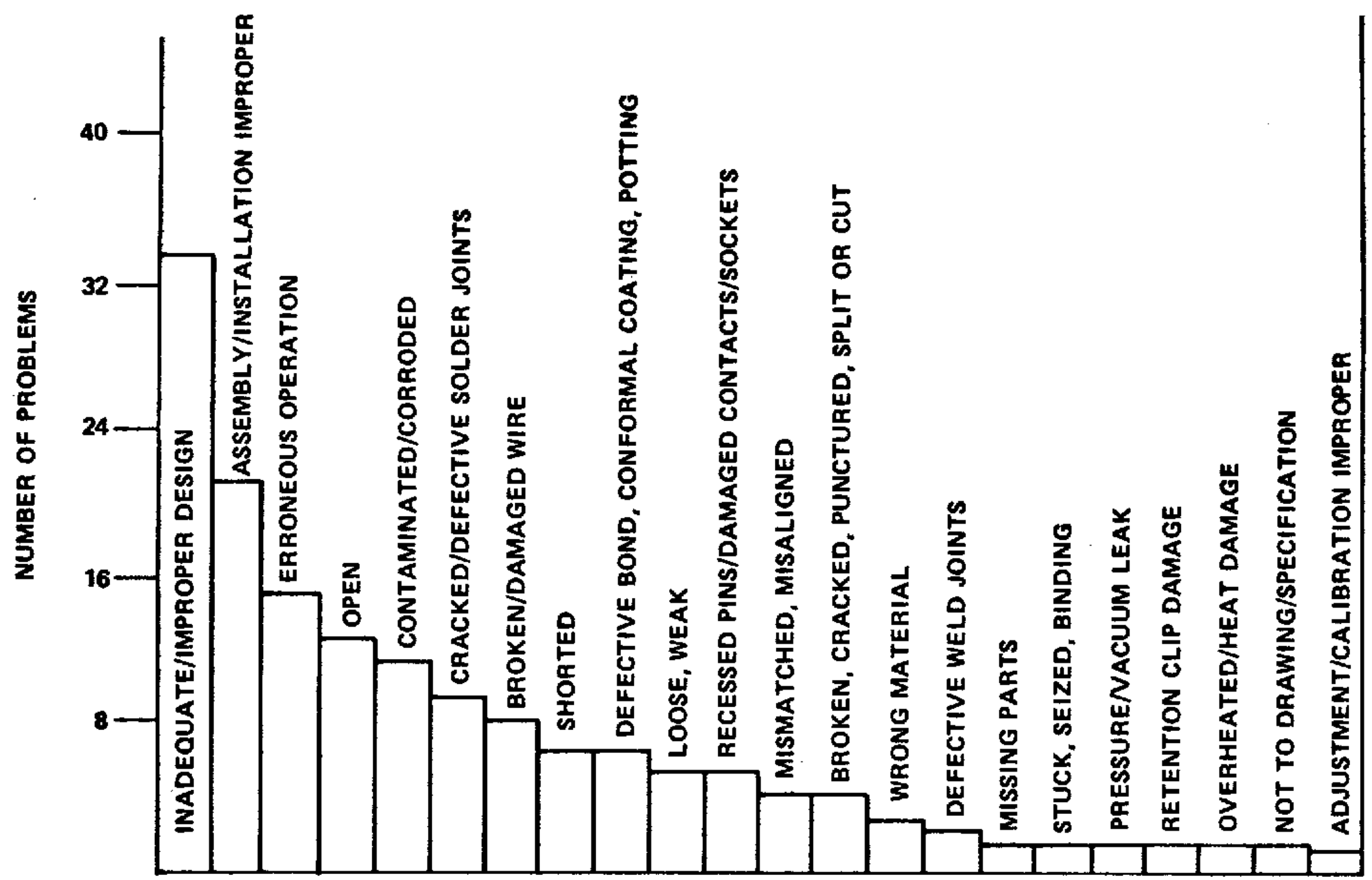

ELECTRICAL PROBLEM SUMMARY

BATTERIES

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Battery	Cell leakage at terminal seals and pressure relief valves.	Marginal design combined with vendor manufacturing defect. Upper braze cup brazed to terminal stud in a cocked position caused increased stresses and braze failure. Also, marginal "O" ring seal in relief valve.	Leakage creates electrical paths and corrosion contamination.	Revise terminal stud seal design and assure adherence to drawing. Add rigid epoxy around stud to enhance seal. Vacuum leak test cells prior to installing in battery case.
2	Battery	Seal leakage	Battery dropped during handling.	Loss of battery functions.	Implement handling procedures.
3	Battery Rack	CBRM's will not power up.	Battery cell shorted to case.	Degradation of battery.	Assure adequate inprocess manufacturing and inspection controls exist.

CABLES, HARNESSES, AND WIRE

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Cable	Open circuit in cable.	Cable mishandling.	Primary Acquisition Sun Sensor would not turn off.	Motivate all personnel to have a sense of awareness against handling damage.
2	Cable	Noise on experiment cables.	Cables not grounded; shields not terminated.	Out of tolerance voltage readings.	Assure complete design review is accomplished prior to test of system.
3	Cable	Antenna cable caught in wing, stretched and pulled out of clamps.	Improper routing of cable.	Damaged cable.	Initiate design review to assure proper cable routing.
4	Cables	Strain gage cable has an open circuit.	Broken wire.	Part fails to function as intended.	Caution personnel in proper handling procedures for delicate strain gages and cables.
5	Cable, Interconnect	Open circuit in coax cable.	Coax center conductor too small.	Loss of signal from temperature sensor.	Initiate design review to assure adequate current carrying capability of conductors.
6	Cable, Interconnect	Connector pin position reversed.	Drawing error.	Improper operation and/or component damage.	Perform design review of drawings prior to release.
7	Harness Assembly	Wire shorting to ground shield.	Sharp point at shield-to-wire splice penetrated wire insulation.	Improper operation of cuff assembly.	Initiate inspection under magnification of wire/shield splices.

CABLES, HARNESSES, AND WIRE (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
8	Wire	Wire insulation damaged and shorted to clamp.	Manufacturing error.	Low resistance reading resulting in malfunction of solar wing.	Initiate training program for mfg. personnel on proper methods of wire/cable routing and clamping. Initiate 100 percent inspection of mfg. operations.

CAPACITORS, RESISTORS, POTS, CIRCUIT BREAKERS AND SWITCHES

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Capacitor	Short	Excessive heat during retinning or installation.	Reflow of internal solder.	Subject printed circuit boards to radiographic examination in accordance with MSFC-STD-355B. Interpret radiographs in accordance with MSFC solid tantalum capacitor X-ray inspection criteria.
2	Capacitor	Electrolyte leakage.	Acid leakage occurring under, around, or through the brazing material used for final sealing.	Low resistance path between a transistor heat sink and a printed circuit conductor.	Inspection for electrolyte leakage with thymol blue as specified in MIL-C-39006. Also, do a litmus paper test to check the presence of acid.
3	Capacitor	Intermittent conditions.	Inadequate controlled drilling of "green" ceramic and inadequate inspection.	Cracking of ceramic and separation between ceramic and palladium-silver frit.	Perform 100 percent neutron radiographic inspection.
4	Capacitor	Short	Application of high ripple currents, or low level reverse voltage.	Silver "bridge" across teflon seal from case to tantalum slug.	Inspect for presence of silver plating on case, seal, and anode. If there is enough silver to justify replacement, select from MIL-C-39006/09B Part Nos. M39006/09-4411 through 5025.
5	Capacitor	Acidic leakage	Excessive etching of leads during cleaning operation	Internal leakage.	Tighten manufacturing process and subsequent inspection controls. Institute screening test techniques.

CAPACITORS, RESISTORS, POTS, CIRCUIT BREAKERS AND SWITCHES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
6	Capacitor, Tantalum	Capacitor failed.	Capacitor soldered to wrong terminal.	Reverse polarity voltage applied to capacitor causing it to explode.	Initiate 100 percent inprocess inspection to verify correct assembly of piece parts.
7	Capacitor, Tantalum	Solder pellet in bottom of case had not been flowed to attach slug to case.	Inadequate process control.	Capacitor failure.	Use capacitors that meet MIL-C-39003 failure rate level P or better and have been X-rayed in accordance with MSFC Solid Tantalum capacitor X-ray inspection criteria.
8	Inductor	Inductors cracked and open.	Mechanical stress on inductor body caused by thermal shock.	Failure to function as intended.	Perform engineering analysis to assure parts are not overstressed by improper bonding or conformal coating. Also, verify leads have stress relief bends.
9	Potentiometer	Bus number 2 adjustment pot gives erratic readings.	Overtorque of set screw on pot.	Improper function of pot.	Assure proper torque procedures are available and require inspection to witness all torque operations.
10	Potentiometer	Pin three loose at lead-case interface.	Lead stresses too great.	Erratic offset bias and unstable output of signal conditioner.	Assure mounting operation does not over stress leads. Impose thermal cycling to screen for defective parts at pre-potting where components can be replaced without scrapping entire assembly.

CAPACITORS, RESISTORS, POTS, CIRCUIT BREAKERS AND SWITCHES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
11	Potentiometer	Potentiometer could not be set to lower resistance values.	Potting material entered the case through pin hole in the seal and obstructed the wiper key.	High output amplifier gain reading in the signal conditioner.	Assure that receiving inspection plans include criteria for inspection for surface defects and are compatible with procurement and military specifications.
12	Resistor	Resistors in power supply changed values causing high indicator readings.	Process deviation in manufacture of resistors.	Erroneous readings.	Periodically evaluate supplier's process controls.
13	Resistor	Parts exhibited a max + 0.02 percent resistance drift while on the shelf.	Resistance may increase for a period that may exceed 250 hrs. after completion of manufacturing and screening processes.	Resistance value shifted positive with time.	Specify the necessary stabilization period prior to final resistance measurement for applications where amount of resistance error would be of concern.
14	Resistor	Unstable parts.	Metal migration of resistive film due to presence of contaminants.	Increased resistance when subjected to about 25 percent rated power.	Perform engineering evaluation of parts to determine they are adequate for intended function.
15	Switch	Broken and bent contact springs.	Improper stress relief annealing of contact springs.	Open condition	Initiate qualification/life testing of piece parts.

CAPACITORS, RESISTORS, POTS, CIRCUIT BREAKERS AND SWITCHES (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
16	Switch	No talk back from thermal control system bypass valve in radiator position.	Failure of the valve talk back switch.	Refrigerator loop could not respond to temperature control demands, which would cause transfer to secondary loop and cause loss of redundancy.	Do not include talk back position switches on valves unless they are absolutely necessary, especially where they can introduce unwanted system failure modes.
17	Switch	Sticking push buttons on OAS keyboard.	Mechanical buildup of tolerances.	Does not perform as intended.	Ensure 100 percent inspections of switches for proper operation.
18	Switch, Magnetic	Meteoroid shield magnetic switch mislocated.	Drawings did not identify correct position of magnet portion of switch.	Inability to latch meteoroid shield after deployment.	Ensure drawings callout correct dimensions and clearance. Incorporate verification checks as part of checkout sequence.
19	Switch Assembly, Micro	Micro switch loose in mounting bracket.	Mounting screws not tight due to absence of torque requirements.	Failure of micro switch to operate, over driving CMG.	Assure proper torque requirements are imposed.
20	Switch, Video	Unable to adjust bias trim pot.	Trim pot would not turn because it was contaminated with potting material.	Failed to function as intended.	Initiate adequate inspection to verify parts are functional prior to use.

CONNECTORS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Connector	Connector pins bent.	Handling damage.	Erroneous operation of unit.	Motivate personnel to be more careful in handling critical hardware.
2	Connector	RF connector has loose rear bushing.	No locking device provided other than 8-10 in./lbs of torque.	Possibility of loosening up and losing continuity.	Provide locking devices for critical circuit connectors.
3	Connector	No continuity through pin C of connector.	Improper mating caused pin C to be bent flush to its own base.	Lack of continuity.	Implement training for personnel in connector mating and restrict mating to qualified personnel.
4	Connector	Contacts could not be inserted in connector holes.	Manufacturer reduced contact shoulder size from 0.136 in. max. to 0.133 in. max.	Potential interference fit.	Inspect all pin and socket contacts for CV connectors to maximum shoulder dimension of 0.133 in.
5	Connector	Power lost at transmitter signal/ power connector.	Socket contacts (split time, open entry type) spread. Test pin falls out.	Loss of continuity with mating pin contacts.	Test for pin withdrawal force. Specify closed entry socket contact for new designs.
6	Connector, Coax	Pins recessed and loose connectors.	Improper manufacturing techniques.	Intermittent/open circuit causing loss of circuit function.	Assure adequate manufacturing and inspection procedures to prevent poor workmanship and inspection escapes.

CONNECTORS (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
7	Connector, Coax	Two types of coax contacts which do not intermate exist for same connector body.	Solder version has pin center contact in receptacle housing and socket center contact in plug housing. Crimp version has socket center contact in receptacle housing and pin center contact in plug housing.	Incompatability in mating.	Verify that compatible contacts are specified to assure mating of connectors during system integration. MSFC prefers crimp-type version of coaxial contact.
8	Connector, RF	Intermittent contact (spread socket) or a short (segment of socket broken off).	Center contact is not captivated and was not flush against dielectric during soldering causing it to protrude.	Socket damage.	Inspect Series "N" RF cable connectors with noncaptivated center contacts for proper position. Check for adequate withdrawal forces. For future applications use only connectors with captivated center contacts per MIL-C-39012.
9	Connector, Zero G	Polarizing index pins fell out.	Insufficient retention.	Inability to complete circuit.	Assure connectors are adequately tested and qualified prior to use on flight hardware.
10	Shorting Plug	Shorting plug is open.	Wiring error during fabrication.	Failed its intended function.	Assure adequate testing of shorting plugs prior to release for use.

ELECTRICAL/ELECTRONIC ASSEMBLIES

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Attitude and Pointing Control	"Start" commands issued prior to power on sequence.	Test procedure error.	"Power on" indications off when bus power is applied.	Assure adequate test procedure review is accomplished.
2	Attitude and Pointing Control	CMG 2 inner gimbal tachometer does not remain at null when outer gimbal is torqued.	Design change incomplete.	Out of tolerance condition.	Initiate configuration control to assure specifications and procedures are updated to be compatible with engineering changes.
3	Blood Pressure Measuring Device	Defective intergrated circuit on PC Board No. 1 in Blood Pressure Measuring Device (BPMD).	Bridging of the conformal coating induced stress which caused a wire to break.	LED displays on the BPMD will not update or change when readings change.	Maintain proper thickness of conformal coating through better application methods and inprocess inspection.
4	Blood Pressure Measuring Device	Degraded operational amplifier on PC Board No. 1.	Electrical overstress received during bench analysis by possible shorting of the output to B+.	Systalic displays read low.	Stress need for extreme care during fault isolation of delicate electronic devices.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
5	Blood Pressure Measuring Device, Automatic	The automatic blood pressure measuring system cuff fill time was too great at an environment of 2 psia and 116°F.	Design error; restricting orifice improper diameter to meet specification at a 2 psia environment.	The slow fill rate would have no effect on experiment or astronaut.	Orifices should be sized and specifications set to meet the space requirement and not ambient conditions.
6	Blood Pressure Measuring Device, Automatic	Plugable PC boards backed out of their respective connectors.	Holding ability of compression pad inadequate because of tolerance build-up.	Plugable P.C. boards lose contact that results in loss of function.	Perform design review and sufficient testing to verify plug-in modules are adequately held in position.
7	Charger, Battery, Regulator Module	Preregulator transistor damaged.	Excess power dissipation during certain startup conditions.	Assembly will not function as intended.	Perform in-depth design reviews and adequate testing to weed out marginal design problems.
8	Control and Display, Console	Power system meters stick when input lines are open.	When meter signal inputs are open, a negative voltage is generated within the meter.	Erroneous bus currents and battery temperature indications.	Update design to add resistance to meter circuitry for meter bias compensation.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
9	Control Moment Gyro Inverter Assembly No. 2.	Amplifier output stage bias resistors burned open.	Poor heat conduction from output transistors to heat sink during thermal vacuum testing. Transistor Belleville springs were improperly heat treated and would not hold tension.	Loss of output from amplifier.	Assure proper vendor control during manufacturing of critical component parts.
10	Control Thermostat.	Thermostat inoperative.	Cold solder joints.	Improper operation.	Perform 100 percent inprocess inspection and verify adequate assembly/inspection procedures/requirements.
11	D. C. Amplifier.	Negative portion of D. C. Amplifier square wave output out of tolerance from zero reference.	Electrical tolerance buildup. Test specification is not compatible with circuit design.	Improper operation.	Assure that test specifications are compatible with design limits of the hardware.
12	D. C. Amplifier	Open channel in D. C. Amplifier.	Electrical overstress externally applied as result of test error.	Loss of one of the 14 thrusters and possible loss of CMG mode in astronaut maneuvering equipment.	Assure test procedure is sufficiently detailed to reduce possible operator error.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
13	Electronic Interface Unit	Incorrect operation of teleprinter.	Condition caused by power transient on control line.	Voltage spike is sufficient to reset teleprinter.	Provide in-depth design reviews and more thorough EMI testing to assure protection from unwanted noise spikes.
14	Ergometer	Circuit sensitive to shape of input pulse.	Inadequate design.	Low heartbeat indications.	Provide for and perform meaningful reliability/design reviews early in program. Perform test program to verify design.
15	Ergometer	Excessive current draw due to mechanical shift in zero adjust potten-tiometer.	No requirement for lock tite on adjustment screw.	Assembly will not function as intended.	Ensure design provides for application of locking/sealing material to adjustable pots to prevent mechanical shift.
16	Ergometer	Water condensing internal to electro-nic module causing slow response to input signals.	Condensation dur-ing humidity testing.	Slow response to signals and eventual short circuit.	Do not test equipment in environment more severe than that in which it is to be used. Add caution note to procedure to avoid sub-jecting component to dew point. If dew point occurs, take steps to dry component prior to further testing.
17	Experiment Support System	Power monitor signal conditioner voltage output will not stablize.	Defective zener diode — excessive voids in eutectic bond between chip and header and between header and external lead.	Improper operation of power signal conditioner.	Replace 1N4611 zener diodes with S1N827A zener diodes.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
18	Experiment Support System.	Lack of interchangeability between acclusion cuffs and electronics modules.	Lack of interface controls on flight and backup hardware.	Out-of-tolerance blood pressure readings.	Implement and enforce an adequate configuration control system.
19	Experiment Support System	Nonflight hardware used in flight backup unit.	There were no serial numbers required for this item until after assembly and functional test. Mfg. inspection records were inadvertently exchanged for the flight unit and trainer prior to serialization.	Out of specification isolation resistance between 28 VDC return on the events timer and the secondary display.	Assure clear markings for nonflight articles and effective records control to prevent mixing.
20	Expiration Spirometer	Position switch on the expiration spirometer does not operate consistently.	Auxiliary actuator arm was misaligned. Manufacturing error due to failure to comply with EO before installation.	Erratic operation of the metabolic analyzer.	Provide adequate inspection points to assure all outstanding EO's are worked correctly.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
21	Expiration Spirometer	Expiration spirometer exhibited excessive noise in the 6 and 7 liter position. Position indicator lock down screw turns with nut, preventing proper lock down of potentiometer.	Potentiometer drive cable improperly installed and position indicator lock down screw also improperly installed.	Improper operation of expiration spirometer.	Implement inprocess inspection to assure proper assembly.
22	Filter, Electromagnetic Interference	Shorted inductor in EMI filter.	Inductor miswired.	Input short in the EMI filter which would cause a high current draw at the next higher assembly.	Impose more stringent inprocess inspection.
23	Fire Sensor Control Panel	Relay did not function properly.	Overstress on relay terminals cracking glass header.	Damage/contamination of internal parts of relay.	Implement 100 percent vendor inspection requirements. Ensure personnel are properly trained and are using correct assembly procedures.
24	Fire Sensor Control Panel	Relay would not operate.	Armature leaf spring in relay was bent and interfered/restricted movement of armature assembly.	Relay inoperative.	Assure adequate inprocess inspection during relay buildup and test.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
25	Generator, Tone.	Defective solder joints.	Inadequate assembly and inspection procedures.	Tone generator does not operate properly.	Assure adequate assembly and inspection procedures exist.
26	High Intensity Light.	Energizing high intensity light caused excessive ripple voltage on bus.	No RFI filters used.	Possible interference to equipment using this bus as a power source.	Use RFI filters where necessary.
27	Intercom Box Panel.	Master alarm indication incorrect	Wires reversed on panel lamps.	Incorrect alarm indication.	Perform continuity testing after installation of critical flight hardware.
28	Inverter, Environmental Control System.	Loss of filter capacitor.	Capacitor lead fatigue during vibration.	Failure of component to perform intended function.	Perform design review to assure drawings require piece parts to be staked to P. C. boards.
29	Mass Spectrometer.	Mass Spectrometer buffer amplifier saturation.	Inadequate magnetic shielding.	Metabolic analyzer display reads out of specification.	Assure design checklist contains provisions for checking magnetic shielding requirements.
30	Master Measuring Device	Power supply failed.	Diode failed as result of thermal stress — momentary surge of 40A.	Failure of component to perform intended function.	Perform design review to assure proper component selection.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
31	Metabolic Analyzer	Improper function.	Split-ring lock washer used to mount transistor stud to heat sink pierced mylar insulation and shorted collector to chassis.	Collector transistor in power supply regulator shorted to chasis.	Perform design review to assure lock washers are not used in direct contact with insulated coating on chasis for transistor installations.
32	Metabolic Analyzer	Loose connections on PC board causing defective trigger circuit in metabolic analyzer.	Poor workmanship.	The oxygen consumed parameter failed to indicate expected values.	Increase training and implement inprocess inspection.
33	Oscillator, RF	Failure to oscillate.	Poor wetting of solder to connector pins.	Loss of transmitted data.	Initiate soldering/inspection certification program.
34	PCM/DDAS Mod 301	Defective transistor transistor.	Heat conductor washer missing from transistor mount.	Transistor overheated and failed.	Verify engineering drawings are correct/ complete. Impose 100 percent assembly inspection.
35	Pre-Amplifier Accelerometer	Pre-Amplifier Assembly non-operational.	Defective weld on feed thru wire.	Loss of intended function.	Initiate welding certification program.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
36	Pulse Height Analyzer	Voltage comparator failed.	Comparator made inoperative due to excessive voltage spike due to high voltage-arching through improperly cured potting and conformal coating.	Failure of component to perform intended function.	Upgrade inspection and fabrication procedure to assure proper cure time is maintained prior to unit going to test.
37	Rapid Pressure Loss Detector	Rapid pressure loss detector alarm received.	Internal instability of detector assembly.	Alarm initiated in error.	Conduct frequent design reviews to assure compatibility of equipment.
38	Receiver/ Decoder, Digital Command System	DCS secondary receiver does not process data properly.	Open diode caused by cold shock.	Diode failed.	Review test requirements to assure proper test criteria.
39	Signal Conditioner	Shorted zener diode in signal conditioner.	Inadvertent reversal of ± 10 VDC power, causing excessive heat and reflow of solder bridging zener diode.	Loss of 2.5 VDC offset voltage for the assembly.	Assure test tools and associated circuitry provide protection from inadvertent power reversals.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
40	Signal Conditioner	Cardiotachometer signal conditioner was out of specification during acceptance testing.	Signal conditioner was calibrated by the vendor but requires calibration within the system.	Possible erroneous output.	Assure that acceptance test procedures provide for in-system calibration when necessary.
41	Signal Conditioner	Common mode output voltage too high.	Improperly matched zener diodes.	Improper signal levels.	Perform design/engineering reviews to assure when matched components are necessary; this requirement is highlighted on drawings.
42	Signal Conditioner, ECG.	Signal conditioner had no output.	Loose connection.	Loss of data.	Impose inprocess inspection prior to potting.
43	Skylab Medical Environmental Altitude Test	Failure caused by bad solder joint on tuning fork in oscillator.	Copper flash over plating on piezoelectric crystal did not fuse.	Vibration/temperature cycles resulted in intermittent operation.	Assure all types of soldering techniques/materials used are qualified/certified.
44	S0-54 Experiment	Misapplication of voltage (overstress) on S0-54 telescope during receiving inspection.	Inadequate test methods/techniques during receiving inspection.	Thermal controller for forward housing failed to operate properly.	Initiate training program to ensure receiving inspection personnel use proper test methods/techniques.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
45	Speaker Intercom.	Select knob is misaligned.	Jam nuts on selector switch loose.	Incorrect operation of selector switch.	Apply retaining compound (i.e., lock tite) on jam nuts.
46	Spectroheliometer.	Resistor improperly connected.	Manufacturing error — technician failed to solder connection.	Unit fails to operate as intended.	Initiate "flight awareness" program, upgrade inspection performance.
47	Summer Assembly.	Output was improper.	Input transistor elements in the operational amplifier were damaged by excessive voltage by using the wrong ohm meter during post pot test.	Loss of rate mode of operation for maneuvering equipment.	Assure that test procedures specify adequate test equipment for each test.
48	Sun End Canister.	Aperture door lever retaining nut and bushing on motor carriage loose.	Design deficiency. No safety locking feature.	Damage to assembly.	Initiate design reviews to look for safety/locking features and provide for same as required.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
49	Tape Recorder.	Loss of sync during data dump from tape recorder.	Improper operation of tape recorder due to design incompatibility between OWS and Airlock Module.	Incorrect data transmission.	Conduct design review to assure compatibility of equipment.
50	Tape Recorder.	Tape recorder inoperative.	Incorrect procedures for pre-run adjustments and operation.	Tape recorder damaged.	Develop detail procedures to assure proper pre-run adjustments are made correctly — equipment is operated properly.
51	Tape Recorder.	Hard over stop not machined properly on tape recorder.	Machining instructions and changes were not clearly reflected on the drawings.	Supply compliance arm locked in hard over against the spring position.	Assure that drawings clearly define machining instructions and also assure that inprocess inspection is sufficient to expose such occurrences.
52	Tape Recorder.	Surface roughness of tape recorder carrier brake was not to specification and some adhesive was left on braking surface.	During rework after redesign the grit blast treatment was inadvertently omitted.	Tape recorder will not operate due to sticking of the brake surfaces.	Assure that rework instructions and drawing notes are adequate to prevent omissions of process steps. Also, assure that adequate inspection and testing is performed to verify recertification after rework.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
53	Tape Recorder.	High resistence on two tracks of tape recorder.	An open and cracked resistor on each of two printed circuit boards caused by improper handling during installation and from thermal stress due to insufficient strain relief in resistor leads.	High resistance across pins on record amplifier board which caused a high resistance on effected track of tape recorder.	Inspect all resistors with 40X magnification prior to mounting. Revise drawings to require adequate strain relief and perform DC impedance check before and after comformal coating.
54	Tape Recorder.	In the 60 in. per second (ips) record mode, tape speed was below normal.	A combination of pinch roller actuator adjustment and a worst case reel brake loading caused brake drag, result-in an inability to reach operating speed.	Distortion of data.	Design pinch roller actuator circuitry to effectively control brake drag and perform adequate testing to assure proper operation in all possible environments.
55	Tape Recorder.	Transistor marginally conductive.	Improperly installed swage terminal, resulting in high resistance.	Failure to start/record.	Perform design review to assure roll type swage terminals are not used on PC boards.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
56	Tape Recorder.	Loss of tape recorder data.	Contamination of record head.	Failure to record.	Assure proper/complete maintenance procedures identify cleaning frequency and method.
57	Tape Recorder Sleep Monitoring System.	Switch for tape recorders No. 1 and No. 2 was wired in reverse.	Wiring diagram error.	Improper operation.	Implement drawing reviews prior to drawing release to assure drawing accuracy.
58	Thermal Conditioning Fan.	Fan did not operate properly.	Fan wires connected to wrong terminals, incorrect setting on elapsed time delay relay.	Fan would not come up to speed.	Perform continuity testing after installation and verify procedures are adequate for proper setting of relays.
59	Thermal Control.	Simultaneous heat exchanger commands received regardless of switch position, all four heat exchangers.	Spacecraft thermal control system circuitry creates a back bias condition, causing on and off lamps to light simultaneously.	Possible loss of thermal control system.	Perform adequate circuit analysis to prevent such incompatabilities within a system. Also, provide adequate testing to reveal such shortcomings in circuit design.

ELECTRICAL/ELECTRONIC ASSEMBLIES (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
60	Timer, Electronic.	Timer failed to operate.	Toggle switch handle damaged — personnel mis-handling of equipment.	Mechanical internal binding — causing intermittent clock operation.	Provide "proper handling of equipment" procedures.
61	Timer, Portable.	Malfunction of electronic timer assembly.	Wire broken and damaged due to handling.	Timer would not operate upon signal, operation intermit-tent.	Establish program to motivate personnel to be more cautious in handling flight critical equipment.
62	Transmitter.	Transmitter output did not meet specification requirements.	Low transmitter output caused by variable capacitor.	When variable capac itor is adjusted to extreme low end, it bottoms out causing resistance short.	Perform design reviews to assure variable components are selected to operate in the mid-range rather than to the high or low side.

INTEGRATED CIRCUITS PRINTED CIRCUIT BOARDS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Integrated Circuit.	Integrated circuit in transmitter had an internal short due to lifted die bond, allowing lead to short against another lead.	Inadequate bond due to low bonding temperature caused by inadequate preheat at startup.	Data loss of transmitter from a single channel to all channels.	Assure procedures and processes are adequate and adhered to, especially temperatures at the start of a production run. Screen 100 percent of all received integrated circuits used in flight systems.
2	Integrated Circuit.	Failure to switch and out of tolerance.	Open metallization at base contact windows.	Severe metallization cracks.	Procure high reliability flight hardware to MSFC specifications. This will assure wafer traceability and SEM analysis of the metallization at wafer level.
3	Integrated Circuit.	No output.	Open metallization trace.	Failed to perform as intended.	Initiate 100 percent screening of IC's and perform acceptance testing to verify manufacture process.
4	Micro Electronic Circuit.	Particle contamination.	Inadequate manufacturing processes.	Microelectronic circuit failure.	Use parts that have passed the monitored vibration/shock test.
5	Micro Electronic Circuit.	Lid sealing techniques using solder (gold-tin preform).	Loose gold-tin balls.	Short circuit across the metallization inside the package.	Use quartz passivated devices qualified to hi-rel. spec. 85M03766.

INTEGRATED CIRCUITS PRINTED CIRCUIT BOARDS (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
6	Micro Circuit.	Cracks in insulating material between lead and lid seam or at lid attach junction in Dual Inline Packages (DIP's).	Temperature cycling on conformal coated P.C. boards, where conformal coating surrounded DIP.	Stress due to conformal coating.	Where possible, use device in flat package, or if pin requirement permits, the round can package. These packages may be conformal coated without destroying package integrity.
7	Micro Circuit.	Open input.	Cracking of glass seal which allowed fine leak.	Formation of dendrites due to corrosion of molybdenum.	Consider using new design which replaces molybdenum with titanium-tungsten alloy and has layer of S_i0_2 over the metallization.
8	Printed Circuit Board.	Record Amplifier Board has intermittent output.	Overstressed solder joints due to a combination of conformal coating and exposure to -40° F.	Possible loss of channel on recorder.	Extreme care should be exercised when using conformal coated P. C. Boards at low temperature.
9	Printed Circuit Board.	CBRM regulator will not turn on.	Solder bridge between two P.C. Boards.	No output from CBRM.	Initiate 100 percent inspection of printed circuit boards during fabrication.
10	Printed Circuit Board.	Extra wire on P.C. card in logic distributor.	Design error.	Fuse blown.	Assure adequate design review.

INTEGRATED CIRCUITS PRINTED CIRCUIT BOARDS (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
11	Printed Circuit Board.	Short circuit, signal to ground.	Ground plane layer of multi-layer P.C. Board misaligned.	Failed to function in intended manner.	Improve inprocess inspection techniques of P.C. Board. Improve P.C. Board test procedures.
12	Printed Circuit Board.	Excessive current leakage through conformal coating at elevated temperatures.	Resistance of the conformal coating is a function of thickness. The coating in this case was very thick and at elevated temperature leakage was excessive.	Diastolic pressure reading would be inaccurate.	Clean prior to coating and apply coating thinly to reduce current leakage. Assure that specification limits are realistic and can be met at higher operating temperatures.
13	Printed Circuit Board.	Open circuit on P.C. board.	Electrical over-stress caused when P.C. Board was plugged into set while power was "on."	Damage to PCB circuit.	Assure test procedures are reviewed by quality control to verify power is "off" during insertion/removal of P. C. Boards.

INTEGRATED CIRCUITS PRINTED CIRCUIT BOARDS (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
14	Printed Circuit Board.	Cracks in conformal coating.	Inadequate process procedures.	Possible moisture contamination.	Revise manufacturing process procedures to incorporate the following changes: (1) Vacuum de-aeration of coating for five to ten minutes at two to four mm Hg at 140° F, plus or minus five degrees, after application and prior to cure. (2) A pre-cure of two hours, plus or minus ten minutes, at 145° F, plus or minus five degrees, followed by curing at 175° F for 16 hours.

POWER SUPPLIES

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Power Supply.	Power supply circuit breaker tripped and would not hold closed.	Ground wire missing on pre-regulator card.	Interruption to experiment power supply.	Perform continuity testing to assure proper installation.

RELAYS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Relay.	Relay failed during testing.	Relay contacts welded due to excess current.	Misapplication or relay.	Perform design review to prevent misapplication of parts.
2	Relay.	Contamination.	Very small non-metallic particles.	Particles lodge between moveable contact and result in no contact closure.	Since it is impossible to eliminate particles of this small size, assess effects of relay contacts failing to make contact and, where a critical application is found, consider adding redundancy.

SEMICONDUCTORS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Diode	Fractured glass and misaligned studs on diode	Handling and/or installation damage	Improper output of next higher assembly	Caution personnel on proper handling and installation and provide adequate pre-pot visual inspection
2	Diode	Diode open	Manufacturing defect, faulty lead to diode contact	An open circuit to the leg band calibration assembly	Review failure history of part to determine if problem is vendor or personnel related and take appropriate action
3	Diode	Diode failed reverse voltage requirements	Flow in silicon lattice structure subsequently augmented by forward conduction stresses	Failure of next higher assembly	Procure diodes of planar construction instead of mesa type
4	Diode	Zener diodes exhibiting early breakdown current in protective circuit	Lack of screening of diodes prior to installation to assure adequate parameters	Telemetry error for oxygen consumed	Provide screening requirements for use of selected piece parts
5	Diode	Separation of cathode lead and die	Use of crimped kovar lead devices, with gold-germanium soldering lead-to-die in cordwood modules	Stresses induced by temperature changes caused the cathode lead-to-die bond to open	Devices in critical applications should be 100 percent screened (burn-in, etc.) in accordance with MSFC Drawing 85M02713

SEMICONDUCTORS (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
6	Diode.	Failed open during manufacturing test.	Compression bonding with glass body material holding chip and lead studs together mechanically.	Open at connection between chip and studs.	Use S1N parts per MSFC Drawing 85M03895.
7	Diode.	Low reverse resistance.	Microcracking of silicon chip on anode region close to silver button contact.	Metal migration through cracks.	On silver anode contact G.E. double heat-sink diodes older than 1970, determine whether single failure point can cause unacceptable performance degradation. If so, replace with silicon contact diode.
8	Diode.	Reverse breakdown voltage.	Contamination	Improper operation of device.	Assure adequate inprocess controls to prevent contamination. Implement tighter screening requirements.
9	Transistor	Transistor open.	Output was grounded accidentally, overstressing the part.	Open base to emitter.	Assure that personnel have been properly trained and cautioned, and assure that sufficient separation of circuits exists to permit measurements.

SEMICONDUCTORS (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
10	Transistor.	Electrical open condition between emitter bond wires and bonding pads.	Embrittling impurity (sulfur, oxygen and silver) in the grain boundaries of the wire.	Horizontal cracks along full length and width of bonds. Wires sheared horizontally at wire bond interface and moved away from bonding pad, leaving part of bonded wires adhering to pads.	For switching applications select parts with low saturation voltage and low leakage current. This results in low power dissipation during the on condition, with reduced thermal stress.
11	Transistor.	Electrical short.	Conductive particle across chip's base metallization and collector region. Weld expulsion was observed in region of header cap weld.	Collector-to-base short.	Implement suitable form of loose particle detection, such as acoustic particle detection.
12	Transistor.	Intermittent or permanent shoring.	Weld splatter during sealing.	Splashes of metal particles become loose during vibration tests.	Use "Weld Splash Barrier Ring" or any other method which will prevent occurrence or spread of weld splatter.
13	Transistor.	Shorted collector to base.	Internal metallic contamination.	Failed to function as intended.	Initiate 100 percent screening to verify manufacturer's process.

SEMICONDUCTORS (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
14	Transistor.	Bond failures.	Excessive bonding pressure, inadequate wire service loop and distortion of bond.	Cracking and separation of bonded wire at heel of bond.	Do not use transistors built with 1-mil AL TC-wedge bonds in future space applications. Observe safe application limits recommended in ALERT MSFC-69-10B for hardware already installed.
15	Transistor.	High leakage current.	Cracked dies, exposed junctions and lifted metallization.	Instability of parts.	Measure all high power mesa transistors at periodic intervals to ensure stability.

TRANSDUCERS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Transducer.	Out of tolerance output levels on transducers.	Calibrated with 24K ohm output load instead of 1 megohm.	Did not function as intended.	Assure proper calibration procedures are used. Require procedure review for completeness and correctness.
2	Transducer.	Loss of output voltage regulation.	Open weld in voltage adjust resistor.	Component malfunctioned during test.	Assure that source inspection and manufacturing requirements are adequate for welding process.
3	Transducer.	Out of tolerance readings on transducer.	Slow leak in transducer case.	Incorrect operation of transducer.	Assure adequate improcess inspection during buildup and test.
4	Transducer.	Transducer readings did not correspond to flow rates.	Contamination of transducer wiring by conductive substance.	Caused conductive path between terminal A and case resulting in unstable operation of transducer.	Assure proper cleanliness requirement are observed during installation and operation.
5	Transducer.	Pressure transducer offset.	Condensation had accumulated in the transducer during humidity test.	Degradation or shift of absolute blood pressure data but no effect on relative readings after failure.	Do not perform humidity tests on items susceptible to condensation unless it is required. Take precautions to protect item from condensation.

TRANSDUCERS (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
6	Transducer.	No output voltage on one secondary winding.	Broken wire and cold solder joints at winding to terminal connections inside the case.	Open winding.	Revise transformer design to incorporate a stress relief service loop in the winding-to-terminal leads. Extend winding leads through the terminals and wrap externally to provide inspectability of solder joints.
7	Transducer, Pressure.	Coolant pump pressure decay.	Transducer output intermittent.	Incorrect pressure readings.	Improve inprocess inspection and manufacturing techniques to assure reliable parts.

UMBILICALS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Umbilicals.	Broken wire at umbilical cable connector pin.	Stress induced during previous rework.	Intermittent open.	Assure that care is taken to prevent over-stressing wires during rework.

MISCELLANEOUS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Brush Material.	Poor mechanical bond between brush block and holder.	Unsatisfactory soldering procedure.	Separation of the brush block from the brush holder.	Initiate change to soldering technique for this type brush material.
2	Drive Assembly.	Drive assembly binding of rotor to starter.	Marginal design including eccen-tricity of rotor and thermal expansion.	Binding and eventual seizing of drive assembly.	Design in dimensional allowances for thermal expansion.
3	Motorized Door.	Aperture door primary motor winding shorted to case.	Motor brush leads too long, allowing leads to short electrically to case.	Loss of motor.	Assure fabrication and inspection techniques are adequate to prevent this type discrepancy.
4	Operation Mechanism.	Aperture door primary motor winding grounding to structure.	Screw missing in switch bracket allowing movement which shorted motor winding.	Loss of motor.	Initiate periodic maintenance inspection of motors, etc.
5	Photon Coupled Isolator.	Erratic operation during temperature cycling.	Poor internal bond in the parts.	Erratic pulse width modulator output/ operation.	Institute a precap visual inspection on all parts and a sample bond pull-to-distruct on each lot of parts.

MISCELLANEOUS (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
6	Stub Antenna.	High VSWR.	Improper antenna assembly.	Failed to perform as intended.	Verify adequate assembly and inspection procedures are available.
7	Water Heater.	Water temperature below specified requirements.	Voltage was below test specification requirements.	Water temperatures below specification requirements.	Assure that specification requirements for interfacing equipment are compatible.

SECTION 2. MECHANICAL

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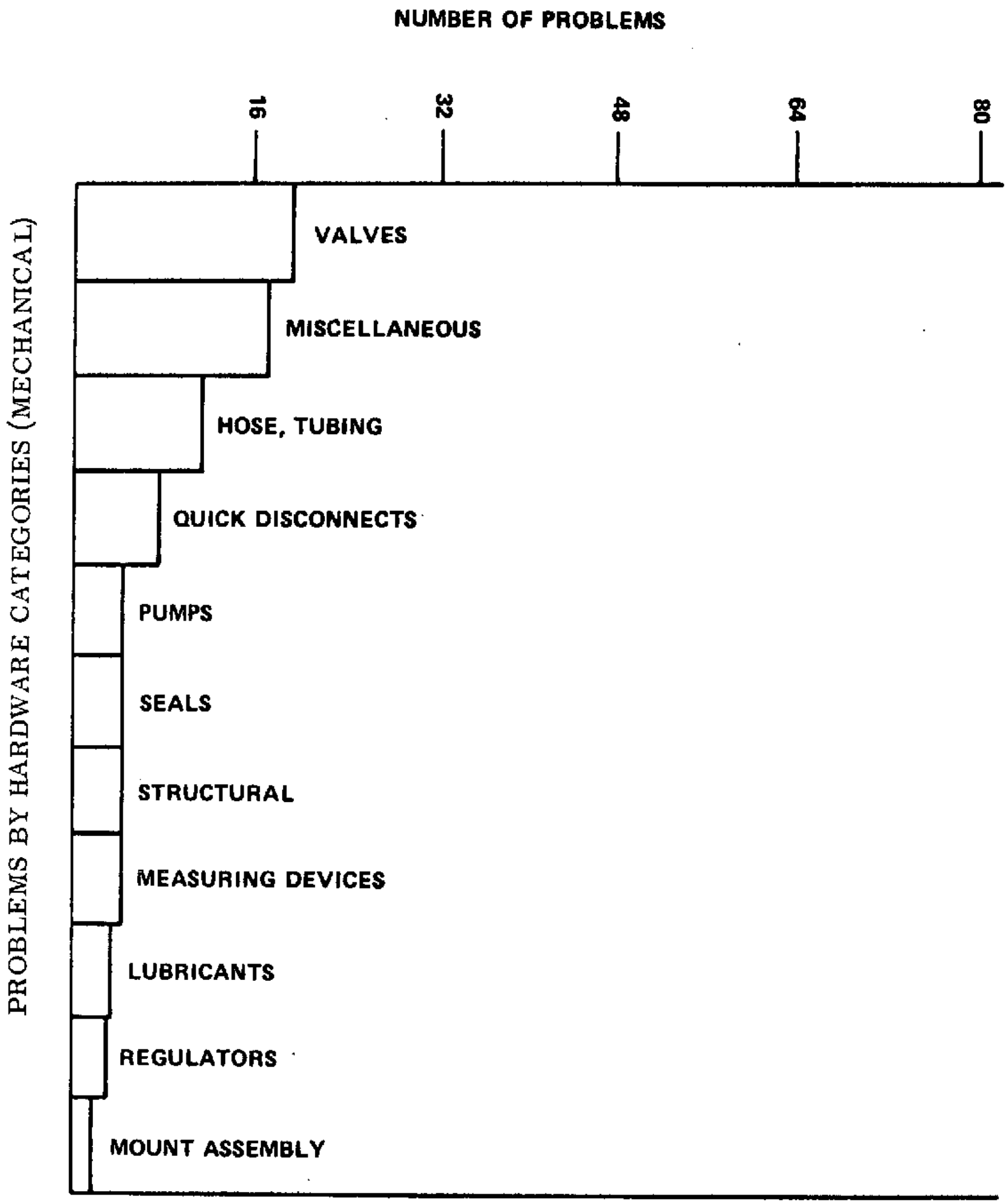
HARDWARE INDEX MECHANICAL

HARDWARE INDEX MECHANICAL

HARDWARE	Page
MISCELLANEOUS (Concluded)	


NUMBER OF PROBLEMS
16
32
48
64
80
VALVES
MISCELLANEOUS
HOSE, TUBING
QUICK DISCONNECTS
PUMPS
SEALS
STRUCTURAL
MEASURING DEVICES
LUBRICANTS
REGULATORS
MOUNT ASSEMBLY
PROBLEMS BY HARDWARE CATEGORIES (MECHANICAL)

PROBLEM INDEX MECHANICAL

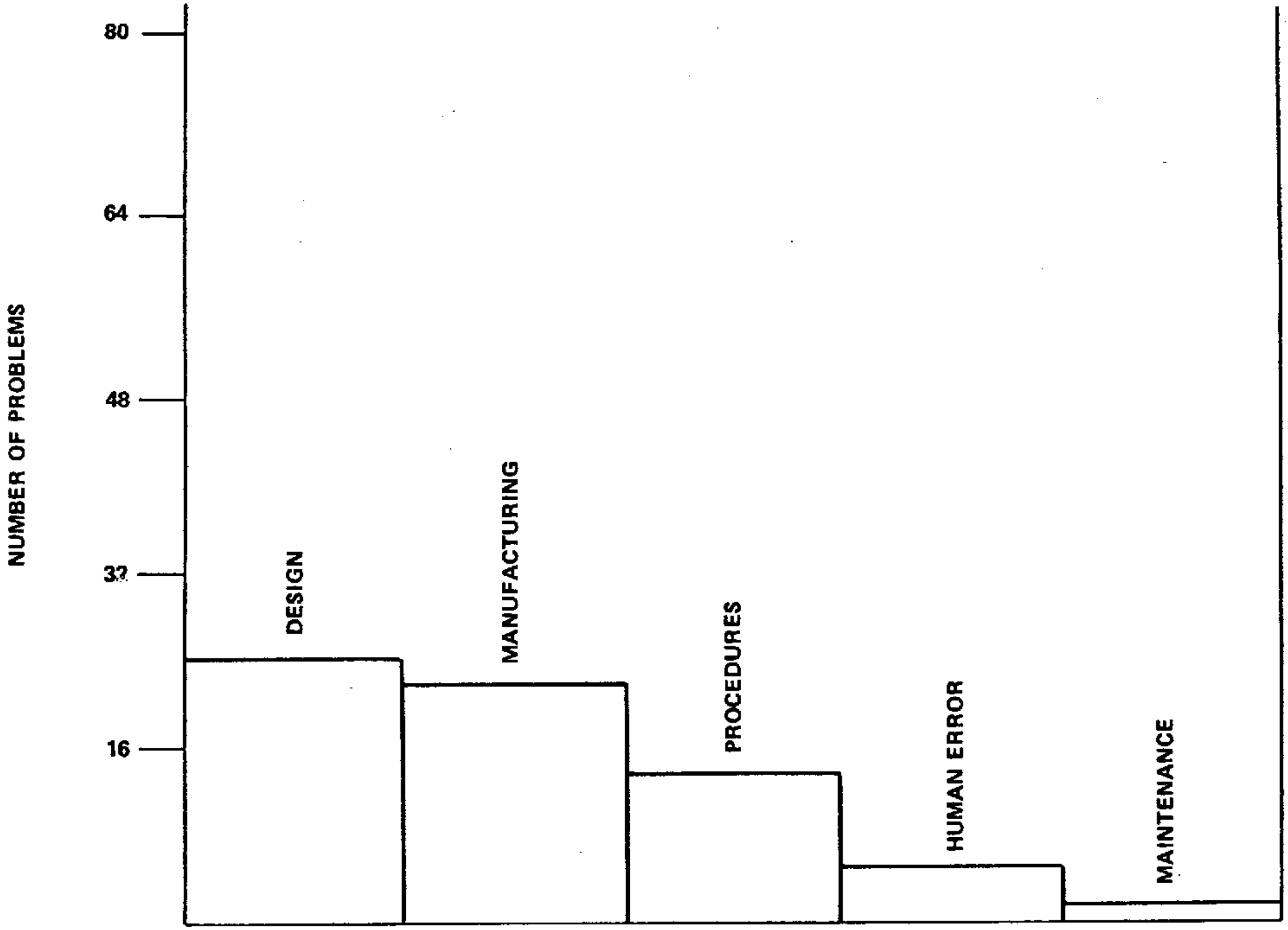
PROBLEM INDEX MECHANICAL

PROBLEM INDEX MECHANICAL

PROBLEM INDEX MECHANICAL

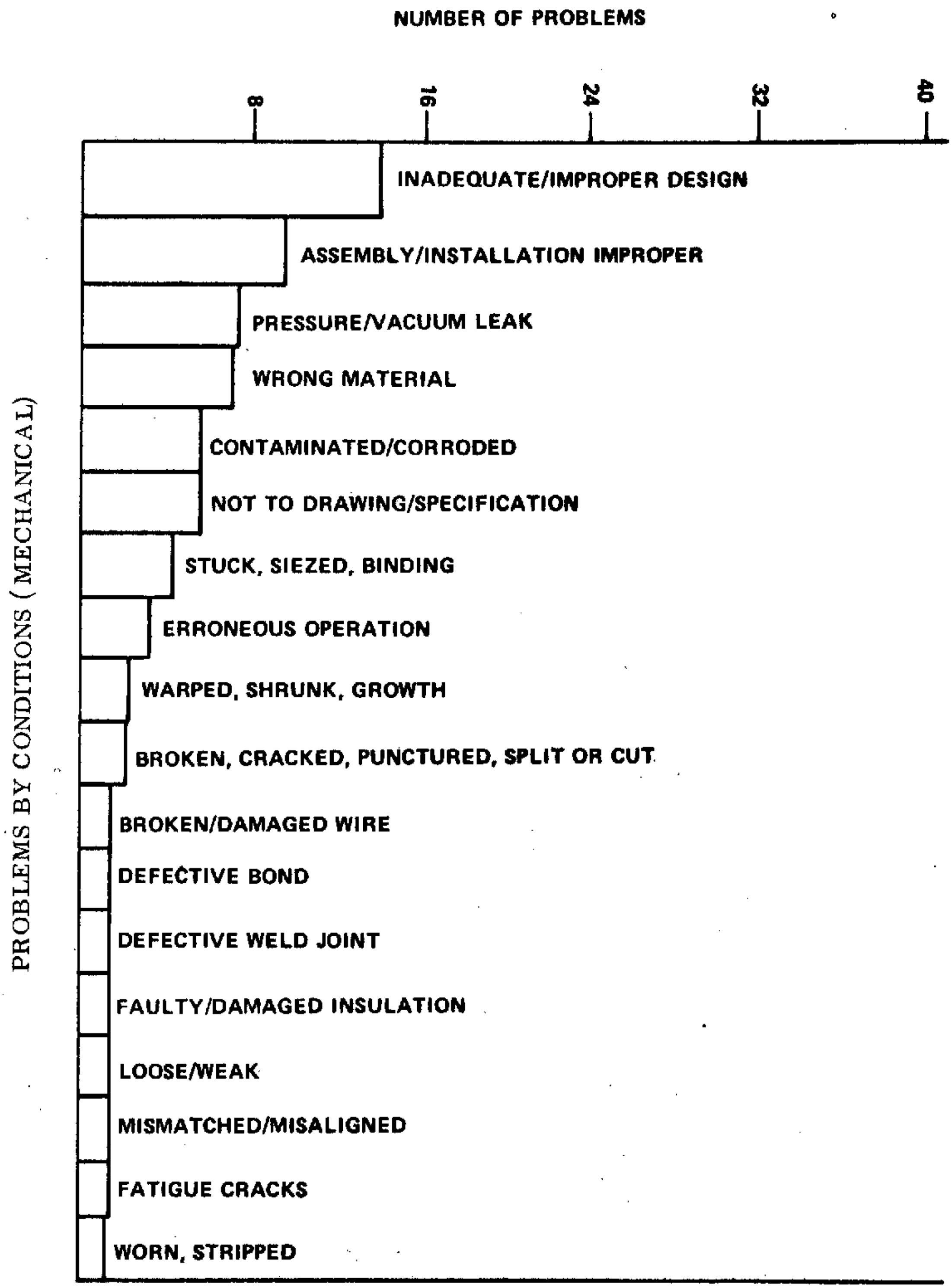
PROBLEM INDEX MECHANICAL

PROBLEMS BY CAUSE (MECHANICAL)



CONDITION INDEX MECHANICAL

CONDITION INDEX MECHANICAL


NUMBER OF PROBLEMS
8
16
24
32
40
PROBLEMS BY CONDITIONS (MECHANICAL)
INADEQUATE/IMPROPER DESIGN
ASSEMBLY/INSTALLATION IMPROPER
PRESSURE/VACUUM LEAK
WRONG MATERIAL
CONTAMINATED/CORRODED
NOT TO DRAWING/SPECIFICATION
STUCK, SIEZED, BINDING
ERRONEOUS OPERATION
WARPED, SHRUNK, GROWTH
BROKEN, CRACKED, PUNCTURED, SPLIT OR CUT
BROKEN/DAMAGED WIRE
DEFECTIVE BOND
DEFECTIVE WELD JOINT
FAULTY/DAMAGED INSULATION
LOOSE/WEAK
MISMATCHED/MISALIGNED
FATIGUE CRACKS
WORN, STRIPPED

MECHANICAL PROBLEM SUMMARY

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FITTINGS/HOSE/TUBING

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Fitting	Fitting would not lock	Fitting was painted in the area of locking feature	Fitting locking feature was binding and not locking	Assure procedures address proper precautions regarding the painting of devices with locking features.
2	Fitting	Transducer to bottle braze joint has an audible leak	Lack of fillet and edge melt	Loss of pressure	Assure all braze joints are made according to established procedures (especially on pressure vessels), visually inspected and X-rayed prior to installation into system.
3	Fitting	Vacuum source port fitting loose	Torque values not high enough	Possible loss of structural integrity	Assure torque values high enough to preclude loosening are specified.
4	Fitting	Cracked swivel nut	Wrong material	Stress corrosion	Verify use of proper material by eddy current method.
5	Hose Assembly	Hose failed pressure decay test at user site	Hose tested incorrectly at user site	Hose rejected in error due to difference in test method between supplier and user	Assure adequate and proper test methods are used and are compatible with supplier test methods and engineering requirements.
6	Hose Assembly	Hose failed in fatigue	Hose mishandled	Hose assembly rendered unfit for application	Assure personnel are trained in proper handling, and installation of critical flight hardware.

FITTINGS/HOSE/TUBING (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
7	Tube Assembly	Decay of pressure during test	Conical seal in tube assembly defective. Tube was twisted during torque operation	Leakage rate above specified rates	Assure proper procedures exist for torque-ing. Operation should require witness by inspection.
8	Tube Assembly	Loose "B" nut on tube assembly — scratch on sealing surface	Improper handling and torque appli-cation	Coolant leaked out	Assure proper procedures exist for inspection and installation of tubing.
9	Tubing	Corrosion	Inadequate con-trol of pickling, rinsing, or drying procedures	Strains and pits on inner surface	Visually do 100 percent inspection at receiving inspection and again when issuing to production. Sample inspect with eddy current and borescope. Pickle and passiva passivate tubing after forming. If tubing is to be brazed, then pickle and passivate prior to brazing.
10	Urine Hose	Collection funnel on UVMS hose would not allow circulation	Football value prevented recirculation	Funnel overflow — spacecraft contami-nation	Provide for and perform meaninfgul reliability/design reviews early in program. Perform test program to verify design.

LUBRICANTS/CHEMICALS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Leak Detector, Liquid.	Leakage.	Stress corrosion due to a high temperature environment in presence of chlorides.	Cracks in 321 stainless steel.	Use leak detection liquids in accordance with MSFC-SPEC-384A which limits chloride concentration to 10 PPM or use other methods of leak detection such as mass spectrometer analysis for space vehicle systems.
2	Lubricant.	Inspiration spirometer drive motor noisy and rough operation.	Incompatibility of lubricant and seal.	Noisy and rough spirometer operation.	Assure that lubricants are compatible with seal material.

MEASURING DEVICE

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Flow Meter.	Operation of flow meter was erratic.	Bearings worn causing binding of turbine.	Flow meter indication erroneous.	Assure maintenance procedures are adequate and require inspection of units based on operating life of parts.
2	Gauge, 0-20 psi H_2O.	Pressure gauge damaged.	Gauge pressurized to 50 psi due to procedure error.	Gauge destroyed.	Assure complete procedure review prior to implementation.
3	Gauge, Strain.	Deployment cable strain gauge reading not repeatable.	Strain gauges not located properly.	Inaccurate solar wing assembly deployment data.	Ensure through test program that deployment cable strain gauges are properly located to achieve repeatability as well as proper deployment.

MOUNT ASSEMBLY

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Mount Assembly.	Mount hub debonded from rubber shock mount core.	Debond of polymer material due to insufficient material in the mount housing.	Core rotation resulting in improper alignment of the guide pin.	Perform design review to determine proper bonding area required.

PUMPS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Methanol/ Water Pump.	Methanol/water pump bearing/ shaft tolerance too tight.	Fiberite bearing material swells in methanol/water solution.	Failure of pump.	Perform design evaluation to determine proper bearing/shaft size and proper bearing material for use in methanol/water solution.
2	Water Pump.	Pump failed to meet output requirements.	Pump would not operate due to contaminant (nickel urthosilicate).	Contamination prevented movement of rotor assembly.	Assure coolant fluid is compatible with pump design selected.
3	Water Pump.	Pump stopped operating.	Lead wires pinched and shorted to ground when pump cage was installed.	Pump would not operate.	Assure adequate installation instructions and caution notes exist. Upgrade inspection and test procedures to verify proper installation prior to power up.

QUICK DISCONNECTS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Quick Disconnect.	Quick disconnect would not lock automatically in connected position.	Standard $2\frac{1}{2}$ coil sleeve spring was too long and forced sleeve to bind.	Quick disconnect had to be manually locked.	Designer should review standard parts used in special applications to assure proper operation.
2	Quick Disconnect.	Quick disconnect leaks.	"O" ring cut by metal particles on burred edge of "O" ring groove.	System unable to maintain pressure.	Assure proper cleaning, deburring and inspection of critical parts.
3	Quick Disconnect.	Quick disconnect leaks.	"O" ring groove in body of coupler oversize.	System unable to maintain pressure.	Assure adequate inspection procedures exist to verify all parameters are checked prior to acceptance of part.
4	Quick Disconnect.	Quick disconnect leaks.	"O" rings had scuff marks, nicks, and lacked lubrication.	System unable to maintain pressure.	Assure adequate procedures exist that require proper inspection and lubrication of "O" rings.
5	Quick Disconnect.	Missing "O" ring fragment.	Small porosities resulted in permeation by air under pressure.	Separation of fragment.	Perform evaluation to determine consequences of "O" ring migration into system.

QUICK DISCONNECTS (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
6	Quick Disconnect.	Flange distorts and may fail "in bearing."	Thinning down the poppet stem flange so that it doesn't bottom against seat sealing surface and carry part of poppet compressive loading due to pressure.	Cracks and gross deformation of poppet valve.	Do not use 0.75 in. Quick Disconnects manufactured between 5/12/72 and 12/31/73. Also, check any larger size since they could have same problem.

REGULATORS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Oxygen Supply Pressure Regulator.	Pressure regulator leaks.	Leak caused by eccentricity of the conical seating surface with respect to the two ends of the valve stem.	Regulator would not maintain pressure.	Assure adequate inspection procedures and techniques exist to verify all parameters are checked prior to stocking or using parts.
2	Regulator.	Unable to purge regulator.	Test procedure error.	Unable to complete regulator purge.	Assure adequate test procedures are available and are compatible with component to be tested.

SEALS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Sealing Device.	Tab locking device does not operate properly.	Tab dimensions are not in accordance with drawing requirements.	Device failed to seal.	Upgrade inspection to assure components are manufactured to drawing/engineering requirements.
2	Seals.	Hatch seals have voids and soft spots.	Insufficient control of material by vendor during seal manufacture.	Lost sealing capability.	Impose process controls during manufacture. Treat sealing surfaces and seals to prevent sticking after installation.
3	Seals.	Leakage at scientific airlock window seal.	Very minor discrepancies in frame and a tool or die mark in one corner of seal.	Possible loss of positive pressure in OWS.	Specify helium leak test after proof pressure test. Rework any leaks that occur during acceptance test. Maintain age control records on seals and assure that seals are compatible with all process chemicals and sealing compounds.

STRUCTURAL

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Film Retrieval Door.	Door latch mechanism jammed in open position.	Improper torque during assembly.	Unable to close film access door.	Assure adequate torque and inspection procedures.
2	Meteoroid Shield.	Bulb seal rolled under forward swing links.	Tension straps at main tunnel mis-located 0.08 in. too high.	Inability to latch meteoroid shield after deployment.	Ensure processing and installation instructions provide necessary detail to achieve proper bulb seal fit and clearance.
3	OWS Structure Assembly.	Panel assembly calfax fasteners will not align with mating framework.	Buildup of tolerances between fairings and structure.	Unable to assemble panel cover.	Assure that cumulative tolerances have been considered; fit check early in fabrication process to verify proper fit.

VALVES/MODULES

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Identification Module.	High resistance from test point to chassis ground.	High resistance due to iridite coating on chassis.	Erroneous identification signals.	Perform drawing review to assure all non-conductive coatings are removed from areas where continuity is required.
2	Astronaut Safety Valve.	Valve deactivates at incorrect level.	Permanent set in valve spring.	Incorrect activation level.	Perform adequate life testing to verify spring is of proper size and material to last through intended life.
3	Chiller Control Valve.	Chiller control valve failed to regulate temperature as required.	Suspect age hardening of the vernotherm valve seat was due to dry storage.	Improper operation.	Perform reviews of storage requirements. Vernotherm valve seat material should be stored wet.
4	Evacuation Valve.	Failure of valve to close on command. Valve seat leaks.	Design deficiencies.	Unable to evacuate control moment gyro.	Perform design review and testing to assure valve operates properly for intended use.
5	Relief Valve.	Contamination.	Inadequate cleanliness requirements.	Improper valve seating.	Assure adequate cleanliness requirements exist.
6	Relief Valve.	Valve shaft length too short to lock setting properly.	Design deficiency.	Valve relief pressure setting subject to change.	Assure proper design of component prior to selection and use.

VALVES/MODULES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
7	Solenoid Valve.	Valve failed to close properly.	Loading on main ball seal which was caused by cold flow of teflon flange seal.	Improper valve operation.	Valve redesigned, replacing teflon seal with "O" ring to achieve metal to metal contact of flange to valve body.
8	Solenoid Valve.	Valve failed to close properly.	Improper alignment.	Improper valve operation.	Verify adequate procedures are written to assure proper alignment.
9	Solenoid Valve.	Short circuit.	Solenoid coil wires pass through a slot in the armature and attach to an electrical connector in top of solenoid cover. Wires should have exited from connector potting at the side instead of from the center.	Stud thru armature and guide assembly chaffed insulation off one of coil wires adjacent to electrical connector.	X-ray or visually and dimensionally check clearance between armature stud and wires.
10	Solenoid Valve.	Low D.C. resistance and insulation resistance.	Defective seal allowed moisture to attack wire which crazed and cracked.	Shorted solenoid coil.	Inspect all seals at assembly.

VALVES/MODULES (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
11	Valve.	Valve inoperative.	Valve failed due to high temperatures caused by low resistance coil.	Valve failure.	Verify engineering release system is effective in updating manufacturing routings to assure latest level parts are used.
12	Valve.	Excessive leakage at the poppet of pressure relief valve.	Contamination in the seal area due to either the machining or crystallized grease (versilube G-300).	Degraded performance in telescope assembly.	Improve machining and inspection methods. Use noncrystallizing grease. (Changed versilub G-300 to braycoat lube).
13	Valve.	Vacuum shutoff valve failed leak test.	Contamination was introduced during rework of threads while installing GSE plate over vent.	Degradation and possible loss of experiment.	Exercise caution when reworking flight equipment. Keep valves closed and covered when not in use.
14	Valve.	Pressure control valve did not meter properly.	Ofifice too large.	Improper operation of metabolic analyzer.	Perform adequate engineering analysis to verify design.
15	Valve.	Spirometer valve failed to function.	Excessive sealant on spirometer diaphragm and screws causing limit switch to react.	Partial loss of experiment.	Provide adequate assembly instructions and implement inprocess inspection points.

VALVES/MODULES (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
16	Valve.	Bellows spring rate below design tolerance.	Design deficiency in retainer.	Lock became disengaged when safety valve was adjusted to spec.	Assure qualification test procedures validate performance specifications.
17	Valve.	Low pressure valve seat material used in high pressure system.	Inadequate configuration control.	Leakage.	Stiffen configuration control requirements.
18	Vacuum Vent Valve.	Breakaway torque incorrect.	Procedures do not agree with drawing requirements.	Improper operation of valve.	Perform design review and verify procedures and drawings are compatible.

MISCELLANEOUS

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
1	Camera Magazine.	Camera magazine jammed.	Inadequate design.	Loss of camera and experiment.	Assure adequate design review for proper materials and lubricants.
2	Canister Boom.	Experiment canister boom has excessive leak rate.	Contamination from metal chips in "O" ring seals and grooves.	Improper operation.	Clean "O" ring grooves and lubricate "O" rings.
3	Detonating Cord.	Long term shrinkage.	Gradual stress relief of composite sheath.	Assemblies too short to install.	Design for possible $1\frac{1}{2}$ percent preinstallation shrinkage in cord length, or a possible $\frac{1}{2}$ percent if thermal conditioning preshrink process is used. Shrinkage can be mini mized by refrigerating cord assemblies (50° F max.), if further control is desired.
4	Diffraction Grating.	Severe degradation.	Overcoating a gold coated main diffraction grating with a thin film of aluminum.	Intermetallic diffusion of aluminum and gold.	Do not use an aluminum overcoat on any noble metal such as gold, platinum, etc., when reflective surfaces are required.
5	Extension Tube.	Inner rod of extension tube assembly broken off at the thread base.	Overtorquing combined with marginal design and improperly machined thread relief.	Loss of two experiments.	Allow an adequate safety margin when choosing materials. Use caution when drilling holes and locating roll pins near threaded ends of rods. Inspection assure that thread rollout and relief are machined to drawing requirements and are not dressed down.
6	Film Camera.	Camera inoperative	Camera shutter bent.	Loss of experiment.	Design protective covers for delicate instruments and instruct personnel on handling procedures.

MISCELLANEOUS (Continued)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
7	Pedal Shaft	Ergometer pedal assembly had full complement needle bearing substituted for caged bearing. Unsuitable bearing lubricant was used and the pedal shaft and retaining pin had dimensional errors.	Failure to comply with specifications	Bending of pedal shaft.	Implement inprocess inspection to assure proper assembly.
8	Retention Snaps	Data retention snap assemblies would not engage properly.	Unit head depth in the male snap was too high and prevented proper engagement.	Inability to hold down data in the MDA.	Assure that drawings specify proper mounting hardware and specify a fit check with mating female snap following installation.
9	Sleeve	Incoming raw stock was not being tested.	Raw stock was from an unqualified source.	Parts did not meet the Rockwell range of hardness.	Require manufacturer and subcontractor, if applicable, to meet MSFC-SPEC-143C.
10	Snap Ring	Snap ring lost spring force and came loose during test.	Inadequate design makes it possible to damage the snap ring during installation.	Leakage and possible damage due to loss of snap ring retainer.	Assure that proper snap ring is specified for each application and that installation procedures are adequate to assure proper installation.

MISCELLANEOUS (Concluded)

NO.	HARDWARE	PROBLEM	CAUSE	EFFECT	REMARKS/SUGGESTIONS
11	S056 Experiment	Camera shutter did not open.	Loose screw retaining decoding magnet on idler shaft.	Magnet oscillated giving false signals to decoding reed.	Improve inprocess inspection.
12	Tape Reel	Interference between tape reel and canister of tape reel return canister.	Design tolerances too close.	Removal of tape reels is difficult.	Assure design tolerances leave room for removal of items which must be changed out.
13	Torsion Rod	Twisted torsion rod.	Overtorque	Piece part degradation.	Revise procedures to include proper torque instructions and inspection witness of torque operation.
14	Water Sampler	Excessive leakage	Inadequate packing material.	Excessive leakage of water sampler port.	Assure assembly procedures are adequate. Update engineering requirements to utilize packing material which will not take permanent set.
15	Zoom Lens Assembly	Zoom lens assembly hung up in 1X position.	Tolerance buildup between gear train and cam assembly.	Telescope will not function as intended.	Inadequate design review and testing of hardware.

SECTION 3. TECHNIQUES

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TECHNIQUE INDEX

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TECHNIQUE INDEX (Concluded)

1 DESIGN FOR TROUBLESHOOTING, REPAIR, AND REPLACEMENT

PURPOSE: To improve ease of repair after assembly and during the mission by location of equipment.

Skylab has proven the need to design future orbiting vehicles so that troubleshooting, repair, or replacement of parts and assemblies can be done after spacecraft assembly or during the mission. With the advent of the Space Shuttle, both manned and unmanned spacecraft should receive this consideration.

a. Mount as many black boxes on the inside of manned spacecraft as possible to prevent the necessity of EVA to troubleshoot, repair, or replace hardware.

b. Design test point panels on or in spacecraft for troubleshooting anomalies.

c. Simplify the removal/replacement of hardware by using a type of quick-disconnect mounting bolt and a standard tool for removal of all mounting hardware.

d. Consider resupply in early design stages.

2 DESIGN FOR MODULAR CONSTRUCTION

PURPOSE: To improve ease of repair after assembly and during the mission by modulerizing construction.

The Skylab Program demonstrated that the astronauts can do repair work in space. Now is the time to design into all future long duration manned space stations or vehicles the capability for repairing in flight through the use of modular construction. Redundant components would be used in the critical application and the system designed so that the failed component could be removed and replaced without disturbing the redundant component that was operating. After the failed component was replaced, the astronaut would have the capability of switching the system manually back to the replaced component to verify that it is functioning properly. The space modules would not have to be kept onboard the space station but could be sent up to the station on the resupply flights.

3 DATA PROCESSING PROVISIONS

PURPOSE: Early planning for data processing and personnel.

Provisions should be made early in the computer software development stage for testing and data reduction requirements and the involvement of flight data reduction personnel. These personnel can learn and contribute to the more effective approach for data acquisition that will provide early visibility to flight data reduction programs and hardware development.

The early planning of the test and checkout facility should consider data transmission capability between the test and checkout facility and the data processing facility. This data transmission capability should make maximum use of existing telephone or coax lines. The capability is required to provide near-real-time data reduction requiring large scale computer systems.

We should consider early development of the data processing software, as the software is a long lead-time item.

4 DIGITAL EVENT EVALUATOR

PURPOSE: Use of Digital Recorder to evaluate both commands and responses between major items of flight hardware.

A Digital Event Evaluator (DEE) was connected to the critical interface between the ATM and the ATM C&D Console. It was programmed to record discrete event changes of both commands from the C&D Console and responses (talk-backs) from the ATM. On-Off discretes and digital commands were processed every 4 milliseconds and printed for post-test analysis. This technique supplemented the data recording capability of the ACE station and provided essential data not normally available through telemetry. Although the DEE has been utilized on several programs for a number of years, the value of the machine together with its flexibility and record of maintenance-free operation make it well worth considering for all future programs.

5 DESIGN FOR MAINTAINABILITY

PURPOSE: Accessibility to C&D Panels and components for troubleshooting and maintenance.

The initial design of the C&D Console for the ATM was oriented toward installation in a modified LEM and, as such, required an extremely compact structure.

This structure later seriously restricted the access to interior portions of the console for trouble-shooting, maintenance, and component changeout. In some cases, the removal of two or three panels and several components was required merely to gain access to a faulty component. This requires excessive demating/mating of connectors and handling of components that could be avoided if greater attention to maintainability was observed during the design phase.

6 BIOMEDICAL INTEGRATED SYSTEMS VERIFICATION TESTS (BISV)

PURPOSE: To build and test to flight specifications to avoid configuration problems.

a. Integrated Systems Level Test — In this test program, all Biomedical subsystems were integrated into a system and verified prior to installation into the flight vehicle drawings. As a result of this type integration, installation in the flight vehicle was flawless, and checkout time and procedure preparation time were minimized.

b. Systems Level Test on Development Hardware — The integrated systems level tests were performed on Design Verification Test Unit (DVTU) hardware prior to the assembly of flight hardware. A number of design modifications were precipitated by this program, ICS's were found to be incompatible and some of the subsystems were found to be totally inoperative in conjunction with others. On all future programs, systems level tests on development type hardware should be strongly considered. Some of the problems identified in this program could have been identified only by systems level tests and had they not been identified until flight hardware, the schedule impact and configuration changes necessitated would have been prohibitive.

c. Preparation of Systems Level Test Procedures for Manned Systems in Astronaut Language and Format and Participation by Astronauts in Test Program — In the BISV all procedures were written with crew participation in mind. (Concluded on next page)

6 BIOMEDICAL INTEGRATED SYSTEMS VERIFICATION TESTS (BISV) (Concluded)

This allowed the crew to help perform the tests without detraining. This resulted in early comments by the crew on hardware operation in flight type setup and in an early refinement of the crew procedures, making procedure preparation downstream much easier.

7 BAKEOUT FACILITY GAS SAMPLING

PURPOSE: Sampling without contamination.

In the ATM Bakeout Facility, problems were experienced with Residual Gas Analyzers that were exposed all the time. As a result, a special sampling chamber was designed and built. This sampling chamber was attached to the main vacuum chamber through a valve. This small chamber was heated to 250° C and had cryosorption roughing and ion pumps for high vacuum. This pumping system produced the least contamination possible. The combination of heat and high vacuum made the sampling head of the analyzer self-cleaning. When it was desired to sample the main vacuum tank, the coupling valve was opened and then closed. The analyzer ran a scan and then the self-cleaning action operated until the next sample. Additionally, the sample chamber could be used on small samples even when the main chamber was not under vacuum.

8 MODULE TESTING WITH AUTOMATIC CHECKOUT EQUIPMENT

PURPOSE: Provide an improved automatic checkout system.

Acceptance Checkout Equipment — Spacecraft (ACE-S/C) computers and associated equipment and computer software were used to verify ATM system performance.

a. This hardware can accommodate independent subsystems and/or integrated systems testing in either a manual, semiautomatic, or automatic operational mode. Large quantities of test data can be processed and displayed in real time, as well as recorded for post test data analysis. ACE-S/C utilizes two programmable decommutators, two CDC-160G computer modules with independent and common memory, digital and analog recording, and various direct driven displays.

b. The two decommutators are used to provide processed data from the ATM (flight data) and ground support equipment. This provides a complete interface for all incoming data. As the decommutators are special purpose computers, they can be modified for changes required in data format or telemetry rate. These signals are then routed to the response or downlink computer.

c. The CDC-160C downlink computer processes and records, in a compressed format, all data per preestablished guidelines. Measured values are routed after any special processing to the designated output device: CRT

8 MODULE TESTING WITH AUTOMATIC CHECKOUT EQUIPMENT (Concluded)

display, event light, recorder, or meter. The downlink computer is in a constant data review mode, with timing determined by the data cycle time.

d. The CDC-160G uplink computer controls stimuli output to the module under test and associated support equipment per preestablished guidelines. Uplink also provides the recording of output commands and control over the system software program tape.

e. Thus, the hardware is capable of performance of complete closed loop operations using the common memory for communication.

9 TEST DATA PROCESSING

PURPOSE: Computer compatability and pooled data reduction.

a. Procedure/Technique

Computer programs for Test Data Processing were developed to be compatible with computer facilities at the several NASA centers where testing of the space vehicle was performed. In addition, formats for calibration data input, data reduction requests, and presentations of data output were standardized to permit a continuity of test operations and a minimum of transitional effort by the test engineers to learn how to obtain the required data at each site.

b. Characteristics of How it Works

The NASA Center having Data Processing requirements coordinates the development of necessary computer software with other centers, early in the conceptual stage, to determine the similarity of computer systems, programming languages, and possible modifications necessary to effect a compatible operating program. Software development considerations may include differences in computer memory size and various optional equipment found on one computer system but not on the other. Trade-offs for the extra involvement of computer programmer time spent to modify a program vs. new development are made.

9 TEST DATA PROCESSING (Continued)

NOTE: On the ATM program for Skylab there were two separate pursuits for data processing capability that allowed compatibility between Centers and thus lessened development costs:

The MSFC Central Processing Computer Facility software development was designed to be compatible with the JSC Central Processing computer facility.

The ACE Computer Facility data processing software, although late in getting developed, did provide for compatibility and lower cost since it was utilized at KSC test facility (O&C Building) after having been developed for use at MSFC and JSC thermal vacuum facility. Throughout testing of ATM at the three NASA center, a considerable library of data reduction programs was developed that was compatible for use on the ACE facility computer. These developed programs became useable for data reduction on the subsequent testing of the ATM Flight Backup Unit (FBU).

c. Previous Background on Data Processing for a Space Vehicle:

Each Center or Facility, whereby a space vehicle article was tested, pusued the test data reduction independent of other Centers' efforts. Duplication of effort was costly and data format presentation to engineers was not standard.

9 TEST DATA PROCESSING (Concluded)

d. The Need for the Compatiability Between Data Processing Facilities:

(1) A savings in computer programming manpower was mandatory due to the late start in software development.

(2) The test personnel testing the space vehicle article (ATM) conducted the testing at the varied centers and required standard processing formats in order to relate test results from one center's testing to another.

e. Application to Future Programs:

Compatible pool test data processing programs could save considerable money. Software development and upkeep costs are a very substantial cost factor. Computer compatibility is necessary, however, and is the least costly in the overall cost picture considering software programming manpower costs for automatic testing and data processing.

10 DESIGN FOR TESTABILITY

PURPOSE: Reduced time and labor costs of testing.

Module Systems

a. Electromechanical Operations — Design for one-g to meet test and checkout and prelaunch and launch operations, as well as the flight environment.

b. Ground Scheme

(1) The grounding scheme should be such that isolation verification is facilitated.

(2) An actual ground bus rather than a fragmented bus in several distributors is preferred.

(3) Systems ground returns should be the minimum number required (preferably one or two for redundancy). Multiple returns through different distributors should specifically be eliminated.

c. Circuit Interlocks — Use simplest circuits with the minimum number of components which meet requirements. Do not use circuits which are susceptible to high frequencies to do low frequency jobs.

d. Electronics Location — Location of low level logic, control and measuring electronics should minimize cable lengths between components.

10	DESIGN FOR TESTABILITY (Continued)

e. Pulsor Circuits — Limit use to where decidedly advantageous. Design for maximum response time permissible. Suppress/isolate both input and output against pulse widths narrower than what is required for circuit performance.

f. Fuses — Fuses must be readily replaceable. They should be rated at maximum current while providing mandatory protection; i.e., do not over protect to the extent of being susceptible to normal system variations and transients.

g. Measurement Sensor/Systems — Accuracy should not be materially affected by interconnecting cabling. Where this is not practical from cost, size, or other considerations, the actual measurements harness should be mocked up and characteristics measured prior to assembly with corrections to be applied to calibration curves.

h. Measurements — Capability to functionally verify each measurement at the ground checkout location should be provided for within the design.

i. Parts — Use parts already qualified for space application. If parts have to be qualified or requalified, schedule parts selection to be finished prior to major system assembly.

10	DESIGN FOR TESTABILITY (Continued)

j. Major CEI's Within Module — In the acceptance testing of the CEI's prior to module assembly, insure interface control and data lines are checked for unintentional responses as well as intentional responses. Shielding, bonding, bus isolation, ICD requirements must be checked prior to assembly. Isolation to ground and resistance values between buses should be recorded in log book for possible subsequent use.

k. Data Systems Interfaces — Completeness, accuracy and understandability of control documents, such as ICD's, IP&CL's, EIDD's, is essential in this area. Insure adequacy of communication and mutual understanding on:

(1) Definition and position of most significant bits in a data word.

(2) Relationship of points on measurement range for checkout and flight operations to the limits of the telemetry system.

(3) Grounding, shielding, and isolation of measurements.

(4) Filtering and expected line drops on both sides of interface.

(Continued)

10 DESIGN FOR TESTABILITY (Concluded)

(5) Uses, restrictions and accuracy of common items, such as central timing and sync pulses. Insure that expected noise and transient characteristics plus waveform distortion effects are specified, where applicable, and verified in CEI acceptance tests and qualification tests.

l. Checkout Complex — Design should provide for use of flight cables between test article and control and display consoles.

m. ECE (Electrical Checkout Equipment) — Include capability of monitoring operational functions from major control and display panels. This is essential in reconstructing events (intentional and unintentional) for troubleshooting of anomalies.

n. Ground Power Substitutes for Module Power — Provide for continuous monitoring of voltage, current, and transients on major buses.

o. Ground Test Measurements — Ground test only measurements and circuits provided through carry-on type hardware should follow the same shielding and isolation design as is used on the flight system.

11 DESIGN FOR OPERATIONS AND MAINTAINABILITY

PURPOSE: Increased ease of maintenance and operation.

Operations and Maintainability

a. Operations — Replacement items like film camera magazines should be easily and readily accessible and should not require major operations, such as roll of module, to gain access.

b. System Alignment — Specifications should be clear and realistic. The specifications should also recognize what is practical in the one-g environment for test verification.

c. Data Recording — Record as much relevant data as possible in the same manner to simplify correlating data during data evaluation.

(1) If time, vehicle attitude, etc., is to be used to post process and evaluate data, record both the same medium (film, printer, etc.) concurrently to prevent time consuming correlation of the two.

(2) This procedure was used on ATM to obtain data of the sun as well as the time the data was taken and the attitude of the vehicle at that time. All was recorded on film concurrently thereby preventing having to correlate the vehicle attitude at time xx with the data taken at time xx. All the data was available in one place, on film.

(Continued)

11 DESIGN FOR OPERATIONS AND MAINTAINABILITY (Concluded)

d. Flight Operations and Sequences — As early as practical and prior to completion of the procedures for the first major systems test (PMC), define the expected operating modes and sequences for launch and in-flight operations. Place under change board control the closeout position of relays and switches, as early as practical.

12 CRYOSORPTION PUMPING

PURPOSE: To provide the cleanest possible method of pumping.

Use of a Cryosorption Pump to evacuate a vacuum system in a 10K environment.

The pump consists basically of a vacuum tight enclosure containing an absorbent material which evacuates the air from a chamber by physical absorption of gas molecules upon the absorbent. Pumping action is initiated by filling the pump reservoir with liquid nitrogen, which chills the absorbent to a temperature near -195° C, thereby approaching the liquefaction temperature of the gases to be evacuated.

The Cryosorption Pump was selected to meet the stringent requirements of a 10K environment. The Cyrosorption Pump contains no moving parts, uses no internal liquids, is free of oil, vibration, and requires no electrical power except for instrumentation and regeneration.

It is ideal for use with vacuum systems where strict clean requirements exist.

13 ZERO G TEST FIXTURE FOR A&PCS VERIFICATION

PURPOSE: To simulate a zero-g condition for testing.

The Zero-g Test Fixture was used in the verification of the ATM Altitude and Pointing Control System. In particular, it was used to allow positioning of the ATM Canister with respect to the rack in a one-g environment. The principal component in the zero-g Test Fixture is a large air bearing which allowed three degrees of freedom (360° in roll, ±2° in pitch and yaw). This was a first attempt of zero-g simulation of this type on any space vehicle system testing at MSFC. This particular fixture was required in order to be able to prove the positioning capability of the Experiment Pointing Control (EPC) actuators in positioning the ATM Canister and the overall A&PCS pointing accuracies in a one-g environment. Since the ATM A&PCS was designed to operate in zero-g conditions, it could not have been tested without the use of this fixture.

In future space vehicle work where it is necessary to simulate weightless conditions during testing, the principal of this air bearing system could be applicable. This is especially true where one large mass must be positioned with respect to another.

14 FLIGHT COMPUTER MEMORY LOAD

PURPOSE: Memory loading in shortest possible time.

The ground computer is used to load and verify flight computer memory. The ground computer reads the data required to load the flight computer memory from magnetic tape. The data is transmitted to the flight computer through its memory load/verify interface to load or verify the flight computer. The flight computer memory could also be verified by performing memory dump and using a ground computer to perform memory compare. Use of this procedure allowed new programs to be loaded and verified in a minimum test time. This capability should be designed into future systems.

Programs and hardware were developed to allow the flight computer to maintain control if part of the memory is inoperative. This was accomplished by designing low and high core such that the program could be loaded into either. These programs could be loaded by MLU/tape recorder or RF uplink.

15 SUN SIMULATOR SYSTEM

PURPOSE: Provide a means of verifying the operation of the fine-sun sensor and the acquisition sun sensor.

The sun simulator system was used extensively in the ATM checkout to verify proper operation of the fine-sun sensor and acquisition sun sensor. This system was also used to verify specific functions of various ATM experiments. The sun simulator utilizes two xenon arc lamps to produce a 12-in. diameter beam with an intensity of one sun constant. The xenon arc lamp was selected over the carbon arc lamp because of its cleanliness, time-uniform intensity, and low RFI generation. Uniform intensity across the test plane of ± 5 percent was achieved by combining the two lamp images and integrating them with two 19 element lenses to form a 361 image array. A sun image size of 0.5 deg half angle was achieved, and the spectral response matched the Johnson curve ± 10 percent over the 0.8 to 1.0 micron range. The sun simulator light beam could be tilted ± 10 deg from the gravity vector with displacement accuracy of ± 4 arc sec. The sun simulator system can be used to checkout sun sensors and certain solar experiments.

16 STAR SIMULATOR SYSTEM

PURPOSE: Provide a means of verifying operation of the star tracker.

The star simulator system was used extensively in ATM checkout to verify proper operation of the ATM star tracker. The star simulator lamp has a three-inch clear aperture and is capable of simulating an "AO" type star between 4300 Å and 7000 Å. The stellar magnitude can be varied from -1 to +4 magnitudes. The simulated star angular diameter is less than 5 arc sec. The star simulator null fixture aligns the star simulator lamp for star tracker null tests, and the dynamic fixture provides a 300 deg circular offset pattern for star tracking test. The star simulator system can be used in future programs for testing gimballed or strap down star trackers.

17 COLOR ANODIZING

PURPOSE: Reduce cost of color anodizing.

The interior of the OWS Spacecraft utilized color anodizing of aluminum hardware surfaces to obtain the required interior color coordination finish. Excessive hardware rejections of color/shading appearance resulted due to an extremely stringent color criteria. A large amount of hardware required rework and inspection which increased operational time/cost without always achieving required results.

Corrective action initiated was the establishing of a more practical inspection criteria utilizing color "chips" as a guide with respect to shading. In addition, an alodining process was utilized. This process was simplier and provided better color results. Hardware color and shading anomalies were real long term fabrication problems affecting cost and schedules. These problems required top management attention during the OWS-1 manufacturing cycle (ground activity) but as recently demonstrated during the OWS-1 mission, were not flight significant and had no adverse effects on the astronauts's performance in space.

It is recommended that future programs requiring color anodizing/aloding recognize the problem of color shading and the personnel interpretation associated with same. A suitable and practical (cost effective) manufacturing and inspection criteria should be established early in the program to minimize hardware rejections.

18 SILICONE CONTAMINATION

PURPOSE: Provide controls to prevent contamination.

Silicone, applied by brush and/or dip application, was utilized in fabrication of the OWS electrical modules to compensate for the differences in the coefficient of thermal expansion between electrical components and the basic epoxy module material. Since silicone is colorless and can easily be transmitted to other pieces of hardware during fabrication buildup and handling, silicone contamination of the module baseplates resulted, causing a poor bonding surface. This condition is directly related to the module baseplate temperature – separation problem (cracking). As a result, a large number of modules were rejected and replaced. Separate silicone application facilities and controls were established to prevent reoccurrence. Future programs should recognize the potential silicone contamination problem of work areas, due to poor component bonding surfaces, emissivity hardware problems, etc. Personnel training and creation of isolated manufacturing silicone application areas appear essential to maintain the necessary hardware fabrication controls.

19 PART IDENTIFICATION AT INSTALLATION

PURPOSE: Provide permanent part identification.

Hardware installed within the OWS did not have permanent identification which conformed to outgassing, flammability, and internal workshop (living quarters) appearance requirements. This required utilizing packaging and/or tag identification prior to hardware installation. After installation, it was necessary to rely on relating hardware drawings to manufacturing paper and utilizing the latter to establish part and serial number identity in support of tests, inspection, and part replacement operations. To prevent potential problems, stringent controls were imposed on hardware flow operations and upon hardware installation requirements (hardware verifications, special buyouts, etc.).

To prevent this problem from recurring on future programs, it is recommended that engineering, early in the program, perform investigations and/or tests necessary to specify type and location of hardware identification (i.e., locate identification on back of part, etch, or utilize other methods of permanent identification, etc.) which will conform to all special environmental requirements.

20 TIME/CYCLE DATA MAINTENANCE

PURPOSE: Real time, time/cycle data.

The recording, maintenance and reporting of time and cycle data on limited operating life items was significantly enhanced on OWS Backup by implementing the following changes:

a. Integration of Time/Cycle data forms into Test Control Procedures.

b. Recording running time and cycles in real time.

c. Computerizing the OWS time/cycle report and publishing weekly.

d. Reassigning the time/cycle recording function from the operating agency to Quality Assurance.

The system previously used on OWS-1 involved after-the-fact retrieval of the data following completion of a given test (TCP). When tests were delayed or conducted out of sequence, the retrieval of the associated time/cycle data was delayed and the interim status was frequently unclear. The new system provides the real time visibility necessary to assure that time/cycle allocations are not exceeded.

21 CREW INTERFACE FIT CHECK VERIFICATION

PURPOSE: Combine fit check and checkout into one operation.

The OWS Fit Check Matrix is prepared and maintained to show the interface verification for Contractor Furnished Equipment (CFE) and Government Furnished Equipment (GFE) to CFE. The task of performing, documenting, verifying and statusing fit checks of interfacing hardware has been greatly simplified by incorporating and integrating the fit check requirements into the test procedure (TCP) that checks out the hardware. As the test results are recorded in the as-run TCP, the fit check results are concurrently documented and verified by Quality Assurance in the Fit Check Matrix. The checkout TCP is not considered complete until all fit check requirements have been met. This approach affords positive control, provides real time status of fit check progress, and eliminates duplication of tasks simply for the purpose of fit checks.

On OWS-1 the requirement for fit check verification was not received until well along in the checkout cycle. The individual blocks of the Fit Check Matrix were, therefore, filled out after the fact and verified by researching as-run TCP's was complicated because the TCP's were not structured to clearly identify fit check requirements and necessitated rerunning and reverification of these requirements.

21 CREW INTERFACE FIT CHECK VERIFICATION (Concluded)

Future programs should recognize the fit check requirements early and provide for meeting them by clearly calling for fit check verification in applicable checkout procedures and installation paper.

22 DISCREPANCY REPORT ACCOUNTABILITY

PURPOSE: Increased useability of quality data.

A new discrepancy logging and accountability system has been developed for real time identification, statusing and tracking of all spacecraft nonconformances from the time the spacecraft is erected in the checkout tower until delivery to the customer. The control is based on establishing separate inspection stations for the spacecraft and supporting areas such as Forward Skirt, Aft Skirt, Spacecraft Interior, Clean Room, Checkout Tower, etc. Each station is held accountable for the numbered discrepancy tags issued which are useable only by that station. Daily status of discrepancies is maintained by each station and loaded into a computer program which is printed out and distributed to reflect which agency has the action at any given time until final disposition has been made. A complete file of all nonconformances, closed and open, against the spacecraft is maintained shipside for immediate referral when required.

This new procedure replaced a system which issued large blocks of discrepancy forms to functional departments and which deferred positive accountability until the tags had been closed and routed to Quality files. Interim status was accomplished by physically locating and reviewing individual tags.

23 CONFIGURATION VERIFICATION

PURPOSE: Provide on-the-spot verification of part configuration.

A near real time system for configuration verification of serialized parts has been developed for OWS Backup which provides for improved control and visibility of the as-build configuration. A computer tab run of the mandatory configuration is prepared by Quality Engineering from released engineering and provided to floor inspectors. Prior to any "OK to Install" on the original installation of a component, the inspector verifies the hardware configuration matches the latest mandatory configuration called out on the QE tab run. The tab run is revised weekly. A similar verification of configuration is made for replacement hardware which is subsequently installed.

The prior approach relied on pre-planned manufacturing paper which may not have logged the latest engineering release. After final assembly, a configuration verification of the overall spacecraft was then performed by review and comparison of as-built manufacturing paper with released engineering. This resulted in late recognition of configuration problems. Removal and replacement of hardware and reaccomplishment of testing which may have been invalidated was then required to bring the configuration into compliance.

(Continued)

23	CONFIGURATION VERIFICATION (Concluded)		
The technique of real time configuration accountability is strongly recommended for future programs because it offers the potential for substantial cost savings by minimizing post assembly configuration changeouts.			

24 FLUREL TUBING

PURPOSE: Provide flame resistant covers for all electrical cables installed in the Multiple Docking Adapter (MDA).

Due to the routing of cables and the desire to pre-fab cables prior to installation into the MDA, it was decided to develop a flexible flame resitant tubing type cover for the cables. Two contractors worked together in developing flurel coated tubing in various diameters for use in the MDA. This tubing provided the required flammability control yet was flexible, easily inspectable and could be installed with no fear of damage to wires.

Although handling and excessive flexing of flurel tubing was found to occasionally cause cracking of the flurel, subsequent investigation revealed that liquid flurel could be used to coat over the damaged or cracked area making a very effective repair.

25 SUPER INSULATION BLANKET FABRICATION

PURPOSE: Provide a better means of attaching the blanket.

The Multiple Docking Adapter has an exterior insulation blanket made of ninety layers of aluminized mylar and ninety-one layers of dacron netting with a total thickness of $1\frac{1}{2}$ in. This blanket is in turn covered by the meteoroid shield.

A unique method was utilized in securing the 91 layers of the blanket. Conventional means is by use of hand ties. This process is tedious and creates uneven thickness of the blankets.

"Swiftachments" were used in lieu of this method. This device is nylon, commonly used in the clothing industry for attaching price tags to garments. The attachment can be purchased in different lengths and installed by use of Swiftachment tool number 08994 and needle number 08995, manufactured by Dennison Mfg. Co., Framingham, Mass. The attachments can be installed fast with uniformity in final thickness of the blankets, with the end product of a much higher quality while fabrication time is significantly reduced. Installation of attachments was drawing notes with a material code developed for purchase of the fasteners.

26 CONTAMINATION OF MAGNETIC TAPE

PURPOSE: Provide a screening technique to determine tape contamination.

The original method was a visual inspection of both sides of the tape as it was being wound from a supply reel to a takeup reel.

Present method consists of using a FR1928 ground recorder reproducer, a bit error rate counter and associated cables. Bit error rate counter is set up to give a printout every 20 feet. Any increase in bit error rate over the established baseline is identified as to location by review of the printout. This enables Quality to determine what areas of tape, if any, will require a visual examination.

During development of the above technique, it was discovered that in addition to picking up small amounts of foreign material, that minute flaws in the oxide side of the tape would show up as an increase in bit error rate.

27 LAMINATED VS. HARDTIP HEADS ON GROUND RECORDER

PURPOSE: Provide best type head for this application.

Magnetic tape screening was accomplished on FL1928 recorders which utilized laminated type record and reproduce heads. All flight tape and flight backup tape was required to meet bit error rate of five errors or less per ten million bits per track on all 28 tracks for any 7300 continuous, unspliced, feet of tape. Approximately 240 reels of magnetic tape was processed to get a total of 50 flight quality tapes.

Hard tip heads, which were developed and procured late in the program were discovered to have at least 20 percent improvement in performance, plus the reliability was greatly improved over the laminated type. The above has resulted in flight data being reduced utilizing the hard tip heads.

Yield of flight tapes would have been much higher if hard tip heads had been available early in the program, when the tape quality screening was accomplished. This also resulted in flight tape, as delivered to the government, being approximately 20 percent higher in quality than what requirements called for.

28 USE OF MODIFIED COMMERCIAL HARDWARE FOR SPACE APPLICATION

PURPOSE: To point out problems in adapting parts not designed for a specific application.

The following items are examples of difficulties encountered when a commercially designed and fabricated assembly is upgraded to space flight status (conformal coating).

P.C. Boards were of commercial design and construction, to which was added a requirement for PR1538 conformal coating. When the plug-in boards were installed in the recorder, it was discovered that there was interference between the coating around the plug-in board connector and the connector on the mother board. Resolution was to mask off the area around the connector, as well as the connector itself.

During conformal coating of large mother boards, which had connectors for the plug-in boards, it was discovered that if the area around the connector and the connector itself was not masked off, the conformal coating could flow into the connector and contaminate the pins.

Silicon type lubricant was used during the manufacturing cycle of the P.C. Boards. This resulted in many problems during conformal coating process. This type of lubricant proved to be impossible to clean off the boards, and conformal coating would not adhere to the surface of any board which had been exposed to this type of lubricant. Resolution

28 USE OF MODIFIED COMMERCIAL HARDWARE FOR SPACE APPLICATION (Concluded)

was to delete the use of silicon type lubricant prior to conformal coating, mask off the component requiring lubricant during conformal coating, add the lubricant after conformal coating, and touch up any exposed areas with type II conformal coating. (Silicon type lubricant was used as a heat transfer agent.)

29 COMMAND CODING

PURPOSE: To allow transmission of any command or its complement.

A coding technique was used that allowed the transmission of any command or its complement. The complementary message concept allows mission control to issue a command even though failures may have occurred in the command decoder, the switch selector, or both. The mission operator simply transmits the complement of the message he has unsuccessfully tried. An all 1's test and all zero test was also implemented for diagnostic purposes. This diagnostic procedure is very helpful in case of a transmission of a faulty command. The all 1's transmission allows the operator to cancel the last message if an execute command has not been issued.

30 TELEPRINTER

PURPOSE: To convey written messages to the astronauts.

A teleprinter was developed for use in the Airlock. This teleprinter is used for conveying written messages to the astronauts in the Skylab. This frees the astronaut from copying large quantities of data by hand. This approach has several other advantages. It frees the astronaut for other productive work. It also reduces the possibility of errors, since mission operations can double check the data prior to transmission. The teleprinter printout is coded in a manner that makes software errors easy to spot.

APPROVAL

RETENTION AND APPLICATION OF SKYLAB EXPERIENCES TO FUTURE PROGRAMS

By V. G. Gillespie and R. O. Kelly

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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