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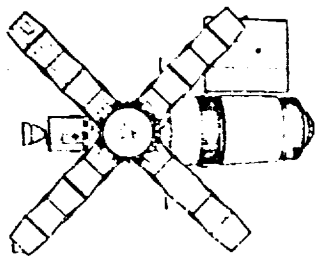

LESSONS LEARNED ON THE SKYLAB PROGRAM

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FOREWORD

The lessons learned in the Skylab Program are described in five basic documents prepared by, and representing the experience of, Headquarters, Johnson Space Center, Kennedy Space Center, and the Skylab and Saturn Program Offices at the Marshall Space Flight Center. The documents are intended primarily for use by people involved in other programs who are presumed to be familiar with the disciplines covered. The format thus favors brevity over detailed treatment.

Authors of the lessons have been encouraged to be candid and the reader may detect apparent differences in approach in some areas. This illustrates the fact that equally effective management action in a particular area frequently can be accomplished by several approaches.

Recommendations and actions described are not necessarily the only or the best approaches. They reflect Skylab experience which must be tailored to other situations and should be accepted by the reader as one input to the management decision-making process. As such, they should be used to help him identify potential problems and to benefit from the approaches that were found to be effective in Skylab.

Many of the lessons are subjective and represent individual opinions and hence should not be interpreted as official statements of NASA positions or policies.

In addition to the Lessons Learned Documents, Skylab Mission Evaluation Reports are being issued by JSC, KSC, and MSFC to provide detailed evaluation results. Experiment scientific results will be disseminated by the principal investigators.

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SECTION 1

OPERATIONS

SKYLAB LESSONS LEARNED

1-1 SYSTEMS TEST REQUIREMENTS

Systems test requirements and specifications should be defined as early as possible, so that GSE can be selected or designed to accomplish the requirements. Late design changes in flight hardware will impact GSE, however, efforts should be made to baseline test and checkout requirements documents several months before delivery of flight hardware to KSC.

BACKGROUND: Late generation of test and checkout requirements and specification documents on Skylab caused GSE design changes throughout the pre-launch period. Additional GSE had to be manufactured locally and much GSE borrowed from GAEC and NR to enable requirements to be satisfied.

1-2 SUPPORT REQUIREMENTS

The Support Requirements Document information should be stored in a computer with all KSC elements having access.

BACKGROUND: Support requirements should be coded by test in the computer. Responsible elements would access only those tests for which they have a need. Basic requirements would be updated as needed. A computerized system for support requirements should reduce overall documentation and thereby effect considerable savings.

REFERENCES: Skylab Part I Requirements Document
LO-RRO-001-72

1-3 SIGNATURE FOR NORMAL WORK

Signature requirements for normal work activities should be limited to full time KSC personnel only. Approval of other centers should not be referred (MSFC, JSC, etc.) for normal work.

BACKGROUND: Requirements for signature of JSC and MSFC representatives were a continuous source of delay during stowage and experiment integration in the Workship and MDA.

REFERENCES: These requirements were specified in the contractor Preflight Operations Procedures (POP's) and in inter-center Agreements.

1-4 FRAGMENTATION OF RESPONSIBILITIES

Do not fragment contractor and/or NASA responsibilities if this can be avoided.

BACKGROUND: Three stage contractors, as well as NASA-Marshall and NASA-KSC were all required to send a 450 MHZ command signal up the LUT, across the Swing Arm Umbilical to the Fixed Airlock Shroud and the ATM. Delays encountered in troubleshooting the transmission lines were frustrating and significant, as technicians, inspectors, and engineers from each organization had to be dealt with.

REFERENCES: IDR #TPS A1320-1, KSC RF CMD MON Open Loop Verification

1-5 INTERFACE INCOMPATIBILITIES

During the design phases, each interfacing contractor should review the schematics of the other interfacing contractor to verify that circuit intent is carried through from end to end. The review of the ICD's alone is not adequate for this purpose.

BACKGROUND: Several cases of incompatibilities between the MSFC and KSC interfaces were noted after AS-206 checkout began. The correction of these discrepancies delayed systems tests and required excessive overtime.

REFERENCES: Reference KSC Request KGB-206-001.

1-6 GSE REFURBISHMENT CRITERIA

Servicing equipment and hardware which is intended to be used on another program must have refurbishment criteria established at the time it is placed in an inactive status.

BACKGROUND: Several units of Gemini Program servicing equipment were utilized on the Skylab Program. However, due to a lack of information on these items, it was extremely difficult to establish the refurbishment requirements.

1-7 TEST POINT IDENTIFICATION

Proper test point identification should be provided to preclude the possibility of connecting GSE to the wrong system for test and making improper flight connections between modules. Various systems have test points located in the same vicinity on the vehicle and improper identification has proven to be a problem.

BACKGROUND: A 900 PSI line was connected to a 20 PSI system during CM checkout in Downey and created damage. A flight connection across the CM/SM interface was made between SM water system and CM water glycol system. In St. Louis a gaseous test hose was connected to the low pressure SUS system and a water tank ruptured. During manufacturing assembly of the Airlock in St. Louis, the installation of the cooling module resulted in improper interconnection between primary and secondary coolant systems. Although every effort is made to avoid accidents, the many thousands of test activities required to prepare hardware for spaceflight provide opportunities for human errors to creep in. Constant vigilance is required to keep errors to a minimum.

1-8 VEHICLE LIFTING HARDWARE

Functionally test all flight vehicle lifting hardware before sending it to KSC. Do have considerable leveling adjustments in the lifting apparatus to compensate for changes in the vehicles c.g Don't allow jack screws that have removable stops to be designed into lifting GSE.

BACKGROUND: In using the AM-MDA 61E010727-1 inverted docking support kit, the screw jack adjustments were found to be inadequate for leveling the vehicle. It also was determined that after maximum extension of the jacks per drawing, no mechanical stop was encountered. By removing an inspection plate, it was discovered that the stop was missing. Further extension of the jack would have released one of the 4 point supports of the sling, and probably caused catastrophic failure of the system.

REFERENCES: DR. No. 61E010727-0001, KM-13008

1-9 EXPERIMENT CHANGES

Do allow the experiment personnel, with KSC engineering concurrence, to implement simple ECP-type changes dealing with decals, nomenclature, cosmetic fixes, bulb changes, etc. and do it himself when the hardware is off module in a bond room or lab. This would insure expert work plus getting the job done much faster than waiting for busy module contractor technicians and QC to get the job done after it is finally scheduled.

BACKGROUND: While waiting for these low priority jobs to be done the usual way, we would have to run tests in a non-flight configuration so that certain goals of testing would not be accomplished, such as operational techniques, connector alignment, mark verification or display verification.

1-10 TRAINING

Significant training is required in software and GSE before an engineer can be used effectively for systems test. Time must be allocated for this training prior to actual space vehicle testing or a schedule impact will occur.

BACKGROUND: Due to the peak man-power requirements not being established until late in the Skylab Program, many contractor engineers came in late without time for proper training. This resulted in a slow down in testing until these engineers were educated in the methods of testing at KSC.

1-11 REMOVABLE LOX COMPATIBLE LUBRICANTS

Ensure that LOX Compatible lubricants, which can be removed by conventional cleaning methods, are designed into LOX components.

BACKGROUND: The contractor operated cleaning laboratory has not been successful to date in removing the LOX compatible fluorocarbon lubricants (KEL-F-90 & KRYTOX) from areas that cannot be mechanically cleaned. The biggest problem item has been tubing which cannot be cleaned mechanically. The lubricant leaves a white powdery looking residue which cannot be removed by any conventional cleaning chemical. This problem is particularly severe with tubing that cannot be mechanically cleaned on internal surfaces.

1-12 "O" RING SPECIFICATIONS

Ensure that all components procured for NASA systems have "Government Specification" O ' rings as substitutes for the vendor parts. This can be accomplished easily during design and will save many thousands of dollars per year O' ring replacements costs.

BACKGROUND: Most' O' rings are replaced each time component is cleaned and refurbished. KSC cleans and refurbishes in excess of 150,000 components per year. Many cases have arisen where the cleaning contractor had to pay from several to more than twenty dollars for a simple "O" ring from the component vendor. If an equivalent government specification "O" ring had been identified as a substitute for vendor parts, it would have been more cost effective. The drawings on the components did not cross-reference "Government spec" part numbers.

REFERENCE: The 79KXXX drawings that are being prepared by KSC Design Engineering do require that vendors either use "Government Specification" O"rings in their designs or provide a substitute "Government Spec." part number for all "O" rings designed into their components.

1-13 STAINLESS STEEL PROCUREMENT

Ensure that all stainless steel tubing is procured and inspected to a specification such as MIL-T8504A. Particular attention should be given to the internal surface which may be covered with a green chromium rich oxide coating formed during manufacture. Do not use this "green tubing" in systems which cannot tolerate particulates.

BACKGROUND: Commercially procured stainless steel tubing may have a green chromium rich oxide coating on part or all of the internal surfaces. This coating may shed copious quantities of particulate under certain conditions. Visual inspection from the end of a tubing length is not generally suitable for detecting the coating. A suitable visual inspection may be obtained by splitting 6 inch lengths of the tubing and treating one of the halves with a HNO_3/HF picking solution. Acceptable tubing will show no differences between the two halves.

1-14 Test and Checkout Procedure Implementation

During the conduct of test and checkout procedures constant vigilance is required to keep human errors to a minimun. In order to maintain the high level of vigilance, the following actions are suggested.

1. Test and Checkout Procedures should be reviewed for completeness and clarity. Better tie-in between integrated procedures and sub-task procedures should be provided, i.e., the integrated TCP should specify what steps in the sub-task procedure should be accomplished; redline warnings and caution notes should be used for all critical operations. Hazards should be identified and appropriate emergency procedures provided.

2. Comprehensive pre-test briefings should be conducted to familiarize all test team personnel with the operations to be performed, the hazards involved, and redline values to be observed.

3. "Red Flag" procedures for control of non-flight hardware should be reviewed to assure they provide adequate control over hardware that must be removed prior to tests/flight.

4. Tests should be scheduled to minimize the relief of operators and pad personnel. When personnel changes are necessary, comprehensive turn-over briefings should be conducted.

5. Upon expiration of special warning conditions, such as hurricanes, space vehicle hardware and supporting systems should be returned and verified to normal configuration prior to resuming scheduled test.

BACKGROUND: Two fuel tank domes were buckled by a partial vacuum during fuel level adjust operations because two vent valves openings were covered with plastic to prevent entrance of water during heavy rainstorms. The covers were inadvertently left on during fuel level adjustment. Shift change occurred just before the incident took place.

REFERENCE: KSC Report of Investigation, Reversal of S-IB 208 Fuel Tank Bulkheads, dated November 8, 1973.

1-15 INSPECTION AFTER EXTENDED STORAGE

Some of the Apollo and Skylab flight hardware now in storage approached the state of the art when it was designed more than ten years ago. The effect of long term storage on some of the materials used in this flight hardware is unknown. An extensive and careful inspection must be performed on all flight hardware subject to extended storage before use.

BACKGROUND: Cracks were discovered in base of S-IB fins during visual inspection. Precautionary measures dictated change out of fins for further inspection, test, and study.

SECTION 2

RELIABILITY AND QUALITY ASSURANCE

2-1 R & QA SURVEYS

When applying the requirement for annual R&QA surveys to short duration contractors, as was the case at KSC on Skylab, it is essential that the survey be scheduled at an appropriate point in the contract. If only one survey is to be conducted, it should be performed after there has been enough hardware processing to be meaningful and yet, early enough so that findings can be corrected sufficiently in advance of the launch. If two surveys are to be conducted one should be during the planning phase to evaluate the contractor's planning efforts and the other during the implementation phase as described above.

For future programs similar to Skylab, intensive audit activity should be the rule during the first year of operation. These audits should concentrate on critical areas and areas of significant deficiencies as revealed by surveys.

BACKGROUND: KMI 5310.1C requires the Survey Office, QA-SUR to conduct annual surveys of all KSC contractors. In the early stages of Skylab operations at KSC, surveys were conducted of McDonnell Douglas and Martin-Marietta R&QA programs. The first surveys were conducted while reliability and quality activities were in the planning stages; these surveys indicated that planning and preparation of procedures and controls were commensurate with program requirements. Subsequent surveys of these contractors were scheduled prior to the Skylab I Launch; these surveys identified some serious potential problem areas and sufficient time was not available for thorough corrective action. The problems identified were primarily the result of a lack of thorough knowledge of KSC operating requirements.

2-2 SINGLE FAILURE POINTS

Assure "before the fact" reviews by management, operations, and design of potential delay or scrub single failure points in order to provide a better understanding of the risks involved and to develop procedure to allow assessment and corrective actions when failures occur.

BACKGROUND: The Skylab ten minute launch window required a thorough review of Single Failure Points in order to assure that management, operations, and design could cope with failures of components and thereby minimize the possibilities of a failure causing a launch delay. These reviews led to the development of procedures to assure prompt assessment and corrective action by operations personnel as failure occurred.

REFERENCES: Skylab Reliability Manual, GP-980

SECTION 3

DESIGN

3-1 THERMAL BLANKET DESIGN

If multi-layer blankets are used for passive thermal control in high traffic areas (such as inner payload bay doors) design them for easy installation and removal.

BACKGROUND: On the Apollo and Skylab Program numerous blankets were used for thermal control. These blankets experienced numerous tears during spacecraft checkout at KSC. If they could be removed for S/C checkout and reinstalled just prior to flight the blankets would not be subjected to damage.

3-2 SENSING PROBE INSTALLATION

Provide a method at Vendor plants to verify proper installation of sensing probes and other measuring devices that are inaccessible at the launch site and cannot be checked until fuel and oxidizer loadings.

BACKGROUND: During S-IVB LH_2 Loading on 20 July 1973, the LH_2 Fast Fill Sensor #2 and the LH_2 Depletion Sensor #4 were determined to be reversed. This reversal caused a system revert.

REFERENCES: Documented on TPR M207-053 and in SL-3 Post Launch Report.

3-3 SHIPPING CONTAINER DESIGN

Design shipping containers such that the cargo can be removed in a vertical direction.

BACKGROUND: The ATM shipping container was designed such that the ATM had to be translated horizontally out the end of the shipping container and then lifted vertically for installation into the clean room. This increased greatly the time required to offload the ATM.

3-4 UMBILICAL DESIGN

Umbilical connections need to be redesigned to reduce the time consuming adjustments currently required.

BACKGROUND: The aft umbilical carrier on the S-IVB stage is installed, measurements are taken, adjustments are made -- then the carrier is ejected. Then re-installed final measurements are taken. The fluid disconnects are then installed one at a time with measurements made. The electrical connectors are then installed. All connections should be made at one time.

REFERENCES: Refer to S-IVB umbilical carrier installation procedures and QD installation procedures.

3-5 QUICK DISCONNECT LEAKAGE

Design quick disconnects to have one of the following protective design features:

1. "Double Action" feature; i.e., internal poppets should seal prior to final collar release. In addition, a positive means of evaluating adquacy of internal seals before initiating final disconnection should be provided.

2. If "Double Action" QD's are not available, positive valve closure should be provided on flight half as closely coupled to the QD as practicle.

BACKGROUND: While QD's are mandatory for certain functions, such as T-0 or remote disconnections and operationally desirable for others such as servicing and R/R maintenance to minimize operational turnaround, misalignment or seal damage can lead to leakage which will reverse any operational advantages of the "Quick" disconnect.

3-6 INCOMPATIBILITY BETWEEN SYSTEM MATERIALS AND THE FLUIDS USED IN THE SYSTEM

Design fluid systems to be compatible with the fluid intended for use. Materials used in component design, plumbing, and valves must be similar on the electromotive series to prevent or minimize bi-metalic corrosion. If additives are necessary to control chemical reactions between materials the fluid mixture must be stable. Materials used inoxygen systems must be proven compatible to prevent a flammability hazard. Temperatures variations of the system fluid must be considered when materials are to be used which are sensitive to extreme variations of temperature. Because of corrosion and instability problems encountered on virtually every program, water systems, especially should be proven with extensive bread board development testing.

BACKGROUND: The suit cooling system on the airlockmodule was extensively investigated and many fluid additive changes generated in order to prevent system degradation. The C&D EREP cooling loop on Airlock/ MDA revealed a serious problem of materials incompatibility during checkout at KSC. Fluid additives and special procedures were required to prepare the system for flight. Reservoir tanks in the suit cooling system and the C&D/EREP loops were changed due to an incompatibility problem with the fluids used. In the past, sever components in oxygen systems were changed due to flammability hazard. Potable water systems have been difficult to service and maintain sterile due to materials incompatibility with bactericides utilized. Special servicing procedures and GSE have been required to minimize system degradation of added bactericide. When utilizing various fluids as cooling media, drinking water, breathing gas, fuels, etc. Each system must be considered individually for hardware fluid compatibility.

REFERENCES: Potable water systems on LM and CM required different bactericides and replenishment to maintain potability. Command module water glycol systems, fuel cell water glycol systems, and GSE each required different fluids. Suit water cooling system additive investigations for Skylab. Water tank bladder failure and tanks changeout on AM/MDA at KSC.

SECTION 4

PUBLIC AFFAIRS

4-1 INFORMATION DISTRIBUTION

Recommend a more efficient system for distribution of mission results in order to capitalize on current program publicity.

BACKGROUND: Educational institutions and educational TV expressed great interest in Skylab experiment results. NASA should have a better system for obtaining visual materials and information related to experiments conducted in space. There seems to be a lag in film footage, slides and publications available for distribution to satisfy the requirement.