

- Panels
6. Historical data
 7. Test procedures Review
 8. materials Review
 9. Design Reviews
 10. Analysis of Fracture Areas



REPORT OF APOLLO 204 REVIEW BOARD

TO
THE ADMINISTRATOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APPENDIX D
PANELS 6 thru 10



36282

APOLLO SPACECRAFT

The spacecraft (S/C) consists of a launch escape system (LES) assembly, command module (C/M), service module (S/M), and the spacecraft/lunar module adapter (SLA). The LES assembly provides the means for rapidly separating the C/M from the S/M during pad or suborbital aborts. The C/M forms the spacecraft control center, contains necessary automatic and manual equipment to control and monitor the spacecraft systems, and contains the required equipment for safety and comfort of the crew. The S/M is a cylindrical structure located between the C/M and the SLA. It contains the propulsion systems for attitude and velocity change maneuvers. Most of the consumables used in the mission are stored in the S/M. The SLA is a truncated cone which connects the S/M to the launch vehicle. It also provides the space wherein the lunar module (L/M) is carried on lunar missions.

TEST IN PROGRESS AT TIME OF ACCIDENT

Spacecraft 012 was undergoing a "Plugs Out Integrated Test" at the time of the accident on January 27, 1967. Operational Checkout Procedure, designated OCP FO-K-0021-1 applied to this test. Within this report this procedure is often referred to as OCP-0021.

TESTS AND ANALYSES

Results of tests and analyses not complete at the time of publication of this report will be contained in Appendix G, Addenda and Corrigenda.

CONVERSION OF TIME

Throughout this report, time is stated in Greenwich Mean Time (GMT). To convert GMT to Eastern Standard Time (EST), subtract 17 hours. For example, 23:31 GMT converted is 6:31 p.m. EST.

**REPORT OF PANEL 6
HISTORICAL DATA
APPENDIX D-6
TO
FINAL REPORT OF
APOLLO 204 REVIEW BOARD**

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A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Historical Data Panel 6. The task assigned for accomplished by Panel 6 was prescribed as follows:

Assemble, review, and summarize historical data on Spacecraft and associated systems as pertinent to the fire incident. Data to be analyzed shall include records such as included in Spacecraft log, failure reports, other quality engineering and inspection documents. Make interpretation on data as to applicability to subject problem.

B. PANEL ORGANIZATION

1. MEMBERSHIP:

The assigned task was accomplished by the following members of the Historical Data Panel:

Mr. T.J. Adams, Chairman, Manned Spacecraft Center (MSC), NASA
Mr. J.H. Dickinson, Kennedy Space Center (KSC), NASA
Mr. J.L. Hansel, North American Aviation, Inc., (NAA), KSC
Mr. D. Buffington, North American Aviation, Inc., (NAA), KSC

2. COGNIZANT BOARD MEMBER:

Mr. G.C. White, Jr., NASA, Washington, D.C., Board Member, was assigned to monitor the Historical Data Panel.

C. PROCEEDINGS

1. GENERAL

a. Panel 6, Historical Data, was established to assemble and review records on Spacecraft (S/C) and associated systems in order to determine the applicability of these records to the Apollo 204 accident. In addition, historical narratives (Enclosures 6-6 and 6-7) were prepared to reflect the relationship and flow of significant review and acceptance points, highlight documentation pertinent thereto, and to present a brief history of the prelaunch operational performed on S/C 012 at Kennedy Space Center.

b. Enclosure 6-2 lists the records reviewed by Panel 6, with an explanation of these records, and the criteria used for judgement of applicability.

c. Throughout the Panel's activities, contact was maintained with MSC-Houston and NAA-Downey and several requests for records review were placed on both organizations,

2. IMPOUNDING AND INVENTORY

a. Impound Procedure - Action was begun within an hour of the Apollo 204 accident to impound all S/C 012 quality documents in accordance with the guidelines contained in the Apollo Mission Failure Contingency Plan dated May 15, 1966. (Reference 6-1.) The impounded records from Launch Complex 34, Flight Crew Systems Laboratory, and Acceptance Checkout Equipment Control Room No. 1 were collected and delivered to the Quality Records Center. A NASA Security guard was posted, with access permitted only to personnel approved in writing by the Board. NAA Downey Quality and Reliability Assurance was notified and immediately impounded all quality pertinent to S/C 012 concurrent with notification to applicable vendors to impound same.

b. Inventory Procedure - The impounded records were inventoried and all documents applicable to the Apollo 204 accident were segregated.

Approximately 42,500 pages of records were catalogued, representing 12,000 documents. Three documents were not accounted for adequately. These documents were Test Preparation Sheet (TPS) S/C 012-SLA-004. Temporary Installation and Removal Record (TIRR) S/C 012-CME-42 and Parts Installation and Removal Record (PIRR) S/C 012-PIRR-(010) No. 132. An evaluation of the type documents concerned discounted any relevance to the accident.

As the documents were catalogued, significant information was recorded on special review forms prepared to enhance accountability and evaluation.

3. REVIEW TEAMS

a. The review teams consisted of Quality and Reliability Engineering Personnel drawn from government, NAA, and the General Electric Company (Apollo Support Division). All review personnel had previously been associated with S/C 012 operations and were familiar with the test history. The review was conducted on a continuous basis in order to make pertinent information available to Panel 6 and other Panels for consideration as rapidly as possible.

4. REVIEW PROCEDURE

a. Data review consisted of determining which Command Module (C/M) records were considered significant (in consonance with criteria delineated in Enclosure 6-2) so as to warrant consideration by other Panels, e.g., the Materials Review Panel 8 was provided with all records pertaining to use of nonmetallic materials. Dissemination of significant records was conducted in accordance with the following criteria:

(1) Relevant Items and Their Disposition:

(a) Chemicals:

All records documenting the use of chemicals, such as cleaning solvents, paints, and other chemicals were forwarded to the Materials Review Panel 8. This category included any reports of leakage in fluid systems.

(b) Nonmetallics:

All records documenting the use of nonmetallic materials in the crew compartment were forwarded to the Materials Review Panel 8.

(c) Electrical:

All pertinent records documenting problems with electrical systems were forwarded to the Integration Analysis Panel 18.

b. Panel 7 activities continued in support of the other Panels. Mainly, this consisted of researching the records to provide data requested other Panels. One example of this is the use of the methyl-ethyl-ketone, (MEK), as a cleaning agent. Since this is a flammable material, and because a partially filled bottle of MEK was found in the White Room after the fire, there was concern over the use of this material. The records search, combined with the interrogation of personnel who were known to have used MEK in the S/C in the three days immediately preceding the accident, enabled Panel 6 to supply information to Panel 8 for their evaluation.

c. Panel 6 also conducted a review of Problem Action Records (PAR's) and Unsatisfactory Reports (UR's). These records are defined in Enclosure 6-2, and the results of the review are given below:

(1) Problem Action Records - Failure Category:

All problem reports in the failure category were reviewed by support personnel at MSC. The reports covered failure-type problems from inception of the Apollo Program through development, qualification tests, manufacturing-vendor tests, field tests, checkout, and flight testing of all Command Modules and Command Modules Systems, subsystems and components throughout the country. Any previous conditions that could be related in some manner to the Apollo 204 accident were reviewed and evaluated. Upon completion of the Panel 6 review of these reports, a total of 39 were identified as requiring further evaluation for applicability by Panel 18 (Enclosure 6-2). In cases where conclusions drawn by an original failure analysis seemed questionable, the results were re-examined. No new conclusions relevant to the Apollo 204 accident were found in the review.

(2) Problem Action Record - Unsatisfactory Condition (PAR-UC):

A review of PAR-UC's was conducted and yielded no new significant information.

(3) Unsatisfactory Reports (UR's):

All UR's written at KSC prior to the accident were reviewed, and only one was considered applicable, i.e., bent electrical connector pins. This problem was identified to Panel 18 as a result of the Discrepancy Record Review (Enclosure 6-4).

5. DISCUSSION

a. Ingress-Egress Log

(1) In reviewing the Ingress-Egress Log, pertinent discrepancies were noted. An Ingress-Egress Log is maintained in accordance with Apollo Preflight Operations Procedures (APOP) No. 0-201, "Access Control of Test and Work Areas" (Reference 6-2). Personnel entering the C/M are required to record on log sheets all tools and other items carried into the C/M. The log sheets for S/C 012 were reviewed and in several cases showed that tools were recorded as having been carried into the C/M, but no record of removal of these items was made. Considering that tools could come in contact with electrical equipment and cause an arc, Panel 6 initiated an investigation of the S/C to look for these specific tools.

b. Shakedown Inspection

(1) Shakedown inspection is defined as a pre-scheduled period when all other operations are discontinued while inspection personnel conduct a visual inspection. This is in accordance with established and approved criteria to detect and record hardware discrepancies.

(2) Panel 6 conducted an investigation to determine how shakedown inspections were scheduled and performed on the S/C. From this investigation, it was learned that there were shakedown inspections performed prior to major test and milestones. However, these inspections were performed without definitive inspection criteria, but were conducted using the inspector's knowledge of previous S/C practices. In addition, the S/C 012 Master Flow Plan was reviewed (Reference 6-5 and it was found that shakedown inspections while not shown in the S/C test flow plan at KSC, are scheduled in bi-weekly and in daily work schedules.

c. Inspection Procedures During Test Operations

At the request of Panel 18, inspection procedures just prior to C/M hatch installation were reviewed. This review disclosed that Inspection monitored this phase of the test operations over the communications network because the White Room space and weight loading limitations prevented having an Inspector witness these functions in the White Room. Procedure APOP-0-202, "Operational Checkout Procedure", (Reference 6-3), states that Inspection will stamp each line item in the procedure requiring Inspection verification. Spacecraft Operations Letter SCO-2-104-65 (Reference 6-11) defines the verification requirements and the functions being performed prior to hatch installation that would have normally required Inspection physical verification.

d. Constraints List

(1) As a result of investigation of open work items, questions arose regarding conduct of tests. The investigation revealed that prior to the start of any test, an open-item review meeting is held by NASA/NAA, in accordance with APOP-0-202, "Operational Checkout Procedure". From this meeting, a list of those items which must be worked prior to the start of test is prepared, and approved by NASA/NAA engineers. The constraints list for Operational Checkout Procedure (OCP) FO-K-0021-1 was examined for content (Reference 6-6) to see if previous tests were listed as constraints. Research disclosed that OCP FO-K-0034 and OCP FO-K-0005 summary sheets (Reference 6-7) had not been signed off as accepted prior to OCP FO-K-0021-1, but were not listed on the constraints list for OCP FO-K-0021-1. It should be noted that OCP numbers are not related to the sequence of test accomplishment. APOP-0-202 does not contain a requirement to list open tests as constraints to subsequent tests, although there is a requirement to review the open items. Individual open items from previous tests are listed on the constraint list for subsequent tests if they are constraints to that test.

Analysis revealed that constraints lists are signed only by NASA/NAA Operations and Engineering with no NASA or NAA Quality control signature indicating approval of the constraints lists.

e. Mandatory Inspection Points

(1) As a result of questions which arose regarding Inspection coverage, APOP-0-202, "Operational Checkout Procedure", was examined to determine if there were any requirements for Mandatory Inspection Points (MIP's). The requirement is not clearly defined in the APOP, although many OCPs do contain MIP's.

MIP's are defined as inspection of actual hardware status.

Normally, Inspection monitors the test to insure adherence to the procedure.

f. Review of Engineering Changes

(1) As a result of review of open work, it was found that a large number of engineering changes were incorporated into the S/C at KSC. Many of these changes resulted from non-fit or non-function problems.

Some of the changes were due to the fact that S/C 012 was the first manned Apollo Spacecraft. Some of the changes were requested by the crew members. The large number of changes made it difficult to establish the vehicle configuration. An example of a major change is shown in Reference 6-8.

g. Retest Requirements

(1) As a result of the review of Discrepancy Records to determine open work, it was discovered that the requirement for retest may in some cases be deferred to a later test, (Reference 6-10). The records covering the work were closed out prior to the retest.

(2) Panel 6 investigated the requirements for retesting of components or subsystems after rework. APOP-T-502, "Discrepancy Recording System", (Reference 6-9) covers the retest requirement, but there is no requirement to keep the discrepancy records open until the retest has been verified. The records are closed out with a statement that the retest will be done in a subsequent test. This can then be deleted by on-the-spot deviations to the subsequent test.

h. Subsystem History

(1) In an attempt to obtain a complete subsystem history from the records, considerable difficulty was experienced. This was due to the fact that the records are not maintained by subsystem. Records are presently filed by category of document (Discrepancy Record, Test Preparation Sheet, etc.). In the event of subsystem problems, it is often necessary to develop the history of the subsystem, including failures, reworks, test results, etc. The present system required a great deal of effort to retrieve the necessary records to provide this history.

D. FINDINGS AND DETERMINATIONS

1. FINDING:

The Ingress-Egress Log (Reference 6-4) discloses several instances where tools and equipment were carried into the S/C, but the log does not show these tools as removed.

DETERMINATION:

The maintenance of the Ingress-Egress Log is inadequate.

2. FINDING:

a. Shakedown inspection periods are not shown in the Master Flow Plan. (Reference 6-6).

b. There are no definitive inspection criteria to perform shakedown inspections for the Apollo Program.

DETERMINATION:

a. Hardware condition prior to major tests and milestones is difficult to establish.

b. Inspection personnel are not able to assess the condition of the S/C for compliance with definitive criteria, but rather assess it in accordance with their knowledge of standard practices.

3. FINDING:

Inspection personnel do not perform a pre-scheduled inspection with a checklist prior to hatch closing.

DETERMINATION:

Inspection personnel could not verify these functions during this period.

4. FINDING:

Formal approval by NASA or NAA Quality Control of the constraints list is not required (Reference 6-6).

DETERMINATION:

NASA/NAA Quality Control cannot discharge their responsibilities without approving the constraints list.

5. FINDING:

The requirements for Mandatory Inspection Points (MIP's) are not clearly defined in the Apollo Preflight Operations Procedures.

DETERMINATION:

Proper Inspection coverage is not assured without clearly defined MIP'S).

6. FINDING:

At the time of shipment of the S/C to KSC, the contractor submitted an incomplete list of open items. A revision of the said list significantly and substantially enlarged the list of open items.

DETERMINATION:

The true status of the S/C was not identified by the contractor.

7. FINDING:

There is no efficient system which readily identifies that results accomplished by rework are verified by retest.

DETERMINATION:

The present system of verification of rework by retest is cumbersome.

8. FINDING:

There is no requirement to maintain records by subsystem classification, nor does the system present status in this fashion.

DETERMINATION:

The recovery of pertinent historical information is extremely difficult.

Enclosures

E. SUPPORTING DATA

- 6-1 Not Used
- 6-2 List of documents reviewed by Panel 6, including criteria for determining applicability to the AS-204 accident.
- 6-3 List of Problem Action Records submitted to other Panels.
- 6-4 Unsatisfactory Report on Bent Pins
- 6-5 List of References
- 6-6 Historical Narrative
- 6-7 Historical Narrative of Prelaunch Operations at Kennedy Space Center

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LIST OF DOCUMENTS REVIEWED

The following are the types of documents reviewed by Panel 6, including a description of each type of document, and the criteria used in judging the applicability of these documents to the Apollo 204 accident.

1. TEST PREPARATION SHEET (TPS):

A document which authorizes work, provides engineering instructions, establishes a method of work control, furnishes historical records, and facilitates inspection under the two categories defined below:

- a. Type "A" TPS: Required to authorize work involving a change of configuration (design change).
- b. Type "B" TPS: Required to authorize all other planned work and tests.

Criteria for review

- a. Agreement between Engineering Order (EO) and TPS.
- b. Unworked, or partially worked, EO/TPS's which are considered significant.
- c. Any configuration changes by TPS without EO coverage.
- d. All non-metallics.
- e. Questionable design changes.
- f. All electrical items.
- g. All solvents or cleaning agents.

2. DISCREPANCY RECORD (DR):

A document utilized to record significant and/or test discrepancies. This document provides for engineering instructions and dispositions, authorizes work of disposition, authorizes facilities inspection, and furnishes historical records under the two categories listed below:

- a. Significant Discrepancy: A discrepancy that (a) cannot be returned to specified configuration, or (b) requires engineering disposition, i.e., (1) functional failure, (2) defective component, (3) discrepancy affecting test schedule, (4) action which could invalidate previously accepted tests, or (5) a discrepancy which could have an adverse effect on mission objectives or be a safety hazard.
- b. Test discrepancy: Any anomaly encountered during integrated testing (testing which unites two or more space systems, e.g., Acceptance Checkout Equipment, Spacecraft Systems or components, etc.) except an obvious deviation or human factor which is immediately recognized and corrected without disturbing the normal progress of the test.

3. DISCREPANCY RECORD SQUAWK SHEET (DRSS): A document used to record minor discrepancies, provide technician supervision instructions, authorize work of the disposition, authorize facilities inspection, and furnish historical records under the category of discrepancy listed below:

Minor Discrepancy: Any deficiency which can be returned to drawing configuration without engineering disposition, e.g., workmanship items, string ties, oversize clamps, unclean areas, past-due calibration, etc.

Criteria for review

- a. All solvents or cleaning agents.
- b. Unapproved non-metallics.
- c. Questionable deviations to drawings.
- d. Any dispositions and/or conclusions not clearly defined.
- e. Dispositions without retest.

4. OPERATIONAL CHECKOUT PROCEDURE (OCP): An engineering document which provides

detailed instructions to personnel for operational checkout and verification of equipment performance. OCP's are based on NAA Process Specifications and those applicable are referenced in the OCP by document number. OCP's: (1) provide technical step by step delineation of required personnel activity for the operation, assembly, handling or test of the equipment and for system(s) involved, (2) provide for insertion of program requirement record data, (3) provide NASA/NAA Engineering and Inspection Acceptance, (4) provide for safety of personnel and equipment.

5. DEVIATIONS: A change to a published OCP, such as changes in equipment lists, test parameters, sequences added or deleted or modified by order of occurrence or content to permit accomplishment of the test. Obvious errors, such as typographical errors, wrong page numbers, etc., are not considered deviations.

Criteria for review

- a. Open Interim Discrepancy Records (IDR's),
- b. Unsatisfactory Closed IDR's (vague),
- c. Parameter Deviations.
- d. Unexplained Deviations.
- e. Deviations not satisfactorily documented.
- f. Other suspected deviations.

6. PARTS INSTALLATION AND REMOVAL RECORD (PIRR): A document utilized to record selected new installations and all removals and reinstallations of previously installed parts. Removals and installations are those components of the end item configuration which are removed or installed, connected or disconnected. This document by itself does not authorize any work.

Criteria for review

- a. Open installations or removals.
- b. Unsatisfactory closeouts.
- c. Unsatisfactory transfers (recapped PIRR or TIR).
- d. Unauthorized installations or removals.
- e. Installations of non-metallics.
- f. Installations without retest.
- g. Part number/serial number changes.

7. TEMPORARY INSTALLATION AND REMOVAL RECORD (TIRR): A document utilized extensively to record Spacecraft installations. It must be removed prior to flight and serves as a historical record. Temporary installations are non-flight Command and Service Module hardware and temporarily installed flight hardware (e.g., fit-check installations), which must be removed prior to flight.

CRITERIA for review

- a. Open installations or removals.
- b. Unsatisfactory closeouts.
- c. Unsatisfactory transfers (recapped PIRR or TIR).
- d. Unauthorized installations or removals.
- e. Installations of non-metallics.
- f. Installations without retest.
- g. Part number/serial number changes.

8. PROBLEM ACTION RECORDS (PAR's): The PAR is a NAA form on which hardware problems are reported for failure or cause analysis, and corrective action. There are two uses for the PAR, i.e., (a) Failure Reporting, (PAR-F), and (b) Unsatisfactory Condition reporting, (PAR-UC).

Criteria for review

The PAR-F's were reviewed for failure analysis to determine what caused the malfunction and applicability to the Apollo 204 accident. PAR-UC's were reviewed to determine if significant items had been reported on this record that had not appeared in other records.

9. UNSATISFACTORY RECORDS (UR's): The UR is a NASA document, used by the government to report conditions which are repetitive, or involve safety of flight. The condition reported may or may not have been reported by the contractor in his paperwork system.

Criteria for review

UR's were reviewed to determine if any significant item was not reported through other mediums.

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PROBLEM ACTION RECORDS SENT TO OTHER PANELS

PAR	TO PANEL	PROBLEM
27094 27049 27057 3958	8	ECS LEAKS
27017 27056	18	UNQUALIFIED PARTS IN GAS CHROMATOGRAPH
24201	18	LEAKS IN QUICK DISCONNECT
163286 171589 171612	18	INTERNAL SHORTS IN TEE - ADAPTER
27204 12460 13484 13485 12470 16605 23437 23500 23502 23686 23660 163740 163378	18	GSE ETHYLENE/GLYCOL FLUID - TRANSDUCER AND RELAY FAILURES
27235		CONTACT RESISTANCE OUT OF SPECIFICATION
23592 16726		GSE CIRCUIT BREAKER OPERATION ERRATIC
3951		ELECTROLUMINESCENT BAR FAILED TO LIGHT
28637		ECS WATER/GLYCOL PUMP FAILED TO OPERATE
171560		CLUTCH VOLTAGE OSCILLATES
171578		TRANSISTOR FAILURE IN CONTROLLER

PROBLEM ACTION RECORDS SENT TO OTHER PANELS (CONTD)

PAR	TO PANEL	PROBLEM
12032 12040 14555 16696 23495 23526 23603	18	GSE - WATER/GLYCOL SERVICE SET
15833	18	BURNT SPOTS ON RELAY MODULE PINS
164203	18	CYCLIC ACCUMULAT OR SOLENOID VALVE STICKS IN FULL OPEN POSITION

NASA - Manned Spacecraft Center					Page <u>1</u> of <u>2</u>		
UNSATISFACTORY REPORT - PART I					1. Category	2. System	3. U.R. No.
					S/C	EPS	A-054
4. Contractor Part Name			5. Contractor Part No.		6. Serial No.		7. Date Reported
Cable Harness Assy. (Crew Compartment)			V16-420302		012		10/11/66
8. Supplier	9. Supplier Part No.		10. Contr. Ref. Drawing No.		11. Time In Use		12. Cycles
NAS	V16-420302		V16-000002		hr. N/A min. sec.		N/A
13. Mission	14. Photos Enclosed		15. No. Previous Failures		16. Previous Failure References		
Apollo	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No		N/A		N/A		
17. Unsatisfactory Condition							
<p>This Unsatisfactory Report documents a recurring problem concerning bent pins in S/C electrical connectors, which if not corrected, could seriously impair the checkout schedules and/or jeopardize subsequent Apollo missions. The following is a summary of the failures encountered at KSC during checkout of S/C 012 which were a direct result of this unsatisfactory condition:</p> <ol style="list-style-type: none"> 1. During Seq. 11-040A of Combined Systems Test (OCP-K-0035), the RCS transfer "B" light was not observed. Troubleshooting isolated the problem to a short circuit within C/M - S/M umbilical connector J3A3. Further investigation revealed that pins # 75 and # 51 were bent and shorting against pins # 50 and # 52 respectively. (Ref. IDR 028 vs OCP-K-0035; DR S/C 012 - S/C 0189; PAR#27056) 2. On September 16, 1966, a check of S/C 012 separation monitor circuits via PCM was made per TPS-099 during Seq. 04 of OCP-K-0035, Combined Systems Test. During this test an out-of-tolerance (0%) indication was obtained. Subsequent troubleshooting isolated the problem to a blown fuse which was later found to have been caused by open jumper wires between Matrix Terminal Boards. (Ref. DR S/C 012 - S/C 0191; PAR#27096) During the repair operation of this problem, connector P1116 was disconnected from J54 of the V16-764042, Event Conditioner to facilitate the connection of a spare fuse into the circuitry previously protected by the blown fuse. Visual inspection of the disconnected plugs P1116 and J54, revealed 8 bent pins. (Ref. DR S/C 012 - S/C 0258 and S/C 0264) 3. Following power-up for the sea level run of the Altitude Chamber Test (OCP-K-0034), an indication of C/M - S/M separation was observed. Troubleshooting revealed a short circuit within the C/M - S/M umbilical connector, J3B3. Further investigation of the connector disclosed that pin # 32 was bent and shorting against pin # 33. It was further noted that pins # 1, # 18, and # 36 were also bent. (Ref. IDR 022 vs OCP-K-0034; DR S/C 012 - S/C 0431; PAR#27105) <p>Since many electrical connectors are practically inaccessible, mating is often a blind operation. As a result, the pins are often bent due to improper connector alignment. To preclude recurrences of this problem, we recommend the following:</p>							
18. Initiator (Signature & Date)				19. Systems Engineer (Signature & Date)			
<i>Chas. E. O'Kelly</i> 10-14-66				<i>M. Guidy</i> 10-14-66			
20. Approved by (Signature, Title & Date)				21. Approved by (Signature, Title & Date)			
<i>Joseph M. Bohak</i> 10-14-66				<i>Tom Buel</i> 10-14-66			

ENCLOSURE 6-4

D-6-15

1. Only connectors/receptacles with sufficient alignment features should be utilized in inaccessible areas. eg. Use of connectors with pin guides would lessen mating difficulties.

27. U.R. No.
A-054

2. Circuits which route through connectors and/or receptacles that have been interrupted subsequent to Integrated Testing at NAA Downey should be reverified prior to shipment of the CSM to KSC. Adherence to this policy would effectually eliminate the prelaunch problems resulting from bent or broken pins incurred during connector remating operations.

It should be further noted at this time that the NAA Standard Repair Manual repair No. 1 ELL.4, authorizes straightening of all pins, size twenty or smaller, for all bend angles up to 90 degrees. We feel that this is a very unreliable fix, as damage may be done to the pins internal to the connector which would not be detected through the prescribed visual inspection. In addition, there is no practical method of determining how many times a particular pin has previously been straightened. Due to these facts, we recommend that the following changes be made to the NAA Standard Repair Manual:

1. Pins with bend angles of less than 20 degrees may be straightened and accepted through visual inspection if it can be definitely determined that the pin has not been previously straightened.
2. Pins that are straightened after being bent at angles of more than 20 degrees should be accepted only after a satisfactory X-ray examination has been made.
3. Pins that are bent in excess of 20° and are inaccessible for X-ray should be replaced. If replacement is not practical, the bent pins should be broken-off and the associated circuit routed through undamaged spare pins if available.

Enclosures: 1. DR S/C 012 - S/C-0189, PAR#27056
2. DR S/C 012 - S/C-0191, PAR#27096
3. DR S/C 012 - S/C-0258
4. DR S/C 012 - S/C-0264
5. DR S/C 012 - S/C-0431, PAR#27105
6. Standard Repair Manual, Repair No. ELL.4
7. Photos (3 ea.)

REFERENCES

- 6-1 Apollo Mission Failure Contingency Plan
- 6-2 Apollo Preflight Operations Procedure Number 0-201
"Access Control of Test and Work Areas"
- 6-3 Apollo Preflight Operations Procedure Number 0-202
"Operational Checkout Procedure"
- 6-4 Apollo Ingress-Egress Log Sheets
- 6-5 Spacecraft 012 Schedule, KSC
- 6-6 Constraint List, Spacecraft 012 Operational Checkout Procedure FO-K-0006/0021-1
- 6-7 OCP FO-K-005A-1 and OCP F-K-0034A, A-1
- 6-8 TPS-012-SC100, "Modification of Quad Heater"
- 6-9 Apollo Preflight Operations Procedure Number T-502, entitled, "Discrepancy Recording System"
- 6-10 DR-SC0838 and DR-SC012-0810
- 6-11 Spacecraft Operations Letter SCO-2-104-65

Readiness Review (CARR) were conducted to support the acceptance and delivery from the Contractor (NAA). These reviews are discussed later.

d. Certification of Flight Worthiness (COFW)

The Certificate of Flight Worthiness (COFW) is a requirement of NASA-Apollo Program Directive No. 6 dated 15 August 1965. NAA was directed to implement this requirement in accordance with the MSC-Houston procedure, "Procedure for the Certification of Flight Worthiness (COFW)" dated 20 June 1966 (Reference 6-15). The COFW is used to certify that each flight stage and module is a complete and qualified item prior to shipment, and is supported by adequate supporting documentation, i.e., the Acceptance Data Package (ADP) and the Material Inspection and Receiving document (DD Form 250). The COFW informs the Apollo Program Director of any deficiencies prior to shipment from the manufacturing sites and from the static firing site. The COFW has requirements for the following documents for the following endorsements: Endorsement one is executed and signed at the completion of checkout at the Contractor's plant by the Contractor, MSC quality representative, and the MSC Program Manager's designee. Endorsement one reflects the final action taken at the CARR and information contained on the DD Form 250. Endorsement number two is executed and signed at the completion of receiving inspection at KSC and is signed by the KSC representative, the MSC quality representative, and the MSC Program Manager's designee. Endorsement number three is executed and signed at the time the Launch Vehicle and Spacecraft are mated, by the same people that signed endorsement number two. Endorsement number four is executed and signed at the completion of the Flight Readiness Review (FRR) by the KSC representative and the MSC Program Manager's designee. The final certification is executed at the time the Spacecraft is declared flight worthy and requires the signature of the Apollo Spacecraft Program Manager (Reference 6-15 and 6-17).

e. Design Certification Review (DCR)

The purpose of the DCR is delineated in Apollo Program Directive No. 7 (Reference 61-8) is to examine the design of the total mission complex (spacecraft, booster, GSE, launch complex, communications network, etc.) for proof of development maturity and assess and certify the design of the Space Vehicle, Launch Complex, Mission Control Center and Manned Space Flight Network for manned flight safety.

f. Flight Readiness Review (FRR)

The FRR as delineated in Apollo Program Directive No. 8 (Reference 6-19) is a two part review consisting of a Program Director's FRR and a Mission Director's FRR. The purpose of the Program Director's FRR is to determine that the space vehicle hardware and Launch complex are ready to commence the mission period. The purpose of the Mission Director's FRR is to make a judgement for initiating the mission period and committing the deployment of world wide forces to support the mission.

g. Review Schedule

The following bar-chart illustrates the Apollo development/review process (See figure 1).

2. DISCUSSION OF SPACECRAFT 012 CHECKPOINTS

This section describes the specific Spacecraft 012 checkpoints in detail. The checkpoint activities, locations, dates, personnel involved, and significant results are included. The checkpoints are discussed in chronological order and present a complete historical summary of the flow of hardware development and key inspection, review and certification checkpoints.

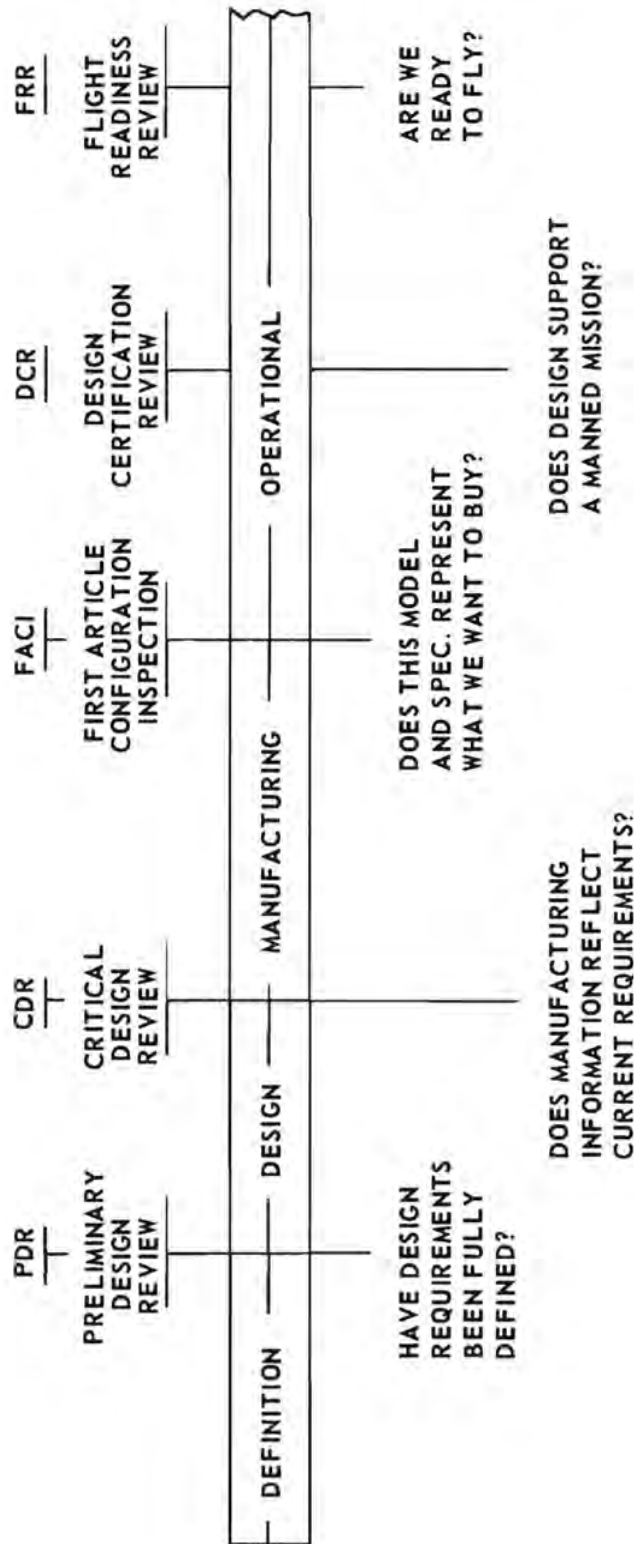
a. Preliminary Design Review (PDR)

The PDR checkpoint was conducted during the period from November 1964 through January 1965 for all Block I spacecraft including Spacecraft 012. As mentioned previously this was a review of both the requirements and the design since Spacecraft 012 had been released for manufacturing. In reality it was both a PDR and a CDR.]

b. Delta Critical Design Review (DCDR)

The intent of the Delta CDR for Spacecraft 012 was to insure that each level of spacecraft flight hardware and ground support equipment (GSE) end item was designed and built to meet all the requirements and was compatible with the planned mission. The review was also intended to determine the adequacy of the spacecraft checkout flow plans. It was held just prior to commencing

DEVELOPMENT/REVIEW PROCESS
(APO DEFINED)



action items are documented in "CARR Minutes and Action Assignments" and "CARR Action Response" (Reference 6-26).

The following summarizes the Downey ACTIONS AND DISPOSITIONS OF THE ABOVE REFERENCE ITEMS] Each item is identified by its respective item number in the Phase II CARR report minutes.

1.7.1 POWER LOSS ON CSM - INVERTER

Problem: During spacecraft testing, power loss occurred.

Resolution: Inverter 1 was determined to be faulty and was removed and replaced. The replacement inverter was installed, checked and determined to be acceptable prior to shipment.

3.6.14 FLIGHT QUAL INSTRUMENTATION STATUS

Problem: Four transducers were determined to not be operating properly.

Resolution: The transducers were replaced and the new transducers functionally verified prior to spacecraft shipment.

3.7.1 SUIT LOOP LEAKAGE

Problem: Leakage noted during Operational Checkout Procedure (OCP) 5051 was greater than the specification allows.

Resolution: It was concluded from evaluations that misinterpretation of data caused the out-of-specification statement. Re-evaluations were made of test data and it was concluded that leakage of the suit loop circuit at time of shipment was within acceptable limits. It was also noted that normal test flow at KSC would verify this conclusion.

3.7.2 DEMAND REGULATOR FAILURE (OXYGEN)

Problem: The demand regulator was determined during spacecraft testing to be inoperative.

Resolution: The regulator was replaced and the new regulator functionally verified prior to shipment.

3.7.3 WATER CYCLIC ACCUMULATOR FAILURE

Problem: During spacecraft testing, the water cyclic accumulator was determined to be inoperative.
inoperative.

Resolution: Two (2) new units were installed before the water cyclic accumulator would pass checkout. The units were installed and checked out and the final unit was determined to be acceptable prior to shipment.

3.7.10 OPERATIONAL CHECKOUT PROCEDURE (OCP) 5051, SUIT LOOP CHECKS

Problem: Checkout per OCP 5051 was not complete at the time of the CARR.

Resolution: OCP was completed prior to shipment. The following problems were transferred to KSC for final resolution. Squawks 54, 58, 59, 60, 61, 62, 63, and 908. (See Reference 6-27, Material Inspection and Receiving, DD Form 250, CF66-51922 numbers, 1, 2, and 3.)

4.6.8 TV CAMERA CHECKOUT - PICTURE DISTORTION

Problem: The TV image was distorted during Crew Compartment Fit and Function Tests

REFERENCES

- 6-1 Apollo Mission Failure Contingency Plan
- 6-2 Apollo Preflight Operations Procedure Number 0-201
"Access Control of Test and Work Areas"
- 6-3 Apollo Preflight Operations Procedure Number 0-202
"Operational Checkout Procedure"
- 6-4 Apollo Ingress-Egress Log Sheets
- 6-5 Spacecraft 012 Schedule, KSC
- 6-6 Constraint List, Spacecraft 012 Operational Checkout Procedure FO-K-0006/0021-1
- 6-7 OCP FO-K-005A-1 and OCP F-K-0034A, A-1
- 6-8 TPS-012-SC100, "Modification of Quad Heater"
- 6-9 Apollo Preflight Operations Procedure Number T-502, entitled, "Discrepancy Recording System"
- 6-10 DR-SC0838 and DR-SC012-0810
- 6-11 Spacecraft Operations Letter SCO-2-104-65

ENCLOSURE 6 - 5

D-6-17

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SPACECRAFT 012 HISTORICAL RECORD

1. APOLLO DEVELOPMENT/REVIEW PROCESS

Apollo Program Directive (APD) No. 6A defines the sequence and flow of hardware development and key inspection, review and certification checkpoints for Apollo spacecraft and is included as reference 6-12. This directive is the basic document that controlled the evolution of milestones for Spacecraft 012.

These checkpoints insure that sufficient visibility is obtained of the status of design, manufacture and testing to adequately determine the integrity of the spacecraft prior to mission accomplishment.

The six key checkpoints defined by APD 6A are:

- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- First Article Configuration Inspection (FACI)
- Certification of Flight Worthiness (COFW)
- Design Certification Review (DCR)
- Flight Readiness Review (FRR)

The PDR, CDR, FACI and COFW are accomplished at selected booster and spacecraft levels of assembly (stages and modules). The DCR and FRR encompass the total mission complex. With the exception of the COFW, the requirements for these formal reviews were further defined by NASA, Houston, in the Apollo Spacecraft Program Office Configuration Management Plan (Reference 6-13), see Appendix E), however, only the PDR, CDR, FACI and the FRR were implemented by the North American Aviation (NAA) in the NAA CSM Configuration Management Plan, SID 65-100 (Reference 6-14) as approved by NASA, Houston, Paragraph 10.6 on page 10-16 was never approved by NASA, Houston, and therefore is not contractual. The Certification of Flight Worthiness (COFW) requirements were established by separate Apollo Program Office direction to NAA (Reference 6-15) and the DCR requirements were implemented by a letter from the Program Manager to NAA, Downey, as confirmed by a supplemental agreement to the contract (Reference 6-16).

These six formal reviews are scheduled jointly by NASA and North American Aviation.

a. Preliminary Design Review (PDR)

The purpose of the PDR is to formally review the design approach of a spacecraft prior to, or very early in, the detail design phase. (See paragraph b. below for a further discussion.)

b. Critical Design Review (CDR)

The purpose of a CDR is to formally review the design of a spacecraft when the design is essentially complete and is intended to precede the release of engineering drawings for manufacture. This review for S/C 012 was in reality a PDR as well as a CDR. It was accomplished after the spacecraft had been released for manufacturing and was a review of both the design and the requirements. The negotiation of the Block I Spacecraft Technical Specification, the Block I Spacecraft Master End Item Specification accomplished the PDR for each spacecraft. This approach was taken because S/C 012 was the first major Block I vehicle with the second manned Spacecraft (S/C 014) being identical. All other Block I spacecraft were to be unmanned and, therefore, were not to be fully configured. The S/C 012 PDR was appropriately used to represent all Block I spacecraft. A Delta CDR was also conducted for S/C 012 prior to testing. The Delta CDR is discussed in detail later.

c. First Article Configuration Inspection (FACI)

The purpose of the FACI is to establish the Configuration Baseline for the spacecraft. It is accomplished by establishing the relationship of the spacecraft as described by released engineering documentation (drawings, specifications) to the spacecraft as manufactured, assembled, and tested. The FACI checkpoint has been implemented for Block II spacecraft only. It was not implemented for S/C 012 or Block I because of the differences between each spacecraft. A baseline configuration is not established until Block II where each spacecraft is to be of the same configuration. Two integrated reviews known as the Systems Assessment Review (SAR) and the Customer Acceptance

ENCLOSURE 6-6

D-6-19

Readiness Review (CARR) were conducted to support the acceptance and delivery from the Contractor (NAA). These reviews are discussed later.

d. Certification of Flight Worthiness (COFW)

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The following bar-chart illustrates the Apollo development/review process (See figure 1).

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This section describes the specific Spacecraft 012 checkpoints in detail. The checkpoint activities, locations, dates, personnel involved, and significant results are included. The checkpoints are discussed in chronological order and present a complete historical summary of the flow of hardware development and key inspection, review and certification checkpoints.

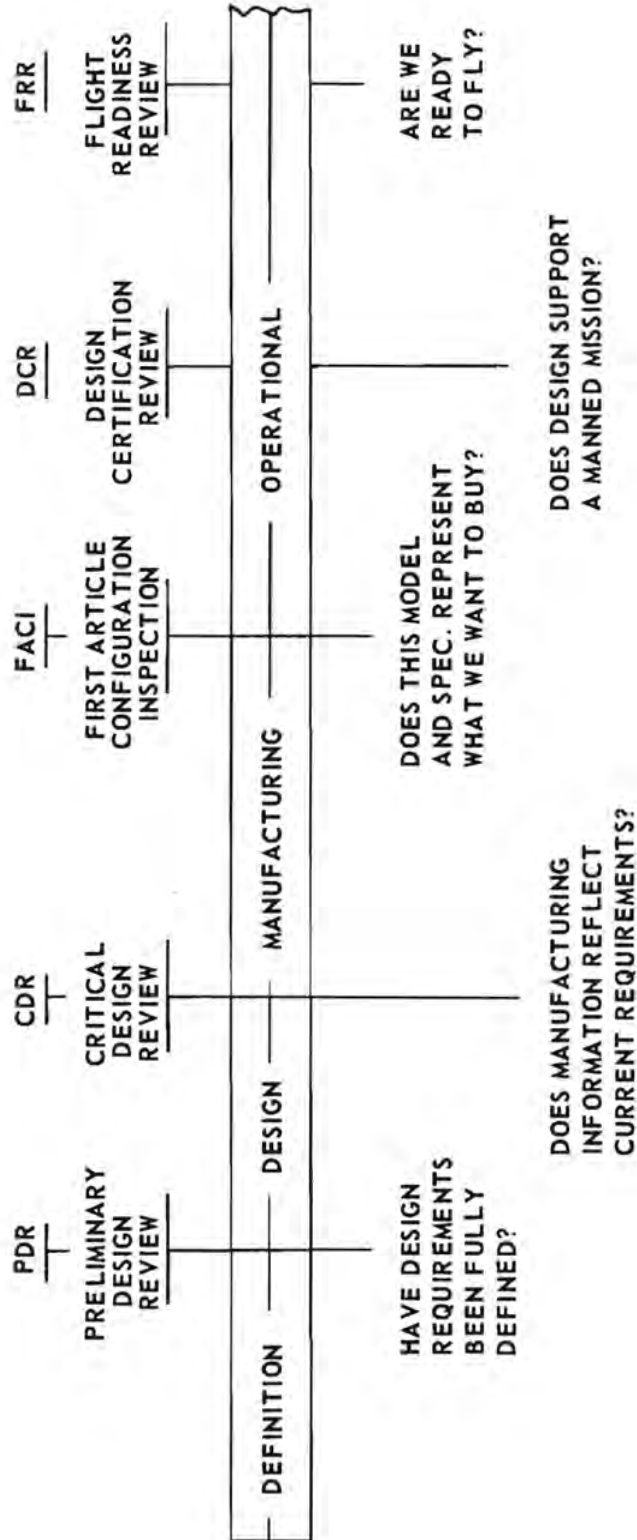
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b. Delta Critical Design Review (DCDR)

The intent of the Delta CDR for Spacecraft 012 was to insure that each level of spacecraft flight hardware and ground support equipment (GSE) end item was designed and built to meet all the requirements and was compatible with the planned mission. The review was also intended to determine the adequacy of the spacecraft checkout flow plans. It was held just prior to commencing

DEVELOPMENT/REVIEW PROCESS
(APO DEFINED)



systems testing on S/C 012. The Delta CDR utilized the CSM 012 End Item Specification, Part I, Performance/Design Requirements Apollo dated 22 February 1965, classified Confidential (Reference 6-20).

For S/C 012 the Delta CDR was held in two phases as discussed in the following paragraphs and is documented in S/C 012 Delta CDR Minutes, Part I, (Reference 6-21) and Part II (Reference 6-22).

(1) The scope of the first phase was limited to the nominal mission (Block I Design Reference Trajectory) and the "as built" configuration of the spacecraft ground support equipment (GSE). In addition, Spacecraft 008, (the thermal/vacuum test article) was reviewed concurrently with Spacecraft 012 primarily to determine the "as built" configuration differences between the two spacecrafts and to arrive at a final determination of the acceptable differences in the S/C 008 configuration. The testing of S/C 008 in the thermal-vacuum chamber at Houston was a constraint to the first Apollo manned mission S/C 012). This Delta CDR commenced on February 11, 1966, with the delivery of the NAA Data Package to NASA-Houston and was concluded with the publication of the Minutes on March 3, 1966. The data package contained 1) documents related to the Flight Mission such as AS-204A Mission Requirements and Design Analysis Report, S/C 012 End Item Specification, Measurement Requirements, Weight Report, Functional Integrated Schematics, Failure Mode and Effect Analysis and Reliability Problem Summaries for S/C 012, and 2) Ground Operations documents such as the Apollo Ground Operations Requirements Plan, Test and Checkout plans and Integrated Checkout Process Specifications. Additional documentation was available at NAA-Downey to support the Downey review. (For details see Reference 6-23, Appendix I)

After the receipt of the NAA Data Package and a technical briefing by NAA, NASA reviews were conducted at Houston, Texas, by five working groups, made up of NASA-MSC representatives. The purpose of these reviews was to identify existing and potential deficiencies, with respect to specific mission requirements, of the spacecraft design or the checkout philosophy and specifications. The Preliminary Requests for Changes (Pre-RFC's) resulting from these reviews were then submitted to a NASA-Houston Review Panel consisting of key management representatives from NASA-Houston.

As a result of the total NASA-MSC review, 137 Pre-RFC's were submitted to North American Aviation (NAA) for their consideration and then for further reviews by the same five working groups, with the addition of NAA representation on each group, at the NAA plant, Downey, California. During these reviews, many Pre-RFC's were resolved or deemed inappropriate primarily because NAA documentation showed that either design changes were in progress or, through additional information, the Pre-RFC was not valid and no change was required.

From the above five working group meetings, 37 Requests for Changes (RFC's) were submitted to the CDR Board for review. The disposition of each of these RFC's is documented in the Apollo Spacecraft 012 Delta CDR Minutes (Part I), dated March 3, 1966 (Reference 6-21). In summary 3 RFC's were rejected, 3 were not applicable, 19 were assigned for studies (10 NAA, 5 NASA, 4 joint) and the remaining 12 required immediate NAA action.

Concurrently with the working group reviews and prior to the CDR Board Review, a crew compartment review was conducted by crew members utilizing a mockup of the crew compartment. All of the Request for Changes (RFC's) resulting from this mockup review were satisfactorily resolved prior to the CDR Board Review on March 3, 1966.

(2) The Part II Delta CDR objectives were to verify compatibility of the S/C 012 design with the requirements of Mission AS-204A (Reference Trajectory) and to assure compatibility of the ground support equipment (GSE) for Launch Complex 34, at KSC, Cape Kennedy.

ENCLOSURE 6-6

D-6-22

This activity began on March 22, 1966, and was completed on April 5, 1966, with the publication of the Minutes of the NASA/NAA Management Review, Spacecraft 012 Delta Critical Design Review (Phase II) Mission Review (Reference 6-22). During the period from March 22 through March 25, 1966, a review was made at MSC by essentially the same five working groups but with primary interest by members from the APOLLO Program Office, the Flight Operations Directorate, and the Flight Crew Operations Directorate. On completion of the NASA Review on March 25, 1966, a total of 53 Review Item Dispositions (RID's) were transmitted to NAA by NASA letter PD2/L1501/66-319. (The Review Item Disposition forms are new NAA forms that have essentially updated and replaced the NAA Request for Change (RFC) forms. They accomplish the same purpose.) Thirteen of these RID's were identified as having significant program or mission impact. A NASA/NAA management review was held at NAA, Downey, on March 29, 1966, where agreements were reached and action items identified for each RID (Reference 6-22).

A second NASA/NAA Management Review was held at NAA Downey on April 5, 1966, where agreements were reached and action items assigned for the remaining 40 RID's, which consisted of requirements for data or revisions to documentation (Reference 6-22).

All of these action items were not closed out by July 19, 1966, for the Phase I of the CARR (SAR Meeting) as evidenced by the Phase I CARR report (Reference 6-24 for example, see page 3-65). They were, however, closed out by the CARR which was held on August 19, 1966, since no RFC's or RID's are reflected as open items. (In this regard, the CARR report is by exception and, therefore, reflects only open items.) The fact that they were closed out prior to the CARR has been confirmed by the NASA-Houston CSM Project Officer in his letter to Chairman of Panel 6, Historical Data. (Reference 6-25)

c. Customer Acceptance Readiness Review (CARR)

The CARR was a two phase review. Phase I was a System Assessment Review (SAR) held at NAA-Downey on July 19, 1966. The SAR was a working level, informal meeting held to assess spacecraft systems testing (all systems functioning for checking interfaces) and enabled the participants to evaluate the system performance and problems. The SAR is a constraint to performing integrated systems testing (mission simulation tests). The systems testing was documented by NAA-Downey in the Phase I CARR report (Reference 6-24) which was submitted by NAA-Downey to NASA-Houston on June 13, 1966.

The SAR meeting minutes and action assignments are documented in the Phase II CARR Report (Reference 6-26). As a result of the SAR meeting, one-hundred ninety-three (193) action items were assigned. One-hundred twenty-seven (127) action items had program or mission impact while sixty-six (66) of the action items were requirements for data or documentation.

The Phase II of the CARR is a formal board meeting to review the results of spacecraft integrated systems testing, the open action items from the SAR, and the action items from the Crew Compartment Fit and Functions (CCFF) review. The CCFF is a review where the spacecraft crew enters the spacecraft and physically verifies the stowage and proper use of crew equipment. The CCFF was initiated prior to the CARR, but was incomplete at the time of the CARR and was completed after the CARR Board Review. The CARR Board Review. The CARR Board determines if the spacecraft is ready for shipment to the launch facility (KSC-Cape Kennedy).

The CSM 012 CARR Board was held in Downey on August 19, 1966. There were 66 items brought before the Board for discussion, 33 of which originated at the Phase I SAR. Sixteen (16) items were determined to have been adequately dispositioned and were closed for future action. Thirty-three (33) items were deferred for resolution at a later date and were not constraints to the shipment of the vehicle. These items fell into the general categories of: work or tests to be accomplished at KSC; resolutions to be made pending results of studies; investigations or qualifications tests; and furnishing NASA with data requested at the CARR meeting. The remaining 17 discussion items were required to be dispositioned at Downey prior to shipment to KSC. The CARR

action items are documented in "CARR Minutes and Action Assignments" and "CARR Action Response" (Reference 6-26).

The following summarizes the Downey ACTIONS AND DISPOSITIONS OF THE ABOVE REFERENCE ITEMS] Each item is identified by its respective item number in the Phase II CARR report minutes.

1.7.1 POWER LOSS ON CSM - INVERTER

Problem: During spacecraft testing, power loss occurred.

Resolution: Inverter 1 was determined to be faulty and was removed and replaced. The replacement inverter was installed, checked and determined to be acceptable prior to shipment.

3.6.14 FLIGHT QUAL INSTRUMENTATION STATUS

Problem: Four transducers were determined to not be operating properly.

Resolution: The transducers were replaced and the new transducers functionally verified prior to spacecraft shipment.

3.7.1 SUIT LOOP LEAKAGE

Problem: Leakage noted during Operational Checkout Procedure (OCP) 5051 was greater than the specification allows.

Resolution: It was concluded from evaluations that misinterpretation of data caused the out-of-specification statement. Re-evaluations were made of test data and it was concluded that leakage of the suit loop circuit at time of shipment was within acceptable limits. It was also noted that normal test flow at KSC would verify this conclusion.

3.7.2 DEMAND REGULATOR FAILURE (OXYGEN)

Problem: The demand regulator was determined during spacecraft testing to be inoperative.

Resolution: The regulator was replaced and the new regulator functionally verified prior to shipment.

3.7.3 WATER CYCLIC ACCUMULATOR FAILURE

Problem: During spacecraft testing, the water cyclic accumulator was determined to be inoperative.

Resolution: Two (2) new units were installed before the water cyclic accumulator would pass checkout. The units were installed and checked out and the final unit was determined to be acceptable prior to shipment.

3.7.10 OPERATIONAL CHECKOUT PROCEDURE (OCP) 5051, SUIT LOOP CHECKS

Problem: Checkout per OCP 5051 was not complete at the time of the CARR.

Resolution: OCP was completed prior to shipment. The following problems were transferred to KSC for final resolution. Squawks 54, 58, 59, 60, 61, 62, 63, and 908. (See Reference 6-27, Material Inspection and Receiving, DD Form 250, CF66-51922 numbers, 1, 2, and 3.)

4.6.8 TV CAMERA CHECKOUT - PICTURE DISTORTION

Problem: The TV image was distorted during Crew Compartment Fit and Function Tests (CCFF).

Resolution: A reverification of the TV image was performed prior to shipment and found to be within acceptable limits.

5.6.17 CALIBRATION CURVES

Problem: The Flight Crew required the Spacecraft panel meter calibration curves.

Resolution: The calibration curves were transmitted to the crew prior to shipment.

5.7.1 FAILURE OF ECS MEASUREMENTS

Problem: The water-glycol pump package pressure measurements CF0025P was found defective. Measurements CF0484T and CF0135R were also faulty.

Resolution: The cause was found to be defective transducers. The transducers for measurements CF0484T and CF0135R were replaced and the new transducers reverified prior to shipment. The transducer for water-glycol pump inlet pressure measurement CF0025P was not replaced and NAA's request for waiver was granted (Reference 6-28).

12.6.3 HATCH DECALS

Problem: Installation of torque limit decals had not been completed.

Resolution: The decals were installed prior to vehicle shipment.

13.6.10 CO2 PARTIAL PRESSURE GAGE

Problem: When power was turned on, the gage went to full scale deflection and triggered the caution and warning system.

Resolution: Additional testing was accomplished prior to shipment and gage operation was determined to be satisfactory although Automatic Checkout Equipment (ACE) readouts did not correspond. Per CARR Board direction, calibration was to be validated at KSC.

13.7.1 RHEOSTAT FAILURE - FLOODLIGHTS

Problem: The rheostat failed to provide a smooth linear resistance change with shaft rotation.

Resolution: The rheostat was removed and replaced. The new rheostat was installed and operation verified prior to shipment.

13.7.2 EVAPORATOR STEAM BACKPRESSURE C&W INDICATION

Problem: The master caution and warning light triggered with no visible indication on the individual display when the glycol evaporator steam backpressure was operated.

Resolution: The problem was found to be a defective switch which was removed and replaced. A retest with the new switch was not performed and was transferred as open work to KSC. (Reference 6-27, Material Inspection and Receiving Document, DD Form 250, Squawk 62, CM Number 1, 2 and 3.)

14.7.1 PARTIAL CREW COMPARTMENT FIT AND FUNCTION CHECK (CCFF) SUMMARY

Problem: CCFF was not completed at the time of the CARR and numerous items were open for evaluation.

Resolution: The CCFF was completed prior to shipment. The following problems were transferred to KSC for final resolution: Squawks 12, 15, 20, 22, 23, 30, 33, 35, 38, 56, 925,

and 929 (Reference 6-27, Materials Inspection and Receiving Document, DD Form 250, CF66-51922, CM numbers 1, 2, and 3).

14.7.2 FLAMMABLE MATERIALS IN CM

Problem: Use of Velcro and other materials in the Command Module (CM) was not considered desirable and was unsatisfactory for flight.

Resolution: Investigation of the CM crew compartment was performed with identification of undesirable materials listed prior to shipment of the spacecraft. NASA participated in the investigation and the results of the investigation are documented in NAA IL 633-300-040-66-1009, dated 22 August 1966 (Reference 6-29). Further documentation is in the Materials Review, Panel 8 Final Report, Section C.8.b.

15.7.1 MDAS CHECKOUT

Problem: The Medical Data Acquisition System (MDAS) was not checked out during the Crew Compartment Fit and Function (CCFF) review.

Resolution: The checkout of the MDAS was performed satisfactorily during the Operational Checkout Procedure (OCP) 5051, prior to shipment.

15.7.2 16 MM CAMERA OPERATION

Problem: The camera was not operable at time of CARR.

Resolution: Camera operation was satisfactorily demonstrated during the second run of OCP-P-5051 and CCFF, prior to shipment.

(1) Description of Material Inspection and Receiving Document, DD Form 250.

In conjunction with the CARR procedures and as a part of the CARR Board actions, it is necessary to officially document the spacecraft configuration at the time of shipment as well as any items of open work to be transferred to KSC-Cape Kennedy for accomplishment. The DD Form 250 is utilized for this purpose and is the formal acceptance of the spacecraft by the government from the contractor.

The status is defined by listing those additions to, and those unaccomplished items from the major module configuration definition of record at the time of shipment (i.e., top level engineering drawings for the spacecraft). The DD Form 250 will normally contain the following information:

- Government Furnished Equipment (GFE) installed
- Field site installations that were installed at Downey
- Removals (normally to support shipment)
- Loose equipment with shipment (to support open work and removals for shipment)
- Actual part shortages
- Open work items (squawks, Engineering Orders, drawings)

On Spacecraft 012, there were four (4) DD Form 250's used (Reference 4-16) since four (4) separate shipments were made as follows:

- Spacecraft complete V14-000002-21 (DD Form 250 CF66-51968, 9 September 66). This form confirms shipment of the total spacecraft and the spacecraft data package.
- LES - V15-000002-221 (DD Form 250 CF66-51886, 22 July 1966).
- CM - V16-000002-191 (DD Form 250, CF66-51922, 1, 19 August 66; 2, 25 August 66; 3, 27 September 66).
- SM - V17-000002-131 (DD Form 250, CF66-51898, 8 August 66).

Two revisions were made to the original Command Module (CM) DD Form 250 (Ref-

ENCLOSURE 6-6

D-6-26

erence 6-27). The first (original) DD 250 did not reflect the true status of the Command Module in that it did not include all of the actual part shortages nor did it list the equipment removed to facilitate shipment. To correct the status of the Command Module, the second CM DD Form 250 was written.

After shipment, additional discrepancies were discovered in the "as shipped" hardware configuration status. Additional shortages, Field Installation Items (FOI), equipment removals, Government Furnished Equipment installed on the CM or accompanying the shipment, and additional items of loose equipment were discovered. The third CM DD 250 was written to correct the status of the Command Module. In addition, the contents of third DD 250 were rearranged to provide a document which was easier to read and understand.

Those CARR items requiring Downey action which were not completed at NAA-Downey, were transferred to KSC, Cape Kennedy, on the DD Form 250 (Reference 6-27).
(2) Certificate of Flight Worthiness (COFW)

A COFW was initiated in accordance with Apollo Program Directive No. 6 for S/C 012 on August 24, 1966, at NAA-Downey. This was endorsement one and is included as Reference 6-17.

d. Design Certification Review (DCR)

The initial phase of the DCR was conducted for the Apollo 204 mission in accordance with the requirements of Apollo Program Directive (APD) No. 7 (Reference 6-18) during the period September 21-28, 1966, and concluded on October 7, 1966. The results of this phase of the DCR are documented in the attachment to an Apollo Program Director's letter dated October 12, 1966 (Reference 6-30). The Apollo Design Certification Board was chaired by the Associate Administrator for Manned Space Flight and the Board Members were as follows:

Director, NASA Manned Spacecraft Center
Director, NASA Marshall Space Flight Center
Director, NASA Kennedy Space Center

Presentations on the spacecraft were made to the Board jointly by NASA-Houston and NAA-Downey personnel. In addition, a memorandum for Design Certification Board (Reference 6-31 -sample) was submitted for the Board's consideration, certifying with contingencies the spacecraft for a manned mission. These memorandums were signed by the NASA-Houston Subsystem Managers and NAA-Downey Design Engineers.

There were a total of 89 action items resulting from the Board's review. In addition, each of the three Apollo Program Managers developed a Certification Contingency List and they are also included as Minutes. These Contingency Lists contain a total of 20 action items.

Action items resulting from all aspects of the review are as follows:

Launch Vehicle	- 29 (No. 11 combined with No. 19)
Launch Complex	- 10 (41 through 49 have no action)
Spacecraft	- 38
Other	- 12
Launch Vehicle Program Manager's Contingency List	- 5
Spacecraft Program Manager's Contingency List	- 8
Launch Complex Program Manager's Contingency List	- 7
TOTAL	- 109

ENCLOSURE 6-6

D-6-27

On October 7, 1966, the Design Certification Board issued the AS-204 Design Certification Document (Reference 6-30, Attachment) which certified the design of the Space Vehicle for flight worthiness and manned safety and the capability of the Mission Support to support a manned mission contingent upon satisfactory resolution of the qualifications, tests, investigations and action items listed in attachments to the Design Certification Document.

The action close out processes continued from October 7 through December 20, 1966, however, during this period the Apollo Program Director made a decision to conduct a Recertification Review to be conducted during the month of December 1966. This action was deemed necessary in view of the large number of action items resulting from the initial review, with many remaining open. The selected date of December 21, 1966, for this second review was influenced by a slippage in the launch schedule caused by the delay in completion of the Environmental Control Sub-system water boiler test at the AiResearch Corporation to correct a previously identified deficiency wherein the water boiler became contaminated and blocked fluid flow (Reference 6-30, Attachment II, item 5.d.).

The status of action items as of December 20, 1966, is contained in the Apollo Program Director's report (Reference 6-32) on that date to the DCR Board Chairman. There were 14 items with incomplete responses and 9 to be closed prior to the FRR. The status as of January 27, 1967, as reported to the Apollo 204 Review Board on March 17, 1967 (Reference 6-33, shows 66 items closed, 4 not required for certification, 2 to be closed out at the AS-204 FRR, 4 with incomplete response and 13 with closure pending the Apollo Program Director's concurrence. There were no new action items as a result of the December 21, 1966 meeting. The updated Action Item Synopsis sheets are included in the Apollo Program Director's status report (Reference 6-32) and appropriately marked to indicate the status as of January 27, 1967.

e. Flight Readiness Review (FRR)

The Office of Manned Space Flight, Washington, D.C., had planned to conduct a two-part Flight Readiness Review for S/C 012 with the purpose as:

Part I - To determine that the space vehicle hardware and launch complex are ready to commence the mission period.

Part II - To determine the readiness of the operational elements for a manned space flight.

Part I would have been conducted by the Apollo Program Director; Part II by the Mission Director. The FRR is defined in Apollo Program Directive No. 8 (Reference 6-19). The FRR would have been held approximately two weeks prior to launch.

MSC, Houston, in conjunction with KSC - Cape Kennedy, would have conducted a Pre-Flight Readiness Review (Pre-FRR) at KSC - Cape Kennedy approximately 3 days prior to Part I of the FRR. Upon completion of the Pre-FRR, a NAA prepared report would have been submitted to the Program and Mission Directors along with the Apollo Spacecraft Program Manager's report. The Apollo Spacecraft Program Manager would have orally summarized these reports at the FRR and provided an update of the spacecraft checkout, failure analysis and qualification status, implementation of Pre-FRR action items and DCR action items.

The basic objective of the Pre-FRR is to evaluate the readiness of the spacecraft, GSE hardware and ACE hardware to achieve the specified mission as documented in the MSC, Houston FRR Procedure (Reference 6-34). Specifically the objectives are to:

- Evaluate all work accomplished subsequent to the delivery of the spacecraft to KSC.
- Determine the status of the hardware with respect to all waivers, deviations, discrepancies, shortages, unresolved checkout problems, generic and spacecraft failures, limited life components, configuration changes, uncontrolled parts, and open work.
- Determine qualification/certification status of spacecraft hardware, including evaluation of test versus flight hardware differences.
- Determine the flight readiness and degree of engineering confidence in the reliability of the

hardware at the point in time of the review.

- Specify action to be accomplished as a result of the review.
- Release the hardware for final launch preparations.

The Pre-FRR review board consists of:

Chairman - Apollo Spacecraft Program Manager, or his designated appointee.

Members - Representative from Engineering and Development Directorate, MSC-Houston.

- Representative from the Flight Operations Directorate, MSC - Houston.

- Representative from the Flight Crew Operations Directorate, MSC - Houston.

- Representative from the Flight Safety Office, MSC - Houston

- Representative from the Medical Research and Operations Directorate, MSC-Houston.

- Representative from the Office of the Director, Plans, Programs, and Resources, KSC - Cape Kennedy.

- Representative from the Office of Assistant Director for Spacecraft Operations, KSC-Cape Kennedy.

Secretary - Representative from the Reliability, Quality and Test Division, MSC - Houston.

The Pre-FRR report (Reference 6-35) was completed by NAA on January 27, 1967, however fifteen (15) preliminary copies were delivered to MSC - Houston on January 25, 1967. The original masters were impounded on January 27, 1967, after the S/C 012 accident. With the Apollo 204 Review Board's approval, copies of the original masters of the Pre-FRR report were made and one copy delivered to the Apollo 204 Review Board Legal Counsel.

All hardware problems in the Pre-FRR report (Reference 6-35) were reviewed to determine which problems may have been related to the accident. These problems are listed in below along with the action taken:

- During Downey and KSC checkout of S/C 012, two inverters experienced "moly-Block" transistor failures. These failures cast suspicion on the conclusiveness of the "Moly-Block" transistor fix for a prior overheating problem. Analysis of the problem revealed no design inadequacies but did show the need for improved screening techniques of the transistors. Such techniques were developed and imposed on the transistors installed in S/C 012.

Action - Inverters to be removed from S/C 012 and analyzed per Review Board Action Items 0041, 0123, 0153, and 0182.

- The Environmental Control System, in particular the Environmental Control Unit (ECU), has experienced several significant problems that had impact on S/C 012. The majority of these problems occurred in qualification testing. The most serious problem was that the water evaporator (water boiler) blocked and would not accept water for evaporation to cool the water/glycol. This problem was eliminated by redesign of the distribution plates and making a filter change. With these and other changes incorporated, the ECU has successfully completed qualification testing. All of these changes were implemented on S/C 012.

Action - ECU to be analyzed per Review Board Action Items 0097, 0102, 0168.

- During the Combined Systems Test at Downey, several caution and warning light indications could not be verified. Troubleshooting isolated the problem to an open circuit within terminal block assembly No. 1 behind the Main Display Console (MDC) C&W Panel No. 11. An x-ray examination of the matrix terminal block assembly (TB-1) revealed seven pins not properly inserted. The pin insertions in the remaining 31 similar TB assemblies installed in the S/C were examined. This examination revealed nine additional discrepant terminal block assemblies.

Action - Terminal Blocks to be analyzed per Review Board Action Items 0160, 0161, 0153.

- Several spacecraft electrical wire harness assemblies were saturated with water-glycol during KSC Checkout Operations. Subsequent investigations have proven that this solution in spacecraft wiring and connectors will support electrolytic corrosion particularly in the presence of a polarizing electric potential.

Action - Wire harness assemblies to be analyzed per Review Board Action Items 0160, 0161.

- Analysis of shielded and unshielded Environmental Control Unit (ECU) electrical harnesses

indicated that numerous connectors were improperly potted. S/C 012 was retrofitted with cables using ML wire and larger backshells. All of these cables have had dielectric testing. These cables have been tested under a corrosive contaminant oxygen and humidity environment and have satisfactorily passed the minimum acceptable insulation resistance requirement. The ECU with these new cable assemblies was installed in S/C 012.

Action - ECU electrical harnesses to be analyzed per Review Board Action Items 0161, 0168.

- Floodlights: Problems which occurred in S/C checkout, characterized by abrupt loss of light output and blowing of internal fuses, were traced to susceptibility to line transients within the floodlight power converter circuit. Circuit design and component changes were made to improve transient susceptibility margin, and units have since been subjected to a more rigorous acceptance test.

Action - Floodlights were analyzed per Review Board Action Item 0169 and it was determined the floodlights were not an initiator or propagator of the fire.

- Bio-Med parameter CJ0002 (Respiration) decreased in level when either crew member pressed Push to Talk (PTT) switch. Modulation was also present when crewman spoke.

Action - Bio-Med harness and Medical Data Acquisition System to be analyzed per Review Board Action Items 0155, 0156, 0165.

- Flexible Polyurethane Foam (FPF). The FPF has failed in the flammability test per MA0115-008 which requires no flame at 400°F in O2. This foam is used in Crew Systems Design and Support, ECU, ECS, and Telecommunications.

Action - The FPF is discussed and future corrective action is outlined in the final report of Panel 8 - section C.8.b. Corrective action is to use a substitute, nonflammable material in future spacecraft.

The Apollo Spacecraft Program Manager's FRR report was approximately 60 percent complete at the time of the S/C 012 accident, but had not been reviewed by the Manager. The existing sections of the report were reviewed to determine if any problems discussed could be related to the accident. The following problems were a result of this review and are in addition to the problems discussed from the Pre-FRR report.

- Polyurethane foam is used as potting in the Electronic Control Assembly (ECA). This potting includes and surrounds printed circuit boards and electronic components. Polyurethane foam gives off a flammable gas at elevated temperatures. These units are installed in the crew compartment and are therefore exposed to an oxygen environment.

Action - The polyurethane foam is discussed in the final report of Panel 8 - Section C.8.b. Corrective action is to use a substitute, nonflammable material in future spacecraft.

- As the result of recent flammability tests, the Uralane Foam 577-1 was found to fail the flammability tests below 400°F. If this foam were used in close proximity to components whose normal or overload condition could reach excessive temperature, a fire could be started. Typical components falling into this category are electrical resistors, capacitors, or malfunctioning diodes.

Action - Corrective action is to use a substitute nonflammable material in future spacecraft as discussed in the final report of Panel 8 - Section C.8.b.

- Of the approximately 1300 nonmetallic materials identified as used in the Command Module, NAA has supplied the following status information:

300 Materials do not meet the criteria established by MC999-0058.

350 Materials are acceptable by these same criteria.

650 Materials have no status as to acceptability.

Due to the type of information, i.e., material lists, bill of materials, etc. used by NAA to compile the material usage list, exact location and amount used is not available in the majority of the cases. Such information is obtainable only by drawing review. This activity is not planned by NAA. In addition, subcontractor compliance has not been either imposed or obtained in all cases. Due to this lack of information, an engineering decision cannot be made on whether a serious problem does or does not exist nor can an assessment be made on the effect on the reliability from a toxicity and flammability standpoint. It is estimated at this time that the identification of the nonmetallic materials is approximately 85-90 percent complete.

Action - Corrective action is outlined in the final report of Panel 8 - Section C.8.b.

REFERENCES

- 6-12 Apollo Program Directive No. 6A MA009-006-1A, dated August 30, 1966, titled "Sequence and Flow of Hardware Development and Key Inspection, Review and Certification Checkpoints".
- 6-13 Apollo Spacecraft Program Office Configuration Management Plan, Revision B, dated March 15, 1966.
- 6-14 NAA-CSM Configuration Management Plan, SID 65-100. Section 10.0, Formal Reviews.
- 6-15 Project Apollo - Procedure for the Certification of Flight Worthiness (COFW) from NASA, MSC, Houston, Texas, dated June 20, 1966.
- 6-16 Apollo Program Manager's letter dated July 13, 1966, subject "Design Certification Review Support for Mission AS-204/SC 012".
- 6-17 Certificate of Flight Worthiness for Spacecraft 012, Endorsement No. 1, dated August 24, 1966.
- 6-18 Apollo Program Directive No. 7, dated April 21, 1966, titled, "Apollo Design Certification Review".
- 6-19 Apollo Program Directive No. 8, dated November 8, 1965, titled, "Apollo Flight Readiness Reviews".
- 6-20 CSM-012 End Item Specification SID 64-1080, dated 22 February 1965. Classified CONFIDENTIAL.
- 6-21 Apollo S/C 012 Delta CDR Minutes of the Meeting. Part I NAA-Downey, California, dated March 3, 1966.
- 6-22 Apollo S/C 012 Delta CDR Minutes of the Meeting. Part II NAA-Downey, California, dated March 29, 1966 and April 5, 1966.
- 6-23 Manned Spacecraft Center, Project Apollo, Plan for Phase I, Delta Critical Design Review, Spacecraft 012, dated January 28, 1966.
- 6-24 Customer Acceptance Readiness Review, Project Apollo, CSM 012, Phase I Report, dated June 1966.
- 6-25 United States Government Memorandum PF2/G-116-67, Subject: Disposition of S/C 012 Delta CDR Action Items, dated March 23, 1967.
- 6-26 Customer Acceptance Readiness Review, Project Apollo, CSM 012, Phase III Report from NNAA-Downey, California, dated 21 July 1966.
- 6-27 CSM Major Module Material Inspection and Receiving, DD Form 250's.
- 6-28 Apollo NAA/NASA Waiver Approval Request. CSM S0001 dated 3-24-66.
- 6-29 NAA Internal Letter dated August 22, 1966, Subject: Flammability Investigation S/C 012 CARR.
- 6-30 Apollo Program Director's Letter, dated 12 October 1966, Subject: AS-204 Design Certification Review.

ENCLOSURE 6-6

D-6-31

- 6-31 Memorandum for Design Certification Board dated September 23, 1966, Subject: Service Propulsion Subsystem.
- 6-32 United States Government Memorandum dated 20 December 1966, Subject: AS-204 DCR Action Items
- 6-33 Datafax transmission from Apollo Program Office Action Center, dated 17 March 1967 supplemented by Letter from APO Action Center, dated 24 March 1967, Subject: AS-204 DCR Record Supplement.
- 6-34 Apollo Spacecraft Program Office Flight Readiness Review Procedure MSC-A-D-66-6, dated October 12, 1966.
- 6-35 Project Apollo, Flight Readiness Review Spacecraft Readiness Review, Spacecraft 012 Report, dated February 1967.

APOLLO REVIEW BOARD

APOLLO SPACECRAFT 012
HISTORICAL NARRATIVE
OF
PRELAUNCH OPERATIONS
AT
KENNEDY SPACE CENTER

Enclosure 6-7

ENCLOSURE 6-7

D-6-33

INTRODUCTION

This report presents a brief historical narrative of the prelaunch operations performed on Apollo Spacecraft 012 at Kennedy Space Center. Each major test that was accomplished is briefly described in addition to significant problems and spacecraft rework required.

For additional clarification, an "as run" bar chart is included. Charts are also included to portray the relationship of spacecraft testing to scheduled and non-scheduled work as a result of design modifications and discrepancies during the prelaunch operations.

Apollo Spacecraft 012 prelaunch checkout at Kennedy Space Center was initiated on August 10, 1967, with arrival of the Service Module portion of the Spacecraft. After arrival at the Cape Kennedy Skid Strip, the Service Module was transported to the Kennedy Space Center industrial area warehouse for painting. Service Module painting is normally delayed until arrival at Kennedy Space Center to preclude abrasions during shipment. The condition of the Service Module paint is of concern since it is a thermal paint and performs a mission function in the environmental control of the Service Module.

With completion of painting, the Service Module was moved to the Operations & Checkout Building and installed in a workstand for installation of the Service Propulsion System engine nozzle plug. The nozzle plug was installed in preparation for accomplishing leak and functional testing of the Service Propulsion System.

After installation of the nozzle plug, the Service Module was moved into the adjacent altitude chamber on August 13. On August 15, the parallel tasks of

receiving inspection and preparations for Operations Checkout Procedure number 4074 were initiated. Receiving inspection is delayed until this point is reached since the required removal of various panels for testing provides better visibility to perform the inspection. Receiving inspection consists of a visual inspection to check the "as received" condition of the vehicle for possible damage incurred during shipment. Operations Checkout Procedure 4074 is a leak and functional test of the Service Module Propulsion System to verify the pressure integrity and functional operation prior to mating with the Launch Vehicle on the launch complex. The actual performance of Operations Checkout Procedure 4074 was started on August 17 and continued through August 27.

In parallel with Operations Checkout Procedure 4074, a Service Module radiator reflectivity test was accomplished per Operations Checkout Procedure 5116. This test confirms the capability of the radiators in the Service Module to remove the heat generated by the Spacecraft systems. In addition to

the accomplishment of these two parallel tasks, two design modifications were incorporated and five discrepant conditions were repaired on the Service Module during this time period.

The Command Module portion of Spacecraft 012 arrived at Kennedy Space Center on the 26th of August, three weeks after arrival of the Service Module. The Command Module was transported directly to the Pyrotechnic Installation Building for weight and balance and Launch Escape System thrust vector alignment checks. Command Module weight and balance checks are performed to determine the weight and center of gravity of the spacecraft. Launch Escape System thrust vector alignment consists of optically ascertaining the proper alignment of the Launch Escape System rocket engine nozzles with respect to the centerline of the CM after mating the Launch Escape System tower to the Command Module. With the completion of these two tasks, the Launch Escape System tower was removed from the Command Module and returned to storage to await reinstallation during final preparations for launch at the launch complex.

The Command Module was removed from the Pyrotechnic Installation Building and transported to the Operations & Checkout Building altitude chamber on August 29 for mating with the Service Module. The Command and Service Module mating operation was started on the 30th of August and required 64 hours to complete. Command and Service Module mating normally requires 16 hours. In this instance, the mechanical hardware utilized to attach the Command Module to the Service Module was of a new design and proved to be difficult to adjust with relation to the Command Module aft heat shield interface. Previous experience was not available since factory checkout plans did not require final installation of the aft heat shield prior to factory Command and Service Module mating. In addition, information (strain gauge calibration curves) required to ascertain when the proper tension adjustment between the Command Module and Service Module was achieved, had inadvertently not been shipped from the factory with the spacecraft, and was subsequently lost. Completion of mating was delayed until calibration curves could be generated locally.

After completion of Command and Service Module mating,

a receiving inspection was performed on the Command Module. With completion of receiving inspection, the accumulation of required design changes, and repair of discrepant conditions was such that a fifteen-day, "no test" work period was initiated. The spacecraft had arrived with 113 approved, but unincorporated design changes (EO's). During this period, thirteen major system design changes (MCR's, Master Change Record) were incorporated, the majority of which were wiring modifications. In addition, various removal and repair and rework activities were conducted. The incorporation of known modifications and repairs at this point in time was required prior to proceeding into Operations Checkout Procedure 0035, Combined Systems Testing, since rework of this nature and scope could invalidate the test. The objective of the combined systems test is to determine that all spacecraft systems perform properly and that no incompatibilities or interferences exist between systems.

On September 15, the Combined Systems Test was commenced and continued until September 17 when testing was stopped in order to determine the cause of two major malfunctions in the spacecraft Caution and

Warning System and Reaction Control System respectively. Investigation revealed that several pins within a Matrix electrical connector (TBI) on the caution and warning main display panel in the Command Module cabin had not been completely inserted during manufacturing. This resulted in a lack of electrical continuity. As a precautionary measure, seven cabin display panels were removed from the spacecraft and x-rayed to determine if a similar discrepancy existed on other Matrix electrical connectors. This activity required two days to accomplish. The Reaction Control System malfunction was determined to be two badly bent pins in an electrical connector resulting in a short circuit to ground. On September 19, Operations Checkout Procedure 0035 was again started and was completed on September 23; however, some additional unresolved malfunctions had been detected. At this point, spacecraft testing was discontinued for an eight-day period to resolve and repair the known malfunctions. In addition, this time period was utilized for various mechanical work and incorporation of two design changes.

With relation to the detected malfunctions, improper

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operation of the fuel cell water-glycol coolant system was determined to be blockage of fluid flow due to installation of a blind (no hole) Voishan seal in a system line. After seal replacement, the system was purged, dried, and reserviced. Other malfunctions repaired during this period included replacement of an oxygen supply valve and resolution of problems in the Telemetry and Guidance and Navigation systems. Also during this work period, a leak developed in the Environmental Control System water-glycol loop due to a faulty soldered joint behind the Display Electronic Control Unit. This was subsequently repaired.

One area of considerable trouble during this time period was the crew couches which had been removed from the spacecraft for extensive mechanical rework. Some twelve separate major discrepancies had been detected and required factory design engineering personnel to travel to Kennedy Space Center to assist in the resolution of design deficiencies.

On October 1, spacecraft testing was reinitiated for a one-day period to demonstrate that the previous electrical malfunctions had been properly resolved

and repaired. At completion of this one-day period of testing, the Combined Systems Test was considered satisfactorily completed and was accepted.

On October 2, a work period was started for the purpose of preparing the Spacecraft for Operations Checkout Procedure 0034, Altitude Chamber Testing. This test involves testing the spacecraft under simulated altitude conditions with the flight crew onboard. Preparation for the altitude test included a leak test to verify pressure integrity of the spacecraft cabin, various crew equipment installations, flushing and servicing the environmental control water system, and the continued reservicing of the fuel cell water-glycol system. During reservicing of the fuel cell water-glycol system, additional leaks were detected and repaired. During the cabin leak test, improper operation of a cabin relief valve was detected. This unit was removed and replaced and the test satisfactorily completed. Also during this work period, a design modification was incorporated, which provided the flight crew with additional mechanical leverage to open the spacecraft hatch. With completion of a crew equipment stowage exercise by the flight crew, the spacecraft was considered ready

for the Altitude Chamber Test.

On October 10, the Altitude Chamber Test was started. This test consists of a sea level run, an unmanned run "at altitude", and two manned tests, or runs, "at altitude". The sea level run consists of testing all systems in a mission sequence to ascertain that systems perform properly and events occur at the correct point in time with relation to the planned flight. The flight crew participates as an integral part of the test. The unmanned run "at altitude" is accomplished to assure the capability of the spacecraft life support systems to sustain the flight crew "at altitude" prior to attempting the manned runs. Finally, the manned altitude runs (one for the prime crew and one for the backup crew) are for the purpose of evaluating the spacecraft systems operation at altitude; compatibility of spacecraft and crew under altitude conditions; and capability of the crew to perform various tasks with the crew stowed equipment.

During the sea level portion of the Altitude Chamber Test, a malfunction was detected in the spacecraft abort system. Investigation revealed three bent pins in the electrical umbilical connector between the Command

Module and Service Module. This problem was corrected and the sea level run was successfully completed on October 13. During the following two days, the unmanned run at altitude was satisfactorily completed.

With completion of the unmanned run, preparation for the initial manned run was initiated. This preparation consisted of servicing the spacecraft environmental control system with potable water; liquid oxygen loading, and fuel cell activation. These tasks were completed on October 17. On the following day the manned run was initiated and continued until a spacecraft electrical power system inverter failed during pump down of the altitude chamber. After replacement of the inverter, testing was again resumed and the run completed on the following day, October 19, with one equipment malfunction, failure of a spacecraft primary oxygen regulator.

Determination of the cause of the regulator failure proceeded with removal of the regulator from the spacecraft and subsequent disassembly of the unit. Disassembly of the unit and further investigation revealed a design deficiency existed in the regulator.

While awaiting a redesign decision on the spacecraft oxygen regulator, various miscellaneous spacecraft work items were accomplished such as replacement of all spacecraft circuit interceptors (improved design), additional x-rays of Matrix connectors, etc. On October 27 a decision was made to remove the Environmental Control Unit from the spacecraft and return to the factory for incorporation of a design change to the water boiler.

Meanwhile, a Spacecraft 017 Service Module propellant tank had ruptured during factory checkout at Downey, California. In view of the tank failure at the factory, it was decided to conduct some special testing on the Spacecraft 012 tanks at the Kennedy Space Center. In order to proceed with the Service Module special tank test and continue work on the Command Module in parallel, the Command and Service Modules were demated on October 29. The Command Module was moved out of the Altitude Chamber and installed in the adjacent integrated work stand and removal of the Environmental Control Unit was started. The Service Module remained in the altitude Chamber and preparation for removal of the Service Propulsion System propellant tanks was initiated. The rationale behind removal of the tanks prior to testing

was to prevent destruction of the Service Module in the event a tank rupture occurred similar to the Spacecraft 017 failure during factory checkout.

On November 2, removal of the Service Module propellant tanks was completed and the tanks were transported to Launch Complex 16 at Cape Kennedy for special pressure testing. During pressure testing, the tanks were serviced with liquid Freon to reduce the hazardous aspect of the test. Complex 16 is a remote area approved for hazardous testing. Tank testing was successfully completed on November 7 and on the following day the tanks were returned to the Operations & Checkout Building. By November 11, tank installation in the Service Module was complete. The following two days were utilized to incorporate an engineering modification on the Service Module propulsion fuel tank plumbing.

On November 13, the Service Module was transported to Launch Complex 16 at Cape Kennedy for Service Propulsion System pressure testing. This was necessary to reestablish overall system confidence at operational pressure after the tanks had been reinstalled in the Service Module.

Pressure testing on the Service Module was completed on November 16 and the Service Module was returned and reinstalled in the Operations & Checkout Building altitude chamber. Two days of preparation and work followed and on November 18, the Service Module was ready for mating with the Command Module.

In parallel with the previously described Service Module activity, work had been progressing on the Command Module in the Operations & Checkout Building integrated workstand. The Environmental Control Unit had been removed and returned to the factory for modification. On November 8, a new configuration Environmental Control Unit was received and installation into the Spacecraft was started. Installation was complete on November 12 and a leak and functional test on the system was initiated. This was completed on November 18.

In addition to the Environmental Control Unit activity described above, other testing had proceeded on the Command Module. A reaction Control System leak and functional test had been performed per Operations Checkout Procedure 4070. This test would normally have been performed at the launch complex as a portion of Operations Checkout Procedure 0005. However,

ENCLOSURE 6-7

D-6-47

since the capability to perform the test existed in the Operations & Checkout Building and time was available, the test was performed to alleviate testing and provide additional contingency time on the launch complex. It is noted that the Reaction Control System Test performed is only a small portion of the Operations Checkout Procedure 0005 that was utilized, and only the Reaction Control System portion was performed. In addition to the Reaction Control System Test, a calibration test on the Guidance and Navigation System was performed at this time as a normal periodic requirement.

Concurrent with preparation of the Service Module for mating, the Command Module was moved from the Operations & Checkout integrated workstand into the adjacent altitude chamber and mated to the Service Module on November 19. With completion of Command and Service Module mating, preparation for continuation of the manned altitude chamber test (second manned run for backup crew) was started. On November 25, a new configuration spacecraft oxygen regulator was installed.

On November 29, servicing of the Environmental

Control System water and water-glycol systems had been completed and power was applied to the spacecraft in preparation for the manned altitude run. During powerup of the spacecraft, evidence (a few drops) of water-glycol was observed on the spacecraft cabin floor under the aft right hand corner of the newly installed Environmental Control Unit. Three days of investigation failed to positively locate the source of the leakage. On December 3, a decision was made to remove the Environmental Control Unit and return it to the factory for further investigation and location of the source of leakage.

While awaiting return of the Environmental Control Unit from the factory, a reverification test was performed on two components (check valves) of the Reaction Control System. These units had failed during the previously described Reaction Control System leak and functional test and had been replaced. Also during this time period an additional leak was detected at a supply line solder joint (lower equipment bay) in the Environmental Control System water-glycol system.

On December 14, the Environmental Control Unit was returned to Kennedy Space Center from the factory.

Extensive testing on the unit at the factory had not confirmed any leakage associated with the unit. After Environmental Control Unit installation was completed, the Environmental Control System was serviced, and again an indication (a few drops) of water-glycol leakage was observed on the cabin floor under the aft right hand corner of the Environmental Control Unit. At this time extensive efforts were made to locate the source of the leak, but were unsuccessful. No leakage was ever noted or observed at this same location apart from the servicing operation. It was assumed that the leakage condition was due to a dynamic action by "O" ring seals and/or other seals as a result of prolonged vacuum during servicing operations and thus would not occur except during servicing. A decision was made to proceed with testing and continue to observe this condition.

Reverification testing of the Environmental Control System was successfully completed on December 20. The crew couches were installed on December 21 and the environmental control water system serviced the following day. The crew couches had been removed for access to remove and reinstall the Environmental Control Unit. Preparations for continuing the altitude chamber test

were continued until December 24 when work was discontinued for the Christmas holiday.

On December 27 and 28, the sea level and unmanned portions of the altitude chamber test were successfully completed. Although these tests had been previously completed, they were repeated to establish confidence for the manned run since a significant amount of spacecraft rework had been accomplished. On December 29 and 30, the second manned altitude run with the backup crew participating was performed and all test objectives were met. It is noted that the final manned run was very successful with all spacecraft systems functioning normally. At the post test debriefing, the backup flight crew expressed their complete satisfaction with the condition and performance of the spacecraft.

After completion of the altitude chamber test, the environmental control water and liquid oxygen systems were deserviced and the spacecraft was removed from the altitude chamber and placed in an adjacent workstand on January 3. The Service Propulsion System nozzle extension was installed and leak checked on the following day. On January 4, the spacecraft was mated to the spacecraft adapter and installation of ordnance devices was started.

On January 6, the spacecraft was moved to the launch complex and mechanically mated to the launch vehicle.

After mechanical mate with the launch vehicle, ground support equipment was connected in preparation for the spacecraft Integrated Systems Test, Operations Checkout Procedure 0005.

The basic objectives of this test are to verify that spacecraft electrical systems are compatible with the launch complex and ground support equipment prior to electrically mating the spacecraft to the launch vehicle and performing overall space vehicle testing.

Test preparations were completed on January 11 and the spacecraft was powered up for the integrated systems test on the following day. This test was completed on January 14. The Launch Escape System tower was mated to the spacecraft on the following day and preparation for the cryogenic loading test, Operations Checkout Procedure 4736 was started.

The cryogenic loading test involves servicing the spacecraft liquid oxygen and liquid hydrogen systems. The basic objective is to assure that servicing can be

performed and that no incompatibilities exist between the spacecraft and ground support equipment. This test also provides early verification of the test procedure and provides practice for the servicing exercise to be repeated later during critical portions of the launch countdown. The cryogenic loading test was completed successfully on January 17 and the spacecraft was deserviced.

With completion of the cryogenic loading test, the spacecraft was electrically mated to the launch vehicle. Verification that proper electrical connection had been made was verified by performing Operations Checkout Procedure 0004. This test was completed on January 18.

At this point the spacecraft was powered down for a one-day work period. Power had been applied to the spacecraft since the initial launch complex test was started (except during launch escape tower installation); as a result, various minor work items had accumulated, the majority of which were configuring the interior of the cabin for flight. In addition, detailed study of test results (data) from the spacecraft Integrated

System Test had indicated possible malfunctioning equipment in the guidance and navigation inertial measurement unit and the stabilization and control system. Further investigation of these two possible problems were continued during this period. The Inertial Measuring Unit (platform) was determined to be acceptable. The Yaw Electronic Control Assembly of the Stabilization and Control System was found to be unsatisfactory and was replaced at a later date.

On January 20, a decision was made to proceed with a practice run of the Space Vehicle Overall Test number 1, Operations Checkout Procedure 0006. The run was a practice run in that it would have to be repeated since the required participation of the Mission Control Center in Houston, Texas, was not available to support the test until some four days later. The prime objective of making a practice run was to identify at the earliest possible time any procedural or hardware compatibility problems. It is noted that up to this point testing had involved the spacecraft and launch vehicle individually except for the Electrical Mate Test. The opportunity to detect overall spacecraft/launch vehicle hardware and procedural problems had not occurred.

It is noted that since initiation of the final manned altitude chamber test, operations had proceeded so well that testing was five days ahead of schedule even after completion of the overall test No. 1 practice run.

The objective of the Space Vehicle Overall Test Number 1 (plugs in) is to ascertain proper operation of the total Space Vehicle (launch vehicle and spacecraft) during a simulated mission sequence from liftoff to completion of the spacecraft reentry and recovery phase. The practice run was completed successfully on January 20. On the following day minor work items and repairs were accomplished with no work scheduled for January 22 (Sunday). On January 23 minor spacecraft work items and repairs continued in addition to preparation for the Houston Mission Control Center Software Integration Test.

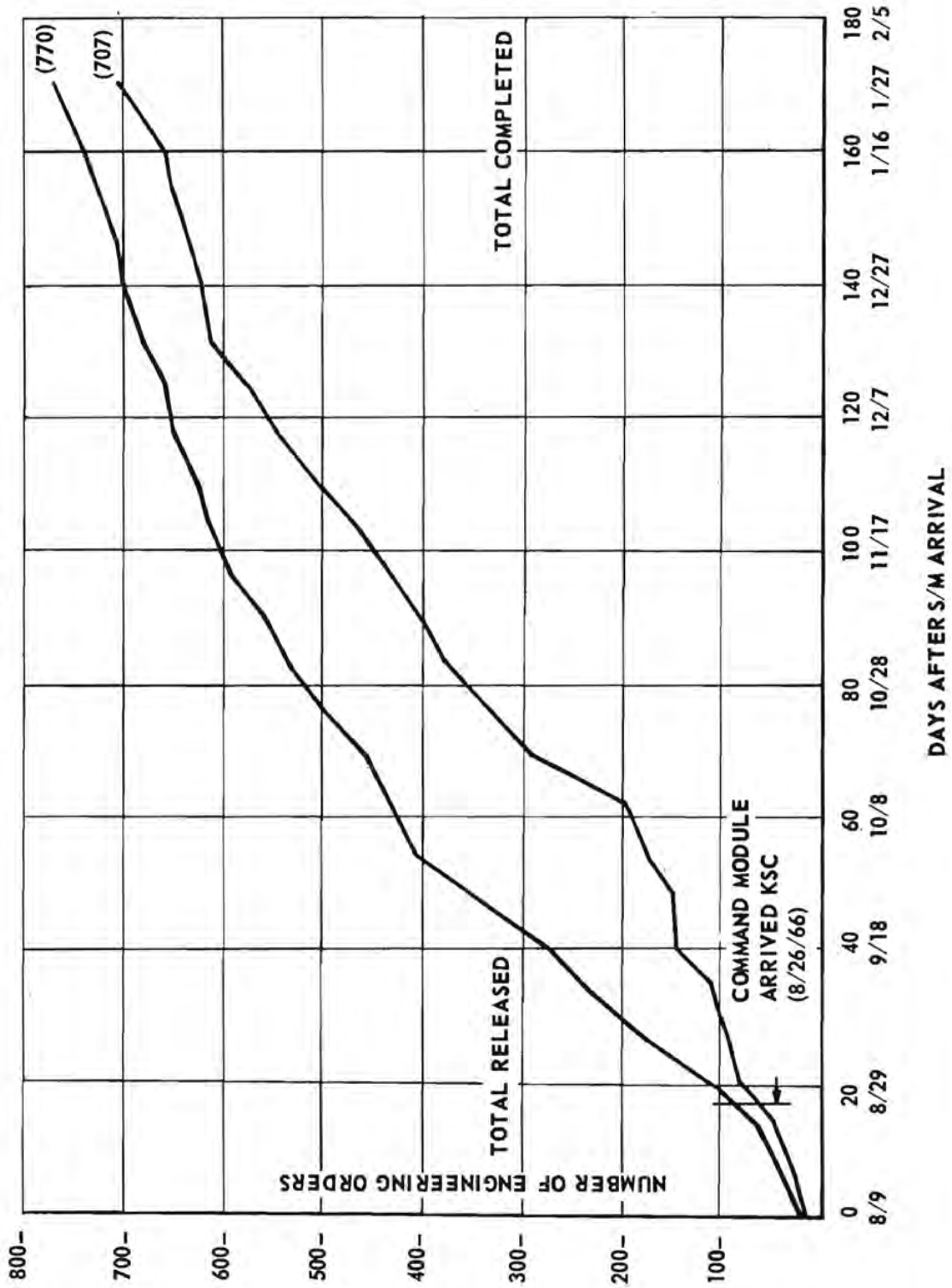
On January 24, the Houston Mission Control Center Software Integration Test was performed per Operations Checkout Procedure 0045. This test verifies that the Houston Mission Control computer programs and equipment performs properly with relation to the spacecraft. This test was successfully completed and the following day the "repeat" run of the Space Vehicle Overall Test Number 1 was made with the Houston Mission

Control Center participating. The test was completed and all test objectives met.

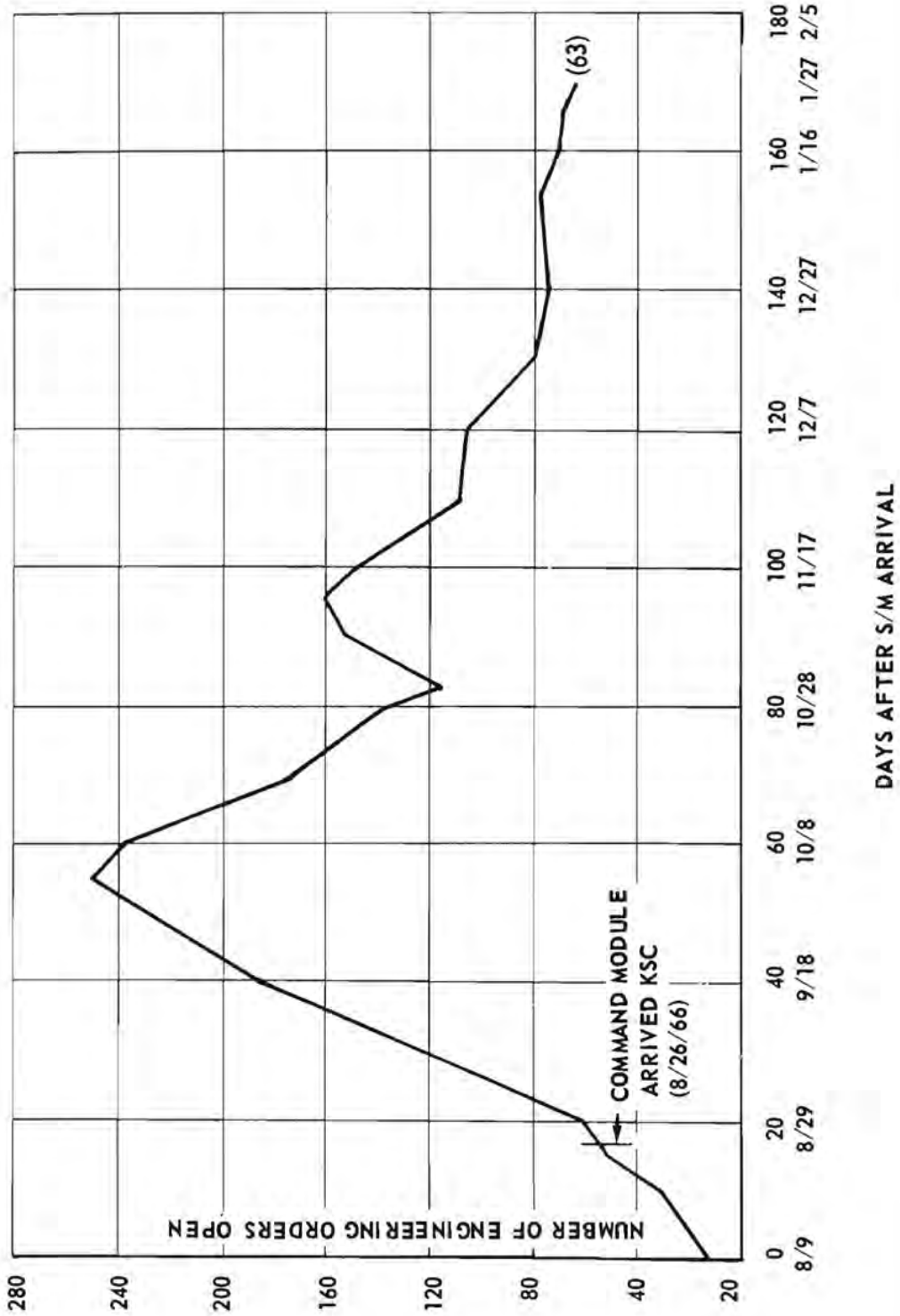
At the conclusion of the Space Vehicle Overall Test Number 1 (plugs in), spacecraft power was left on in order to perform a detailed system test on the yaw Electronic Control Assembly and the Guidance and Navigation System. These systems were suspected of malfunctioning due to a detailed data review of the Operations Check-out Procedure 0005, Integrated Systems Test. It was determined that the yaw Electronic Control Assembly was defective. The unit was replaced and retested satisfactorily. The Guidance and Navigation System was found to be functioning properly. Spacecraft power was removed and preparation for Space Vehicle Overall Test Number 2, Operations Checkout Procedure 0021, was started.

The prime objective of the Space Vehicle Overall Test Number 2 is to verify performance of the total space vehicle during a simulated mission sequence with the space vehicle as near launch and flight configuration as possible. This test was initiated on January 27, 1967,

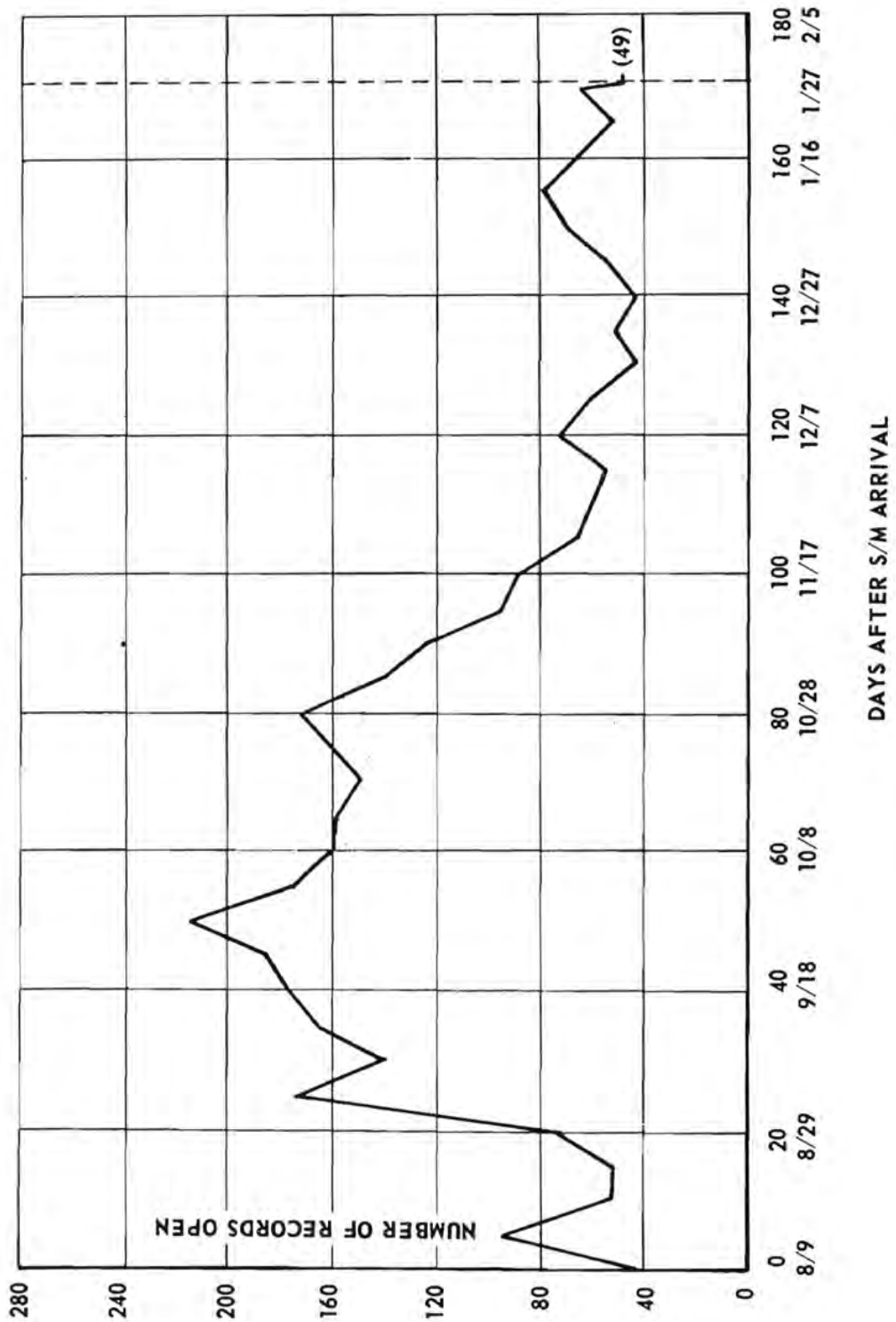
CUMULATIVE ENGINEERING ORDERS
SPACECRAFT 012



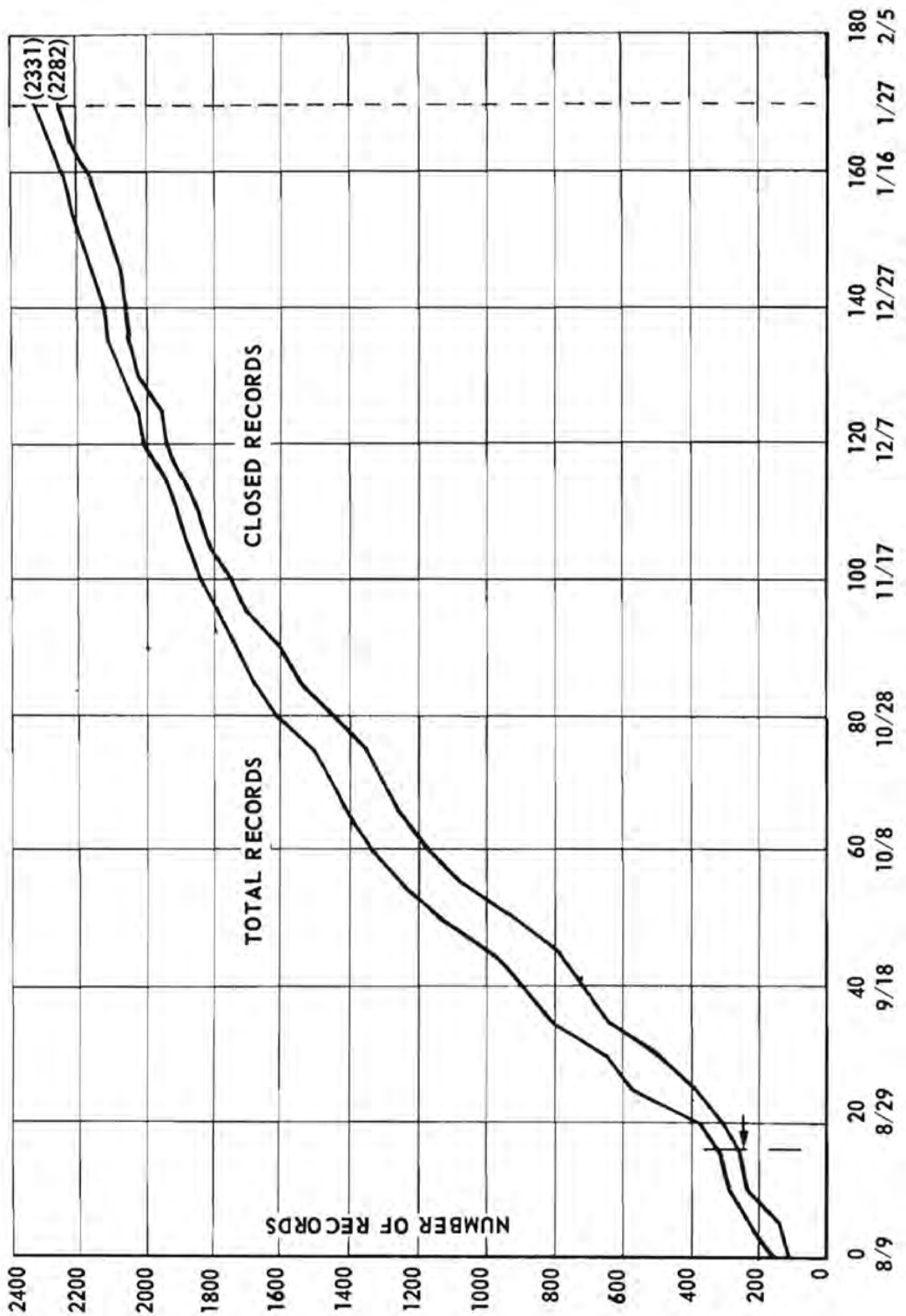
UNCOMPLETED ENGINEERING ORDERS
SPACECRAFT 012



TOTAL OPEN DISCREPANCY RECORDS
AND DISCREPANCY RECORD SQUAWKS
SPACECRAFT 012



CUMULATIVE TOTAL DISCREPANCY RECORDS
AND DISCREPANCY RECORD SQUAWKS
SPACECRAFT 012



AUGUST - 1966

SEPTEMBER - 1966

10 12 14 16 18 20 22 24 26 28 30 1 3 5 7 9 11 13 15

SM ARRIVAL & MOVE TO WAREHOUSE

PAINT SM IN WAREHOUSE

MOVE TO WORKSTAND IN O&C BUILDING, INST SPS NOZZLE PLUG

MOVE TO ALTITUDE CHAMBER

PREP FOR SPS LEAK & FUNCT. TEST

SPS LEAK & FUNCT. TEST

CSM

MOD & WORK PERIOD, PREP FOR OCP K 0035.

DEMATE LES AND MOVE TO O&C BUILDING

THRUST VECTOR ALIGNMENT

WEIGHT & BALANCE CHECKS

CM ARRIVAL AND MOVE TO PIB

NOTES:

■ NORMALLY EXPECTED TESTING AND WORK.

▨ ABNORMAL TESTING, WORK, AND MODIFICATIONS.

SEPTEMBER - 1966

OCTOBER - 1966

15 17 19 21 23 25 27 29 1 3 5 7 9 11 13 15 17 19 21 23

CSM

COMBINED SYSTEMS TEST. OCP K 0035
POWER DOWN. REPAIR MATRIX CONNECTOR

MOD. & WORK PERIOD

REVERIFICATION TEST, COMPLETE OCP K 0035

MOD. & WORK PERIOD, PREP FOR OCP K 0034

SEA LEVEL RUN, OCP K 0034

POWER DOWN, REPAIR CM/SM SEP. SIG.

PREP FOR UNMANNED RUN

UNMANNED RUN, OCP K 0034

PREP FOR MANNED RUN, H₂O + LO₂ SERVICING

MANNED RUN, OCP K 0034

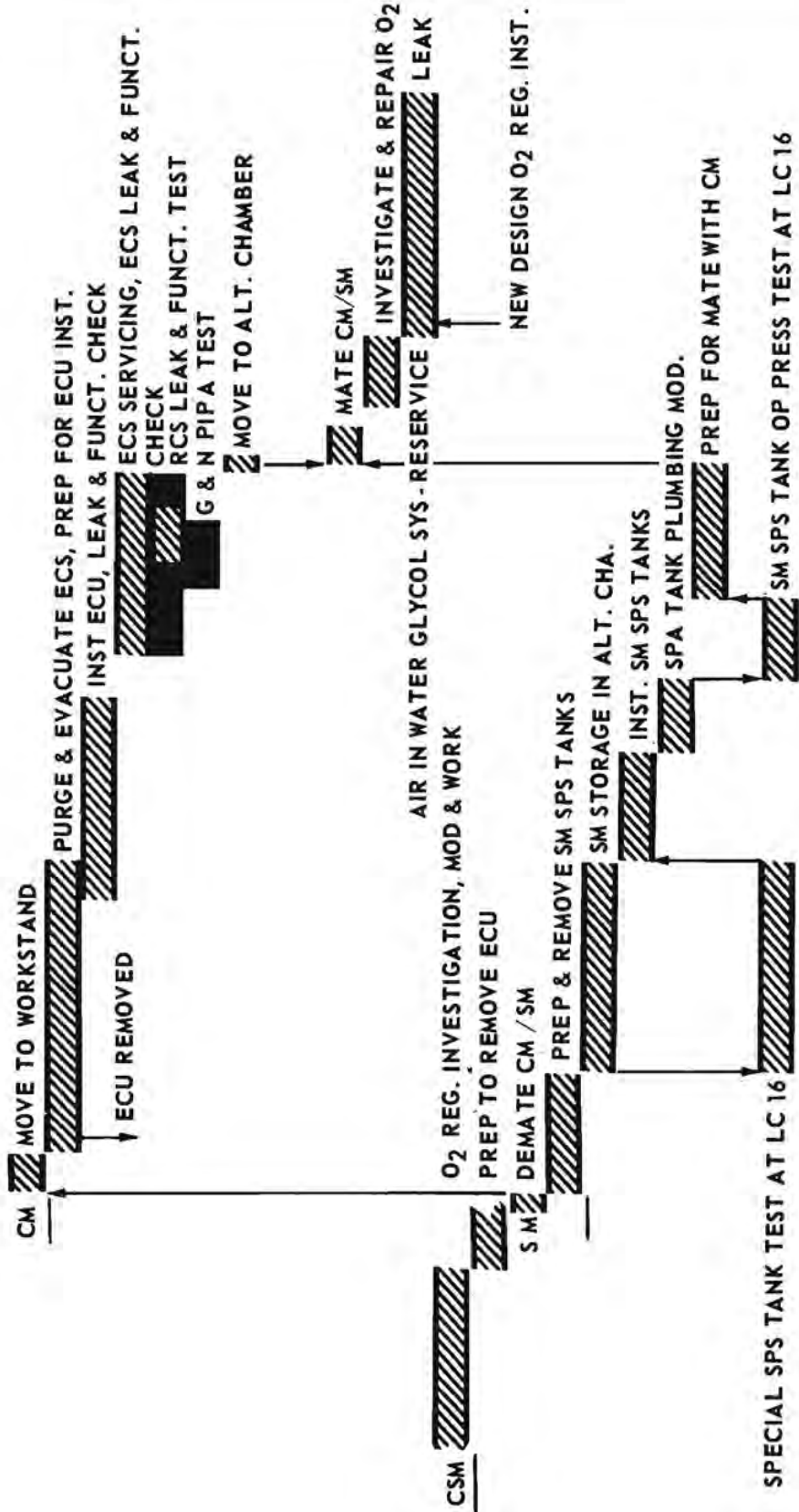
POWER DOWN, REPLACE INVERTER

O₂ REG INVESTIGATION, MOD. & WORK PERIOD

OCTOBER - 1966

NOVEMBER - 1966

23 25 27 29 31 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30



DECEMBER - 1966

30 2 4 6 8 10 12 14 16 18 20 22 24



JANUARY 1967

26 28 30 1 3 5 7 9 11 13 15 17 19



JANUARY - 1967

FEBRUARY - 1967

7 9 11 13 15 17 19 21 23 25 27 29 31 2 4 6 8 10 12

■ PREP FOR OCP K-0005

■ INTEGRATED SYSTEMS TEST, OCP K-0005

■ LES INSTALLATION

■ CRYOGENIC TANKING TEST, OCP K 4736

■ CSM/LV ELECTRICAL MATE & EDS TEST, OCP K 0004

■ OVERALL TEST NO. 1 (PLUGS IN) OCP K 0006 (DRY RUN)

■ SOFTWARE INTEGRATION TEST (MCC-H) OCP K 0045

MINOR SPACECRAFT WORK ■

PREP ■

■ OVERALL TEST NO. 1 (PLUGS IN) OCP K 0006

■ SPECIAL YAW ECA TEST

■ PREP FOR OVERALL TEST NO. 2 (PLUGS OUT)

■ OVERALL TEST NO. 2 (PLUGS IN) OCP K 0021

APOLLO SPACECRAFT 012
HISTORICAL NARRATIVE FOR PERIOD
OF
SPACE VEHICLE OVERALL TEST NO. 2 PREPARATION

ENCLOSURE 6-7

D-6-67

INTRODUCTION

This report presents a brief historical narrative of the period encompassing final preparation for the Space Vehicle Overall Test No. 2 (plugs out), Operations Checkout Procedure 0021.

The initial portion of the report describes the various types of operational meetings and procedural methods used during the period of checkout described. The final portion of the report includes a chronological listing of pertinent events that occurred in preparation for the plugs out test.

DESCRIPTION OF MEETINGS

Open Items Review

The purpose of an Open Item Review is to examine all paperwork that exists at that point in time depicting work that must be accomplished to the Spacecraft and Ground Support Equipment. The basic documents utilized in an Open Item Review are the NAA Spacecraft and Ground Support Equipment Status Reports. At an Open Item Review a constraints list is developed which indicates the work that must be accomplished prior to proceeding into the next spacecraft test. A test constraint is defined as that open work item which if not accomplished would interfere with, or prohibit, the successful completion of a spacecraft test.

Test constraints are normally broken up into two basic categories: constraints to powering up, and constraints to powering down. A constraint to applying power to the spacecraft busses normally indicates work which must be performed that would require modifications (removal and replacement) of spacecraft and/or Ground Support Equipment. Judgement is utilized to recognize hardware availability and work and retest time available in subsequent operations. A constraint to removing

power from the spacecraft busses normally indicates investigation and retest that should be accomplished at that point in the test operation but which would not prohibit the conduct of that test procedure.

Open Item Review Meetings are co-chaired by the NASA Spacecraft Test Conductor and the NAA Test Project Engineer. Functional groups represented at an Open Items Review are as follows:

<u>NAA</u>	<u>NASA</u>
Test Project Engineering	Spacecraft Test Conductor
Engineering (S/C & GSE)	Engineering (S/C & GSE)
Operations	Project Engineering (S/C & GSE)
Inspection	Operations
Shop	Inspection
Service Engineering	Flight Crew Representative
Operations Integration	

Open Item Reviews are normally conducted several days prior to a test in order that appropriate time will be available to work off the identified constraining items.

At the Open Item Review Meeting, the Spacecraft and Ground Support Equipment Status Reports are reviewed and those open items considered to be constraints for the forthcoming test are identified. The identified

constraints are compiled into a single "constraints list" and published shortly after the open item review meeting, usually within three hours. The constraints list identifies the tasks to be worked by system and indicates the responsible person to accomplish close-out of the item.

The constraints list cover sheet identifies the applicable spacecraft test constrained by the list and provides for NAA and NASA approval signatures. Two types of approvals are required. The initial approval signatures indicate that the list is official and are obtained prior to distribution of the list. The final approval signatures indicate that all constraints listed have been worked and closed out. This approval is obtained just prior to going "on station" to start the test. Constraints list approvals are provided by the NAA Test Project Engineer and the NASA Spacecraft Test Conductor.

After completion of the Open Item Review Meeting and subsequent distribution of the constraints list, new items of work are continuously assessed by the NAA and NASA operations engineers. As each new item of work is released, the operations engineer contacts the applicable system engineer to discuss disposition

of the item. The system engineer may or may not proceed to the spacecraft area at this time and actually write the disposition. The main object of the discussion is to maintain the operations engineer's knowledge of new constraints.

Regardless of the previously described discussion relative to the disposition all new items are added to the Spacecraft and Ground Support Equipment Status Reports. New spacecraft work items are reflected daily in the form of an addendum to the basic Spacecraft Status Report utilized at the Open Item Review Meeting. New ground support equipment work items are also reflected in addendums to the Ground Support Equipment Status Report. These addendums are issued weekly or more frequently as required by the amount of new items. Utilization of these status report addendums occurs in real time and at the daily 0800 Status Meeting and 1430 Scheduling Meeting described below.

It is noted that after initial generation of the official constraints list, newly identified constraints become a part of the list in two different manners. If time permits, a revised constraints list is generated. In the absence of appropriate time for revision, the appropriate sheets of the Spacecraft and Ground Support

Equipment Status Report addendums are attached to the original constraints list. The attached addendum sheets are marked to indicate the constraining additional items.

Daily Status Review Meeting

The daily 0800 Status Review Meeting is a general coordination meeting to review the work accomplished during the past 24 hours and to discuss new work items that any have been generated during that same period of time. The following personnel attend the 0800 meetings.

NAA

Sr. Test Project Engineer
Asst. Sr. Test Project Engr.
Engineering Representative
GSE Representative
Inspection
Shop
Service Engineers
Quality Engineering
Downey Project Engineering
Logistics
Safety Engineering

NASA

Chief Test Conductor
Spacecraft Project Engr.
Operations
GSE Project Engr.
Inspection
RASPO Representative
Support Contractor Representative

Following the 0800 meeting, new work items are scheduled on the Working Schedule Planning Sheet by NAA and NASA Operations personnel. This Planning Sheet is used to schedule all work that must be accomplished on the space

craft and projects three weeks into the future. The Planning Sheet is updated daily if required and is used in supplement to the overall spacecraft schedule. The Planning Sheet is not an official document (not signed by either NAA or NASA) but is given wide distribution throughout the NAA/NASA Test organizations.

In preparation for the 0800 Status Meeting, a complete review of the updated Spacecraft Status Report is conducted by the NASA and NAA operations engineers. This review is usually conducted at the spacecraft where all inspection logs are available to verify the status report.

Daily Scheduling Meeting

At 1430 each day a scheduling meeting is conducted at which the spacecraft work schedule for the next 24 hours is generated. Planning Sheets are utilized at this meeting for reference. At the 1430 meeting, the Spacecraft and Ground Support Equipment Status Report addendums are reviewed to determine if additional constraining work items exist which should be scheduled

for work. The 1430 schedule meeting is attended by the following personnel:

NAA

Representatives from
each system
GSE Representatives
Operations
Quality Engineering
Safety Representatives
Inspection
Downey Project Engineering

NASA

Representatives from
each system
GSE Representatives
Operations
NASA MSC Representative
Flight Crew Representative
Inspection
NASA Headquarters Representative

Support Contractor Representatives and other personnel as required also attend this meeting to support the operation.

Note that the individual spacecraft systems are represented individually at the 1430 Daily Scheduling Meeting whereas at the 0800 meeting an engineering coordinator is the only engineering representative.

Pretest Briefing

A Pretest Briefing is a meeting conducted by the NAA Test Project Engineer and the NASA Spacecraft Test Conductor prior to each test to review various aspects of test with other members of the test team. Each

systems engineer presents a summary of his particular system status with relation to state of readiness for the test. Any open items (constraints) existing at that time are identified and anticipated problems associated with the closeout of same prior to the test are discussed. If the test is eminent, a "Go" is requested from each system engineer indicating his complete state of preparedness for the test.

All pertinent operational ground rules for the test are reviewed and past problems of an operational nature are discussed. Specific attention is directed to any hazardous aspects of the test and test discipline. The method of handling certain paperwork during the test, such as procedure deviations, is reviewed and the integration engineer responsible for writing deviations is identified.

A Bar Chart of the test is also reviewed on a system by system basis to briefly review the intent of the test and the manner of accomplishment. The meeting is normally concluded with an announcement of the "on station" time and time for initiation of GSE setup and spacecraft switch list accomplishment.

Personnel normally attending Pretest Briefing are as follows:

<u>NAA</u>	<u>NASA</u>
Sr. Test Project Engineer	Spacecraft Test Conductor
Test Project Engineer	Project Engineer
System Engineers	Operations Engineer
Operations Engineers	System Engineers
Shop Supervision	GSE Engineering
Quality Control	Quality Control
Safety	RASPO
Service Engineers	Flight Crew Systems
Downey Project Engineer	ACE Engineering
GSE Engineers	Flight Crew Representative
ACE Engineering	

It is noted that separate pretest briefings are held for the test team technicians. In this instance only those operational aspects of the test involving the technicians are discussed.

Post Test Debriefing

A Post Test Debriefing is a test team meeting held subsequent to a test for the purpose of determining if the test objectives were met. The Interim Discrepancy Record (IDR) log is reviewed on a system by system basis. Each system engineer explains any problems encountered during the test, the implication of same, and establishes

the post test status of his system.

At the completion of a test, spacecraft power is normally left on for troubleshooting if problems have been encountered during the test. In this event, the post test debriefing is not held until spacecraft power is removed. It is also noted that a complete review of test data is not available at the time of the post test debriefing and it is not uncommon for IDRs to be generated at a later date when a complete data review is available.

A post test debriefing concludes with the decision to perform additional troubleshooting, await further detail data review for analysis, or consider the test complete and proceed into the next test, as the situation warrants. Personnel normally attending post test debriefings are as follows:

<u>NAA</u>	<u>NASA</u>
Sr. Test Project Engineer	Spacecraft Test Conductor
Test Project Engineer	Project Engineer
Systems Engineers	Systems Engineers
Operations Engineer	ACE Engineering
Quality Control	Quality Control
GSE Engineers	Operations Engineering
Downey Project Engineer	Flight Crew Systems
ACE Engineering	RASPO
	Flight Crew Representative
	Flight Crew (if applicable)

CHRONOLOGICAL LISTING

1. January 23, 1967, 1030. Open Item Review Meeting for Operations Checkout Procedures 0006 (Plugs In) and 0021 (Plugs Out). A constraints list was developed with the following open items:
 - Operations Checkout Procedure 0006 (Plugs In)
 - Constraints to power up - 11 open items.
 - Constraints to power down - 16 open items.
 - Operations Checkout Procedure 0021 (Plugs Out)
 - Constraints to power up - 26 open items.
 - Constraints to power down - 2 open items.

The power up constraints that were developed for Operations Checkout Procedure 0006 were also to apply to Operations Checkout Procedure 0045 (MCCH Software Integration Test) scheduled to be run prior to Operations Checkout Procedure 0006.
2. January 23, 1967, 1230. Pre-test Briefing for Operations Checkout Procedure 0045 and 0006. This meeting excluded the test team technicians.
3. January 23, 1967, 1430. Daily scheduling meeting.
4. January 23, 1967, 1530. Pre-test Briefing, Operations Checkout Procedures 0045 and 0006 for first shift test team technicians.
5. January 23, 1967, 2400. Pre-test Briefing, Operations

5. Checkout Procedures 0045 and 0006 for second and third shift test team technicians.
6. January 24, 1967, 0400. Power on for Operations Checkout Procedure 0045. The constraints list for Operations Checkout Procedure 0006 had been signed off prior to start of the test.
7. January 24, 1967, 0800. Daily status meeting.
8. January 24, 1967, 1430. Daily scheduling meeting.
9. January 24, 1967, 2030. Operations Checkout Procedure 0045 completed. Spacecraft power remained on to close out Operations Checkout Procedure 0006 (Plugs In) constraints. Those spacecraft systems which had no constraints were powered down. A post test debriefing was conducted "on station" on an individual system basis through review of real time recordings and all new Interim Discrepancy Reports (IDR).
10. January 25, 1967, 0400. Operations Checkout Procedure 0006 was started.
11. January 25, 1967, 0800. Daily status meeting.
12. January 25, 1967, 1430. Daily scheduling meeting.
13. January 26, 1967, 0300. Operations Checkout Procedure 0006 (Plugs In) completed. A post test debriefing was conducted on station on an individual systems basis through review of all new IDR's and real time records.

13. Spacecraft power was left on for troubleshooting associated with the Guidance and Navigation System and the Yaw Electronic Control Assembly. IDR's had been written on these systems as a result of detailed data review of the Integrated Systems Test, Operations Checkout Procedure 0005. IDR's were constraints to power up for Operations Checkout Procedure 0021 (Plugs Out).
14. January 26, 1967, 0800. Daily status meeting.
15. January 26, 1967, 0900. A meeting was held at Complex 34 to review the spacecraft readiness status for the Plugs Out Test with the following personnel in attendance:

NAA

Senior Test Project Engr
Asst Senior Test Proj. Engr

NASA

Chief Spacecraft Test Conductor
Spacecraft Test Conductor
Senior Operations Engr

This meeting was held in order to verify that the spacecraft would be ready to proceed into the Plugs Out Test on the following day and that the NASA Spacecraft Test Conductor could commit the spacecraft for that test to the Test Supervisor. At that time, it was determined that the remaining constraints to the Plugs Out Test (accomplishment of which were required) was the retest of the Yaw Electronic Control Assembly, a spacecraft removals review, and completion of the test checklist.

Based on discussions with engineering personnel, it was agreed that several items that appeared on the constraints list could be waived for the Plugs Out Test, but that they must be accomplished prior to the Flight Readiness Test (Operations Checkout Procedure 0028). The results of this meeting were submitted to the NASA Spacecraft Project Engineer for evaluation. It is noted that a waiver is obtained when it is determined that a work item cannot be accomplished to meet a specific test schedule and that the particular work item is not an absolute test prerequisite, but rather preferential to that test. This procedure has been followed on each of the Apollo spacecraft operations at Kennedy Space Center.

16. January 26, 1967, 1000. Space vehicle post test debriefing. The NASA Chief Spacecraft Test Conductor, NASA Spacecraft Test Conductor, and the NAA Test Project Engineer attended the Plugs In Debriefing held by the NASA Space Vehicle Test Supervisor at Complex 34. At the conclusion of that meeting, the spacecraft status for the Plugs Out Test was summarized. A portion of this summary included the fact that all of the spacecraft data from the Plugs In Test had not been completely reviewed and that there were still final preparations and work items to complete before being ready to meet the scheduled power on time.

17. January 26, 1967, 1430. Daily scheduling meeting.
18. January 26, 1967, 1800. Spacecraft power removed.
Power was removed from the spacecraft busses at 1800 on January 26 following replacement and successful retest of the Yaw Electronic Control Assembly.
Additional Guidance & Navigation System testing had indicated that the system was operating satisfactorily. IDR constraint to these two systems were closed out.
19. January 26, 1967, 1900. Meeting to discuss revision to Operations Checkout Procedure 0021 (Plugs Out). On January 26 at 1900 a meeting was held to discuss the Operations Checkout Procedure 0021 to be utilized for the Plugs Out Test. A revision to the Plugs Out procedure had been issued earlier in the day at 1730. There was some concern with the timeliness of the revision and its possible affect on the time critical sequences of the test. It was concluded, however, that the revision had been properly reviewed and approved by the test team and a decision was made to proceed with the procedure and test as scheduled.
20. January 27, 1967, 0600. Operations Checkout Procedure 0021 (Plugs In) pre-test briefing.

21. January 27, 1967, 0635. Test Team on station for Operations Checkout Procedure 0021 (Plugs Out).
22. January 27, 0735. Spacecraft power on for Operations Checkout Procedure 0021 (Plugs Out). The test team went on station immediately after the pre-test briefing and the NASA Test Conductor and NAA Test Project Engineer received a "Go" from each Systems Engineer and the Pad Leader verifying readiness to proceed with the test. The Environmental Control Systems Engineer and the Pad Leader stated that they were running late with their preparations but that the remaining work could be completed in parallel with the power up operation. These preparations were required in order to establish the Environmental Control Systems Ground Support Equipment Test configuration required for gaseous oxygen servicing. These preparations were completed satisfactorily at 0900 at which time the Environmental Control System Test was initiated. The Stabilization and Control Systems Engineer gave a qualified "Go" based on incomplete data review. At the start of the test, the NASA Test Conductor and the NAA Test Project Engineer requested that an Interim Discrepancy Record (IDR) be written to document the fact that there was no signed off constraints list for

the Plugs Out Test. The status of each item not signed off on the operations engineers' master constraints list, in addition to those open items accumulated since the generation of the constraints list, were to be provided in the disposition of the IDR at the completion of the test. The Test Conductors chose to request an IDR rather than to sign the constraints list since it was not complete and "up-to-date". The disposition was never documented on the IDR since all documentation was impounded at the time of the incident. It is noted that the constraint list and all open items that were generated between the time of the constraints list generation and the incident had been reviewed (and determined satisfactory to proceed) by NAA/NASA Operations and Systems Engineering personnel.

23. January 27, 1967, 0800. Daily status meeting

Summary of Operations Checkout Procedure 0021
Unsigned Constraints List Situation

- A. A constraints list was developed for Operations Checkout Procedure 0021, but was not signed prior to proceeding into the Plugs Out Test since it did not represent an accurate picture of all open paper work due to the additional work generated from January 23 to January 27, 1967. The constraints list had not been formally updated due to the limited time available between tests.
- B. The constraints and additional open work items generated after development of the constraints list were under constant review by the test team.
- C. Two meetings were held daily between systems personnel (or their representatives) and operations personnel at ^{time} which the status of spacecraft open items was discussed.
- D. A number of items on the constraints list were evaluated and deferred for accomplishment until after the Plugs Out Test, but prior to the Flight Readiness Test (Operations Checkout Procedure 0028).
- E. The status of the spacecraft was known at the time of the test by systems engineering and operations personnel. Readiness reports were received from all operations and systems engineering personnel prior to power up and there were no open work items to constrain the running of the Plugs Out Test.

**REPORT OF PANEL 7
TEST PROCEDURES REVIEW
APPENDIX D
TO
FINAL REPORT OF
APOLLO 204 REVIEW BOARD**

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TEST PROCEDURES REVIEW

A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Test Procedures Review Panel, 7. The task assigned for accomplishment by Panel 7 was prescribed as follows:

Document test procedures actually employed during day of incident. Indicate deviations between planned procedures and those actually used. Determine from review potential changes that might alleviate fire hazard conditions or that might provide for improved reaction or corrective conditions. Review these changes with respect to applicability to other test sites or test conditions.

B. Panel organization

1. MEMBERSHIP:

The assigned task was accomplished by the following members of the Test Procedures Review Panel:

- Mr. D. L. Nichols, Chairman Kennedy Space Center (KSC), NASA,
- Mr. F. G. Bryan, Kennedy Space Center (KSC), NASA
- Mr. J. M. Twigg, Kennedy Space Center (KSC), NASA
- Mr. C. O. Brooks, Marshall Space Flight Center (MSFC), NASA
- Mr. W. Petynia, Manned Spacecraft Center (MSC), NASA
- Mr. W. F. Cahill, North American Aviation (NAA), KSC
- Mr. R. H. Jones, North American Aviation (NAA), KSC
- Mr. J. C. Wright, North American Aviation (NAA), KSC, Technical Assistant
- Mr. J. W. Cuzzupoli, North American Aviation (NAA), Downey
- Mr. E. E. Dale, North American Aviation (NAA), Downey
- Mr. C. C. Harshberger, North American Aviation (NAA), Downey (Alternate)
- Mr. R. L. Swanson, North American Aviation (NAA), Downey (Alternate)
- Mr. H. H. Luetjen, Mc Donnell Company KSC

2. COGNIZANT BOARD MEMBER:

Mr. John J. Williams, Kennedy Space Center, NASA, Board Member, was assigned to monitor the Test Procedures Review Panel.

C. PROCEEDINGS

1. In response to the Apollo 204 Review Board, the Panel derived detailed objectives as follows:

a. Document test procedures actually employed during day of accident. Verify and cross-correlate following sources of information.

(1) Official Operational Checkout Procedure(OCP) FO-K-0021-1, :Plugs Out Test, With Deviations, and associated procedures.

(2) Voice Tape of Test

(3) Cabin configuration as found vs. OCP

(4) GSE configuration as found vs. OCP

(5) Test Conductor's log

(6) Test Project Engineer's log

(7) Test Supervisor's log

(8) Pad Leader's Report

(9) North American Aviation (NAA) Test Monitor report

b. Research the relationship between hardware changes and retest thereof in the period between Altitude Chamber Test and Plugs Out Test.

c. Compare procedural difference between the Altitude Chamber Test as run and Plugs Out Test as run.

d. Document the development of the as run procedure used for the Plugs Out Test.

(1) Chronological development of test philosophy and of the actual OCP.

- (2) Relationship between test as developed and MSC/NAA Downey test requirements.
 - (3) Effect of philosophy changes on the test.
 - (4) Assess adequacy of the technical review of the OCP prior to its use.
 - (5) Assess adequacy of the safety review of the OCP prior to its use.
 - (6) Review late-change control.
 - (7) Review deviation control during test.
 - (8) Evaluate test discipline from voice tape.
- e. Evaluate total procedural interface with respect to adequacy and complexity.
- (1) OCP FO-K-0021-1
 - (2) GSE checklist
 - (3) Crew countdown
 - (4) What procedures did crew carry on board and use?
 - (5) What TPS's if any were used to supplement OCP's?
 - (6) Space Vehicle Plugs Out procedure
 - (7) Support documentation
- f. Evaluate potential effect of automation upon safety of operation.
- g. Review overall control of testing requirements with regard to timelessness, level of control, and technical integration.
- (1) Ground Operations Checkout Plan (GORP)
 - (2) Process Specifications and Test Specifications
 - (3) Vehicle Test Planning
 - (a) Downey
 - (b) KSC
 - (c) MSC
 - (d) Other test sites
- h. Evaluate potential changes to vehicle hardware and test procedures to include experience gained from Apollo and other related Programs.
- (1) Investigation areas in which minor design changes may allow significantly improved checkout capability and alleviate hazardous conditions.
 - (a) Solicit recommendations from contractor and NASA checkout personnel.
 - (b) Solicit recommendations from procedure writers.
 - (2) Review testing philosophy and specific procedures utilized.
 - (a) Other Apollo test sites
 - (b) Other Manned S/C programs
 - (c) Manned Launch Vehicles

2. TEST PROCEDURE EMPLOYED DURING DAY OF ACCIDENT

A master copy of the Space Vehicle Plugs Out Integrated Test FO-K-0021-1 S/C 012/014 was developed documenting the procedure as run on the day of the accident. This master procedure used the Quality Control Record copy of the test as a starting point. Information obtained from the test engineers' copies of the Operational Checkout Procedure (OCP) was added.

Voice recordings of communication channels used during time of test were reviewed. Procedural functions performed were checked in the master procedure as they were verified by audio reply. Deviations from published procedures were noted and investigated.

Two (2) intercom channels, designated Black 3 and Black 4, were recorded throughout the test. These two channels were superimposed upon one track of recording tape. The recording was adequate to reconstruct the events immediately prior to the accident. During earlier periods of the Plugs Out Test, Spacecraft test activity took place on approximately half of the fifteen channels assigned to Spacecraft operations. Complete reconstruction of the activity during this period was not possible due to the lack of recording.

The Quality Control (QC) copy of the OCP, which Panel used as a baseline, was incomplete. Operating method did not require continuous QC monitoring of each communications channel in use during test.

Spacecraft switch positions specified in the OCP were compared with the as-found post accident positions. There were no functionally significant differences except for the main bus tie switches (2). Telemetry data indicates the bus tie switches were positioned by the crew subsequent to the detection

of the fire. The procedural sequence in which each switch was last positioned was also identified. One significant circuit breaker (CB-116) position was noted. The closed circuit breaker, as specified by the OCP, applied power to gas chromatograph cable although the instrument had been removed and documented by approved procedures.

3. RELATIONSHIP BETWEEN HARDWARE CHANGES AND RETEST THEREOF

A. Records were researched to determine relationships between hardware changes and retest verification made during the period between the Altitude Chamber Test (OCP FO-K-0034-A) and the OCP run on the day of the accident. Appropriate modifications, rework, and discrepancy items were defined for more detailed review. The review included Interim Discrepancy Records (IDR), Discrepancy Records (DR), Test Preparation Sheets (TPS), and Engineering Orders (EO), which were worked between the Altitude Chamber Test (OCP-K-0034-A) and the Plugs Out Test (OCP FO-K-0021-1). Both of these tests were run with the spacecraft hatch closed and an oxygen (O₂) cabin environment. Emphasis was placed on review of electrical changes, such as modifications to spacecraft wiring, replacement of electronic boxes, and Ground Support Equipment (GSE). The required retest was performed for all spacecraft changes except for those noted in Enclosure 7-2.

Definition of retest required and the point at which it constrains subsequent testing, is determined by the responsible NASA and NAA System Engineers. Documentation of these requirements is defined by Apollo Pre-Flight Operations Procedure (APOP) Manual No. T-501, 5.1.

b. An open item review prior to starting any test is required by Apollo Pre-Flight Operations Procedure (APOP) No. 0-202. This was accomplished and a constraints list compiled on January 23, 1967, four days prior to the implementation of the test. The review allowed lead time for accomplishment of the open items prior to the test. However, additional open items were accumulated on the daily Spacecraft status Report in the form of released Test Preparation Sheets (TPS), Discrepancy Records (DR's), Discrepancy Record Squawks Sheets (DRSS's), and Interim Discrepancy Records (IDR's). This accumulation of open items was not added to the constraints list. Systems engineers were expected to be aware of these items which were published in the Daily Status Report. The Panel requested clarification from the NASA Chief Spacecraft Test Conductor (CSTC). The response statement is included as Enclosure 7-2. According to referenced enclosure, the accumulation of open items was "under constant review by the test team." The enclosure indicates that certain items were evaluated and deferred until after Plugs Out OCP FO-K-0021-1 and prior to Flight Readiness Test (FRT).

The NASA Spacecraft Test Conductor (Organization Chart; Enclosure 7-1) normally gets a sign-off by each systems engineer verifying that no constraints to the test exists in his system. The Test Conductor can, therefore, affix his signature to the Constraints List verifying that all constraints have been resolved. The Test Conductor is required by APOP 0-202, paragraph 6.3.6, to sign the Constraints List prior to beginning the test.

The Test Conductor and NAA Test Project Engineer agreed to proceed with the test based upon the reasons listed in Enclosure 7-2. The available Constraints List was not signed off since it was not complete list of all open items due to the additional work generated from January 23 to January 27, 1967. Interim Discrepancy Record No. 001 was issued noting that the Spacecraft was powered up without the Constraints List formally signed off.

This Panel did not evaluate whether the open items, as discussed in the referenced enclosure, contributed to the incident. This item was referred to Panel No. 18 of the Review Board for analysis.

4. COMPARISON OF ALTITUDE CHAMBER TEST AND PLUGS OUT TEST

The differences between the OCP's were evaluated in an attempt to identify functions which may have been improperly performed in the Plugs Out Test. The procedural differences were attributable to required configuration differences with one exception.

During the Altitude Chamber Test only those functions required prior to altitude simulation were performed with cabin pressures greater than sea level, and an O₂ environment. During Plugs Out, all testing after hatch closeout was to be accomplished with the cabin at greater than sea level pressures and an O₂ environment. In the Altitude Chamber, the cabin was pressurized with O₂ four times (varying from 1 hour to 2 hours 30 minutes) for a total of 6 hours 15 minutes at pressures greater than sea level. This length of time is two and a half times as long as the cabin was pressurized with O₂ prior to the accident during Plugs Out Test.

The analysis of differences, and methods of implementation between the Altitude Chamber Test and Plugs Out Test, has not provided any discrepant conditions that could contribute to the cause of the accident. The Test Configuration differences are covered in the report of Panel No. 1.

5. DEVELOPMENT OF THE PLUGS OUT TEST

The Plugs Out Test procedure was reviewed to determine the adequacy of the system used in developing the OCP.

a. The chronological development of the Plugs Out Test philosophy and OCP was documented (Enclosure 7-3).

The Plugs Out Test was defined in preliminary form on July 12, 1966. In September, the crew emergency egress practice was added to the test procedure, to be performed at the conclusions of the Plugs Out Test. The preliminary OCP was released and reviewed in October. In November the OCP was modified to provide closed hatch operation during the test. The approved OCP was released on December 13, 1966. The revisions designated as dash one (-1), was released on January 26.

b. The relationship between the test as developed and MSC/Downey test requirements was reviewed.

The MSC test requirements document is the Ground Operations Requirement Plan (GORP). It is primarily a flow plan through the various test locations used to prepare the vehicle for flight. The definition of testing to be performed varies in detail from test to test. While some specific testing requirements are defined, emphasis is more on sequence than on specific technical requirements. The NAA, Downey prepared test specification for the Plugs Out Test (Process Specification MAO-0201-3214, Revision B, dated August 19, 1966) is written in test procedure format. This document contained outdated pretest switch lists, and a GSE listing not compatible with GSE available at KSC. It lacked the detail of engineering specifications to which systems should be tested, and was not directly relatable to overall vehicle test planning at KSC. The process specification is an internal contractor document used to prepare test procedures for NASA approval.

NAA personnel at KSC (NAA, Fla) prepared an overall test plan for KSC covering operations from receipt of the vehicle to launch. SP 64, S/C 012 Test Outline, was published and presented to MSC for review containing the outline of the Plugs Out Test. Specific procedures for system operation were based on the Test Outline and NAA Downey Test Procedures. They were also extracted from previously run procedures at KSC. The Plugs Out Test Procedure meets the intent of both the MSC GORP and the NAA Downey Test Specification.

c. Effect of philosophy changes on the test was evaluated.

Major changes such as closed hatch, O₂ cabin environment, and crew emergency egress practice were generated and implemented subsequent to the preliminary Plugs Out OCP preparation. These changes were made with sufficient lead time to allow timely incorporation into the procedure.

d. The adequacy of the technical review of the OCP was assessed.

The technical review of the OCP was as adequate for initial release of the procedure. NASA and NAA engineering representatives for each system, participated in the review prior to approval of the Plugs Out Procedure. A detailed review of the subsequent revision showed that the percentage of changes attributable to technical error in the original procedure was approximately one percent.

e. The adequacy of the safety review of the OCP prior to its use was assessed.

The KSC Safety Office did not receive or review the procedure since it was not submitted as a hazardous test. (Enclosure 7-5.) All participants in the test failed to realize the extent to which hazard potential existed. This is evidenced by the following: (a) a Safety Office review of the procedure was not made, (b) Pad Emergency Procedures were not prepared, and (c) Fire fighting and ambulance equipment were not on the pad during the test. This procedure was handled in accordance with normal operating methods as shown in Enclosure 7-4.

f. OCP revision control was reviewed.

The basic procedure, OCP FO-K-0021-1, was released and distributed on December 13, 1966 and consisted of 275 pages. Following the release, there were many changes in the OCP. These changes were collected and incorporated into "flimsies" (preliminary copies), six (6) of which were circulated for systems engineering review two days prior to the test. The resulting revision, consisting of 209 replacement pages, was distributed at 5:30 p.m., January 26, 1967, 14½ hours before start of the test.

The technical changes to the OCP were not as great as the number of changed pages would indicate. The actual changed lines represented less than 25 percent of the revision with the remaining 75 percent being required to allow full page replacement. (If one side of a page is changed, both sides must be reprinted.) The reasons for these changes were researched. The basic causes for change were defined:

- (1) To make the OCP compatible with the updated Flight Crew Checklist.
- (2) To make the OCP sequences similar to the Spacecraft Launch Countdown which was first published on January 23.
- (3) To perform the Emergency Detection System Test at a different time due to new Launch Vehicle requirements.
- (4) To incorporate the experience gained from running the Plugs In Test (OCP-K-0006).
- (5) To incorporate items existing in the Space Vehicle procedure.
- (6) To delete the Guidance Computer erasable memory update since the Mission Control Center Houston (MCCH) was unable to support the test.
- (7) To incorporate general operational improvement.
- (8) To correct the OCP technical and typographical errors.
- (9) To perform certain crew stowage operations transferred from the Altitude Chamber Test to the Plugs Out Test.

A copy of the entire revision has been annotated, with the reasons for the change, and submitted as reference material.

A number of the changes were not avoidable, considering the first-of-a-kind mission. However, the changes were not integrated into OCP revisions and released early enough to allow test personnel to become completely familiar with the test as it was to be run.

g. Review deviation control and documentation during test.

A review of the 106 OCP deviations written during the test showed that they were handled in accordance with requirements of APOP No. 0-202. This procedure permits performing deviations during the test with the documentation of the deviation to be coordinated subsequent to the test. The forms were not completed during the test in many cases and the impounding of documents prevented their normal post-test completion. As a result, the Panel had to work from incomplete records.

h. Evaluate test discipline from voice tape

The overall test discipline displayed by the voice tape recordings was generally adequate, but was hindered by communications difficulties. There was considerable evidence of uncoordinated switching during the period of communications troubleshooting which left the Spacecraft Test Conductor in doubt as to on-board system configuration.

A contributing factor to this undesirable condition was the chronic difficulty which had been experienced with communications during previous tests.

During the period of difficult communications between the Flight Crew and Spacecraft Test Conductor, the procedures to isolate the problem appeared haphazard and uncoordinated. The troubleshooting did not isolate the cause of the poor communications, even though several hours were spent in trying various links and communications configurations. Troubleshooting at times was being run independently from three locations; the Spacecraft, Launch Complex 34, and the Manned Spacecraft Operations Building (MSOB). This occurred due to lack of a single controlling station to coordinate and direct the total troubleshooting effort.

6. REVIEW OF PLUGS OUT TEST SUPPORT DOCUMENTATION

A list of documents required in direct support of the Plugs Out Test was compiled (Enclosure 7-18). The purpose, scope and operational interfaces of these documents were evaluated to determine their overall technical and/or operational adequacy and complexity.

a. Crew Checklist and OCP

One potential source of confusion was the overlap between the pre-launch switch configuration contained in the OCP (prepared at KSC) and that in the Apollo Crew Abbreviated Checklist (prepared at MSC). It was determined that no copies of the Apollo Crew Abbreviated Checklist were taken into the spacecraft. The crew had copies of the OCP Switch Checklist but no copies of the entire OCP.

b. The Ground Support Equipment (GSE) Checklist

The GSE Checklist adequately defines required pre-test setups. The procedure refers to other documents for the step-by-step installation of equipment but effectively retains control of overall test setup operation.

c. The Space Vehicle Plugs Out Procedure

The Space Vehicle Plugs Out Procedure was written as the overall control document for the Plugs Out Test. The intent of the space vehicle procedure was to provide the Test Supervisor with the interface points required to maintain overall control in the test. The space vehicle procedure also covers both launch vehicle and spacecraft interfaces with external organizations such as the Eastern Test Range, Mission Control Center, Houston, etc. The space vehicle procedure accomplished this function. Actual launch vehicle operations were performed from a launch vehicle procedure under the direction of Launch Vehicle Test Conductor. Similarly, the spacecraft team under the direction of The Spacecraft Test Conductor operated from the spacecraft OCP.

Each of the procedures provides specific data for performing independent operations usually by different groups of personnel. To combine or modify any of these documents would possibly increase the confusion and complexity of the end objectives. The documentation as defined fulfills its intent and no significant requirements for changes are noted by the Panel.

7. POTENTIAL EFFECT OF AUTOMATION UPON THE SAFETY OF THE OPERATION

Acceptance Checkout Equipment (ACE) system capability and the ACE to spacecraft interface was reviewed. While some computer program changes were proposed to aid checkout and improve safety (Reference 7-7), no significant area was found where additional automation could substantially increase safety without a significant enlargement of the ACE to spacecraft interface. ACE computer programs neither contributed to the accident, nor could they have been used in the existing ACE configuration to reduce or extinguish the fire.

Computer program and hardware design precludes the ground computer from operating the existing GSE and facility systems pertinent to extinguishing a fire. In addition, existing fire retardant or extinguishing systems are inadequate to cope with such an emergency. If active fire retardant or extinguishing systems are added in the future, a careful analysis should be made before automating these systems. Activating emergency systems such as nitrogen purge or pressure relief may present additional hazards to personnel.

In reviewing the existing method of activating safety systems on both the Spacecraft and GSE, it is evident that additional remote control capability should be considered for systems such as:

- a. Service Structure Water Deluge
- b. ECS Control
- c. Electrical Power
- d. GN₂ Deluge
- e. Pressure Supply and Control
- f. Cryogenic and Hypergolic Supply

8. CONTROL OF TEST REQUIREMENTS

A review of overall control of testing requirements with regard to timelessness, level of control, and technical integration was accomplished. This task was treated in two basic parts. Part a. dealt with the review of Apollo S/C 012 pre-launch test and checkout documentation. Part b. of the task encompassed the review of pre-launch test and checkout documentation, planning and control as applied to other similar programs as related to Apollo Spacecraft.

a. S/C 012 Pre-launch Test and Checkout Documentation.

Documentation can be categorized into four major types:

- (1) Pre-launch Checkout Requirements
- (2) Test Specifications and Criteria
- (3) Checkout Plan
- (4) Checkout Procedures

The first two categories represent the requirements imposed upon the pre-launch operations and the last two, methods for implementing these requirements.

(1) Pre-launch Checkout Requirements

Pre-launch checkout requirements are established in the Ground Operations Requirements Plan (GORP). This document, as currently approved, establishes the contractual baseline for the sequential flow of the Spacecraft and for the tests to be conducted at each test station in the flow. The GORP is prepared by NAA, Downey as a contractual document for MSC-Houston, requiring joint NAA/MSO approval (Class I). The GORP effectiveness as a test requirements document is

hampered by its original intent as a GSE provisionin document. The GORP also contains considerable detail not directly applicable as requirements. Because of this level of detail it is difficult to maintain the GORP current through formal contractual channels.

The GORP is a Class I document between MSC and NAA but in the case of CSM 012 it was not formally submitted to KSC by MSC. NAA releases the requirements through its internal document distribution system which constitutes formal direction to its field organization. Implementation of the GORP by NAA, Florida results in a situation whereby the contractor may, in fact, provide direction to KSC.

(2) Test Specifications and Criteria

The Test Specifications and Criteria for Apollo are contained in the NAA generated process specifications MAO-201-XXXX. For CSM 012 the document was written in a procedural sequence format, rather than by system, making determination of the actual engineering hardware performance values and tolerances difficult. The specifications were not updated to provide the latest configuration and tolerances. However, NAA, Downey personnel were assigned to Florida on a temporary basis to assist in interpreting the requirements. This information is made available to NASA-KSC by the NAA, Florida at KSC. The Process Specification documents do not require NASA, MSC approval and are not sent to MSC for information unless specifically requested (Class III). The requirements contained therein are not necessarily screened by MSC or KSC. These specifications are generated within NAA, Downey and forwarded to NAA, Florida to be implemented in the Operational Checkout Procedure.

(3) Checkout Plan

The Checkout Plan for Apollo is contained in the Florida Facility Test Flow Plan. This document is prepared by NAA, Florida for NSA-KSC approval. The Test Flow Plan establishes the flow of the vehicle through KSC, the sequence of tests to be performed, and the activities to be accomplished in each OCP at each test location. The plan implements the intent of the GORP but may not implement the operational requirements in the precise manner stated in the GORP. There is no formal requirement for the plan to be submitted to either MSC or to NAA, Downey for review or approval. It is used extensively by pre-launch and launch operations personnel of both NASA/KSC and NAA, Florida.

(4) Checkout Procedures

The pre-launch OCP's are written locally at KSC by NAA-Florida and approved by NASA-KSC. These procedures are forwarded to both MSC and NAA, Downey for review. However, because of the late release of the OCP's an acceptable before-the-fact technical review of the procedures, other than by local KSC personnel, has not been feasible. The OCP's provide a detailed step-by-step procedure for the accomplishment of an activity or task during the pre-launch and launch operations at KSC. The OCP's are related to a particular task or functional activity and are based on the GORP, the Florida Facility Test Flow Plan and the Process Specifications (Enclosure 7-4).

b. Control of pre-launch test requirements

A detailed review of the overall control and implementation of the pre-launch operational requirements and the test specifications and criteria was accomplished. This review was centered primarily around the type of documentation used on programs similar to Apollo and the type that was used specifically for S/C 012. The review also encompassed the adequacy of content and timeliness of the documents to support its intended use. The Panel interviewed representatives from the following:

Marshall Space Flight Center, Kennedy Space Center, for the Saturn 1B and Saturn V Launch Vehicles

North American Aviation, Manned Spacecraft Center and Kennedy Space Center, for the Apollo CSM Spacecraft

McDonnell Company Manned Spacecraft Center Resident Gemini Program Office at KSC, and Kennedy Space Center for the Gemini Spacecraft

The types of documentation used by the above programs were obtained and reviewed by the Panel for definition of requirements and the implementation of these requirements in pre-launch checkout operations at KSC (Enclosures 7-6 and 7-7).

(1) Saturn

Delegation of pre-launch checkout and launch implementation responsibility from MSFC to KSC was the significant feature of the Saturn Launch Vehicle Program. This relationship was complemented by the existence of detailed inter-Center agreements and by KSC controlled supplemental contracts with stage prime contractors to implement the delegation. The engineering pre-launch checkout requirements, specifications, and criteria are formally controlled by MSFC, Enclosure 7-7. This control is

accomplished by having the necessary documentation prepared by the respective stage contractors for MSFC. The documents, upon MSFC approval, are then levied upon KSC and its stage contractors for implementation. A formal response is required from the KSC stage contractor to MSFC via KSC. This response is in the form of checkout plans and procedures. A significant characteristic of this method of control is that formal contractor direction is accomplished only through MSFC/KSC channels. The stage prime contractor home/field relationship is one of informal technical coordination and communication.

(2) Gemini

The MSC Resident Gemini Program Office (RGPO) at KSC provided for rapid response to operational changes. This was primarily accomplished by after-the-fact contractual closure of open items, and changes on a quarterly basis.

Pre-launch checkout requirements were prepared by the contractor's field organization at the launch site with parallel feedback to the home plant, MSC-RGPO, and MSC-Houston.

(3) Apollo

The Apollo Spacecraft pre-launch operational requirements flow is characterized by a highly centralized control exercised by the MSC-Apollo Program Office at Houston. Since MSC approval is required prior to implementing detailed operational changes in pre-launch planning, there is an inherent slow response loop which constrains normal pre-launch activity. The lack of detailed inter-Center agreements relating to the delegation and control of spacecraft pre-launch operations at KSC is another factor. This lack of detailed agreement clouds the definition of MSC and KSC roles and missions and the interface involved, leading to misunderstandings.

The S/C Contractor at Florida is subject to technical direction from both KSC and its home plant. This direction may be conflicting. Clarification of S/C Contractor pre-launch direction at the field site would materially improve the implementation and control of pre-launch operations.

c. Improvements Currently in Progress

During the course of the investigation, it was determined that several significant changes are presently being made in the system of pre-launch checkout documentation and management control.

It was determined that the s/c Contractor (NAA) is in process of preparing a specification covering spacecraft checkout requirements applicable to factory acceptance (Contract End Item Specification, Part II). This document is Class I and requires approval sign-off by MSC-Houston. The S/C Contractor (NAA) has, since early January 1967, initiated action to develop a new type of checkout requirements and specification document to cover field operations. This document will represent a logical extension of the Contract End Item Specification, Part II, in that it will provide requirements and specifications tailored to field pre-launch checkout operations. The new specification will replace a multitude of existing subsystem, interface, and integrated system level specifications. It will be system-oriented and will take precedence over the existing specifications.

This type of document will satisfy the intent of the test specification and criteria document as required for testing at KSC. The authority for, and description of, the new format of specifications is stated in Enclosures 7-9 and 7-10.

Several major changes intended to improve the control of Apollo Spacecraft pre-launch operations requirements are also underway in response to the direction received from the Apollo Program Director in the NASA-OMSF memorandum of January 31, 1967, subject: Minutes of Meeting at KSC, January 26, 1967 (Enclosure 7-11).

9. POTENTIAL IMPROVEMENT IN CHECKOUT CAPABILITY

The panel investigated areas in which minor design changes may be made which will permit a significant improvement in checkout capability in the areas of safety and alleviation of hazardous conditions.

This task was treated in two basic parts. Part a. covered recommendations from contractor and NASA test and checkout personnel in the area of hardware changes. Part b. covered recommendations for improvements in the areas of operations and procedures.

a. Recommendations for Design Changes to Hardware

The Panel interviewed NASA, KSC and NAA, Florida system engineers with regard to recommendations for design changes affecting either spacecraft or GSE hardware. Their comments and recommendations were categorized by spacecraft subsystem with an explanation of the reason for the change and the advantages that will be gained if the change is incorporated. Panel 7 screened and evaluated the proposed changes on the basis that the change would provide increased margins of safety or that the improvement in the checkout operations will contribute to safer operations. The review included a comparison of the master measurement lists for Block I and Block II spacecraft. The system engineers submitted 110 recommendations for design changes. Of these changes 92 effect the Apollo, 1 the LM and 17 the GSE.

Results of this review were forwarded to Panels 9 and 18 for final review, disposition and closeout.

b. Recommendations for Changes to Procedures

The Panel evaluated potential changes to test procedures as a result of investigating areas in which such changes may allow significantly improved checkout capability to alleviate hazardous conditions. Interviews and briefings were conducted with procedure oriented engineers and management personnel from Apollo and other related programs. The methods and procedures are sound in concept for both administrative and technical direction and control of the preparation, publication, release, and revision of OCP. However, in post test evaluation, the content (and scope) of test deviations should be evaluated by test management to ascertain that test objectives have been met and that procedure preparation was adequate.

c. Review of Philosophy and Procedures

Review testing philosophy and specific procedures utilized on other manned programs and launch vehicles.

(1) This item was investigated by addressing a number of questions to the various programs and sites in order to understand the different test policies, operating standards, and test management structures.

Programs and sites considered were:

- (a) Apollo - KSC
- (b) Apollo - Houston (Space Environmental Simulation Laboratory)
- (c) Apollo - Downey
- (d) Gemini - KSC
- (e) Saturn - KSC
- (f) Titan - (Titan I, Gemini Launch Vehicle, and Titan III)
- (g) LM - KSC (Planned Approach)

The questions asked were:

- (a) Does Safety review all test procedures?
- (b) Is there a formal work item review prior to each test?
- (c) Does Q C monitor the operation and in what capacity?
- (d) How are test deviations written and approved?
- (e) How and to what extent does the Government monitor and control tests?
- (f) Are tests run by engineers or technicians or by both?
- (g) Who (Q C, Safety, Design Engineering, Operations Engineering) may stop or scrub a test?
- (h) How thoroughly are procedure changes documented?
- (i) Who determines if a procedure is hazardous?
- (j) Does the local operations group have design change authority?

(2) By studying the answers to the questions provided by representatives of the sites, the Panel was able to compare those operations with Apollo-KSC operations to illustrate areas of possible improvement. These areas are listed below:

(a) Safety Review of Procedures - Martin Titan uses the policy of having Safety review all all procedures for possible hazardous operations, rather than giving the operations engineers the responsibility for deciding which operations are hazardous. This item is also discussed in Paragraph 5e of this Report. It was found that for Apollo operations Safety does not review all procedures.

(b) Formal Review of Work Items Prior to Tests - The three Apollo sites were all found to have similar procedures for reviewing open work prior to beginning major tests.

(c) Q C Monitoring of Test Operations - At all Apollo spacecraft sites the policy pro-

vides for Q C to monitor tests and provide an as run copy. The policy is not fully implemented since not all operations are monitored full time. This item is also discussed in Paragraph 2 of this Panel Report.

(d) Test Deviations - In the case of the Apollo operations at KSC and Downey, and the LEM operations at KSC, engineering supervision (one level above the operations systems engineer) does not approve procedure deviations. In the case of the two launch vehicles and the MSC Apollo operation the supervision approval is by signature during the test.

(e) Government Monitoring of Tests - The only significant difference noted is that the Saturn operation does not use NASA Q C to formally monitor test operations. The KSC Launch Vehicle Operations (LVO) systems engineers are required to monitor tests, and thus provide the required NASA surveillance.

(f) Procedures Not Run by Engineers - Tests are run by engineers in all cases except that of Martin Titan where technicians are used on a regular basis to run tests.

(g) Authority to Stop a Test - It was noted that Safety can stop a test in progress at all sites, either directly or through the Test Conductor depending on the type of test in process.

(h) Real Time Procedure Deviation Documentation - All sites had policies requiring that this be done.

(i) Determination of Hazardous Procedures - In four of the seven cases it was found that both Safety and Operations personnel made determinations as to whether a particular procedure was hazardous. In the remaining three cases only Operations personnel determined such. In all cases Safety personnel reviewed in detail those procedures declared hazardous regardless of who made the declaration.

D. FINDINGS AND DETERMINATIONS

1. FINDING:

The Panel documented the Plugs Out Test Procedure (FO-K-0021-1) as it had been performed. DETERMINATION:

The Test Procedure did not contribute to the accident. There was a defect in the procedure in that power was applied to the uncapped gas chromatograph power cable after the gas chromatograph had been removed from the spacecraft.

2. FINDING:

209 pages of the 275 page OCP were revised and released on the day before the test. Less than 25 percent of the line items, however, were changed. Approximately 1 percent of the change was due to errors in technical content in the original issue of the procedure. In addition, 106 deviations were written during the test.

DETERMINATION:

Neither the revision nor the deviations are known to have contributed specifically to the incident. The late timing of the change release, however, prevented test personnel from becoming adequately familiar with the test procedure prior to its use.

3. FINDING:

During the Altitude Chamber Tests the cabin was pressurized at pressures greater than sea level with an oxygen environment 2-1/2 times as long as the cabin was pressurized with oxygen prior to the accident during Plugs Out Test.

DETERMINATION:

The spacecraft had successfully operated at the same cabin conditions in the Chamber for a greater period of time than on the pad up to the time of the accident.

4. FINDING:

The Plugs Out OCP was not classified as hazardous.

DETERMINATION:

The hazard level was not recognized and consequently the procedure was processed through the review cycle as a non-hazardous procedure.

5. FINDING:

Only local control is provided for certain systems which may require remote control for safety reasons, such as service structure water and hypergolic supplysources.

DETERMINATION:

The full potential of the safety systems is not utilized due to the lack of remote control capability.

6. FINDING:

The open item constraint list was not formalized as required by APOP No. 0-202.

DETERMINATION:

Pretest constraints were evaluated informally on a system-by-system basis by the test team. (Enclosure 7-2)

7. Finding:

Troubleshooting of the communication problem was not controlled by any one person, and was at times independently run from the Spacecraft, Launch Complex 34 Blockhouse, and the Manned Spacecraft Operations Building. Communications switching, some of which was not called out in the OCP, was performed without the control of the Test Conductor.

DETERMINATION:

The uncontrolled troubleshooting and switching contributed to the difficulty experienced in attempting to assess the communication problem.

8. FINDING:

KSC was not able to insure that the spacecraft launch operations plans and procedures adequately satisfied, on a timely basis, the intent of MSC. Changes to S/C testing by KSC could not be kept in phase with the latest requirements of MSC. Pre-launch checkout requirements (GORP) were not formally transmitted to KSC from MSC.

DETERMINATION:

Pre-launch test requirements control for the Apollo Spacecraft Program is constrained by slow response to changes, lack of detailed KSC-MSC inter-Center agreements, and by the lack of official NASA approved Test Specifications applicable to pre-launch checkout.

9. FINDING:

The Test Specifications for Spacecraft 012 were not written in a convenient to use format, did not contain field tolerances, were not NASA approved, were not maintained up-to-date, and were not transmitted to NASA/KSC.

DETERMINATION:

The lack of usefulness of the Test Specifications has been recognized by NAA, Downey and measures intended to correct the situation have been initiated (Enclosures 7-9 and 7-10).

10. FINDING:

The decision to perform the Plugs Out Test with the flight crew, closed hatch, and pure O2 cabin environment made on October 31, 1966, was a significant change in test philosophy.

DETERMINATION:

There is no evidence that this change in test philosophy was made so late as to preclude timely incorporation into the test procedure.

E. SUPPORTING DATA

Enclosures

- 7-1 Test Team Organization
- 7-2 Memo for Record, Open Item Review
- 7-3 Plugs Out Test Development History
- 7-4 Procedure Development Flow Plan
- 7-5 Safety Office Memo, Procedure Review
- 7-6 Program Control of Prelaunch Test Requirements
- 7-7 Flight Vehicle Test Documentation
- 7-8 Plugs Out Test Support Documentation
- 7-9 NAA Memo, Test Specs & Outlines
- 7-10 NAA Memo, Process Specifications
- 7-11 Minutes of NASA Inter-Center Meeting
- 7-12 Spacecraft Configuration Comparison
- 7-13 List of References

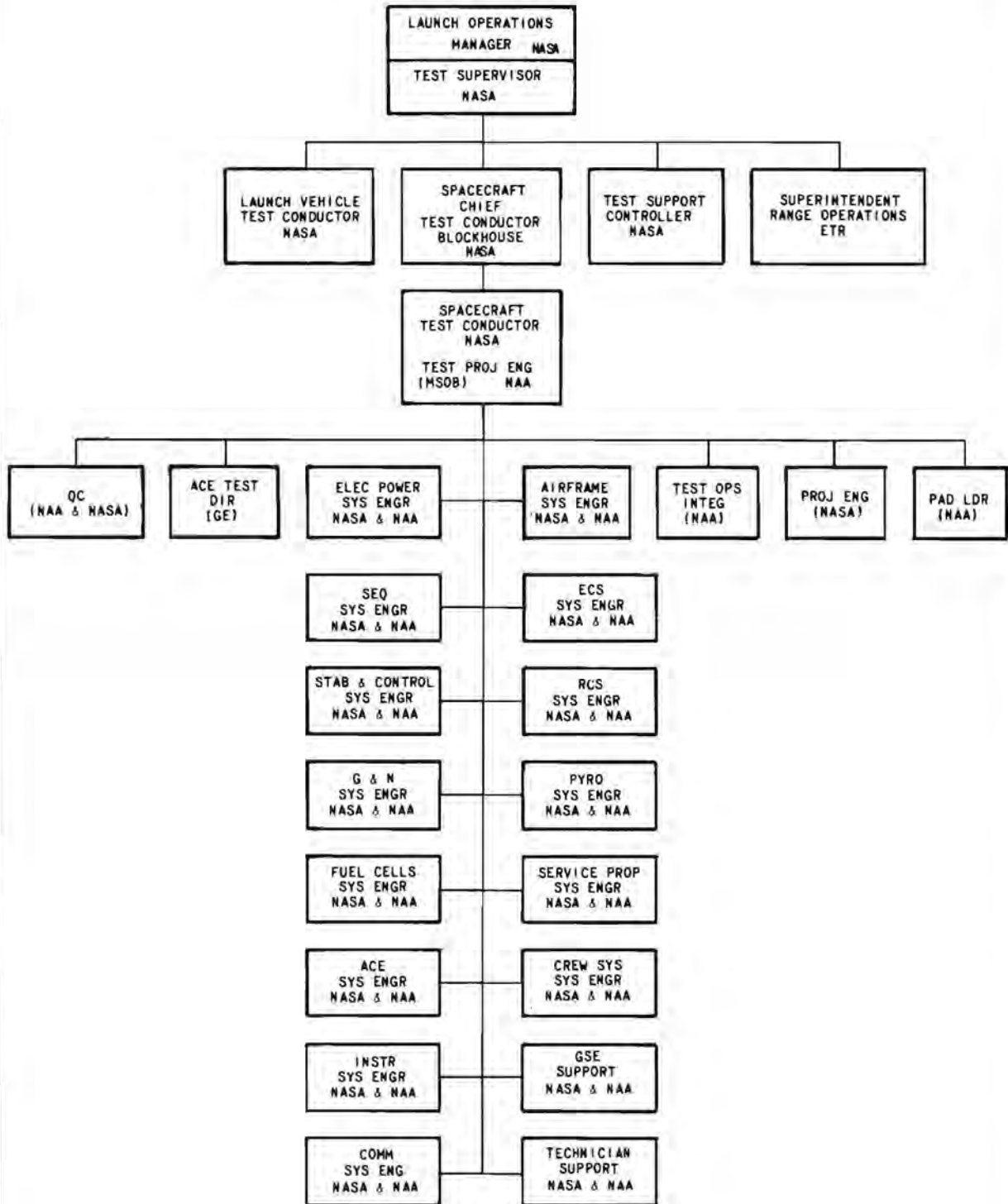
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GLOSSARY

AC	Alternate Current
ACE	Acceptance Checkout Equipment
AFETR	Air Force Eastern Test Range
AGC	Apollo Guidance Computer
APOP	Apollo Preflight Operations Procedure
BMAG	Body Mounted Attitude Gyro
B/P	Boilerplate
BPC	Booster Protective Cover
CCA	Contract Change Authorization
CDDT	Count Down Demonstration Test
C/M	Command Module
CMD	Command
C/O	Change Order
COMM	Communications
CRT	Cathode Ray Tube
CSM	Command Service Module
CSTC	Chief Spacecraft Test Conductor
CX	Complex
DC	Direct Current
DR	Discrepancy Record
DRS	Discrepancy Report Squawks
DSE	Data Storage Electronics
DSE	Data Storage Equipment
DSEA	Data Storage Equipment Assembly
DSKY	Data Storage Key Board
ECA	Electronic Control Assembly
ECS	Environmental Control System
EDS	Emergency Detection System
ELS	Earth Landing System
EO	Engineering Orders
EPS	Electrical Power System
FCS	Flight Control System
FCSD	Flight Crew Support Division
FCSM	Flight Combustion Stability Monitor
FEO	Field Engineering Order
FEO/FCA	Field Engineering Order/Field Change Analysis
FRT	Flight Readiness Test
FS	Full Scale
G&N	Guidance and Navigation
GAEC	Grumman Aircraft Engineering Corporation
GFE	Government Furnished Equipment
GMIL	Goddard Merritt Island
GN	Gaseous Nitrogen
GORP	Ground Operations Requirements Plan
GSE	Ground Support Equipment
IDR	Interim Discrepancy Record
IMU	Inertial Measurement Unit
INSTR	Instrumentation
KSC	Kennedy Space Center
L/C	Launch Complex

GLOSSARY (Continued)

LEB	Lower Equipment Bay
LEM	Lunar Excursion Module
LM	Lunar Module
LO ₂	Liquid Oxygen
LOS	Loss of Signal
LV	Launch Vehicle
LVO	Launch Vehicle Operations
MCC-H	Mission Control Center, Houston
MCR	Master Change Record
MDAS	Medical Data Acquisition System
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSOB	Manned Spacecraft Operations Building
NAA	North American Aviation
NAA-FF	North American Aviation, Florida Facility
OCP	Operational Checkout Procedure
OMSF	Office of Manned Space Flight
PCM	Pulse Code Modulated Data
PGNS	Primary Guidance Navigation System
PIRR	Permanent Installations and Removal Records
PLSS	Portable Life Support System
P/N	Part Number
PP	Peak to Peak
PSIG	Pounds per square inch - gage
PTT	Push To Talk
QC	Quality Control
RCS	Reaction Control System
RCS/SPS	Reaction Control System/Service Propulsion System
RGPO	Resident Gemini Program Office
S/C	Spacecraft
S/C AGC	Spacecraft Automatic Ground Control
SCS	Stabilization and Control System
SEDR	Specification
SEQ	Sequencers
SLA	Service-LM-Adapter
S/M	Service Module
SMJC	Service Module Jettison Controller
SPS PU	Service Propulsion System - Propellant Utilization
STC	Spacecraft Test Conductor
TAIR	Test and Inspection Record
TB	Terminal Board
TIRR	Temporary Installations and Removal Records
TPE	Test Project Engineer
TPS	Test Preparation Sheets
TVC	Thrust Vector Control
UDL/UHF	Up Data Link/Ultra High Frequency
W/G	Water-glycol
WMS	Waste Management System



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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APOLLO 204 REVIEW BOARD

IN REPLY REFER TO

TO: Chairman, Panel 1 & Panel 7

FROM: Deputy Manager, Operations Management, KE-2

SUBJECT: Memorandum for the Record

1. To clarify the records and provide an explanation of procedures followed to insure spacecraft readiness for OCP-K-0021-1, Plugs Out Test, the following information is submitted.

2. On 1/23/67 at 1030 an open item review was conducted with the S/C 012 NAA/NASA Test Team. Outstanding (open) items against the spacecraft were reviewed and a listing of 55 items was generated that were considered constraints in one of four categories. These four categories were:

- a. Constraint to power up for OCP-K-0006 (Plugs In Test), 11 items.
- b. Constraint to power down for OCP-K-0006, 16 items.
- c. Constraint to power up for OCP-K-0021, 26 items.
- d. Constraint to power down for OCP-K-0021, 2 items.

Names of the responsible NAA system engineers were assigned to each item and the cover sheet was signed by the NAA TPE and the NASA STC.

3. On 1/24/67 power was applied to the spacecraft at 0400 and OCP-K-0045, MCC-H Interface Test, was conducted. The test was completed at 2030 and power was maintained on the spacecraft.

4. On 1/25/67 at 0400 the Plugs In Test was started and was completed at 0300 on 1/26/67. Power was not removed from the spacecraft. The portion of the constraints list applicable to this test was signed off prior to the start of testing.

5. A review of the new work items (i.e., the delta accumulated since the creation of the constraints list) was conducted in the daily recap/review meeting held at Complex 34 on both 1/24/67 and 1/25/67 at 0800.

ENCLOSURE 7-2

D-7-19

NOTE: Following this meeting the items are scheduled on the planning sheet by NAA and NASA operations personnel. These updated planning sheets are passed out at the 1430 daily scheduling meeting where the schedule for the next 24 hours is created. This meeting is attended by NAA/NASA S/C and GSE Engineering, NAA/NASA Operations, NAA/NASA Quality Control, plus support personnel safety representative, NASA-MSD and NASA-Headquarters personnel and others as required. The depth of engineering coverage is far greater at the daily scheduling meeting than it is at the 0800 meeting since the 0800 meeting is attended by the NAA Engineering Coordinator and the NASA S/C and GSE Project Engineers who represent their respective organizations in lieu of having all engineering disciplines present. At the daily 1430 meeting the S/C open items status report is once again reviewed for additional items that can be scheduled for work.

6. On 1/26/67 the S/C open items were reviewed at the 0800 meeting but there were so few changes since 1/25/67 that no new planning sheet was created.

7. On 1/26/67, at 0900, a meeting was held at Complex 34 to review the general S/C readiness for the Plugs Out Test. Participants in this meeting were:

- C. Gay, Chief Spacecraft Test Conductor, NASA
- C. Chauvin, Spacecraft Test Conductor, NASA
- E. Reyes, Senior Operations Engineer, NASA
- B. Haight, Senior Test Project Engineer, NAA
- C. Hannon, Assistant Senior Test Project Engineer, NAA

It was the opinion of this group that the remaining open items from the constraints list could be accomplished prior to the scheduled power up time for the Flight Readiness Test. The remaining constraints for Plugs Out were retest of the Yaw ECA, review of the removals and completion of the checklist. The results of this meeting were passed on to Engineering for evaluation.

8. At 1000 on 1/26/67, Messrs. Gay, Chauvin, and Edson (NAA TPE) attended the Plugs In Debriefing held by DLO-1 at Complex 34 and at the conclusion of that meeting summarized the S/C status for the Plugs Out Test. A portion of this summary included the facts that all of the S/C data from Plugs In had not been completely reviewed and that there were still final preparations and work items to complete before being ready to meet the scheduled power on time.

10. Constraining test items, which were originally listed as open constraints to the test, were released by the NAA responsible systems engineer for each respective system by contacting the NAA Operations Engineer on duty at LC-34, who then signed off the respective item on the constraint list. In addition, those items which were completed and sold off were signed by the NAA Operations Engineer on duty.

11. Following replacement and retest of the Yaw ECA, the S/C was powered down at approximately 1800 on 1/26/67. This was the first power down period since 0400 on 1/24 and power was off until approximately 0730 on 1/27.

12. On 1/27/67 at 0600, Pre-test Briefing was held with systems engineers, operational personnel, technicians and inspectors in the MSOB.

13. The test team then went on station and the STC and TPE received a "Go" from each Systems Engineer and from the Pad Leader verifying readiness to proceed with the test. ECS stated in their status report that they were running late with their preparations. SCS gave a qualified "Go" based on incomplete data review. The Pad Leader indicated he had additional ECS set-ups to complete and that they could be accomplished in parallel with power up.

14. An IDR requested by the STC and TPE was written at the start of the test documenting the fact that there was no signed off constraints list for the Plugs Out Test. Status of each item not signed on the Operations Engineer's constraint list plus the delta was to have been provided in the disposition of the IDR upon completion of the test. This was not accomplished as all documentation was impounded at the time of the incident.

15. On 1/27/67, the 0800 meeting was held at Complex 34 and the planning sheet for 1/25/67 was updated accordingly. Reference Enclosure #3.

16. The constraints list and the additional S/C open items have been reviewed since the incident and their status reverified. The results of this review are included as a part of this report as Enclosures #1 and #2.

17. The constraints list that was being signed off by Operations Engineers upon work completion and/or waiver was at the complex on level A8 of the service structure. A copy of this list is included as Enclosure #4.

18. Summary

- a. A constraints list was created for OCP-K-0021 but was not signed off since it did not represent a true picture of all open paper due to the additional work generated from 1/23 to 1/27.
- b. The constraints and additional open items generated after development of the constraints list were under constant review by the test team.
- c. Two meetings are held daily between systems (or their representatives) and operations personnel where the status of S/C open items is discussed.
- d. Certain items were evaluated and deferred until after Plugs Out and prior to FRT.
- e. The status of the S/C was known at the time of the test by systems and operations personnel. Readiness reports were received from all factions prior to power up and there were no open work items to constrain the running of the Plugs Out Test.

C. Gay, Deputy Opns Mgmt, NASA

Concurrence:

NASA

NAA

STC _____
 SR OPS Rand E. Ryzan
 S/C Proj Engr H. C. ...

SR TPE _____
 ASST SR TPE B. ...
 TPE Li ...
 Elect Sys Chief ...
 Mech Sys Chief _____
 Telecomm Sys Chief ...

EVALUATION OF CONSTRAINTS LIST

DR RECAP FROM CONSTRAINTS LIST

<u>DR#</u>	<u>SYSTEM</u>	<u>DESCRIPTION</u>
923	RCS	No readout on panel 12 for S/M RCS He temp. Originated as IDR-035, OCP-0005, upgraded 1/19/67. EO 477825 - Ref - TPS S/C 012 C/M 008. Panel 12 temp installed on temp installation for 0006, 1/23/67. Was left installed to support OCP-0021. Step 5 of DR-S/C 923 specified to remove panel 12 for potting check. Item was left open because potting was not completely cured at installation. Measurement was replaced and retest was accomplished per OCP-0006.
858	ECS	a. Crew reported eyes smarting during first hour at altitude and discomfort (due to heat) periodically during remainder of test at altitude. b. Originated as IDR 079, OCP-0034A-1. Transferred to DR-S/C 858 1/4/67. c. Suit hose umbilical was removed from S/C and sent to malfunction lab for analysis of interior for LiOH and other eye irritants. Sample analysis report was attached to hose and sent to FCS lab. d. 2.5 micrograms of LiOH found in -71 suit hose. e. DR-S/C 858 - conclusions were left open for retest and evaluation during OPC-0021.
864		Communication problem that was corrected by working TPS S/C 493 (sold) and DR was open for retest in OCP-0021. VHF/AM communication was unintelligible when the crew was in pressure suits. Modified cables were evaluated during OCP-0006. Required further evaluation during OCP-0021 with suited crew.
916		a. When either crewman pushes PTT parameter CJ0002J(resp.rate) is modulated in negative direction approximately 20% full scale. b. Originated IDR-029 OCP-K-0034A-1. c. Was to be retested per OCP-K-0021. d. Problem could not be duplicated, therefore, was held open for evaluation during OCP-K-0021.
932		a. Seq. 04-048 measurement SS-01-20X (SLA Sep. Monitor) reads 0% at de-com. b. Originated as IDR-0008, during OCP-0006 (dry run). c. Troubleshooting per continuation sheet directed to remove defective separation monitors upon engineering direction. d. Defective separation monitor was not replaced prior to going into OCP-K-0021.

932 (Cont'd)		<p>e. Portion of DR which was a constraint, i.e., CSM umbilical reinstallation, was accomplished. f. Replacement of separation monitor scheduled for 1/28 - required installation of SLA platforms.</p>
684	EPS	<p>a. Wire routing to LEB XX strut lights is unacceptable. Wire much too loose--should be routed so as to lie flush on upper bulkhead. b. Originated as P/A SQK #9. c. EO release was pending and in meantime TPS S/C 469 was partially worked to correct discrepancy. d. DR-S/C 684 was left open due to pending EO release.</p>
714	EPS	<p>Floodlight connectors left and right couches are not adequately protected or supported to preclude damage by crew when changing couch position. b. Originated as P/A SQK #11. c. DR-S/C 714 was partially corrected per TPS S/C 469 - Ref EO 586488. d. DR-S/C 714 was left open due to shortage of parts.</p>
865	EPS	Sold 1/26/67.
878	EPS	Sold 1/27/67.
922	EPS	Sold 1/24/67.
884	G&N	Sold 1/24/67.
905	G&N	<p>Results of fine alignment test were unsatisfactory. Was IDR-038 of OCP-0005, Fine Alignment Test. Was rerun prior to OCP-K-0021. Rerun reverified original discrepancy. Out of spec condition required waiver. Waiver had not been requested at this time. No constraint.</p>
915	G&N	Sold 1/26/67.
908	F/C	Sold 1/25/67.
344		<p>Was IDR-072 - OCP-0035-1. When AC inverter #2 to AC Bus 1 On, a master alarm occurred. A successful attempt to duplicate the problem was performed prior to power down from OCP-K-0006. The data was returned to Downey for engineering evaluation.</p>
909	F/C	<p>Electrical noise was evident on O₂ tank #1 temp measurement SF0041. Ref IDR-018 - OCP-4736 and IDR-0008 - OCP-0005. a. Noise was 8% FS of PP superimposed on normal reading - Ref IDR 018. Correction of problem (harness replacement) scheduled for 1/28. b. O₂ tank #1 (SF0032) measurement cycling between 23-48. Closed by OCP deviation (without cryos measurement was not meaningful). Part a. required additional input.</p>

- 918 F/C Was IDR 009 in OCP-4736. No pressure indication on panel 13 of H₂ tank pressure. Troubleshooting accomplished. (EO 467267 scheduled for 1/28) Scientific matrix block was intermittent. EO changed pin location. Not accomplished
- 831 FCS Was IDR-001 from OCP-8240B. Nephelometer could not be removed from stowage compartment without excessive pull. Foam cushion was removed and returned to bond room. A new nephelometer foam cushion was installed in spacecraft on evening of 1/26/67 per TPS S/C 547 and EO 565265. A portion of this task required a piece of foam to be bonded onto the door on the nephelometer storage compartment. This was not accomplished and was considered no constraint to OCP-K-0021 since nephelometer was not installed.
- 899 Biomed Was IDR 027 of OCP 0005. Simulator voltage was 6.8VDC, should be 16 ± 4 VDC. Troubleshooting revealed improper designed "T" adapter. Disposition was that Downey was aware of the problem and a redesign was required. Relay in all but two "T" adapters draws more current than voltage divider is designed for. This causes low voltage because source is not regulated. Part No.V16-601396, S/N 06362 AAF 8453 of defective adapter sent to Downey. S/N 3603, Part No.V16-601396 was installed in SSRP position on 1/24/67. (not same design S/N 06362 above)
- 126 FCS TV camera mount assembly spring could not be installed, spring broke while installing during OCP-K-0034A. Disposition was to redesign spring. The spring was to be replaced per an EO from Downey. As soon as new spring was received DR could be closed.
- 165 FCS T-adapter, pin #2 of P3 is protruding approx 1/4" above other pins. Disposition was to remove pin as it was a spare and not required and was suitable for 0034A. DR held open until replacement adapter arrival. Above T-adapter sent back to Downey. The one in the S/C was S/N 3603 and the S/N of DR'd one is 8453.

(Sold Items on OCP-0021 Constraint List)

- 0865 Closed 1/26/67.
 Problem: 12/27/67 OCP-0034A-1 IDR #034
 Primary floodlight control rheostat causes lights to blink in the full on position.
 Action: Floodlights were replaced per TPS S/C 485. Recheck completed per S/C DR 0865 during OCP-0006-1. New floodlights did not flicker. Floodlights emitted a low buzzing noise.

0878 Closed 1/27/67

Problem: PAS #92 LM DSEA splice cable makes 90° bend as it comes out of recorder.

Action: Remove straight backshell and install 90° backshell. Work complete 1/27/67. Cable stowed in S/C for OCP-0021.

0884 Closed 1/26/67

Problem: 10/21/66 OCP 0034-7 IDR #116 trans to OCP 0034-A IDR #012

Recorder 15 shows IMU temp CG 5006 IMU delay CG 5008, comp power fail CG 5030; CRT PG11 L14 shows mark error 1.

Action: Troubleshooting disclosed problem was

545 ECS

- a. Waste management system and S/C H₂O system cleanliness level verification.
- b. Perform EO 548578.
- c. Flushed waste management system urine dump line.
- d. Originated IDR #1 - no sample analysis available for step 11 of EO 548578. A verbal report of a satisfactory sample was received by R. MacDonald of NAA from Pan Am Lab.
- e. Purge and dry urine dump.
- f. Step 2 TPS/545 was not performed because it wasn't scheduled to be done until OCP-0021 was completed. Step 2 is to perform an H₂O flush of potable, waste and supplemental subsystem to kill the bacteria present and should be done as close to launch as the schedule permits.

493 COMM

- a. Reduce noise in mike to audio center.
- b. Sld 1/26/67.
- c. Installed noise limiters in audio center.

225 EPS

- a. Disable SPS PU sensor fail lights.
- b. EO 466789.
- c. Sld 1/23/67.
- d. Removed wire #K-348C20 from P3 and cap.

469 EPS

- a. Wire protection in crew compartment.
- b. Ref EO 586488, MCR-1831.
- c. Installs protective covering over S/C interior TB's wire harnesses and connectors.
- d. Steps 5,6,7,9,10 (pending cure short stamp) (11,13,14,16) are sld.
- e. Not complete due to part shortage (17,15 12,8,4,3,2,1).
- f. Configuration considered acceptable for test.

543 EPS

Installation of SMJC batteries in S/M and pyro batts in C/M for 0006 and remove after test. Installation portion completed.

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Problem: 10/21/66 OCP 0034-7 IDR #116 trans to OCP 0034-A IDR #012
Recorder 15 shows IMU temp CG 5006 IMU delay CG 5008, comp power fail CG 5030; CRT PG11 L14 shows mark error 1.
Action: Troubleshooting disclosed problem was caused by depression of check condition lamps push button on G&N GNIC panel with IMU operate power on and G&N in course align mode. No constraint to further testing.
- 0908 Closed 1/25/67
Problem: OCP 4736 IDR #0008 O₂ flow FC #1 will not shut off when O₂ purge valve is cycled.
Action: Valve was found to leak. Valve was replaced and retested per section B on continuation sheets this DR. Retest was acceptable.
- 0915 Closed 1/26/67
Problem: 1/17/67, dust on lens and mirror on G&N telescope and sextant optics.
Action: Remove dust covers and clean lenses.
- 0922 Closed 1/27/67
Problem: 1/18/67
1. Unable to verify I/D on pyro connectors E18SQ9 (P9) and E18SQ7 (P7) per TPS S/C 012 - 534.
2. Connectors A18SQ1 (P3) in SLA is IDed as A155Q1 (P3) and A18SQ2 (P1) in SLA is IDed as A15SQ1 (P1).
3. The following connectors are not connected per TPS-534: S1551 SQ2, S1552 SQ1, C19SQ14 (P480) and C19SQ12 (P77).

0922 (Cont'd) Action:
 1. ID the connectors.
 2. Connector ID's as called out per the TPS in error. TPS corrected per mod.
 3. TPS modified to disconnect only those connectors connected.

869 AF Problem: Panel 312 is not identified as such and panel 313 has paint on the ID decal.

 Action: Identify panel 312 as panel 312 and remove paint from ID decal on panel 313. Sold.

891 RCS/
 EPS Problem: Connector C05WBP495 in RCS roll access has been disconnected without a PIRR being written and had been connected to GSE cabling.

 Action: Reverify connector and record on proper NAA documentation. Sold.

GSE-572-1-0026 Was IDR 070 (0005A) - could not establish two way communications over GSE intercomm, 1/18/67.

 Action: Repatch 572-J-box and return to original configuration after launch. 572-J-box was repatched and a satisfactory comm check was completed..

TPS RECAP FROM CONSTRAINTS LIST

<u>TPS S/C</u>	<u>SYSTEM</u>	<u>DESCRIPTION</u>
534	EPS	Inspection of pyro connector for correct P/N and correct keying and insert. Sold 1/23/67. Ref DR S/C 922 (sold).
537	SEQ	Support "Q" ball installation. TPS written to support activity required by IBM. Re-evaluated prior to test as no constraint.
555		Hand control removal and inspection and was cancelled by TPS 561.
561		TPS cancellation of TPS 555. Sold 1/24/67.

- 545 ECS a. Waste management system and S/C H₂O system cleanliness level verification.
b. Perform EO 548578.
c. Flushed waste management system urine dump line.
d. Originated IDR #1 - no sample analysis available for step 11 of EO 548578. A verbal report of a satisfactory sample was received by R. MacDonald of NAA from Pan Am Lab.
e. Purge and dry urine dump.
f. Step 2 TPS/545 was not performed because it wasn't scheduled to be done until OCP-0021 was completed. Step 2 is to perform an H₂O flush of potable, waste and supplemental subsystem to kill the bacteria present and should be done as close to launch as the schedule permits.
- 493 COMM a. Reduce noise in mike to audio center.
b. Sold 1/26/67.
c. Installed noise limiters in audio center.
- 225 EPS a. Disable SPS PU sensor fail lights.
b. EO 466789.
c. Sold 1/23/67.
d. Removed wire #K-348C20 from P3 and cap.
- 469 EPS a. Wire protection in crew compartment.
b. Ref EO 586488, MCR-1831.
c. Installs protective covering over S/C interior TB's wire harnesses and connectors.
d. Steps 5,6,7,9,10 (pending cure short stamp) (11,13,14,16) are sold.
e. Not complete due to part shortage (17,15 12,8,4,3,2,1).
f. Configuration considered acceptable for test.
- 543 EPS Installation of SMJC batteries in S/M and pyro batts in C/M for 0006 and remove after test. Installation portion completed.
- 510 EPS a. Circuit interrupter test.
b. Mod #2 - retested all circuit interrupters because could not verify that travel limiters were not left installed on initial testing.
c. Mod #1 - EO 602525, EO 566969-1&2, added connectors.
d. Sold 1/26/67.
- 536 G&N a. Sextant mirror housing plug.
b. Applied Loctite primer and finish coat to mirror housing plug (14 hr cure).
c. Sold 1/27/67.

- 400 FCS a. Install temp plugs on G&N optics.
b. Steps 1,2,3 bought off.
c. Step 4 removes after flight items are installed.
d. No sold until item "c." is complete.
- 511 FCS Perform EO 582263, portable floodlight stowage bag installation. Sold 1/27/67.
- 021 FCS a. Installation of cushion and container crew and scientific "G".
b. Work EO 501694 - Install Scientific "G".
c. Step #1 & #2 hex stamped because flag note 4 of V16-880168 not complied with.
d. Intent of EO not complied with.
e. Scheduled to be accomplished during stowage exercise 2/3 & 2/4.
- NOTE: Step #1 and #2 were hex stamped because intent of EO 501694 had not been fully accomplished as the GFE equipment called out in V16-880168 had not been installed and stowed.
- 079 FCS a. Work EO 582206
b. Adds 2 spare -51 cobra cables.
c. Cobra cables were on temp install.
d. Per OPC-K-10011 deviation. This EO would be accomplished for launch.
- 505 Perform OCP-K-0006. Accomplished 1/26. No constraint.
- 506 Perform OCP-K-0021.

IDR RECAP FROM CONSTRAINTS LIST

OCP-0005

IDR-15 - Observed momentary LOS at time when cabin air fan, suit compressors (2) and glycol pump were switched on (individually) and off.

Results - AC buses were monitored and voltage transients were confirmed. Transients were within spec for inverter operation with full load on bus. IDR condition written with minimum load on bus. Additional testing to be accomplished prior to power down from OCP-K-0021.

IDR-48 - Problem with TV hardline from CX-34 to MSOB.

Results - Troubleshooting disclosed patching problem at MSOB. Not retested prior to OCP-K-0021. Retested during OCP-K-0021.

IDR-61 - GMIL reported poor quality of DSE reverse dump.

Results - Hardware design dictates that we should not dump in reverse direction. Evaluated as no constraint to OCP-K-0021. Test was performed in OCP-K-0006 and resulted in a forward dump mode only that was acceptable to FCS.

IDR-12 - While manually loading K-start tape, word error 1, sync error 3, and momentary PGNS were displayed at 01736E (just before tape listing stop).

Results - Results are normal. Close per OCP deviation.

IDR-13 - CH0413 reads - 0.1 and CH0613 reads - 2.199 and blinking, both should be zero.

Results - Troubleshooting indicated that problem is in ACE carry-on equipment. No GSE DR number available. ACE carry-on not utilized in OCP-K-0021.

IDR-66 - Non-verify received on K-start and TL fail indication observed in S/C.

Results - Troubleshooting disclosed that the S/C AGC had operated properly with erroneous information on uplink to the AGC. The failure indication was attributed to external noise, generated within the ACE uplink system, and responded to by the guidance computer as the first "one" bit into the computer. This spurious bit then caused a failure in the computer verification of the next legitimate data transmitted via the K-start. (The same problem was observed and verified on S/C 017 and the noise was found to originate in a R-start execution.)

IDR-72 - SCS executed C180, 184 and 172 and did not receive a confirm indication.

Results - This was transferred to GE software DR 322. The problem only occurred when using ACE uplink load 3. No change was made to software and a workaround was utilized by initiating and terminating from the same start. IDR was sold 1/25/67.

IDR-77 - When R-187 was executed, noise peaks appeared on recorder 26, GC1022, 1032, 1502, 1512, 1522 and 1532.

Results - Problem appears to be crosstalk between SCS and G&N systems. IDR still open for SCS and G&N further evaluation. Was considered no constraint to OCP-K-0021.

IDR-80 - Measurement CH1038 noisy when TVC power applied.

Results - Troubleshooting indicated bad Yaw ECA. IDR transferred to S/C DR 940. ECA was removed, replaced and retested successfully prior to OCP-K-0021 (with exception of frequency response test). Frequency response was scheduled for 2/1/67.

OCP 0006

IDR-2 - AC bus 2 phase C reads 112.4VAC on CRT and 117VAC in S/C. (within tolerance)

Results - No conclusion at this time. Signal conditioner appears to be drifting. Considered a S/C problem but requires further investigation to verify. Considered no constraint.

IDR-9 - Sold.

OCP 0034A-1

IDR-5 & IDR-37 - Did not receive He isolation #2 opening indication when thrust on was initiated.

Results - Troubleshooting (KSC & Downey) disclosed present GSE instrumentation is marginal with respect to providing positive readout of SPS He and pilot valve signals. IDR's were transferred to GSE DR GC484-7 -0041 & -0042. No constraint to OCP-K-0021.

MISCELLANEOUS ITEMS

1. SP113 is a test in which the meter readings in the S/C are compared against the PCM data. All system engineers were to compare their measurements and write an IDR against any reading out of tolerances established. Partially accomplished in OCP-K-0006 and further data was being obtained in OCP-K-0021.
2. This item was generated by DR 932 (Instr) in which measurement No.SS0120X read incorrectly. All engineers were advised as to what functions go through this connector and to write an IDR on any anomaly noted. Was monitored during OCP-K-0006 and no anomalies were noted.

EVALUATION OF ADDITIONAL OPEN ITEMS

The following items represent new work tasks that were entered into the S/C TAIR books between the completion of open items review and the start of OCP-K-0021. A status and/or explanation for each item is provided.

1. TPS 547 - Install nephelometer cushion MCR 1875 logged 1/24/67. Item was partially worked third shift 1/27 but was not completed. It was not considered a constraint to the test.
2. TPS 548 - Markings on panel #23 MCR 1863 logged 1/24/67. Not considered a constraint.
3. TPS 553 - Remove ablator plugs; add pore seals, logged 1/23/67. Continuing exterior task which is accomplished NIB. No constraint.
4. TPS 556 - Assemble soft BPC in warehouse, logged 1/23/67. Completed for OCP-K-0021.
5. TPS 562 - Cover rough edges on crew couch, MCR 3563, logged 1/24/67. Scheduled for 1/31/67. No constraint.
6. TPS 563 - Change from 1 man rafts to 3 men raft, logged 1/24/67. Scheduled for 2/1/67. No constraint.
7. TPS 568 - Install BPC parts, logged 1/25/67. Accomplished 1/27 to support OCP-K-0021.
8. TPS 581 - Determine reflectivity of S/M coating, logged 1/27/67. Received after planning sheet dated 1/27 was originated. Planned for completion after OCP-K-0021. No constraint.

9. DR 0933 - Ding in CM floor, logged 1/23/67. Completed 1/26 - in cure - not sold. No constraint.
10. DR 934 - Valve markings on CM panel 307, 311 and 314 do not line up, logged 1/23/67. Scheduled for 1/31. No constraint.
11. DR 938 - Rain water in tower leg area, logged 1/24/67. Water dried out 1/24. No constraint.
12. DR 939 - Three dents in SM sector 6, logged 1/24. Sold 1/27.
13. DR 0944 - Washer dropped in F/C #1 sector 4, logged 1/25/67. Sold.
14. DR 949 - Scratches on SLA, logged 1/26/67. Under evaluation. No constraint.
15. TPS 554 - Ball valve #3 position potentiometer change, logged 1/24/67. Work accomplished. Required EO verification. No constraint.
16. TPS 575 - Monitor CM isolation valve temp, logged 1/26/67. Monitoring was being accomplished during OCP-K-0021.
17. DR 0947 - WMS blower on more than 24 hours, logged 1/26/67. ECS blower - not to be run during test. To be replaced after test. No constraint.
18. TPS 580 - Event timer checkout, logged 1/26/67. No constraint. Check on 8 day wind up clock.
19. DR 0936 - Panel 206 wind and set control stuck in the in position, logged 1/24/67. Completed 1/26. No constraint.
20. DR 0940 - Measurement CH1038 noisy when TVC power applied, logged 1/24/67. Yaw ECA replaced 1/26. Retest accomplished, less frequency response, 1/26. No constraint.

21. TPS 552 - Wiring change EO 467267, logged 1/23/67. Ref DR 0918 on constraints list, changed position of wire in matrix block. Task deferred until after Plugs Out. Scheduled for 1/28.
22. TPS 565 - Transport 2 pyro batteries per OCP-K-0006, logged 1/24/67. Accomplished less post test removal.
23. TPS 569 - Install S/C ordnance, logged 1/25/67. Scheduled for 1/31/67. No constraint.
24. TPS 577 and 579 - Transport and install battery for OCP-K-0021, logged 1/26/67. Accomplished less post test removal.
25. DR 0937 - Bonding material used not acceptable inside CM, logged 1/24/67. Work done per B/P. Used MA0106-70 - waiver letter #192-20-66/309 permits material usage. Area involved approximately 1 square inch. No constraint.
26. DR 0948 - Connector J-54 broken, logged 1/26. DR voided. Problem already covered on MR #250. Signal conditioner ACE carry-on connector.
27. DR 943 - Circuit breakers on panel 150 not in proper configuration per procedure, logged 1/24/67. Procedural problem circuit breakers closed in error caused draining of pyro batteries during OCP-K-0006 dry run. Batteries replaced prior to OCP-K-0006 sell run. DR sold 1/27/67.
28. DR 0945 - Panel 200 reads out H₂ regulator pressure. Should be O₂ regulator pressure, logged 1/25/67. System not involved in test. No constraint.
29. TPS 566 - Removal of hand controller, logged 1/24/67. Completed less post test removal of spare hand controllers. One spare rotational and one spare translation controller installed for test.

30. TPS 573 - Install decals of computer codes, logged 1/26/67.
No constraint.
31. DR 941 - Locking ball retainer ring for telescope flight
cover missing, logged 1/24/67. GSE covers installed - no
constraint.
32. DR 946 - L₂ tank #2 exceeded replacement point by operating
90 hours, logged 1/25/67. No constraint - awaiting waiver.
33. TPS 528 - Determine stowage location for additional food,
logged 1/26/67. Scheduled 2/3/67. No constraint.
34. TPS 538 - Installation of container V16-332131, logged 1/26/67.
Sold 1/27. No constraint.
35. TPS 549 - Perform OCP-K-8240C section 2 part 2 of Crew
System Stowage procedure, logged 1/23/67. Scheduled 2/3
and 2/4. No constraint.
36. TPS 564 - Fit check of octopus cable, logged 1/24/67.
Accomplished 1/25 and 1/26.
37. TPS 570 - Install and checkout of crewman optical alignment
sight, logged 1/26/67. Scheduled 2/3 and 2/4 - no constraint.
38. TPS 583 - Installation of stowage items to support OCP-K-0021,
logged 1/27/67. Accomplished prior to crew ingress.
39. DR 0942 - Grommet damaged tee adapter, logged 1/24/67.
Sent to lab - no constraint. This tee adapter was the
second of two good ones. Had unused pins missing. Not
used in S/C for OCP-K-0021.
40. DR 0950 - Cushion assembly for scientific "T" compartment
has damage one edge of assembly, logged 1/26/67.
No constraint.

41. DRS 878 - Fiberglass covers for gears (2) on docking mechanism were missing. Had not yet been scheduled. No constraint.
42. DRS 880 - Fiberglass covers P/N V16-531826-1 and -2 were not installed per print. Had not yet been scheduled. No constraint.
43. DRS 884 - Thermal shrink sleeving was not properly shrunk. No constraint.
44. DRS 886 - Transferred to DR 0945.
45. DRS 892 - Door #9, -Y axis on the SLA had a loose washer and there was dirt and other foreign material inside. Scheduled to work on a non-interference basis. No constraint.
46. DRS 894 - CMD position had two loose cobra cable clamp screws. Had been dispositioned to tighten the screws and had not been scheduled. No constraint.
47. DRS 895 & 896 - Written against the BPC during test preps. No constraint to test.

23 January 1967

CONSTRAINTS LIST - OCP-K-0000/0021 (Reference 23 January Status Report)

All power-up constraints to OCP-K-0000 have been satisfied.

NAA

NASA

All power-up constraints to OCP-K-0021 have been satisfied.

NAA

NASA

This listing identifies all constraints to OCP's 0000 and 0021 S/C 012 tests per constraints meeting held 10:30 AM on 23 January 1967.

W. E. Jones 1-23-67
NAA

C. A. [Signature]
NASA

CATEGORY	TPS/DR	TASK DESCRIPTION	RESP. ENGR.	DNR UP	0003	CONSTRAINT
						0021
Misc. (1)	TPS 505	PIER'S/TIER'S 10011 Checklists 10010 Placards	All	X		
	TPS 506	PIER'S/TIER'S 10011 Checklists 10010 Placards	All			X
APPL/PYRO (2)	TPS 534	Pyro connector keying So L/D	Patterson	X	OK CP Drawing R.F. Lete Wash	
	TPS 537	Support 0-2-11 Installation	Patterson			
ECS/SPS(3)	IP 0003	No. removed on Panel 12 for S/A ECS temp.	Trubs		X OK as is for S/A ECS	
	0081-1-1 ECS 0003 057	Monitor Sodium Isolation valve oper.	Trubs		TRANSFER TO ASE FOR PROVISIONAL	
ECS (4)	ECS 545	Vacuum Waste management system cleanliness level - Part I of WPS only	Griffith		X R.F. Lete Wash	
	DR 0058	Eyes starting	Griffith		X R.F. Lete Wash	
	00054 DR 015	Expendable LOS	Griffith/ Harner		X	W/00054 A-100 R.C.M.
OSM (5)	OSM 543	incorporate Mod Kit (LCA 1844) Sold	Costiguy		X	X R.F. Lete Wash
	DR 0054	VEZ/VE comp. unintelligible with procedure segments on	Costiguy		X	
	DR 0916	CJG002 is modulated when PTT is punched	Costiguy			

indicates Engineering Resolution required.

CATEGORY	TPS/DI	TASK DESCRIPTION	REP. NAME	0006 PWR UP	COMPLAINT 0021 P.A UP
NOR (5)	0005A-1 L21 013	TV system retest	Ostiguy	Z	
	GS3 D3 572-1-0013	Communication system retest	Ostiguy	X	
		Houston Communications Check			
INSTR. (6)	TPS	CIA-348 reinstallation			Series 0065
	DA 0532	Availability of light weight headsets small comm. and P-2000's 1000 - 1000 components - P-2000 for installation. The contract will be with B.P. Hanson			<i>Signed by Pvt. H. H. P. 5/1/60</i>
	0005A-1 ISR 031	Availability of spare parts	Sargent	Z	<i>for with the lead of B.P. Hanson</i>
	TPS 225	5000 lbs 300 lb sensor fall light	Vallin		<i>Sold B.P. Hanson Ryche NASA</i>
EP3 (7)	TPS 433	Wiring protection OK for test of P. Hanson	Vallin		Z
	TPS 510 166 2	Circuit interrupter test	Vallin		
	TPS 543	Battery installation OK for test of P. Hanson	Vallin		
	DA 0604	Wiring routing to L23 OK for test of P. Hanson	Vallin		
	ER 0714	Floodlight support OK for test of P. Hanson	Vallin		X
	DA 0635	Primary floodlight operation OK for test of P. Hanson			X
	ER 0078	L23 L25A splice cable	Vallin		X

CATEGORY	TRG/DT	TASK DESCRIPTION	RESP. ENGR.	PWR UP	0006	CONSTRAINT	3
ECS (7)	0002	Pyro connections (reference TPO 534)	Vallin	X			
	0001-1		Vallin				X
	0002						
	0003	Exhaust air flow sensing plug	Dennett				X
	0004	Shows 1 VV temp. 1 VV delay comp. pwr. fail 2 c/w. shows 2 early error #1	Parris		X		
	0005	Two alarm anomalies	Perrin		X		
	0006	Constant 0.15					X
	0007	0.15					X
	0008	Verify on 3-start, TL fall in S/C	Parris				X
	0009	TL 0.13 reads improperly	Schultz/Buzz		X		
ECS (8)	0010	new D & S/C 0.13					
	0011	2-Start execution anomaly	Schultz/HACC				X
	0012		Schultz				
	0013	Hand Controller installation/inspec.	Schultz				
	0014	O ₂ Purge valve monitor - fuel cell #1 pressurization	Schultz/Buzz				
	0015	0.13 0.13 is noisy					
	0016	Panel 13 E2 Tank #2 pressure indication	Dvorak				
	0017		Dvorak				
	0018						
	0019						
ECS (9)	0020						
	0021						
	0022						
	0023						
	0024						
	0025						
	0026						
	0027						
	0028						
	0029						

117

Prior to Mission Run

X and up of C. Perry J. H. Ward

X and up of C. Perry J. H. Ward

X and up of C. Perry J. H. Ward

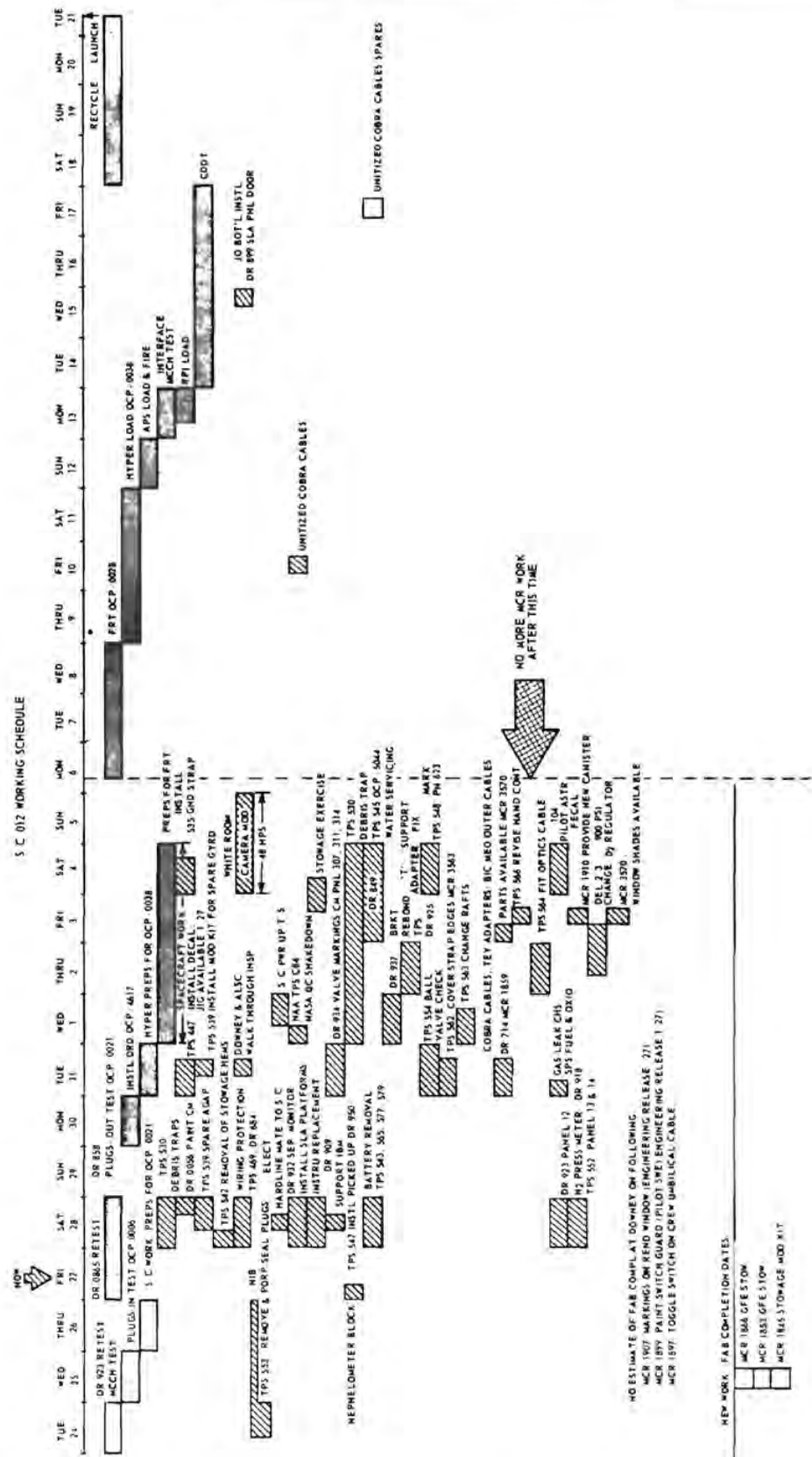
X and up of C. Perry J. H. Ward

X and up of C. Perry J. H. Ward

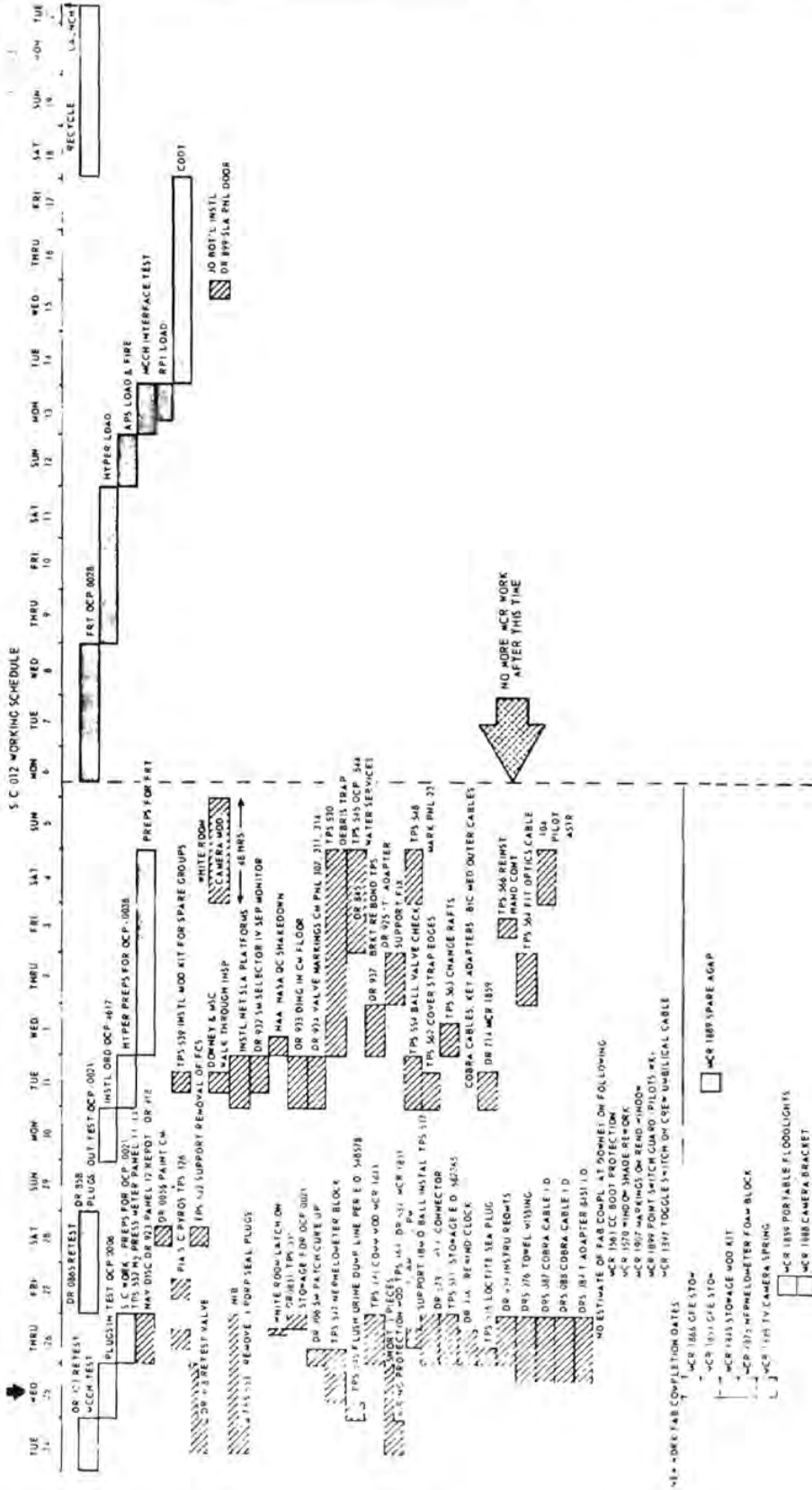
X and up of C. Perry J. H. Ward

CATEGORY	TPS/DX	TASK DESCRIPTION	RESP. ENGR.	COEFC.			PER UP	PER UP	PER UP
				0003	PER DJ	0021			
SIC (10)	DR 0344	When A/C inverter #2 was connected to A/C Bus #1 the master alarm came on.	Brandon		X				
	0005A-1 IL3 077	R187 execution anomaly	Brandon		X				
	FCS (11)	TPC 400	CSH optics plugs installation	Corley <i>Not required P.P. Simon</i>			X		
		D1 0031	Kapalculator installation/removal	Corley <i>Not required P.P. Simon</i>			X		Storage
		TPS 511	Work ID 582263	Corley <i>Not required P.P. Simon</i>			X		Storage
ERS (12)	DR 0609	Sim. voltage is 6.8, should be 16	Corley				X	Need T-Adapter	
	T 1 001 (LAB)	Installation of scientific "G"	Corley <i>Not required P.P. Simon</i>			X		Storage	
	TPS 070 (LAB)	Work ID 500006	Corley				X	Storage	
	D1 0103 (LAB)	TV camera mount spring broken	Corley <i>Not required P.P. Simon</i>				X	Storage	
	D1 0105 (LAB)	Pin #2 of E1 protruding	Corley				X	T-Adapter	
MPC. (1)	D1 009	Panel 312 and 313 ID	Griffith	<i>Not required P.P. Simon</i>			X		
	D1 001	Panel 307, 311 & 312 valve markings	Griffith				X		
		SP113 to be filled out and evaluated	All				X		
		Revert due to pulling of CSH unb. connector 215 and circuit interrupter actuation	All				X		

S C 012 WORKING SCHEDULE



S.C. 012 WORKING SCHEDULE



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DEVELOPMENT HISTORY

PLUGS OUT TEST

OCP-K-0021

12 July 1966

- SP-64,, "S/C 012 Test Outlines"
published for a preliminary
review to be completed by
20 July 1966.

- PURPOSE OF OCP-K-0021

A. To verify overall S/C L/V
compatibility and demonstrate
proper function of S/C systems
with all umbilicals and GSE
disconnected.

B. To verify no electrical inter-
ference at time of umbilical
disconnect.

10 August 1966

- SP-64, retitled "S/C 012 - S/C 014
Florida Facility Test Flow Plan"
was published.

- PURPOSE OF OCP-K-0021 - No changes

- Presented to Checkout Management Panel #24, (MSC/KSC/NAA).

- No significant changes to L/C 34 testing were requested by the Checkout Management Panel.

- TEST CONFIGURATION

A. S/C and L/V were mechanically mated, and were electrically mated through fuse boxes.

B. S/C Internal Power Sources:

1) Pyro batteries (test) installed.

2) Entry and Postlanding batteries installed.

3) SM jettison controller (SMJC) batteries (test) installed.

4) GSE test batteries used to replace fuel cells.

5) GSE power to Spacecraft busses.

C. Installed Pyros disconnected and shorted.

D. Forward Heat Shield installed.

E. CM and SM RCS Simulators connected.

- F. G and N Flight Ropes.
- G. ECS CM W/G circulation.
- H. Operational TV camera mounted.
- I. LES installed and electrically and mechanically mated to CM.
- J. Flight Qual and DSE Recorders loaded with Degaussed Tapes.
- K. ACE Carry-on disconnected.
- L. Physiological Simulators installed (MDAS connected).

6 September 1966

- Reviewed and redefined plus-time operation, specifically regarding the scope of G&N programs to be conducted during the altitude chamber runs and plugs out tests. This was done to adequately divide all the G&N checkout among the separate OCP's which have plus-time mission sequences.

19 September 1966

- Flight crew requested emergency egress practice prior to Countdown Demonstration Test due to hazardous conditions in the CDDT resulting from fully fueled Launch Vehicle.

- 20 September 1966 - Rough draft sent to keypunch for preliminary flimsy printout, delivered 21 September.
- 26 September 1966 - Flimsy copy of OCP to NAA Safety for electrical hazard review.
- 27 September 1966 - Decision made in NASA/NAA OCP Control Board Meeting this date to run emergency egress test after completion of the mission runs in OCP-K-0021. The following was then coordinated with the back-up crew Command Pilot:
- A. Back-up crew to participate in the test, then the prime crew would perform a normal ingress and the emergency egress test during L/V reset period. (See sequence 07-310, Page 7 - 56 of OCP-K-0021-1.)
- B. GSE air and open hatch for simulated mission by back-up crew. Full hatch close-out (including Boost Protective Cover) for prime crew emergency egress test.
- C. Prime Crew wanted normal pre-T-O ingress and closed hatch during simulated flight missions, but

the ELS Sequencer Controller
Pressure Stimuli Generator
(C14-451) would have interfered
with hatch close-out.

D. The purpose of OCP-K-0021 was
changed to add, "C. To verify
astronaut emergency egress pro-
cedures (unaided egress)."

E. On this date, review comments
from 21 September were sent to
keypunch for a second set of flimseys.

4 October 1966

-Third set of flimseys printed for
mark-up.

19 October 1966

- Distributed printed preliminary
hard copies of procedure for review.
Had been submitted for printing on
14 October.

30 October 1966

- Formal review meeting held. Attended
by all systems except G&N.

31 October 1966

- In accordance with Astronaut and
checkout team desires, and following
a technical investigation, it was
agreed to delete the ELS Sequencer
Controller Pressure Stimuli Genera-
tor from the test thus allowing the

following test philosophy changes:

- A. Allow performance of normal flight crew countdown. (OCP-K-5117) (This is the astronaut procedure from wake-up to arrival at the launch complex.)
- B. Back-up crew to perform their normal launch day functions.
- C. Prime crew to ingress and run entire test as on launch day.
- D. Emergency egress test to be performed by prime crew after simulated landing.
- E. Normal cabin hatch close-out and running of the test on O₂ were results from these decisions

7 November 1966

- Crew Systems Stowage was added to be performed as part of the test setups per request of local MSC crew support personnel.

15 November 1966

- G&N information available. Coordination with L/V procedures in progress.

21 November 1966

- Received the mats for printing the basic issue of OCP-K-0021.

7 December 1966

- Six copies of the final master flimsy were presented to Systems Engineering for final review.

- 10 December 1966 - Final mats approved, cover sheet signed, sent to print shop.
- 13 December 1966 - Procedure published and released formally.
- 13 January 1967 - Meeting held at KSC attended by the prime crew Pilot (MSC), Lou DeWolf (FCSD), Tom Grier (FCSD), Don Nichols (KSC), and F. J. Powell (NAA), the following items were discussed and tentatively agreed to:
- A. Back-up crew was to perform a panel-by-panel check of all C/M controls during "Back-up Crew Pre-Launch Checks." (See sequence 8.5, 8.6, and 8.7 of OCP-K-0021.) These checklists were to be conducted on a switch-by-switch basis over the intercom.
 - B. After ingress, the prime crew was to perform a panel sweep of the display console and associated panels which can be reached from couches (lower equipment bay not to be re-checked). This checklist was not to be called out over the intercom.
 - C. The information to be contained in the switch lists in Items A and

and B above, were discussed and mutually agreed upon. This information was subsequently provided to FCSD for incorporation in Section 1 and Section 2 of the Crew Abbreviated Checklist.

D. Panel nomenclature was called out in all switch lists. In a case where simplification of call outs could be made, the Test Conductor was to combine such call outs as "Main A", "Main B", and other similar switch nomenclatures.

E. Plugs In, Plugs Out, Flight Readiness, and Countdown test procedures were revamped to a standard minus time operation from approximately T-2 hours to liftoff.

F. All S/C 012 OCP's had been written utilizing the 14 November 1966, S/C 012 Crew Checklist (SM-2A-03) as a reference document.

From this date (1/13/67), NAA was in the process of updating procedures to the 5 January 1967, version plus

the changes that would be supplied by FCSD in their 16 January 1967, revision.

23 January 1967

- Preliminary Launch Countdown, OCP-K-0007, was published. This procedure provided a baseline from approximately T-3 hours to T-Zero for use in the Plugs Out Test.

26 January 1967

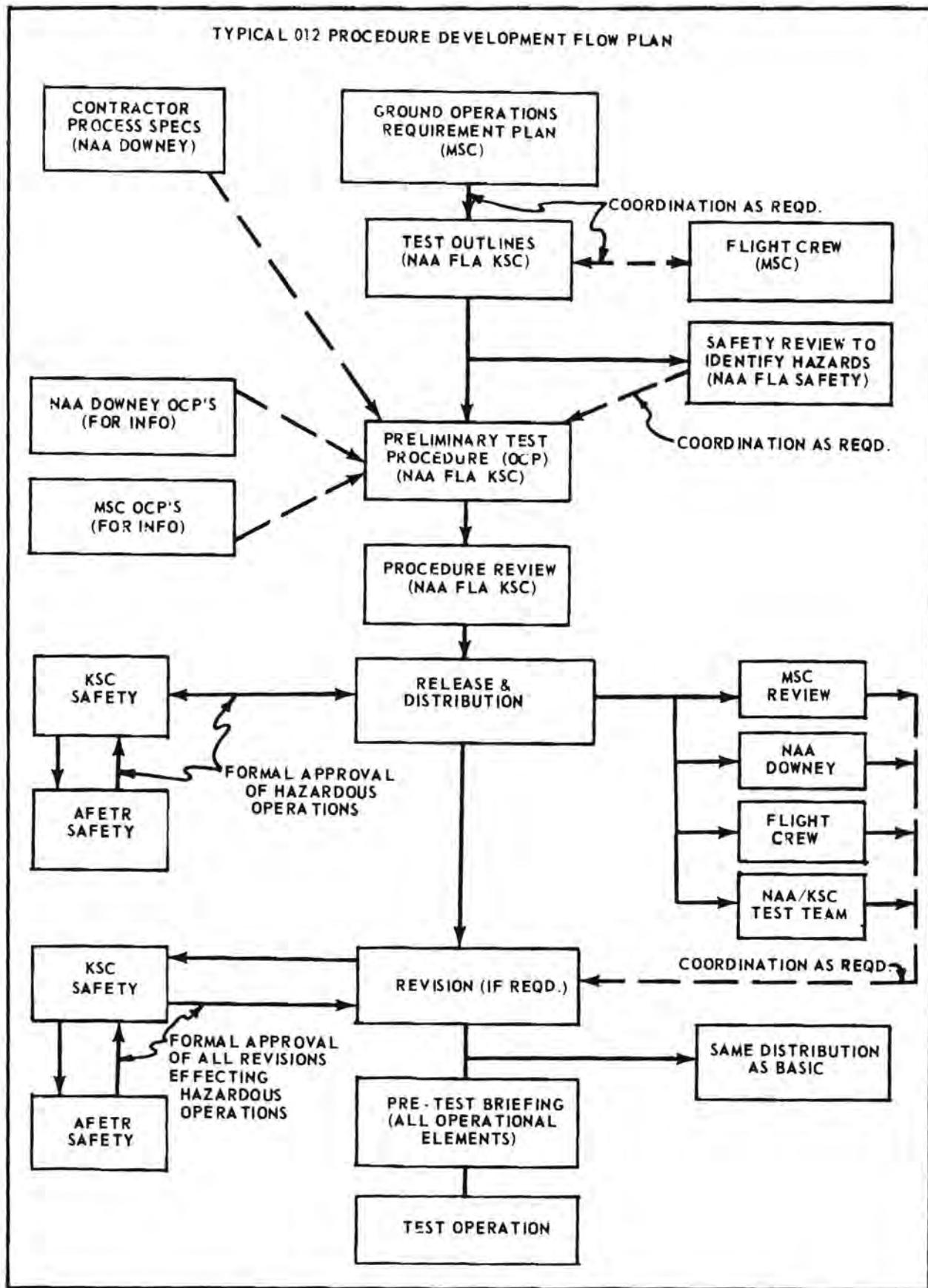
- (5:30 p.m.) Rev. -1 consisting of 209 pages was released with update from OCP-K-0006, Plugs In Test experience, plus 4 weeks information accumulations and incorporation of agreements made in the 13 January meeting. See Attachment 7-3 for details and dates related to the reasons for the -1 Revision of OCP-K-0021.

27 January 1967

• - (10:00 a.m.) -1 Revision A delivered. All changes affected plus time sequences only. (Four typed pages in lieu of having to write on-station deviations.)

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TYPICAL 012 PROCEDURE DEVELOPMENT FLOW PLAN



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UNITED STATES GOVERNMENT

Memorandum

TO : Apollo 204 Review Board Panel - Task No. 7
Test Procedures Review/Attn: Nichols, Chairman

DATE: February 13, 1967

FROM : Chief, Safety Office, RE

RE-1/106/Barnott:mr
867-3973

SUBJECT: Test Procedures Review for Hazardous Operations

1. The requirement for the KSC Safety Office and the Air Force Range Safety review of test procedures for hazardous operations is specified in Section I, paragraph 3, page A-1 of KMI 1710.1, Attachment A, dated October 4, 1966, and Section C, paragraph 3, page C-5 of AFETRM 127.1 Range Safety Manual dated 1 November 1966.
2. Some operations that have been specified as hazardous in nature are as follows:
 - a. Propellant servicing
 - b. Pressure testing
 - c. Pyrotechnic (ordnance) work
 - d. Radioactive and toxic material operations
 - e. Operations with hazardous gases
3. The responsibility of submitting hazardous test procedures for Safety approval is with the contractor. A test to be conducted on Cape Kennedy requires 5 copies of the Test Procedure to be submitted to the KSC Safety Office. One of these copies is retained by the KSC Safety Office and one is sent to Bendix Systems Safety for comment; three copies are then forwarded through the Apollo/Saturn I-V Requirements Branch, DK-3, to Air Force Range Safety (ETOSH) for review and approval.
4. Comments from ETOSH and Bendix Systems Safety are submitted to the KSC Safety Office, who in turn transmits the comments to the contractor for incorporation into the OCP.
5. It should be noted that the AFETRM 127-1 Range Safety Manual requires a minimum of 30 days for review of documents. Apollo Procedure submittals have been very delinquent in meeting this time requirement. The late submittal of procedures has repeatedly been brought to the attention of North American and Spacecraft Operations in various meetings and correspondence. Some procedures have been submitted with as little as two days



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ENCLOSURE 7-5

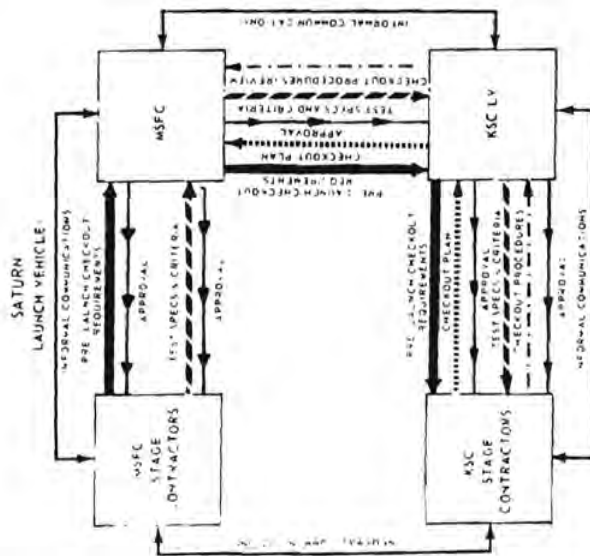
D-7-57

allowable Safety review time. Also, changes to an approved procedure have been published on the day of the test, thereby eliminating any allotted time for Safety review.

6. OCP-0021, S/V Plug Out Integrated Test was reviewed for S/C 009 and was classified as a non-hazardous test, thereby eliminating required Safety approval. This type procedure is not again submitted to KSC Safety for review unless it is changed in such a way as to make the operating hazardous. OCP-0021 for S/C 012 was not submitted to the KSC Safety Office for approval.

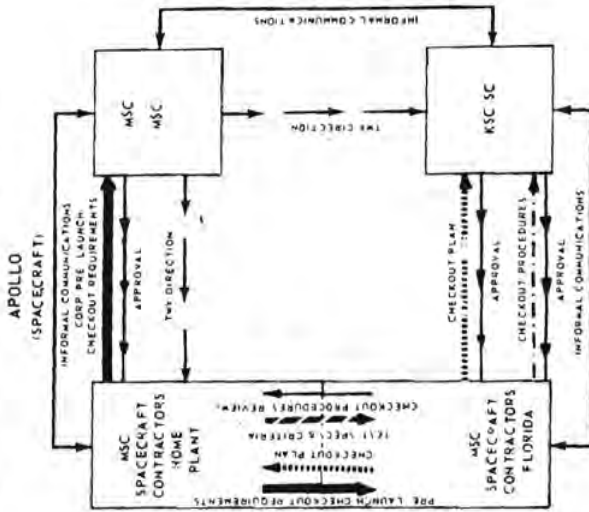
John R. Atkins
for John R. Atkins

PROGRAM CONTROL OF PRE-LAUNCH TEST REQUIREMENTS



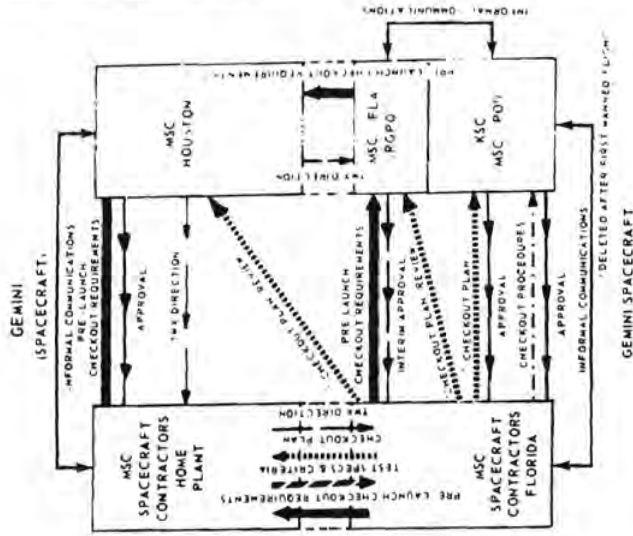
SATURN LAUNCH VEHICLE

- 1 DELEGATION OF PRE-LAUNCH CHECKOUT AND LAUNCH IMPLEMENTATION RESPONSIBILITY TO KSC FROM MSC
- 2 A. FORMAL INTER-CENTER AGREEMENTS
- B. KSC CONTROLLED SUPPLEMENTAL CONTRACTS TO IMPLEMENT DELEGATION



APOLLO SPACECRAFT

- 1 CENTRALIZED AUTHORITY RETAINED AT MSC
 - A. SLOW RESPONSE LOOP
 - B. MSC APPROVAL CONSTRAINS NORMAL PRELAUNCH ACTIVITY
- 2 INTER-CENTER AGREEMENTS NOT FORMALIZED
 - A. INTERFACE OF CENTERS ROLES AND MISSIONS NOT CLEARLY DEFINED



GENINI SPACECRAFT

- 1 LAUNCH SITE AUTHORITY WITH QUICK RESPONSE CAPABILITY TO MEET DYNAMIC NEEDS OF REAL TIME OPERATIONS
- 2 MSC CONTRACTUAL LOOP NON-RESTRAINING WITH AFTER-FACT CLOSURE ON QUARTERLY BASIS

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FLIGHT VEHICLE TEST DOCUMENTATION

SATURN LAUNCH VEHICLE

APOLLO SPACECRAFT

GEMINI SPACECRAFT

PRELAUNCH CHECKOUT REQUIREMENTS

PURPOSE: Defines and Levies General Checkout and Operations Requirements.

PRELAUNCH TEST AND AND CHECKOUT REQUIREMENTS

GROUND OPERATIONS REQUIREMENTS PLAN

SEDR 9882

1. Class I Document (KSC)
2. Prepared by MSFC Stage Contractor for MSFC

1. Class I Document (S/C Contractor)
2. Prepared by
 - A. S/C Contractor (Home Plant)
 - B. KSC Informal Inputs to MSC
3. Approved by MSC Contracting Officer
4. Content
 - A. Operations Outlined in Detail
 - B. Specific System Operation Defined
 - C. Flow Oriented -- Factory thru Launch Site

3. Approved by MSFC Stage Manager
4. Content
 - A. System Oriented
 - B. Treats System Functions not Methods or Sequences
 - C. Launch Site Oriented

5. Format -- Tabular
6. Delivery Schedule
 - A. Original -- 1 to 2 Months Prior to Vehicle Delivery
 - B. Revisions -- as Required

SUMMARY: Requirements are Levied without Restraining Sequence or Method of Implementation.

1. Class I Document (S/C Contractor)
2. Prepared by
 - A. S/C Contractor (Florida) (with KSC Inputs for MSC)
3. Approved by MSC Contracting Office (after GPO Agreement)
4. Content
 - A. Program Document with Table Showing Requirements per Vehicle
 - B. Treats Test Objectives, not Methods or Sequences
 - C. Launch Site Oriented
5. Format -- Tabular
6. Delivery Schedule
 - A. Original -- 1 to 2 months Prior to Delivery
 - B. Revisions -- Updated at 3 month Intervals (Includes after the Fact Changes)

SUMMARY: Prepared at Launch Site with Real Time Approval Allowing after-the-fact Contract Revision.

5. Format -- Tabular
6. Delivery Schedule
 - A. Original -- 18 Months Prior to Delivery Due to Its Utilization as a GSE Provisioning Document
 - B. Revisions -- Continuous

SUMMARY: Optimum Effectiveness not Achieved as a Test Requirements Document Due to its Utilization as a GSE Provisioning Document and the Excessive Level of Detail in its Contents.

TEST SPECIFICATIONS AND CRITERIA

PURPOSE: To Furnish Specs and Criteria Applicable to System Performance During Prelaunch and Launch Operations.

PRELAUNCH CHECKOUT SPECIFICATIONS AND CRITERIA (KSC)

1. Class I Document (KSC)
2. Prepared by MSFC Stage Contractor for MSFC
3. Approved by MSFC
4. Content
 - A. Systems Information by System
 - B. Field Tolerances by System
5. Format - Tabular
6. Delivery Schedule 1 to 2 Months Prior to Vehicle Delivery

SUMMARY: One Integrated Document Per Stage Scoped to Cover Normal Testing, Troubleshooting, And/or De-tailed Testing.

PROCESS SPECIFICATION MA0201-XXXX (BLOCK I)

1. Class III Document
2. Prepared by S/C Contractor (Home Plant) Engineering For External Use
3. Approved by Contractor Proj. Engr.
4. Content
 - A. Step-by-step Like a Checkout Procedure
 - B. One Integrated Document Per Test
5. Format - Written Like Launch Site Checkout Procedures
6. Delivery Schedule Four Months Prior to Test

SUMMARY: Scoped by Test in a Format Which Makes Its Use, As a Reference Document for Specific System Values, Difficult.

PERFORMANCE AND CONFIGURATION SPECIFICATION (MAC REPORT A-900)

1. Class I Document (S/C Contractor)
2. Prepared by S/C Contractor (Home Plant) for MSC
3. Approved by MSC Contracting Office
4. Content
 - A. Mission Performance Specification by System
 - B. Configuration by System
5. Format - Narrative/Tabular
6. Delivery Schedule Two Months Prior to Spacecraft Delivery

SUMMARY: One Integrated Document Per S/C, Scoped to Cover Normal Testing Level, Troubleshooting And/or Detailed Testing Required is Referenced to Lower Level Documents.

CHECKOUT PLAN

PURPOSE: To Provide an Outline of the Testing and Checkout to be Performed.

CATALOG OF LAUNCH VEHICLE TESTS

1. Class I Document (KSC)
2. Prepared by KSC Stage Contractor for KSC
3. Approved by MSFC Upon Submission
4. Content
 - A. Test Objectives
 - B. Brief Test Description
 - C. Test Support Requirements

5. Format - Narrative
6. Delivery Schedule
 - A. Original - 6 Months Prior to Vehicle Arrival

SUMMARY: KSC Response to the MSFC Prelaunch Test and Checkout Requirements.

FLORIDA FACILITY TEST FLOW PLAN

1. Class III Document
2. Prepared by MSC S/C Contractor (Florida) for KSC
3. Approved by
 - A. S/C Contractor (Florida)
 - B. KSC
4. Content
 - A. Test Objectives
 - B. Brief Test Description
 - C. Detailed SC/GSE Configuration Matrices

- D. Detailed Outline of Each Test and Operation
- E. Safety Requirements
5. Format - Narrative and Tabular
6. Delivery Schedule
 - A. Original - 2 Months Prior to SC Arrival

SUMMARY: Locally Generated at KSC To Define Scope and Method of Spacecraft Checkout at KSC.

TEST OPERATIONS PLAN (SEDR 301)

1. Class III Document (S/C Contractor)
2. Prepared by S/C Contractor (Florida) for KSC
3. Approved by
 - A. S/C Contractor (Florida)
 - B. KSC
4. Content
 - A. Test Objectives
 - B. Brief Test Description
 - C. SC/GSE Configuration

- D. Brief Test Outline
- E. Hazards (Safety)
5. Format - Narrative
6. Delivery Schedule
 - A. Original - 7 Months Prior to SC Arrival

SUMMARY: Document Replaced After First Manned Launch By Test Matrix Containing Similar Information.

CHECKOUT PROCEDURE

PURPOSE: To Provide Detailed Step-by-step Procedure for Performing Each Test and Operation.

DETAILED OPERATING PROCEDURE (DOP)

OPERATION CHECKOUT PROCEDURE (OCP)

SERVICE ENGINEERING DEPARTMENT REPORT (SEDR)

1. Prepared by Local Contractor for Local NASA
2. Approved by Local Contractor and Local NASA
3. Content - Detailed, Step-by-step Procedure
4. Delivery Schedule -
 - A. Preliminary - 30 Days Prior to Use
 - B. Final - 5 Days Prior to Use
 - C. Revisions - As Required

SAME

SAME

DOCUMENTS REQUIRED IN DIRECT SUPPORT ON THE PLUGS OUT TEST

1. Spacecraft Plugs Out Procedures FO-K-0021 S/C 012/014
2. Launch Vehicle Plugs Out Procedure
3. Space Vehicle Plugs Out Procedure. I-20015-SA204
4. GSE Checklist FO-K-10011 S/C 012
5. Crew countdown FO-K-5117 S C 012

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AO-67-32

INTERNAL LETTER

North American Aviation, Inc.

Date 23 February 1967

TO Apollo Supervision
Address 42-820, 818, 41-696/697

FROM J. L. Pearce, 42-818 ZK1A
Address S. M. Treman, 41-696-697 HCSJ

Phone 867-6151
923-1121

Subject Memorandum of Understanding - Coordination of
Preparation of Engineering Test Specification
and Major Test Outline Document for Florida
Facility Block II Apollo Spacecraft Test
Operations

The purpose of this memorandum is to record understanding of responsibilities for coordinated preparation between the Florida Facility and Downey Spacecraft Design of the test specification and criteria and FF Major Test Outline documents for Block II Apollo spacecraft operations at KSC.

Specifically, C/O Integration and Combined Systems (D/697-400) is responsible for the preparation of a document to provide requirements for Block II spacecraft functional test and servicing operations to be performed at KSC. The document is to be modular in form and generally system-oriented. It shall be consistent with the requirements of the applicable Block II S/C GORP.

The document will be prepared with the direct support of Florida Facility Apollo Engineering (D/820) and Apollo Operations (D/318). Active coordination channels will be established to assure that the form, content, and details of the document meet the needs of Apollo S/C operations as planned and scheduled by the Florida Facility organization.

Florida Facility Apollo Operations (D/318) is responsible for the preparation of the Major Test Outline document applicable to Block II S/C KSC operations in coordination with D/820. This document will meet requirements contained in the test specification and criteria document and will be in accordance with the applicable Block II S/C GORP. The document will be submitted to D/820 for review and concurrence. The document will simultaneously be provided to D/696 and 697 for review and comments. These comments will be provided to D/820. D/697-400 will provide technical support to D/818 as necessary during document preparation. A summary of the contents of the FF Major Test Outline document is enclosed (See Attachment 1).

D/820 is responsible for assuring that OCP outlines satisfy the requirements of the test specification and criteria document. D/820 will take necessary action to assure that these documents are compatible. D/820 will, in this capacity, directly support

ENCLOSURE 7-9

D-7-67

AO-67-32

J. L. Pearce/S. M. Treman

23 February 1967

Page 2

D/697-400 in the timely on-the-spot assurance of test specification/OCF outline compatibility.

Following initial EO release of the test specification, Downey changes must be implemented utilizing existing Engineering procedures. Copies of EDC's will be supplied to FF for advance information. Changes initiated by FF must be implemented utilizing the FEO/FCA system.

A flow chart depicting the channels of communications and coordination is enclosed (See Attachment 2).

To facilitate coordination and implementation of the provisions of the memorandum, single point contacts will be named in Departments 818, 820, and 697-400. The prime coordination contact at KSC for interfacing with D/696 and 697 will be provided by D/820.


J. L. Pearce
Director CSM
Florida Facility


S. M. Treman
Director
Spacecraft Design

cc: G. W. Jeffs
R. L. Benner
A. B. Kehlet
G. B. Merrick
L. G. Rochester
M. Karp
J. P. Proctor
R. E. Barton

DEFINITION OF SECTIONS OF THE
FLORIDA FACILITY MAJOR TEST OUTLINE DOCUMENT

SECTION A

Internal Power Configuration Plan

A chart showing usage of batteries, battery substitute units, fuel cells, fuel cell simulators and fuel cell substitute units as a function of various major KSC tests.

SECTION B

GSE Utilization Plan

A chart showing usage of GSE models and DTT's on a per test basis.

SECTION C

Spacecraft Test Plan

1. A chart showing types of missions and aborts on a per test basis.
2. A prose description of each test defining the test objectives and clarifying the goals of the days activities.

SECTION D

Test Limitations

1. References appropriate placards and limitations guide.
2. References appropriate KSC and EFR safety limitations.
3. Describes the limitations of the allocations of activities per test to insure that total KSC testing does not exceed limits.

SECTION E

Spacecraft Flow Plan

A sequential listing of the details of the test flow plan intended as a guide to checklist preparation.

SECTION F

Plan of System Testing

Either a prose description or a matrix, as appropriate, showing the plan for all KSC test on a per system basis. It is intended to be a convenient guide to all parochial interests to examine the plot of each system in Florida. This section also includes a table of measurements tested and on-board display correlation with telemetry on a per test basis.

SECTION G

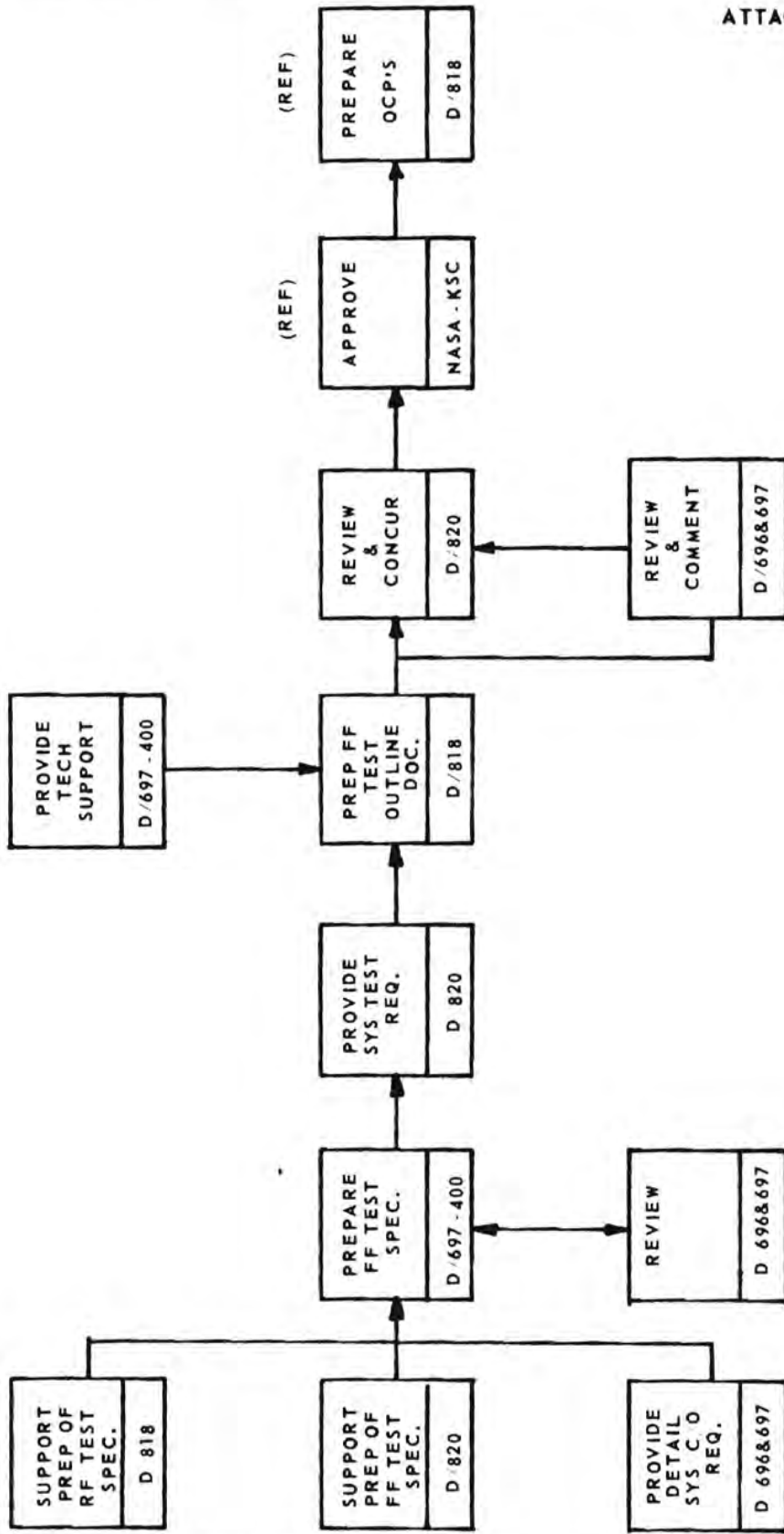
Mission Test Sequence

A sequential listing of all normal or backup event blocks. Does not conform to the flight plan. The intent is to detail all items occurring while going thru an exercise. Test outlines would then pick out selected blocks for performance as appropriate considering the primary test objectives.

SECTION H

Test Outlines

A detailed step by step outline of each OCP from beginning to end. Each item in the outline would be the same as a block title in either the Appendices or the Mission Test Outlines.



ENGINEERING C/O REQUIREMENTS FLOW TO FF

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INTERNAL LETTER

AO-67-34

North American Aviation, Inc.

Date 2 March 1967

TO Apollo Supervision
Address 42-820, 818, 41-696/697FROM J. L. Pearce, 42-818 ZK1A
Address S. M. Treman, 41-696/697 HC30Phone 867-6151
923-1121Subject Memorandum of Understanding -
Concerning the Form, Content, and Intent of the Block II
Florida Facility Engineering Checkout Process Specification

- REFERENCES: (a) Memorandum of Understanding, J. L. Pearce and S. M. Treman,
Coordinated Preparation of Engineering Test Specification
and Major Test Outline Document for Florida Facility
Block II Apollo Spacecraft Test Operations, dated
23 February 1967
- (b) Meeting at Florida Facility, 28 February 1967, Attended
by E. E. Dale, W. F. Cahill, W. L. Eckmeier, W. F. Edson,
H. E. Heilman, R. H. Jones and T. H. Lindsay

The purpose of this memorandum is to describe the format and objectives of Sections 4.0 and 5.0 of the CSM Checkout Process Specification being prepared for Florida Facility Block II spacecraft prelaunch checkout operations by D/697-400, Checkout, Integration and Combined Systems. This memorandum is an addendum to Reference (a) in order to provide the details of the Process Specification.

The proposed specification, in consonance with the Vehicle Plan (GORP) for Block II Apollo spacecraft, is the logical extension of Part II of the Contract End Item Specification in that the latter document contains only Downey located post-manufacturing checkout operations.

Florida Facility D/820 Systems Engineers and D/818 Operations Integration Engineers and Publications Analysts require firm, accurate, and timely engineering documentation from Downey Spacecraft Design in order to plan and prepare mission oriented Operational Checkout Procedures (OCP's) for those Apollo CSM spacecraft intended for checkout and launch from the KSC. The following stipulations and definitions defined at the Reference (b) meeting will produce a readily usable document to satisfy this requirement:

A. Stipulations -

1. The specification should provide Downey Engineering CSM checkout requirements; and these should be compatible with the applicable GORP. Tests subsequently identified at the Florida Facility as special or additional requirements will be coordinated with Engineering and EO's generated for permanent specification changes.

2. For KSC checkouts required, it should provide requirements and planning constraints in Section 4.0 and specifications and criteria including operational constraints in Section 5.0. These data should be in the form of hardware performance values and tolerances relative to a specific operating condition.
3. The specification should be subsystem oriented and must be approved by Subsystems Design Groups.
4. It should include a definition of relationship to other documents and will take precedence over subsystem level process specifications. Subsystem specs are not effective at F/F.
5. It should be controlled by the Engineering change system including field change procedures.
6. An EO on a subsystem process specification will not be effective on this specification. However, changes applicable to this specification must be generated immediately to keep the specifications compatible.
7. Initial issue of Section 4.0 should be five (5) months before CSM arrival at KSC. Initial issue of Section 5.0 should be four (4) months.
8. It should be updated 30 days before CSM arrival at KSC; subsequent updating at 30 day intervals should be accomplished until a final EO incorporation is accomplished after launch.
9. A tabular form should be used for stimuli and measurement tolerances, torque values, etc (with respect to system condition).
10. The Launch Mission Rules will take precedence for launch.

B. Definitions -

Section 4.0 - "Checkout Requirements" (Definition of the Engineering requirements per subsystem for checkout at KSC.)

Presents the following: (See Exhibit No. 1 attached)

1. Test code number
2. Brief description of the required subsystem checkout.

J. L. Pearce/S. M. Treman
2 March 1967
Page 3

3. Statement of major checkout planning constraints (e.g. is a prerequisite to another checkout; time/cycle limitations).

Release date for this portion of the specification will be five (5) months prior to spacecraft delivery. Subsequent updating at 30 day intervals.


Section 5.0 - "Specifications" (A statement of hardware performance values per subsystem with respect to a specific input or operating condition.)

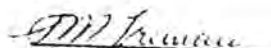
Presents the following: (See Exhibit No. 2 attached)

1. Brief system functional performance description.
2. Measurement number and title.
3. Stimuli characteristics (e.g. amplitude, frequency, duration, pressure, etc.).
4. Performance (output characteristics with tolerance expressed as nominal +/-XX, in engineering units; also may involve other characteristics such as acceptable leakage rate, as applicable and should be compatible with Launch Rules.)
5. Operational constraints affecting specified performance values.
6. Critical spacecraft configuration and interface requirements.

Release date for this portion of the specification will be four (4) months prior to spacecraft delivery.

This memorandum states the mutual agreement of the undersigned to the form, content and intent of a single checkout process specification for each Block II Apollo CSM that will receive a prelaunch checkout at KSC.


J. L. Pearce
Director CSM
Florida Facility


S. M. Treman
Director
Spacecraft Design

cc: G. W. Jeffs
R. L. Benner
A. B. Kehlet
G. B. Merrick
L. G. Rochester
M. Karp
J. P. Proctor
R. E. Barton

EXAMPLE

CHECKOUT REQUIREMENTS

(Section 4.0 of C/O Spec for Florida Facility)

TF0001

ENVIRONMENTAL CONTROL SYSTEM
SERVICING, ACTIVATION, AND VERIFICATION

Perform an ECS servicing, activation, and verification of the primary and secondary water-glycol loops, oxygen system, and suit loop system.

Performance of this checkout is a prerequisite to CSM system activation and verification operations.

TH0012

STABILIZATION AND CONTROL SYSTEM
FREQUENCY RESPONSE

Perform an SCS frequency response checkout to demonstrate capability to gimbal the SPS engine, using both primary and secondary gimbal motors, with the proper magnitude, rate, and direction.

Frequency and step response must be verified in both the LEM OFF and LEM ON operating conditions.

EXAMPLECHECKOUT SPECIFICATIONS

(Section 5.0 of C/O Spec for Florida Facility)

ENVIRONMENTAL CONTROL SYSTEM

The specifications applicable to ECS servicing are as follows:

FF5026P	W/G Supply Pressure	55 +/- 15 PSIA
FF5027Q	W/G Flow	200 +/- 20 Lb/Hr
FF5028P	W/G Diff Pressure	35 +/- 15 PSID
FF5029T	W/G Return Temp	55 +/- 10 Deg. F
FF5030T	W/G Supply Temp	35 +/- 10 Deg. F

The above specifications apply after system stabilization.

STABILIZATION AND CONTROL SYSTEM

The specifications applicable to SCS/SPS engine frequency response are as follows:

<u>INPUT AMP</u> (Deg./Sec.)	<u>FREQ.</u> (CPS)	<u>TIME</u> (Sec.)	<u>MEAS.</u>	<u>NOMEN.</u>	<u>VALUE</u> (W/ TO L)
3.0	0.318	15	CH3517	Gimbal Pos, Pitch	(XXX+/-X)

MINUTES OF MSC/KSC/OMSF MEETING AT KSC
JANUARY 26, 1967

1. In accordance with an OMSF TWX 362 2204, dated December 22, 1966, a meeting was held at KSC (attendees listed in Attachment 2) to review spacecraft checkout experience over the past year and discuss actions that might be taken to improve checkout of subsequent spacecraft. Items discussed were those submitted by MSC and KSC prior to the meeting (Attachment 3).
2. The discussion of the agenda items resulted in the following agreements or actions:
 - a. MSC and KSC to continue to track the 7 configuration verification discrepancies found by KSC on a spot check of 30 odd pieces of hardware to assure that the configuration control paperwork eventually reflects the "as is" condition and review the time lag between the hardware reconfiguration and the time this reconfiguration is reflected in the paperwork. A similar type spot check will be made on S/C 020.
 - b. MSC and KSC will review the Cape receiving inspection records on 017 and consider the preparation or modification of inspection criteria for those items where the presence of well written criteria would tend to reduce inspection variances among Quality Control personnel.
 - c. KSC will provide a Quality Control inspector to participate in the final inspection of subsequent spacecraft at Downey through spacecraft 102. MSC will also provide a NASA Quality Control inspector to participate in spacecraft receiving inspections at the Cape through 102. Data collected during these inspections will be used to refine and improve inspection methods and criteria.
 - d. MSC will provide direction to see that all contractor and GFE non-flight hardware is clearly marked and so identified in the spacecraft paperwork.
 - e. KSC will bring to the appropriate Program Manager's personal attention any non-flight hardware that is installed on a space vehicle and not clearly marked.
 - f. KSC and MSC will arrange a subsequent meeting to discuss the other actions recommended in the KSC handout to improve overall quality and review the use of the Engineering Disposition Book.
 - g. MSC indicated that PAR closeout action by NAA reflects the engineering order number or other specific written corrective action that has been taken to correct the problem.
 - h. MSC will check to determine why EO number E15-420603 and 604 were not incorporated in spacecraft 017 before delivery to the Cape.

- i. MSC will check recurrence control applied to the cabin relief valve (part number ME - 284 - 0149 - 0021) to assure that the system is operating as it should.
- j. KSC will provide MSC a specific list of areas where it would be helpful to consolidate several process specifications into a single process specification which summarizes requirements.
- k. MSC will review MSC and NAA non-metallic crew bay material requirements documents to update them and assure they are compatible.
- l. MSC will review NAA documentation on functional checkout and/or PIA time cycles on spare components and provide written guidance to KSC.
- m. MSC will review the list of hardware problems presented by KSC in discussing design problems (electrical switch, communications cables, bi-metallic interfaces, DSE recorder, signal conditioner fuses, hand controller cable covering, water glycol and O₂ line installation) and assure that appropriate corrective action is in process.
- n. MSC is preparing a revised flow plan and is reviewing the technical requirements to which the system and subsystem is tested as it progresses from assembly through checkout at the Cape. This system will be implemented for Block 2 spacecraft and will provide a better overview of the total testing done on flight hardware before launch. It will also assist in providing better visibility into the test status of hardware when the DD 250 is signed.
- o. MSC will recheck the list of items indicated under Part VI, Level of Testing, in KSC handout to assure that the problems indicated have been fed back into NAA for appropriate corrective action.
- p. MSC and KSC will take action to arrange for a joint review of the classes of problems found during checkout of each particular spacecraft after it has flown and discuss corrective action that can be taken to reduce the same type of problem on subsequent spacecraft.
- q. MSC is taking action to assure closer control over the listing of engineering orders in the Configuration Verification Records of the appropriate spacecraft in accordance with the effectivity point in the EO.
- r. MSC and KSC will have a meeting the week of February 13 and formally coordinate the Block II CSM, the LEM and the integrated Ground Operation Requirements Plans (GORP). Any unresolved problems will be presented to the KSC Program Manager and the MSC Program Manager for decision or submission to higher management levels for resolution. KSC will formally sign the basic GORP documents and approve all subsequent changes in writing. Coordination and sign-off on the GORP will be binding on both parties. Additional testing of the type specified in the GORP will not be added at

the Cape without formal coordination. Changes recommended by either party will be officially submitted to the other party for approval. Contractual direction to the contractors will not be provided by CCA until coordination has been accomplished. As a part of the meeting during the week of February 13, MSC and KSC will develop a written change procedure to permit expeditious revision of the GORP. During this meeting consideration will also be given to reviewing a proposed system for controlling operational checkout procedures (OCP's) including the necessary interface with engineering orders.

- s. MSC (Mr. Kapryan) and KSC (Mr. McCoy and Mr. W. Williams) will develop a proposed procedure for integrating into a single Board the present MSC Configuration Control Board at the Cape and the KSC Spacecraft Change Implementation Board. This proposal will include membership, responsibilities, appeal procedures, documentation, signatures, and other appropriate items. This proposal will be prepared for coordination and approval of the KSC Program Manager and the MSC Program Manager. After completion of FRT approval to remove or replace spacecraft flight hardware (components, panels, cables, etc.) will require approval of appropriate KSC and MSC personnel. KSC will develop written procedures to implement this basic policy, and coordinate it with MSC (Mr. Kapryan).
- t. A discussion of the procedure for processing of failed hardware led to reconfirmation that MSC makes the decision as to where failure analysis is to be conducted.
- u. MSC will review the paperwork associated with the expeditious return of failed hardware to a vendor for repair and return to the Cape and make appropriate changes to facilitate the process.
- v. The return of ACE Station No. 5 from GAEC to the Cape will not take place before August 1, 1967. Therefore checkout at the Cape through the summer of 1967 will be limited to 4 ACE stations. KSC will review ACE program development verification, number and experience of maintenance personnel and other factors associated with utilization of their ACE equipment and will develop by March 1, 1967, any necessary recommendations to assure checkout schedule will support the OMSF official working schedule. MSC (Dr. Lanzkron) will provide necessary assistance in considering the use of MSC ACE equipment to assist in software development.
- w. The Apollo Program Office (OMSF) is developing revised schedules which will show a working schedule based on an earliest possible launch date and assuming clean hardware is delivered from the factory. These dates are to serve as objectives for everyone to work toward in an effort to launch as early as hardware will permit and still assure mission success. This schedule will receive further review and discussion during the time period February 8-10.

/S/ Samuel C. Phillips
Director, Apollo Program
OMSF

/S/ Joseph F. Shea
Manager, Apollo Spacecraft
Program Office, MSC

/S/ John G. Shinkle
Manager, Apollo Programs Office
KSC

/S/ Rocco A. Petrone
Director, Launch Operations
KSC

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SPACECRAFT CONFIGURATION

Altitude Chamber (K0034A) Versus Pad 34 Plugs Out (K0021)

ALTITUDE CHAMBER

Umbilical In
Carry-on Disconnected
Water/Glycol - Internal Circulation
H₂ Tank Pressurized with GN₂
Cryogenic O₂ Supplied by GSE
Water Tanks Filled
Inner Hatch Installed
Outer Hatch Not Installed
LV Simulator Attached
GSE Power Supplied Through S/C Umbilical
Boost Protective Cover Not Installed

PAD 34

Umbilical In
Carry-on Disconnected
Water-Glycol - Circulated Through Spacecraft From GSE
Gaseous O₂ Supplied by GSE
Water Tanks Empty
Inner Hatch Installed
Outer Hatch Installed
Mated to Booster
Fuel Cell Substitute Unit Utilized

GENERAL INFORMATION (ALTITUDE CHAMBER RUN)

During the altitude chamber run, the spacecraft was powered up and all systems verified prior to crew ingress. After crew ingress, suit integrity tests are made and the inner hatch is closed.

The following functions were performed in the listed order after inner hatch closure:

- a. Cabin purge and leak check.
- b. Sleep switches installed in cobra cables (not applicable to plugs out, pad 34).
- c. Post ingress switch list performed.
- d. Logic and pyro busses armed.
- e. VHF FM, C-band transponder and S-band checked.
- f. Coolant temperature lowered to 45 ± 5 degrees F and the water glycol trimmed.
- g. Gas chromatograph signal checked.
- h. Battery bus ties placed from off to auto.
- i. Battery relay bus, battery A and B, circuit breakers closed.
- g. Guidance system put in gyro compassing mode.
- k. The spacecraft was taken up to altitude. All testing and mission functions from here on were performed under altitude conditions (cabin pressure 5.71 psia, suit pressure 6.14 psia).

This points out that during the altitude runs, minimum testing is accomplished at sea level pressures. Whereas during the pad operation all testing is accomplished at sea level pressure.

The following list itemizes system tests performed on K0034 and K0021 prior to hatch closure:

G&N	K0034	K0021
AGC Operational Test	X	X
DSKY Pushbutton Check	X	X
Uplink/Downlink Check	X	X
Bank Sum Check	X	
C-Relay Alarm Checks	X	X
G/N Operations Test	X	X
Optics Power-on Test	X	X
GMC C/Lock Alignment	X	X
Negative Delta T	X	
SCS		
SCS Activate	X	X
BMAG Warm-up	X	X
RF		
RF System VHF/FM Test	X	X
C-Band Test	X	X
Recovery Beacon	X	
VHF/AM Test	X	X
HF Test	X	
S-Band and TV	X	X
UDL/UHF	X	
UDI		
End-to-end	X	
INSTRUMENTATION		
DSE	X	X
Flight Qual Recorder	X	X
ECS		
(See General ECS Configuration)		

The following list itemizes system tests and general configuration deltas between K0034 and K0021 after hatch closure and prior to lift-off for mission run. Coded (a) designates test is performed at altitude.

	K0034	K0021
Cabin Purge and Leak Test	X	X
Auto Water Boiling	X(a)	
SPS Abort and Reset	X(a)	
EDS Test		X
Normal Mission Preps	X(a)	X
Sleep Switches Installed in Umbilicals	X	
SPS Engine Gimbaled (MTVC)		X
RCS Static Firing		X
Floodlights On		X
FCSM SCS in SCS Mode		X
FCSM G&N Mode	X	
RCS Prop Isolation Circuit Breakers Closed		X
TVC Power 1 and 2 On	X	
Direct RCS On	X	
SCS Channel A/C Mode	X	
2 Engine Out in Auto Mode	X	

LV Rates in Auto mode	X	
Water Accumulator in Auto Mode	X(a)	X
Non-Essential Telecon on AC 1	X	
Non-Essential Telecon on AC 2		X
Cryogenic Quantity Amplifiers On	X	
Drinking Water Supply On	X	
Gas Chromatograph Panel On	X	
(Not Installed for K0021)		
Battery C to Main Bus A - Open	X	
Battery C to Main Bus B - Open	X	
Battery Vent in Vent	X	X
O ₂ Heaters in Auto	X	
H ₂ Fans in Auto	X	

ECS PREPARATION PROCEDURE AND SYSTEM TEST

Comparison of ECS configuration in the manned altitude chamber run OCP K0034 and L/C 34 OCP K0021 Plugs Out Test.

	K0034	K0021
GSE WATER GLYCOL ADJUSTMENTS		
ECS Prep (GSE)	X	X
Trim Unit No. 1 and 2 Verification (GSE)		X
Refrigeration Unit 1 and 2 Verification (GSE)		X
Adjust R1 on S14-140 (GSE)	X	X
Transfer Trim and Refr Units to ACE control		X
Transfer accum. quantity to remote (GSE)		X
Transfer Trim and Refr units to manual (GSE)		X
S/C SYSTEM VERIFICATION		
Cabin Air Fan Checks	X	X
Suit Compressor Checks	X	X
ECS Pump Check	X	X
ECS Coolant Loop Check	X	X
Pressurize H2 Tanks with N2	X	
Cabin Temp Control Checks	X	
Glycol Pump Deadhead Check	X	
O2 Tank Purge	X	
Suit Circuit Purge 98% O2 (Note 1)	X	X
Cabin Press Using S14-079 at Hatch Adap	X	X
O2 Press Relief Valve Crack Press	X	X
O2 Press Relief Valve Reseat Press	X	X
O2 Purge 20 Min at 14.7 psia	X	X
O2 Purity (Note 3) % in Cabin	X	X
Increase O2 Pressure to (Note 2) Press and Perform Leak Check	X	X
Install Hatch Plug	X	X
Install Outer Hatch		X
ECS CONFIGURATION PRIOR TO LIFT OFF		
ECS Radiators On	X	X
Battery Vent	X	X
Glycol Compressor Pump 1 on AC	X	X
Cabin Air Fans On	X	X
Suit Compressor Pump 1 on AC 1	X	X
Gas Chromatograph Cabin Auto	X	
Gas Chromatograph Start	X	
Waste Tank Inlet Auto	X	X
Potable Tank Inlet Open	X	X
Press Relief Both	X	X
Waste Tank Servicing Valve Closed	X	X
Cabin Repress Closed	X	X
Direct O2 Flow Reg Off	X	X
Pot H2O Heater Off	X	X

Cabin Temp Auto (R4) Full Decrease	X	X
Cabin Temp (S12) Manual	X	X
Steam Press (S23) Auto		X
Steam Press (S24) Incr/Decr Enter (OFF)	X	X
Temp in (S25) Manual (Note 4)	Auto	X
Glycol Evap H2O Flow (S22) OFF (Note 5)	X	X
H2O Ind (S10) Potable	X	X
Suit Evap (S8) Manual	X	X
Waste H2O Tank Refill (S36) OFF	X	X
H2O Accum (S26) Auto 1	X	X
H2O Accum (S22) OFF (CTR)	X	X
H2 Fans OFF	Auto	X
O2 Fans OFF	X	X
O2 Heaters OFF	Auto	X
O2 Pressure Ind Surge Tank (S28)	X	X
H2 Heaters OFF	X	X
Suit Ht Exch Gly Evap	Note 6	X
Demand Reg Selector 1 and 2	Note 6	X
Demand Reg (Suit Test) OFF	X	X
Oxygen Surge Tank ON	X	X
O2 S/M Supply ON	X	X
O2 Entry ON	X	X
Glycol Reservoir Inlet Open	X	X
Water and Glycol Tank Press Regulator and Relief Normal	X	X
Glycol Reservoir Bypass Close	X	X
Glycol Reservoir Outlet Open	X	X
Glycol to Rad Open	X	X
Safety Latch OFF	X	X
Cabin Press Relief Right (Boost Entry)	X	X
Emergency Cabin Pressure OFF	X	X
PLSS Fill Valve Closed	X	X
O2 Main Regulator Normal	X	X
Suit Evap OFF	X	X
Evap H2O Auto	X	
Glycol Reserve OFF	X	X
H2O Accumulator 1 and 2 Remote	X	X
Glycol Evap Temp in Full Cool	X	X
Suit Flow Relief OFF	X	X
Suit Evap Glycol ON	X	X
Glycol Accumulator ON	X	X
Glycol Evap H2O Control Bypass OFF	X	Bypass
Suit Circuit Return Air Manual Valve Close	X	X
Surge Tank Press Relief Valve Auto	X	X
Glycol Press Bypass 1 and 2 ON	X	X
Louvers Cabin Open	X	
Drinking Water Supply ON	X	No Info
Cabin Temp As Is Battery Vent	X	No Info

- NOTES: 1. Suit loop purge is performed twice prior to crew ingress in 0034.
2. 3-3.5 PSIG OCT 0021 and 5±.2 PSIG in OCP 0034.
3. 75% O2 purity required OCP 0034 and 95% O2 purity required OCP 0021 prior to crew ingress.
4. Difference is at 180 K altitude performing water boiling.
5. On for 3 minutes and then off in OCP K0034.
6. Removed by deviation 13-01 to update OCP to latest SW list configuration.

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LIST OF REFERENCES

Reference documents used in the preparation of this report are as follows:

References

- 7-1 Spacecraft Operational Checkout Procedure FO-K-0021 - S/C 012-014, updated Jan. 25, 1967. Titled: "Space Vehicle Plugs Out Integrated Test", dtd Dec. 13, 1966
- 7-2 GSE Checklist FO-K-10011-S/C 012. Titled: "LC-34 Checklist", dtd Oct. 25, 1966
- 7-3 Crew Countdown FO-K-5117-S/C 012. Titled: "Flight Crew Countdown", dtd Jan. 26, 1967
- 7-4 Vehicle Plan for Spacecraft 012 & 011 Section II, Part I. Ground operations Requirements Plan (NAS 9-150), SID65-304-2-1, dtd June 19, 1966
- 7-5 Process Specification MA 0201-3214, Titled: "Overall Test No. 2 with Plugs Out Checkout Requirements for Spacecraft 012 & 011, Florida Facility, Launch Complex 34", dtd August 19, 1966
- 7-6 Spacecraft Operational Checkout Procedure FO-K-0034-A-1, Titled: "CSM Altitude Chamber Test", dtd Dec. 20, 1966
- 7-7 Apollo Pre-Flight Operations Procedure T-501, Pages 4 & 5. Titled: "Work Authorization - TPS", dtd June 27, 1966
- 7-8 Apollo Pre-Flight Operations Procedure O-202, Titled: "Operational Checkout Procedure", dtd May 13, 1966.
- 7-9 Interim Discrepancy Report (IDR) No. 001 for OCP-K-0021, dtd Jan. 27, 1967
- 7-10 Daily Status Reports, Titled: "Status Report Spacecraft 012", dtd Jan. 23, 1967 and Jan. 27, 1967
- 7-11 S/C 012 Test Outline, SP-64. Titled: "S/C 012 - S/C 014 Florida Facility Test Flow Plan", dtd Aug. 10, 1966
- 7-12 Space Vehicle Plugs Out Procedure, I-20015-SA 204, Titled: "Space Vehicle Systems Plug Drop Test", dtd Jan. 18, 1967
- 7-13 Apollo Crew Abbreviated Checklist Mission AS-204, dtd Jan. 23, 1967
- 7-14 KSC Prelaunch Test and Checkout Requirements for S-IV-206 and Subsequent, NAS 8-14000, dtd Dec. 5, 1966
- 7-15 Prelaunch Test and Checkout Requirements for Saturn S-IB Stages, SDES-66-424, dtd Aug. 12, 1966
- 7-16 Catalog of Launch Vehicle Tests, Saturn V, Apollo/Saturn 501, Section III of III Sections, Standby Procedures, GP-307, dtd Jan. 15, 1967
- 7-17 Catalog of Launch Vehicle Tests, Saturn V, Apollo/Saturn 501, Section I of III Sections, Test Procedures, dtd Jan. 15, 1967
- 7-18 Apollo/Saturn V Checkout Plan (AS-500F), K-V-041, dtd May 1, 1966
- 7-19 Test Specification and Criteria, KSC Prelaunch Checkout and Launch Operations, S-IVB-206, 1B67207, dtd Dec. 8, 1966
- 7-20 S-IVB-502 Stage End Item Test Plan, 1B63789, dtd Nov. 18, 1965
- 7-21 KSC Prelaunch Test and Checkout Requirements, S-IVB-1B, 1B66258, dtd May 24, 1966
- 7-22 Annotated Copy OCP FO-K-0021-1
- 7-23 EDS Overall Countdown Test, FO-K-0042
- 7-24 Spacecraft Launch Preparation Test Outlines, Report No. 9882, McDonnell Aircraft Corp., SEDR 9882, dtd Dec. 14, 1964
- 7-25 Gemini Spacecraft Number 12 Performance, Configuration Specification, A900-12, dtd July 30, 1965
- 7-26 Project Gemini, Production Spacecraft Test Plan for Spacecraft Number 2, SEDR 301-2, dtd Feb. 25, 1964
- 7-27 Test/Operations Production Spacecraft at AMR Facility, SEDR 309-1, dtd July 26, 1963
- 7-28 Project Gemini Test Operations Production Spacecraft at AMR Facility, SEDR 309-X, dtd Aug. 30, 1963
- 7-29 Titan III Test Procedure Manual, MC-66-2, dtd Feb. 1, 1966

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**REPORT OF PANEL 8
MATERIALS REVIEW
APPENDIX D-8
TO
FINAL REPORT OF
APOLLO 204 REVIEW BOARD**

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A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Materials Work Panel, 8. The task assigned for accomplishment by Panel 8 was prescribed as follows:

Assemble and summarize data and analyses related to flammability of spacecraft materials. Results of other programs as well as Apollo shall be considered. Requirements for additional testing shall be recommended. Review Apollo test conditions for adequacy. Make recommendations for materials or configuration changes to alleviate fire hazard. Perform analyses as appropriate to determine overall energy balance, correlations with temperature and pressure buildup, etc.

In addition to the above briefly summarized Work Statement, a detailed Work Statement was prepared and submitted to the Board on February 1, 1967, which contained the following salient features in keeping with above Work Statement:

1. Assemble, summarize, compare and interpret requirements and data describing the flammability of nonmetallic materials exposed to the crew bay environment of the spacecraft and in related applications.
2. Specify and authorize performance of tests and/or analyses to furnish additional information as to flammability characteristics of these materials alone, and in combination with fluids known or postulated to have been in the Spacecraft 012 cabin.
3. This panel, in support of Panel 5 - Origin and Propagation of Fire shall interpret and implement the requirements for analyses of debris removed from the spacecraft.

B. PANEL ORGANIZATION

1. MEMBERSHIP

The assigned task was accomplished by the following members of the Materials Work Panel:

- Mr. W. Bland, Chairman, Manned Spacecraft Center (MSC), NASA
- Mr. A. Busch, Kennedy Space Center (KSC), NASA
- Dr. A. Staklis, Manned Spacecraft Center (MSC), NASA
- Mr. W. Riehl, Marshall Space Flight Center (MSFC), NASA
- Mr. A. Archer, North American Aviation, Inc., KSC
- Mr. R. Olsen, North American Aviation, Inc., Downey
- Mr. E. Welhart, McDonnell Company, St. Louis

2. COGNIZANT BOARD MEMBER

Dr. M. Faget, Manned Spacecraft Center (MSC), NASA, was assigned to monitor the Materials Work Panel.

C. PROCEEDINGS

1. APPROACH

The activities of the Materials Panel were divided into three major categories in implementing the panel work statement (Ref. 8-74, 8-75, and 8-76):

- a. Determine the nonmetallic materials configuration of Spacecraft (S/C) 012.
- b. Determine combustion characteristics and properties of these materials.
- c. Conduct special tests and investigations.

The special tests and investigations conducted are separated into four broad areas:

- a. Fire Initiation
- b. Fire Propagation
- c. Materials Criteria and Controls
- d. Displays and Information

Within the fire initiation investigation, several studies were undertaken. These dealt with potential spark ignition sources, spontaneous ignition sources, and impact ignition sources.

The fire propagation investigation was divided into six subcategories. These included the usage and properties of flammable materials on S/C 012 and a theoretical analysis of materials combustion. Temperature mapping of S/C 012, the flammability of water/glycol, simulated mockup testing of materials configurations similar to S/C 012 and an evaluation of substitute materials for flammability were also included.

The criteria and controls investigation was directed to an evaluation of existing acceptance criteria for spacecraft nonmetallic materials located in the crew bay and to a determination of the effectiveness of controls of materials usage in design and fabrication.

The displays and information activity was directed to a determination of methods for presenting materials location and usage information, alternate nonflammable materials and materials properties and characteristics in graphical and usable form.

Status of the Materials Panel investigation program and special displays were maintained at KSC for use by Materials Panel Members and supporting personnel and by other Apollo 204 Review Board activities.

2. SCOPE OF THE REPORT

The scope of this report includes the following major categories of investigations:

- a. Configuration of nonmetallic materials, including changes, in S/C 012.
- b. Results of routine materials tests to determine combustion properties.

3. DETAILED TASK PROCEDURES

The following sections present technical results of Materials Panel investigations. The presentations include the objectives of the study, methods utilized and details of the results. The proceedings presented in this report are in general abstracted from more detailed reports referenced in Section E, Supporting Data.

4. NONMETALLIC MATERIALS CONFIGURATION OF S/C 012 COMMAND MODULE

a. OBJECTIVE

The nonmetallic materials configuration of S/C 012 was an essential element to evaluate materials combustibility data, potential ignition sources, propagation paths and intensity. A review of existing documentation was undertaken to develop a list of S/C 012 materials and test data.

b. APPROACH

A format containing required data was prepared. Data covering as-designed materials configuration, as-installed materials configuration from Discrepancy Report Squawks (DRS's) and Test Preparation Sheets (TPS's) and test data were included in compiling the S/C 012 nonmetallic materials list.

c. DATA FORMAT

The format is divided into four major sections: material description, location in the S/C, test information and quantity of material used. A sample data page is provided in Enclosure 8-2, Section E.

d. SOURCES OF DATA

- (1) Design configuration data. Supporting References 8-1 through 8-13 were utilized.
- (2) Test data. Supporting data References 8-14 through 8-27 were utilized. In addition, data available from the activities described in 5., "Routine Materials Tests", were added as they became available. Test data at oxygen (O₂) pressures to 21 psia covering the major combustible materials which contributed to the fire were available (Reference 8-91).
- (3) Test conditions for existing data are shown in Table 1.
- (4) Configuration changes. Documentation covering materials added to S/C 012 at KSC was reviewed. The documents reviewed included Discrepancy Reports (DR's), DRS's, and TPS's. The nonmetallic materials were identified and the amount used was noted. Photographs of the S/C as received at KSC and photographs of the S/C shortly before the fire were also reviewed for materials location and quantity.

(5) The crew bay materials usage lists of all contractors and suppliers were assembled into a master usage list. This list contains all of the materials that could have been used on S/C 012 but is not an as-built configuration list. This means that some of the materials on the list may not have been used and others may appear more than once. (Reference 8-28). See Enclosures 8-11 to 8-17 for location.

TABLE 1. SOURCE AND TEST CONDITIONS FOR EXISTING MATERIALS DATA

Note: All vertical tests are downward.

Source	Test	O ₂ Pressure (psia)	Number of Tests
Collins (5-64)	Flash	15	61
	Fire	15	
	Autogenous Ignition	15	
Mass. Inst. of Tech. (1-67)	Flash	5	31
	Fire	5	
	Combustion Rate (Vertical)	5	
Hamilton Standard	Flash	5	200
	Fire	5	
	Autogenous Ignition	5	
	Combustion Rate (Horizontal)	5	
NAA (Hughes) (to 1-67)	Spark Ignition to 400°F	15	102
NASA (to 12-66)	Combustion Rate (Vertical)	5	112
Brooks	Combustion Rate (Vertical) (Horizontal)	5	66
Grumman	Autogenous Ignition	5	48
	Combustion Rate (Horizontal)	5	

e. MATERIALS USAGE SUMMARY

A summary of the nonmetallic materials used or suspected of being used in the Command Module (C/M) of S/C 012 is presented in Table 2 (Ref. 8-28).

TABLE 2. MATERIALS USAGE SUMMARY

Generic Type	Products Identified
Solvents	18
Lubricants	86
Foams	82
Thermal Insulations	7
Fabrics	395
Tapes	123
Encapsulants	164
Electrical Insulations	185
Plastics	394
Elastomers/Rubbers	238
Paints and Coatings	222
Laminates	78
Adhesives	322
Glass	39
Command Module, Coolant	1
Miscellaneous	174
Total	2,528

f. MATERIALS ADDED AT KSC

Of the listing in Table 2, the following materials shown in Table 3 were added at KSC. (Ref. 8-55 and 8-64).

TABLE 3. MATERIALS USED IN THE C/M AFTER DELIVERY

Material Category	Number of Material Types	Quantities (Approximation)
Adhesives	9	32 ounces
Lubricants	8	10 ounces
Paint and Coatings	6	9 ounces
Encapsulants	6	12 ounces
Tapes	13	80 square inches
Solvents	4	Unknown
Miscellaneous	29	Several instances of large quantities, Ex: 960 in ³ polyurethane foam, 7 lb. Velcro, etc.

The complete documentation of all DR's, DRS's, TPS's used in preparing this compilation are available and were bound into volumes by categories.

g. ESTIMATED TOTAL QUANTITIES OF MATERIALS

In addition to the document review a determination was made of the appropriate mass of major combustible materials which were directly exposed to the cabin environment (not in closed boxes or stowage compartments) in S/C 012 at the time of the accident (Ref. 8-57, 8-64) see Table 4.

TABLE C-4, ESTIMATED QUANTITIES OF MAJOR COMBUSTIBLES EXPOSED TO CABIN ENVIRONMENT ON S/C 012 AT THE TIME OF PLUGS OUT TEST

Material	Function	Total Weight (lbs)	Portion Installed at KSC (lbs)	Portion which was non-flight (lbs)
NON - GFE MATERIALS				
Velcro Pile	Zero-G attachment mechanism	3.9	1.1	
Velcro Hook	Zero-G attachment mechanism	5.9	4.5	
Uralane 577	ECU Insulation Pads on floor	5.2	2.4	2.4
Trilock	Couch Pads	2.7		
Green Nylon	Covering for O ₂ suit hoses	0.2		
Raschel Knit (nylon)	Debris Net	2.4	1.3	
Cotton Cloth	Remove-before-flight tags	0.5	0.5	0.5
Plexiglas	Display panels	1.8		
	Flood lamp covers			
Nylon Webbing	Tie-down straps	3.9		
	Couches			
	Storage Compartments			
Nylon oxford cloth	GSE Window covers	1.0	1.0	1.0
Nylon cord	Electrical cable tie wrap	9.1		
Nylon tape	Crew provisions equipment	5.7		
	Binding for debris nets			
Paper (non-flight)	OCP, Note paper	6.9	6.9	6.9
Paper (flight)	Flight/Preflight checklists	1.0	1.0	
Velostat	Covering for Uralane floor pads	0.1	0.1	0.1
Silicone foam	ECS Line insulation	5.0		
GFE MATERIALS				
Cotton cloth	Garments	4.3		
Lexan	Visors	3.0		
Nomex fabric	Garments	6.4		
Nylon Oxford	Garments	3.5		
TOTAL		72.5	18.8	10.9

Displays have been prepared showing the location of Velcro, Uralane Foam, Raschel Knit and Space Suits used in S/C 012 and their location (See enclosures 8-11 to 8-17).

h. Nonmetallic Materials Status

A review of the acceptability and test status of materials identified on this list to the NAA MC999-0058 criteria was accomplished. The approved and waiver status of materials in Government Furnished Equipment (GFE) to MSC-A-D-66-3 (Ref. 8-85), was also determined. The results are reported in a subsequent section on Criteria and Controls.

i. SUMMARY

The nonmetallic (potentially combustible) materials configuration for the major elements of the as-designed configuration of S/C 012 and for the modifications actually installed at KSC was obtained (Ref. 8-28). Results have been tabulated in a standard format and reviewed for status. Tests have been initiated where data were not available. (See Paragraph 9). The precise nonmetallic materials configuration of S/C 012 was not obtained. There is some uncertainty about the materials used in the black boxes and materials applied during assembly at Downey.

5. ROUTINE MATERIALS TESTS

a. OBJECTIVE

As the compilation of data described in Section 4, "Nonmetallic Materials Configuration of S/C 012 Command Module" proceeded it became evident that test data were not available on the majority of materials used. A routine testing program was implemented to develop test data on some of these materials at one atmosphere or 16.5 psia oxygen (Ref. 8-31).

b. PROCEDURE

Procedures for testing were prepared and accuracies determined using Nomex cloth as a standard (Ref. 8-80). The following procedures were prepared:

- Nonmetallic Materials Combustion (Propagation) Rate Test
- Autogenous Fire Point Determination
- Flash and Fire Point Determination of Nonmetallic Material
- Combined Thermogravimetric Analysis and Spark Ignition Test
- Electrical Wire Insulation and Accessory Spark Ignition Test
- Electrical Wire Insulation and Accessory Flammability Test

c. STATUS OF MATERIALS TESTING AS OF MARCH 8, 1967
(Ref. 8-80 and 8-98)

- 2,527 Materials identified and tabulated
- 665 Materials determined to require testing
- 474 Materials orders
- 446 Materials shipped by supplier
- 429 Materials received at MSC
- 280 Tests in progress
- 245 Tests completed

d. REPORTS

Additional test results applicable to this Section of the report will be contained in Appendix G. Test data are logged in to the Materials List (Ref. 8-28) as they are reported.

e. RESULTS

Results obtained on several samples of materials used in large quantities in S/C 012 are listed in Table 5. Prior test data at 5.0 psia oxygen are also shown for comparison (ref. 8-33 and 8-91).

TABLE 5

Average Downward Flame Propagation Rates (In/Sec)			
Material	Oxygen Pressure		Ratio of Burning Rates
	5.0 psia	16.5 psia	
Raschel Knit (Blue)	0.4	1.0	2.5:1
Velcro Hook (Blue)	0.5	0.8	1.7:1
Velcro Pile (Blue)	1.4	2.5	1.8:1
Trilock	1.1	1.8	1.7:1
Polyurethane Foam	2.1	4.5	2.2:1

As stated, the above data are downward rates, i.e., the slowest rate possible at 1 g in 16.5 psia oxygen pressure. Upward rates are much higher. The average overall rate for materials as installed in S/C 012 will be much greater than those shown above.

f. SUMMARY

The materials which probably contributed heavily to the fire burned at least twice as fast at the accident conditions (16.5 psia) than that at which they were evaluated for space flight (5 psia).

6. SPECIAL INVESTIGATIONS AND TESTS - FIRE INITIATION

Early tests were primarily concerned with materials (solvents and liquids) that might ignite with electrostatic sparks or with low energy arcs.

The extremely low energy reported to ignite solvents and gases in 15 psia of oxygen prompted a search for possible presence of solvents in the spacecraft especially as they might be absorbed on flammable solids thereby sensitizing them to ignition and promoting propagation. The approximate spark ignition thresholds of flammable solids with and without absorbed solvents and glycol coolants were evaluated in laboratory tests. The electrostatic charging of materials and the space suit were studied. Arcing of audio circuit connectors in various concentrations of a solvent in 16.5 psia oxygen atmosphere were also tested.

Impact ignition in gaseous 16.5 psia oxygen was suggested from liquid oxygen experience and is being tested.

Water/glycol spillage and cleanup simulations on wire bundles and connectors are in progress to study corrosion-induced short circuits and electrical heating or arc ignitions.

Spontaneous ignition was also evaluated as a potential source mechanism (Ref. 8-33).

a. RETENTION OF SOLVENTS

OBJECTIVE

Investigate the contribution towards the fire of any solvent absorbed by the more widespread non-metallic materials in the cabin by evaluating solvent evaporation data and analysis.

PROCEDURE 1

Air-dried samples were weighed, saturated with liquid solvent, and allowed to air-dry until essentially free of solvent while being weighed.

RESULTS 1

Velcro hook samples soaked in methyl-ethyl-ketone (MEK) for ten minutes absorbed 3.2×10^{-5} lb in² of solvent. When evaporated into 50-percent relative humidity 75°F room air, they retained as much as 40-percent of the solvent for 5 hours (Ref. 8-103).

PROCEDURE 2

Tests with samples of Velcro pile, Uralane, Velostat covered Uralane, and couch material saturated with MEK for approximately ½ minute, air-dried for either 15 minutes or for 1 hour and then covered so that evaporation from the material had to take place by diffusion under the edge of an inverted 20 cc conical cover were conducted as described in Ref. 8-41. These tests were designed to determine the likelihood of vapor entrapment by equipment placed on saturated materials.

RESULTS 2

Diffusion of MEK and air under the edge took place rapidly. Vapor concentration fell below the 1.9-percent lean limit of flammability in less than 1 1/2 hours (Ref. 8-103). However, the results would be modified (1) if the edges of the material were sealed, (2) if the materials were not allowed to dry or (3) if the ratio of edge area to volume were very small. In these cases evaporation would be reduced and trapped pockets and/or heavy film layers of flammable mixture solvent vapors could have existed at the time of the fire.

SUMMARY

Velcro hook material can become saturated (after 10 minutes) with small amounts of MEK (3.2×10^{-5} lb/in²). When exposed to a 50-percent relative humidity, 75°F environment the solvent retention in the sample decreases after 5 hours to 40-percent of the total amount absorbed.

Combustible concentrations of MEK solvent were not released into air from wetted Velcro pile, Uralane foam and couch material except for a short 1 1/2 hour period under conditions which restricted diffusion of vapor and air through the material to an area under the edge of the covering object.

The presence of significant volumes of concentrated solvent vapor in the spacecraft is unlikely. However, the retention of solvents in the surface layers of solid flammable materials could possibly contribute to their ignition (Ref. 8-103).

b. MATERIALS ODOR EVALUATION

OBJECTIVE

Odors resembling "sour milk" and MEK (see Materials Time Line, Enclosure 8-8) were reported. The objective of this analysis was to identify potential sources of these odors.

RESULTS

The evaluation of the "sour milk" odor involved the review of the K-bottle O₂ analyses, the Beckman Analyzer analyses, a gas sample taken at the crew mouthpiece and earlier sample analyses from August 29, 1966 to January 23, 1967. The review of the K-bottle analyses revealed no unusual impurities and the gas analyses met specifications as required. The analysis of gas from the two Beckman Oxygen Analyzers revealed no significant information on "sour milk" odor.

The gas sample taken at the crew mouthpiece on January 27, 1967 revealed approximately 400 ppm of unidentified hydrocarbons which could contribute to an odor condition (lab report Number TS75381 indicated odor to be of human origin).

A summary of previous analyses including earlier manned altitude testing samples revealed no significant information to identify any "sour milk" odor.

Re-Interrogation of witnesses revealed the following:

(1) There were no reports to the contrary that "only very minor amounts of solvent were introduced to the cabin on January 27, 1967" and these were by way of slightly dampened, wiping materials. No "spillage" or "dripping" of solvents was recalled.

(2) There was agreement that no one smelled anything of significance in the cabin during hatch closeout activity.

(3) There was general agreement that the strongest odors were detected at initiation of the first (20 minutes) cabin purge operations, approximately 3:32 pm EST, and decreased toward a "slightly detectable" level at completion of the second (10 minute) cabin purge operation approximately 4:18 pm EST. The odor was detected both within the white room and outside on Level A-8. There is also evidence which tends to indicate that this odor was emitting from the steam duct just below the lower edge of the cabin hatch. An on-site review revealed that the configuration could allow some of the flow of gas from the steam duct to be deflected up into the white room and some of it could also be deflected downward into the general area of Level A-8. The other emission points of this odor were at the gas analyzer inlet bleed port and at the analyzer squeeze bulb exhaust port. Odors were detected at these points during environmental sample extraction.

(4) Description of the odor by the persons interrogated was that it was (1) MEK, (2) smelled "like" MEK, or (3) smelled like a solvent.

It appears that a fair degree of uncertainty is associated with identification of odors. Data indicate that the first threshold of smell for solvents such as MEK and isopropyl alcohol is approximately 0.01 percent to 0.03 percent by volume. The concentration that might be described as strong, irritating, and/or sickening is in the range of 1 percent to 4 percent by volume.

Samples of gas taken from the Ground Support Equipment (GSE) prior to the accident and also from the reassembled GSE system at the site provided negative results on significant hydrocarbon content. Solvents initially in the GSE would have been purged dry in the process of cabin purging. There is no reason to expect that further investigation will uncover a proof of solvents introduced by the GSE system.

SUMMARY

No particular suspect item was identified as emitting a "sour milk" odor although some of the Room Temperature Vulcanizing (RTV) potting compounds have distinct, pungent odors that probably come closest to fitting this odor description.

It is possible that accumulated solvent vapors could have been expelled through the steam duct during cabin purge.

Since the Command Pilot opened his faceplate for approximately 4 minutes at 6:19 pm EST and did not report significant odor concentrations it is likely that there were no solvent mixture concentrations in open areas (areas where the cabin fan produced reasonable flow). It should be noted that outward flow from the faceplate opening does not preclude cabin odor detection.

There is no evidence that significant concentrations of organic vapors existed in the spacecraft at the time of the accident (Ref. 8-54).

c. ELECTROSTATIC SPARK IGNITION

OBJECTIVE

The objective was to investigate the possibility of generation of sufficient electrostatic energy by movement of a suited astronaut to ignite combustible fuel-oxygen mixtures and materials of the type found in the S/C. Solid materials with remnant solvent had to be evaluated to determine required energy for ignition (Ref. 8-29).

PROCEDURES AND RESULTS

(1) Nylon fabrics, Raschel knits, polyethylene and neoprene were tested by rubbing with nylon. Only the nylon materials had appreciable charges generated on them at 50 percent relative humidity. Those that did not develop charges at 50 percent were tried again at 8 percent relative humidity and found to be still without appreciable charge (Ref. 8-32).

(2) In the laboratory a suit on a subject was charged by rubbing with nylon. He sat and then reclined on a linoleum covered metal table used to simulate spacecraft couches. Volt-

ages and energies induced were somewhat higher than the values later obtained in the spacecraft itself.

Capacity measurements were made using a 60 cps capacitance bridge and a radio frequency capacity meter. For the reclining subject they ranged from 500 to 600 picofarads. For the metal parts of the suit an increase over the theoretical values is explainable by coupled capacity of other objects such as the suit neoprene bladder and other metal parts.

TABLE 6

Maximum Voltages Induced and Energies Calculated		
Item	Potential, KV	Energy, Millijoules (mj)
Neck ring	2.1	1.36
Exhaust fitting	2.2	0.15
Inlet fitting	2.2	0.15
Zipper	1.7	0.56
Wrist ring	1.9	1.1
Subject and EKG lead	3.3	3.75

Resistances to ground which were measured at 10^9 to 10^{11} ohms would result in some loss of electrostatic energy during the process of measurement.

(3) A suited subject in C/M 014 at 8 percent relative humidity showed it was possible to obtain comparable capacitances to ground as in the laboratory. The subject's motion on the couch resulted in the generation of one (1) KV (Ref. 8-104 and 8-105).

(4) Capacitance spark tests showed that certain materials are ignitable by spark energies as follows (Ref. 8-79):

Material	Dry	Damp
Uralane foam	190 mj	40 mj (MEK and isopropyl alcohol)
Cotton (constant wear garment)	▪	210 mj (dampened with face oil)
Velcro	▪	200 mj (ethylene glycol)
▪ No ignition up to 300 mj		

SUMMARY

Sufficient electrostatic energy (about 4 mj) can be stored on a suited astronaut to ignite MEK vapor and methane in 14.7 psia O₂ (0.002 to 0.004 mj required) (Ref. 8-42). Samples of suit and other spacecraft materials were not ignited by this energy level even when soaked in combustible fluids which were then allowed to evaporate for about 5 hours in a laboratory environment before being subjected to the spark test.

d. COBRA CABLE SPARK IGNITION TEST

OBJECTIVE

Reports of Cobra Cable connect-disconnect actions immediately prior to the fire were received. A test was designed to investigate the possibility of igniting flammable MEK mixtures in high con-

centrations of gaseous oxygen. This was accomplished by breaking and mating spacecraft connectors with power applied. For the test, two cables were fabricated using spacecraft approved materials and spacecraft qualified Deutsch Connectors.

PROCEDURE

The test setup consisted of three power circuits routed through the Deutsch Connectors in the pressure chamber to loads outside the chamber. The loads were identical to the circuit loads used in C/M 012. The communications load was an identical impedance (600 ohms) to that of a pressure suit helmet headset. The biomedical load was a physio-simulator. The simulator has a DC-DC converter which is flight-qualified and identical to the three used by astronauts in S/C 012. The converter had an input impedance of 300 ohms when loaded.

The spacecraft microphone amplifiers were powered from a 28-volt DC battery through a series-dropping resistor. Therefore, the spacecraft power source did not present any significant inductance. The test power supplies did present some inductances, since no dropping resistor was used. This test, therefore, presents a more severe arcing condition than the spacecraft system which was simulated.

Three separate AC to DC rectifier/transformer power supplies were used, one for the right microphone 16.8 VDC, one for the left microphone 16.8 VDC and one for the biomedical converter 28.2 VDC (Ref. 8-48 and 8-49).

RESULTS

With the circuit previously described increasing concentrations of solvent were established in the pressure chamber. During the first test the chamber was filled with air at ambient conditions. In the ambient condition the Deutsch Connectors were separated three times under circuit load. During the connector breaks 200-frame-per-second 16 mm pictures were taken to record any sparks or ignition. No sparks or ignitions were noted either visually at the time or on the film.

The second test setup was run with 97-percent oxygen at ambient in the chamber. The oxygen concentration requirement was 96-percent or greater. Chemical analysis revealed the oxygen concentration to be greater than 97-percent. With power on the circuit the connectors were separated a minimum of two times. No sparks were generated with sufficient energy to ignite the connector.

Other tests were performed with MEK concentrations of 2.0-percent, 4.0-percent, 8.0-percent, and saturated (less than 15.4-percent with the remaining atmosphere having an oxygen concentration of greater than 97-percent). A minimum of three separations and remates were performed at each mixture level. No sparks were initiated with sufficient energy to ignite the mixtures.

Modification No. 1 reconfigured the circuitry so that the current was increased to 150 ma. This is 2.5 times maximum operating current which approximates the worse case. Namely, the maximum current drain encountered if the biomedical power were shorted in the spacesuit umbilical. The connectors were separated several times with 4.0-percent gaseous volume of MEK in the chamber. No sparks were generated of sufficient energy to ignite the mixture.

Modification No. 2 configured the circuitry so that single wired pins could be pulled at 60 ma, 28 VDC (normal operating conditions). The pins were pulled twice at MEK concentration of 4.0-percent and once at 15.0 percent. No sparks were generated with sufficient energy to ignite the mixture. No sparks were seen by an observer or recorded on the high speed film (Ref. 8-48 and 8-49).

SUMMARY

Separating simulated Cobra Cable audio and biomed 16-volt circuits produced neither visible arcs nor ignition. Separations of connections at maximum nominal power with MEK-saturated O₂

and at 2.5 times nominal power in MEK concentrations to 4 percent, all in 16.4 psia oxygen produced no ignition. Tests using flight type Cobra Cables with audio center loads and battery power supply will be reported in Appendix G.

e. IMPACT SENSITIVITY OF MATERIALS IN GOX

OBJECTIVE

It is known that many materials in contact with liquid oxygen (LOX) are capable of exploding or igniting when subjected to mechanical shock or some other sudden energy surge. Organic materials of the type used in S/C 012 such as netting, lubricants, foams and Velcro are examples of ignitable substances.

Whether such materials form impact-sensitive hazards in low-pressure gaseous oxygen was unknown. Thus it was decided to investigate the feasibility of this method of fire initiation in gaseous oxygen at 16.5 psia and with typical flammable materials in S/C 012.

RESULTS

A standard method of evaluating the compatibility of materials with LOX has been used by Marshall Space Flight Center. The test equipment is shown in Reference 8-30. The test equipment was modified to permit impact of materials in contact with gaseous oxygen at slightly above atmospheric pressures. This corresponds to spacecraft conditions. Impacts are applied by a 20 lb plummet falling 43 inches and delivered through a 1/4-in. diameter striker pin face (less than 72 foot-pound). The chamber was purged with sufficient oxygen to maintain a 5 psig differential for fifteen minutes then bled off to 16.7 psia prior to impact.

The following materials were tested under impact in contact with gaseous oxygen (GOX). Each was applied to a 1-inch diameter disc of aluminum for test purposes:

- Velcro Hook (pressure-sensitive adhesive backing)
- Velcro Pile (pressure-sensitive adhesive backing)
- Velcro Hook and Pile together (pressure-sensitive adhesive backing)
- Velcro Hook - Cross-cut grooves to expose adhesive
- Velcro Pile - Cross-cut grooves to expose adhesive
- Velcro Hook - Creased intentionally during application
- Velcro Pile - Creased intentionally during application
- Raschel Knit

Six Velcro hook samples were run. No fires resulted but in two of these burnt odors resulted. Three samples of Velcro pile on the hook were run. In these one burnt odor was detected and one sample ignited and burned vigorously. Of three samples of Raschel Knit impacted to date two ignited and burned (Ref. 8-30).

SUMMARY

These tests have shown that mechanical impacts on Velcro or Raschel Knit in contact with 16.5 psia O_2 can produce ignition and burning. A survey of spacecraft loose and movable objects revealed no possible high-impact condition on flammable materials.

f. AUTOGENOUS IGNITION SCREENING TEST OF S/C 012 MATERIALS

OBJECTIVE

Tests were undertaken to determine if combinations of solvents and materials could lead to unusually low spontaneous ignition temperatures in the oxygen atmospheres used in the S/C 012 test.

PROCEDURES

The tests were run in stainless steel pressure vessels equipped with a viewing port, thermocouple and a method of maintaining a 16.5 psi O_2 atmosphere together with a heat source. All samples were exposed to programmed heating, culminating at 400°F for ten minutes. They were then examined. Samples for gas chromatographic analysis were taken.

Materials which have a significant capacity for absorption of solvents such as foams and fabrics were tested in the as-received condition. This was done after soaking in methyl-ethyl-ketone, isopropyl alcohol, 50-50 ethylene glycol/water and in various combinations of these fluids. Samples were allowed to dry for approximately 5 hours prior to testing. Materials exposed to these tests were as follows:

Uralane Foam
Velostat
Velcro (various colors), Hook and Pile
Raschel Knit
Trilock

Materials tested without solvents were as follows: (Ref. 8-46 and 8-93)

Epon 828	Minn Hon 6745A Oil
Mystic Tape	Bray Oil Lube 812
DC 4 Lubricant	PR 240 AC Lubricant
Rayclad Sleeving	Versilube 300
EC 1469 Adhesive	DC 33 Lubricant
Aero Shell Grease	NOPCO Foam A 206
AiResearch Grease	3M, No. 27 Tape
DC 30-121	Nomex-HT-1 Suit Fabric
Epon 828 + Versamid	RTV 90 Encapsulant
115	RTV 577 Encapsulant
Stycast 1090	RTV 560 Encapsulant
Epon 934	Organoceram
EC 1469	

SUMMARY

No autogenous ignition of materials tested was detected at or below the 400°F test limit even samples treated with cleaning solvents.

g. EFFECT OF WATER/GLYCOL ON WIRE BUNDLES

OBJECTIVE

This task was undertaken to determine the effects of spacecraft cabin environment on electrical wire bundles of S/C 012 types which had been exposed to water/glycol at some previous time.

It has previously been observed that flammable aircraft wire insulation such as polyvinylchloride (PVC) and nylon may burst into sustained flames in air even though adequately protected with circuit breakers. This can occur provided the following conditions are present:

- (1) Insulation on adjacent wires is damaged to the conductors.
- (2) Sufficient moisture is present to bridge the damaged areas.
- (3) An electrical potential exists between the conductors of the damaged wires. (Ref. 8-38, 8-39 & 8-78).

These wet-wire fires were observed without tripping circuit protective devices because the current through the wires may be as low as 10 percent to 20 percent of the regular wire current at the time of ignition. The above results were recorded in a Lockheed Company film (Ref. 8-92 and 8-94).

The present task was undertaken to determine whether spacecraft wire bundles were susceptible to fire initiation and propagation as observed in the Lockheed tests.

PROCEDURE

Tests are in progress at NASA Manned Spacecraft Center on wire bundles. The test procedure includes a method for keeping the wire bundles moist with the water/glycol solution. Several wires in each bundle have intentionally-damaged wire insulation. The tests will be continued for at least several months to verify whether or not the effect of the water/glycol is appreciable.

In a special test Teflon covered shielded wire that had been purposely cut through to the conductor and exposed to ECS coolant caught fire. The fire occurred after about 8 hours in ambient atmosphere with less than 5 amperes passing through the conductor. The coolant was applied as droplets into the damaged area (Ref. 8-107).

SUMMARY

Initial test results show that fire initiation is possible. Additional test results applicable to this section of the report will be contained in Appendix G.

h. EFFECT OF WATER/GLYCOL ON CONNECTOR ASSEMBLIES

OBJECTIVE

Water/glycol coolant spillage occurred on a number of wire bundles and connectors used in S/C 012. The objective of this test program is to evaluate the effect of water/glycol and of the cleaning procedures used on S/C 012 on connectors similar to those used in S/C 012.

PROCEDURE

A series of tests have been defined to determine the effects of water/glycol spillage on wire bundle assemblies with connectors. A total of twenty-nine harness assemblies were ordered from NAA Downey for this testing. The assemblies are as follows:

V16-420337, CO5W5-P91	5 assemblies
V16-420303, CO5W5-P167	5 assemblies
V16-420308, CO3W15-P50	5 assemblies
V16-420307, CO3W15-P58	5 assemblies
V16-420316, CO1W1-J94	5 assemblies
836598-1-1	1 assembly
836600-1-1	1 assembly
836602-1-1	1 assembly
836599-1-1	1 assembly

These wire harness assemblies were selected since they represent harnesses that have been subjected to water/glycol (MBO 110-006, Type II) spillage on S/C 012. These harnesses are ECU cable harnesses, SCS-ECA cable harnesses and spacecraft harness assemblies located under the ECU.

The test environment is 75°F, 100 percent oxygen at 14.7 psia. These types of tests will be carried out as follows: (Ref. 8-83)

(1) Test A - Dip the cables and connectors in water/glycol for 30 seconds and allow to drip dry. Disassemble the connectors and clean per the procedures used on S/C 012. Rejoin the connectors and apply spacecraft voltages and currents and monitor the results.

(2) Test B - Test B is the same as Test A except the connectors are not cleaned and dried.

(3) Test C - Immerse the cables and connectors in a bath of water/glycol in the O₂ atmosphere. Apply spacecraft voltage and currents and record all readings. Allow the wire bundles and connectors to remain immersed in the water/glycol solution and continuously record circuit resistances.

Tests A and C will be run at KSC while Test B will be run at White Sands Test Facility.

SUMMARY

Test results applicable to this section of the report will be contained in Appendix G.

i. REVIEW OF KSC CONNECTOR TEST WITH WATER/GLYCOL

OBJECTIVE

A test conducted during October and November 1966 at KSC on a connector which had been subjected to ethylene glycol in which shorting occurred under DC load came to the attention of the Panel. This test was investigated for applicability of the fire investigation.

RESULTS

A review as contained in Ref. 8-66 and 8-67 of test requirements, objectives, test techniques and results related to the special test show that test personnel were properly concerned about the effects of water/glycol spillage on spacecraft electrical equipment. To evaluate the effect of water/glycol on S/C connectors they chose to apply a worse-case condition to a worse-configuration spacecraft-type electrical connector in a set of laboratory tests to check the effectiveness of a proposed vacuum-environment cleaning technique. Accordingly, a spacecraft-type connector partially equipped with pins and wires but without plugs in unused pin holes or potting applied to the exposed ends of the connector was dipped in a water/glycol solution of the type used in the C/M. This resulted in water/glycol being introduced directly into the components of the connector. After a number of operations involving resistance measurements, vacuum drying, room air storage, disassembly, cleaning, washing in water/glycol solution, reassembly and "drip drying," the connector was tested with active AC and DC circuits. The DC circuit failed because of an internal short. A later test at less voltage (28 compared to 35) was run for about the same length of time without failure.

SUMMARY

In analyzing test techniques, test results and statements made by the main participants in this test, it appears that the environment and the hardware were not representative of spacecraft equipment or environment but represent an extreme set of conditions which have not been known to exist in S/C operation. Thus, the results are not directly applicable to Apollo S/C equipment. Currently planned laboratory tests of real spacecraft connectors and cables wetted with water/glycol constitute a better source to judge the hazard of such events.

7. RESULTS OF SPECIAL INVESTIGATIONS AND TESTS - FIRE PROPAGATION

This section of the report deals with investigations and tests to evaluate the propagation of the fire.

The effect of foam insulation burning in 16.5 psia oxygen on aluminum oxygen supply lines in causing failure to these lines was evaluated. Investigations of the leakage of water/glycol solutions and residue were also undertaken. Temperature mapping of S/C 012 based on the condition of materials in various locations was investigated. The correlation of Command Module mockup tests with the S/C 012 configuration and condition was also investigated.

An analysis of combustion characteristics of materials was undertaken to evaluate the S/C 012 non-metallic materials configuration from a combustibility standpoint.

a. EFFECT OF BURNING FOAM INSULATION ON OXYGEN LINES

OBJECTIVE

The objective of these tests was to determine if burning foam insulation on aluminum oxygen supply lines in 16.5 psia oxygen could cause failure of these lines.

PROCEDURE

Uralane foam insulation was placed in separate tests on and under oxygen lines and ignited in 16.5 psia oxygen. Foam thickness and weight was selected to duplicate the amounts used on S/C 012. The oxygen lines were selected to represent lines used in S/C 012 (1/4-inch outer diameter, .035-inch wall thickness).

Normal oxygen flow was maintained in these lines throughout the test. The following specific tests are planned:

- (1) Foam insulation around a 100 psia aluminum line.
- (2) Foam insulation placed under a 100 psia aluminum line.
- (3) Foam insulation near a soldered joint of a 100 psia aluminum line.
- (4) Foam insulation placed under a 900 psia aluminum line.
- (5) Insulation and lines configured as in S/C 012 per test request.

RESULTS

Tests number 1 and number 2 are completed. No failure of the aluminum lines occurred when the foam insulation was burned (Ref. 8-98).

SUMMARY

Foam insulation representative of a single insulated line as installed in the S/C 012 ECU when burned in a 16.5 psia oxygen does not cause failure of a 1/4-inch, .035-inch wall thickness, 100 psia aluminum oxygen line.

Results from the remainder of the tests pertinent to this section of the report will be reported in Appendix G.

Additional tests are planned to determine the effect of a burning foam on soldered joints and 900 psia oxygen lines and lines configured as in S/C 012. These additional test results applicable to this section of the report will be contained in Appendix G.

b. WATER/GLYCOL LEAKAGE IN SPACECRAFT

OBJECTIVE

It was postulated that water/glycol (Ref. 8-96 and 8-97) leakage in S/C 012 could have contributed to the propagation or initiation of the fire. This study was initiated to determine the instances of water/glycol spillage in S/C 012, 009, 011, 017, and BP 014.

RESULTS

General: A review of documentation was conducted to determine the extent of water/glycol leakage in S/C 008, 009, 011, 012, 017, and BP 014. The records disclose that the water/glycol was MB0110-006 Type II. The following summary is a result of the review:

Vehicle Number	Instances	Total Leakage (Oz.)
S/C 008	1	16
S/C 009	1	2
S/C 011	6	52
S/C 012	6	90
BP 014	14	96 - 160 (est)
S/C 017	7	Unknown

No failures of spacecraft or boilerplate cables, harnesses, components or connectors have been attributed to the effects of water/glycol leakage.

S/C 012 The following instances of water/glycol leakage have been recorded against the ECS of S/C 012.

(1) ECU Removal at Downey - 2 pints. Approximately 2 pints of water/glycol leaked during ECU removal at Downey on August 12, 1966.

(2) Glycol Diverter Valve at KSC - Few tablespoonsful. On September 15, 1966 the glycol diverter valve was noted to be leaking at the rate of "approximately one drop/minute" (DR S/C 0188). This situation was corrected by adjusting the valve mounting bracketry to relieve the side loading effects which apparently were causing the leak. The DR was closed on September 26, 1966. The leakage had not caused other components or wire bundles to become wetted with water/glycol.

(3) Cold Plate IMU Supply Line, Weld Joint at KSC - 1 pint. On September 28, 1966 "three water/glycol leaks" were noted to be in existence "behind inverters - Lower Equipment Bay" (DR S/C 0289). The leakage was corrected by the replacement of existing solder unions with B-nuts and union. Following leak check and re-insulation of the affected lines the area exposed to water/glycol, including electrical connectors, was wiped with distilled water applied from a squeeze bottle, blown dry with GN₂, flushed with "denatured alcohol" from a squeeze bottle and dried again with GN₂. The electrical connectors were cleaned "inside and out". The subject DR (0289) was closed on September 30, 1966. DR-0305 was initiated against the water/glycol contamination to electrical connectors and wire harnesses which resulted from the leak documented on DR-0289. DR-0305 was closed by referencing the cleaning steps which were taken on DR-0289.

(4) Transducer CF0550 Removal/Rotation at KSC-2 pints (Oct. 11, 1966). The spillage of water-glycol which occurred during the operations documented on DR S/C 0436 was controlled to the extent that no water/glycol contamination of components or wire bundles was incurred.

(5) Pump Leak (1st) ECU Servicing at KSC - 1/2 cup (Nov. 30, 1966). Following ECU removal and subsequent investigation at AiResearch it was found that some evidence of leakage existed on the water/glycol pump flanges. Although leakage at this point in the system could not be verified the isolation of the leakage point to the pump flange area was the "best guess" available. (Reference DR S/C 0737).

TPS S/C 418 documents the tests which were performed on the ECU at AiResearch. The only leak source which could be determined was in the area of the pump filter housing. The observed leak was very minor (documented as "one drop" IDR 001, TPS S/C 418).

(6) Pump Leak (2nd) Servicing at KSC - 1/4 cup (Dec. 20, 1966). DR S/C 0811, which is still open, documented a water/glycol leak which "seeped down I-beam and extended to the wire harness on the C/M floor". The area was dried and the water/glycol did not reappear. The DR was to remain open until after the FRT (OCP-K-0028) at which time it would be closed.

The leak source was documented as being "exclusively associated with (water/glycol) servicing". Through 1830 on January 27, 1967 no failures on S/C 012 cables, harnesses, or connectors were attributed to the effects of water/glycol leakage. Total leakage 90 ounces (estimated).

From a review of the referenced documentation it may be concluded that the only water/glycol leak which wetted nearby electrical connectors and components was the leak at the solder joint at the IMU coldplate water/glycol supply line. The other leaks apparently did not contaminate electrical components or wire bundles. The water/glycol from the IMU coldplate leak wetted several connectors. These connectors were demated and cleaned to eliminate the possibility of water-glycol contamination inside the connector. The affected connectors were:

Yaw ECA: J-96, J-95, J-94, J-93, J-92

Auxiliary ECA: J-97, J-98, J-99, J-100

Pitch ECA: J-101, J-102, J-103, J-104, J-105

Each of these connectors was cleaned by water flush-gaseous nitrogen (GN₂) dry-denatured alcohol flush-GN₂ dry method. Each of the referenced connectors was potted.

During the inspection of the area in the C/M which could have been contaminated by the coldplate leak, black boxes were removed in sequence until the inspection of connectors and cables revealed that water/glycol had not reached the specific area being inspected. At that time the ECA units noted were determined to be the only units affected by the leak (Ref. 8-70).

SUMMARY

There have been 35 instances of water/glycol leakage on the Spacecraft listed with a total leakage of approximately 320 ounces including the 6 instances and 90 ounces on S/C 012. There have been no failures of cables, harnesses, connectors or components attributed to water/glycol leakage. The 14 connectors which were wetted with water/glycol on S/C 012 were demated and cleaned.

c. FLAMMABILITY OF WATER/GLYCOL RESIDUES

OBJECTIVE

It was desired to determine whether a thin film of water/glycol on a surface (from a drip or stream along the floor or wall) could be ignited at room temperature or slightly above by a flame impinging directly on the liquid surface.

PROCEDURE

Tests were made in which a flame was applied directly on the surface of a thin film of water/glycol/inhibitor mixture, pure glycol and films of the C/M coolant mixtures after exposure to vacuum. All flammability tests were conducted in 14.7 psia oxygen.

RESULTS

(1) Fifty drops of C/M coolant spread onto a 3-inch x 3-inch glass plate and a 1/8-inch x 3-inch x 3-inch aluminum plate would not propagate a flame in 14.7 psia O₂ when ignited by a 1/2-inch diameter 1-1/2-inch long paper cylinder. Burning of the coolant immediately adjacent to the paper produced small flashes and sparks for about a one-inch radius around the fire.

(2) The same test using C/M coolant fluid was performed using stainless steel plate with a 1/16-inch deep "V" groove. Ten drops of coolant were placed in the groove and five drops on the paper cylinder. The paper burned for 90 seconds and there was some progression along the groove as the plate heated.

(3) A test similar to (2) but using pure ethylene glycol took 3 to 5 seconds to propagate along the groove.

(4) The same test using C/M coolant fluid was performed on aluminum and stainless steel plates after 18, 24, 46, and 48-hour storage in room air. The fire burned out in both cases in about 10 seconds leaving about two thirds of the coolant on the plate. There was some sparking around the flame in all cases.

(5) When the 50 drops of standard coolant fluid on an aluminum plate was held under reduced pressure about 80 hours and then ignited the fire spread to the residue and was visible over the entire surface. The residue burned completely within 15 seconds after ignition. The same test on a stainless steel plate with a coolant exposed to dynamic vacuum for 9-1/2 hours shows partial burning of the coolant film.

(6) Tests performed by Raychem Corporation also showed that the evaporation residue from water/glycol will propagate a flame (Ref. 8-100).

(7) A test was conducted to determine if Teflon insulated wire soaked with water/glycol would propagate a flame. This test simulated the wiring in the SCS junction box which was burned in S/C 012. None of the samples would propagate a flame when ignited (Ref. 8-40 and 8-77).

SUMMARY

In 14.7 psia oxygen:

(1) A pure ethylene glycol film on a stainless steel plate will propagate a flame at room temperature.

(2) Water content in the C/M coolant will prevent flame propagation on thin films. Air drying for 48 hours does not produce a combustible mixture.

(3) Films of C/M coolant placed on horizontal stainless steel or aluminum plates and exposed to vacuum for extended periods at room temperature will propagate a flame if ignited.

(4) Residues from previous C/M coolant spills in S/C 012 could have provided a fuel.

(5) Single wires and three-wire bundles were soaked with water-glycol and either air-dried or vacuum-dried and did not propagate a flame.

d. TEMPERATURE MAPPING OF S/C 012

OBJECTIVE

A study was initiated to determine the major heat zones in S/C 012. Samples of nylon Velcro were used which had been heated to various temperatures. As part of this study the materials in the S/C were evaluated to determine which ones would allow ready comparison of hot and cool zones in the spacecraft.

PROCEDURE

Combustible materials were used throughout the spacecraft including nylon Raschel Knit and some plastic buttons or knobs on panels. Some of these were damaged but not entirely consumed. The reference material selected was Velcro. Samples of nylon Velcro were heated in an oxygen atmosphere at 16 psia at the White Sands Test Facility Laboratories. Each specimen was stopped at its assigned temperature, preserved, and photographed for degree of damage and color. Specimens were obtained for each 50°F increment between 300°F and 600°F.

RESULTS

The evidence that the fire was more intense on the left side than on the right side is summarized as follows:

Material	Type/Degree of Damage	
	Left Side	Right Side
Aluminum Panels	Blistered and whitened	No blistering. Some panels almost undamaged.
Velcro	Mostly burned off. Some of the patches are only partially burned.	Largely surface burning. Patches melted and dripped more than they burned.
Teflon Insulation	Extensive damage. On some wires the insulation is completely burned.	Mostly surface damage.

In general combustible materials were burned throughout the spacecraft particularly on the floor and around the sides. The materials listed subsequently which were in the S/C at the time of the fire were evaluated and an estimate of their role in the fire is as follows:

DEBRIS NETS - Virtually consumed or melted. These were probably instrumental in propagating the fire around the S/C.

VELCRO - This was another major material for flame propagation. Combustion varied from complete burning to only surface burning.

VELOSTAT PLASTIC SHEETS - These were consumed in nearly all areas. The material was a fuel but did not appear to be instrumental in spreading the fire.

FOAMS - A major fuel in the fire. The foam on the floor and on the ECU was nearly consumed.

COUCH MATERIALS - These pads and cover materials were partially consumed in the fire.

TEFLON WIRE INSULATION - It did not appear to act as a fuel for the fire by itself and was intact in most areas of the spacecraft. The wire insulation was damaged by the fire in those areas where flame impinged directly on the insulation. Areas where the wires

were bare of Teflon reached temperatures in excess of 800°F.

The data from the above summary were combined with the condition of the Velcro observed in the S/C to obtain the temperature chart presented in Enclosures 8-4 and 8-5 (Ref. 8-43). It was observed that the number of conditions in the S/C fire were not all reproduced in the test plan. As a result the temperature ranges in the diagram are approximate (Ref. 8-34, 8-35, 8-36, 8-37, 8-43, and 8-44).

SUMMARY

An estimate was made of temperatures attained at various locations in S/C 012. This was based on burning, melting, and other effects observed on aluminum alloys, Velcro and Teflon wire insulation coupled with calibration type exposures of Velcro materials to various temperatures and times. The most intense heat was in the lower left front area. Over 1000°F was attained on surfaces on the left side. However, in some isolated pockets temperatures did not exceed 400°F.

e. CORRELATION OF C/M MOCKUP TESTS

OBJECTIVE

These tests were made to (1) evaluate the integrated combustibility of materials as they interact in a fire representative of the S/C 012 accident, (2) to correlate test results with observations made on materials in S/C 012 after the accident, and (3) to compare the observation of (1) with tests at lower partial pressures of O₂.

RESULTS

Test	Description	Status
1	Engineering Simulation of S/C 012 16.5 psia O ₂	Complete Feb. 26, 1967
2	All-Up Simulation of S/C 012 16.5 psia O ₂	Complete Mar. 4, 1967
3	S/C 012 Materials Configuration 5 psia O ₂	Complete Mar. 8, 1967
4	New Materials Configuration 14.7 psia Air	Scheduled Mar., 1967
5	New Materials Configuration 5 psia O ₂	Scheduled Mar., 1967 (Ref. 8-98)

Comparison of the measured rate of pressure rise and the minimum rate calculated from materials characteristics is discussed in the subsequent section 7 g. "Thermochemical Adiabatic Analysis of Fire Development". The test results are available in documented form. A test report covering material usage and placement forms a portion of the backup data for this report (Ref. 8-11 through 8-17 and 8-28), and in the form of motion picture films (Ref. 8-87 and 8-88). Additional information is contained in film (Ref. 8-99).

The 5 psia tests utilized approximately the same nonmetallic materials configuration except that Velostat-covered foam and nylon coverings on the suit hose were not included. Also, no oxygen was added during the 5 psia tests as was done in the 16.5 psia tests.

SUMMARY

Judging from an initial review of test results and comparing the external appearances of materials from S/C 012 and the mockup tests an effective reproduction of the S/C 012 accident was accomplished.

Review of the films of the 16.5 psia test indicates that after about a 10-second period the fire was propagated very rapidly by the Raschel Knit. Velcro and Uralane foam also were major fuels in the conflagration.

Fire simulation mockup tests at 5.0 psia resulted in a much lower fire propagation rate, less extensive fire damage before O₂ supply exhaustion and a cabin pressure rise from the fire that was limited by the cabin pressure relief valve. The intensity of the fire in 5 psia O₂ although less than at 16.5 psia was still incompatible with crew safety and could be fatal to an unsuited crewman.

The results of additional tests applicable to this section of the report will be contained in Appendix G.

f. FIRE PROPAGATION TEST OF RASCHEL KNIT AS INSTALLED.

OBJECTIVE

Determine fire propagation rate for Raschel Knit material in a configuration as installed in C/M 012 along the floor and side wall intersection near the ECU.

PROCEDURE

Raschel Knit was installed in the test chamber with the long dimension (about 2 feet) horizontal and the narrow dimension (about 8 inches) aligned about 20 degrees from the vertical. Ignition was accomplished by a Nichrome wire element touching the Raschel Knit at about the mid-point of the vertical dimension and a measured distance from the end point. The chamber atmosphere was about 100 percent O₂ and near ambient pressure.

RESULTS

Preliminary results from two tests, reference 8-106, obtained with a visual observation and stop watch technique gave average rates of about 2 inches per second.

SUMMARY

Horizontal flame propagation rates of fairly large pieces of Raschel Knit material as used in C/M 012 below the ECU in oxygen at ambient pressure have been measured at about 2 inches per second. This rate is about twice as fast as the downward rate obtained with small samples in nearly the same environment during materials screening tests. This large increase shows the importance of testing materials in the intended-use arrangement.

g. THERMOCHEMICAL ADIABATIC ANALYSIS OF FIRE DEVELOPMENT

OBJECTIVE

The objective of this analysis is to correlate S/C 012 and boilerplate temperature and pressure changes with time. This will establish energy balance correlations with the combustion characteristics of materials.

SUMMARY

A supporting task showed that the total energy available from complete combustion of the Raschel Knit, Velcro, Trilock, and Uralane foam present in S/C 012 was over 300,000 Btu. Only about 3300 Btu (based on an adiabatic process) would be required to raise the interior pressure of the C/M from 16.5 psia to 36 psia. Thus many times more fuel was available than necessary to provide sufficient heat on burning to reach estimated burst pressure (approximately 20 psi positive differential). The minimum energy (approximately 3300 Btu) could be obtained from only about 4 ounces of Raschel Knit, Velcro, or polurethane foam, or 1/2 pint of Command Module water/glycol coolant (ref. 8-61).

Limited theoretical calculations indicate that burning of either Raschel Knit or Velcro alone would probably release a sufficient quantity of heat to raise the cabin pressure from 16.5 to estimated burst pressure (36 psia) in less than fourteen seconds from initiation. By this time a quantity equivalent to a hole of over 14 in. radius would have been burnt in the Raschel Knit and approximately 11 in. in the Velcro, consuming at least 3.8 ounces of either material and less than 2 percent of the available oxygen.

Based upon a number of known and estimated conditions and assumptions the minimum rate of pressure rise as a function of time was calculated (enclosure 8-6). This curve is based primarily on the slowest rate of combustion of Raschel Knit, i.e., in the vertical downward direction and its heat of combustion. For reference purposes pressure measurement from S/C 012 and the estimated curve (from Panels 3, 5, and 10) are also shown for comparison on the same plot. Pressure measurements during the 16.5 psia mockup test (SMD-2B) at MSC (normalized to a zero time base and 16.5 psia starting conditions) are also plotted.

Fire development characteristics vary with initial starting conditions. Thus, similar theoretical analyses were made for space conditions, i.e., assuming external vacuum and internal 5 psia pure O_2 and using Teflon and Raschel Knit materials as limiting cases. The maximum or 'most favorable conditions were assumed for the burning of the Teflon.

The approach consisted of calculation of the minimum amount of heat necessary to raise the crew bay pressure from 5 psia to that under consideration. The amount of Teflon or nylon necessary to produce this amount of heat and the times necessary to consume these amounts were then calculated. The baseline burning rate of Teflon (5 mil film) was taken as 0.38 in/sec measured in the upward direction and burning in a semicircular fashion in 1 g. Admittedly, such a favorable condition for Teflon burning probably will never occur. However, even under such conditions at least 80 seconds would be required to reach the estimated burst pressure. In this time frame normal adiabatic expansion of the gas would not occur because the heat sink capability of the structure would be utilized partially. This heat sink capability would give additional time to take corrective action. For example, it would take in excess of 25 seconds to heat the cabin gas to 160°F (assuming that the ECS was inoperative). Thus, the burning of Teflon sheets is not likely to cause overpressurization and structural failure of the Apollo C/M. (Ref. 8-56, 8-59 and 8-47). However, as indicated previously Teflon can propagate a flame so that its use over wide areas of the S/C should be limited.

h. THEORETICAL COMBUSTION ANALYSIS

OBJECTIVE

The objective of this investigation is to evaluate combustion processes and data from other fire incidents to acquire further insight into initiation and propagation of fire in spacecraft. A second objective is to evaluate proposed remedial approaches involving materials selection and placement.

PROCEDURE

These analyses are being carried out by the Atlantic Research Corporation.

RESULTS

In preparation.

SUMMARY

Test results applicable to this section of the report will be contained in Appendix G.

8. RESULTS OF SPECIAL INVESTIGATIONS AND TEST - DESIGN AND INSTALLATION CRITERIA AND CONTROLS OVER MATERIALS

This action presents investigations undertaken to evaluate design and installation criteria and controls over materials used in S/C 012.

a. NAA CRITERIA AND MATERIALS PROCEDURES

OBJECTIVE

The objective of this investigation was to evaluate existing criteria and controls covering flammability of materials in effect by the prime contractor.

SUMMARY

With respect to the S/C 012 fire, the NAA Specification MC999-0058 (Ref. 8-84) and MAO 155-008 covering the selection and usage of nonmetallic materials for flight had the following inadequacies:

- (1) The criteria did not require any combustion rate testing.
- (2) There were no restrictions on total quantities of combustibles which could be placed in the cabin.
- (3) The criteria did not require any restriction on quantities or location of particular materials.
- (4) Material selection flammability criteria were not stringent enough.
- (5) Requirements for flammability control of nonflight materials, including the usage of flammable solvents, were not established.

With respect to the implementation of controls, the following inadequacies were determined:

- (1) The existing system for controlling installation and usage of materials to the established criteria was not effective.
 - (2) Controls were design-oriented but were not restrictive.
 - (3) Control and documentation of subcontractor materials usage was not adequate (Ref. 8-71, 8-72, 8-89, 8-55 & 8-63).
- b. NASA/MSC CRITERIA AND MATERIALS CONTROL PROCEDURES COVERING THE SELECTION AND USAGE OF NONMETALLIC MATERIALS FOR FLIGHT OBJECTIVE

The objective of this investigation was to evaluate existing criteria and controls in effect for government furnished equipment.

SUMMARY

With respect to the S/C 012 fire, the NASA MSC-A-D-66-3 and MSC-A-D-66-4 criteria had the following inadequacies:

- (1) The criteria did not require evaluation of ignition and combustion rate at 16.5 psia oxygen. The criteria were oriented toward flight conditions of zero g and 5 psia oxygen.
- (2) The criteria which specified combustion rate tests (downward) yielded results at the lowest rate possible in a one-g environment.
- (3) The total quantity of combustible materials which could be used in the cabin was not limited.
- (4) The materials selection flammability criteria and restrictions on individual quantities and locations were not stringent enough (Ref. 8-85 and 8-86).
- (5) Requirements for flammability control of nonflight materials, including usage of flammable solvents were not established.

With respect to the implementation of controls, the following inadequacies were determined:

- (1) Many materials used were qualified only by successful usage on prior programs.
- (2) The existing system for controlling installation and usage of materials to the established criteria was not effective.
- (3) Control of flammable materials installation was exercised by several organizations which tended to act independently.
- (4) Control and documentation of contractor materials usage was not adequate. (Ref. 8-8, 8-9, 8-73 & 8-90).
- (5) NASA criteria was not contractually imposed on the S/C contractor.

A physical "walk-through" inspection of S/C 012 was conducted at Downey on August 20, 1966 as part of the CARR activity. As a result of that inspection, nylon-Velcro chafe guards were removed from the electrical harness assemblies on the S/C floor and those around the sides and beneath the crew insertion hatch.

Subsequent to that inspection and after delivery the materials identified in tables 3 and 4 were added. Materials added included Raschel Knit debris nets, a large amount of Velcro, and Velostat plastic sheets and foam pads.

A "walk-through" inspection for S/C 012 was scheduled for January 29, 1967 to review the arrangements of the large usage materials in the crew bay. (Ref. 8-89). While the results of this planned but not accomplished inspection can only be speculated, it is anticipated that the team made up of the same experienced people who had previously inspected S/C 012 at the factory and S/C 008 at MSC would have been concerned with the extensive use of Velcro and Raschel net (Ref. 8-60).

A similar inspection was made of the S/C 008 crew bay area before the altitude chamber tests were conducted in the Space Environment Simulation Laboratory at MSC. This inspection resulted in a number of changes including removal of the nylon-Velcro chafe guards, polyvinyl bags, a wooden wire bundle stiffener and the rework and qualification testing of a sealed Teflon and beta cloth for the polyurethane floor pads.

"Walk-through" inspections of spacecraft with NASA/NAA personnel have been utilized to perform a check of the installation of the nonmetallic materials visible in the cabins. During such inspections it has been possible for the team to judge on the basis of the NAA criteria and NASA criteria.

As noted the NASA effort to update the existing NAA Nonmetallic Materials criteria and control procedures had not been completed prior to January 27, 1967. Some of the more significant milestones on the updating efforts are listed in Ref. 8-101. Many of the contractor responses to NASA requests were in the form of status reports presented at regular NASA/NAA management meetings. The NAA responses culminated in a January 10, 1967 letter (Ref. 8-102) which was not acceptable to the NASA. Later, agreement was reached as confirmed in NASA TWX's of January 17, 1967 in item 15 and 18 of Ref. 8-101. This resulted in the January 27th revision of MC999-0058(E) which reflected the adoption of NASA criteria (Ref. 8-50 and 8-51).

The adoption of the NASA criteria through change to the contractor's nonmetallic materials criteria (MC999-0058) would not necessarily have prevented this accident because the cause has not been identified and because the NASA criteria also had some shortcomings as noted. However, the relative effectiveness of these two criteria is shown in Enclosure 8-27 by a comparison of the status of the major flammable materials attached to the spacecraft relative to these criteria. The two most significant differences were the restrictions given to the application of Velcro and the Uralane foam in the NASA criteria. Such restrictions would have prevented the installation of these materials any closer than 12 inches to electrical leads. This would have made a significant difference in the amount of both of these materials installed in the spacecraft at the time of the accident. The difference in the amount of permissible Velcro on and by the hatch and on the floor is shown by comparing the Velcro installation in Enclosures 8-17, 8-8 and 8-9. Only the Velcro shown in red in Enclosures 8-8 and 8-9 would have remained. Much of the Velcro used to support the Raschel would have been prohibited. Under the same enforcement assumption, most of the foam would have been removed.

c. REVIEW OF WIRE BUNDLE TESTING

OBJECTIVE

The objective of this analysis was to review the results of government and industry tests on the subject of ignition and flammability of spacecraft wires.

PROCEDURE

Available test and evaluation data on spacecraft wire bundles were reviewed (Ref. 8-95).

SUMMARY

Although flammability by itself may not be in every case the deciding factor, silicone rubber and polyolefin are so flammable that they appear to have limited usefulness at least in an oxygen atmosphere. On the other hand, H-film appears to be relatively fire resistant. Teflon insulation on electrical wiring propagates a flame in high concentrations of oxygen only when heated.

d. AVAILABILITY OF ALTERNATE MATERIALS

OBJECTIVE

The more prevalent flammable materials in the cabin are nylon debris netting, nylon Velcro, polyolefin couch padding, polyurethane foam and suit material. The objective of this task was to determine if nonflammable or less flammable alternate materials are available for replacement of combustible materials in the spacecraft.

RESULTS

The following materials are suitable for strengthening, insulating, cushioning and filling to reduce combustion rate of a bonded product. They are documented in various government, industry and manufacturers' reports as being nonflammable:

Fiberglass	Potassium Titanate
Beta Fabric	Eccospheres
JM Microfibers	Asbestos
Q felt	Silica
Min-K	Cabosil

Government and industry documents present a great deal of data concluding that fluorinated plastics and elastomers have a very slow burning rate and are difficult to ignite in 5 psia oxygen. It is known that fluorinated polymers will produce harmful gases when subjected to temperatures over 600°F. Gases produced during flaming are not as harmful. The following are candidate fluorinated plastic and elastomeric matrix materials:

Teflon (TFE)	Kynar
Teflon (FEP)	Fluorel
Kel-F (CTFE)	Viton A
Fluorosilicones	

Typical commercial materials with low burning rates comparable to Teflon or which are nonflammable are presented in the following table (Ref. 8-58, 8-59, and 8-69).

Material	Type
Kel-F	n-CF ₂ -CFCl
Aluminum Screen	Silicate coated
Metal Net	
Fluorocarbon Elastomers	n-CF ₂ -CF ₂ Cl-n
Fiberglass	
Armalon Felt (PBX-7700B)	Teflon
J.M. Microfiber Felt	
Min-K Felt	Ceramic
H-Film	Aromatic
Sellev	Polyimide
Inorganic Paper	Ceramic
Crystal M, MP, or MG	
Sauereisen	Ceramic
Cement No.'s 28, 29 or 51	(Cold Set)

Displays of available materials are shown in Enclosures 8-18 and 8-19. Attachment methods as replacements for Velcro are shown in Enclosure 8-20.

SUMMARY

Nonflammable (or significantly less flammable) materials which probably will meet the use requirements for most of the flammable materials used in S/C 012 were determined to be available

from commercial sources (Ref. 8-59). For example, fiberglass screens or fabrics are essentially non-flammable items which probably can serve as debris traps. Ceramic fiber batts in nonflammable covers are available for use as cushions, insulations, etc. Final choices of materials should be verified by test approximating their applied configurations.

e. CREW COMPARTMENT PROCESSING AND ENVIRONMENT TIME LINE

OBJECTIVE

The objective of this analysis was to determine the history of the materials processes and environment time line for S/C 012 crew compartment during January 1967.

PROCEDURE

A detailed review of certain C/M related documentation, including DR's, DRS's, and TPS's, was undertaken to define those nonmetallic materials, which were installed or utilized within the crew compartment of the C/M since its receipt at KSC. Interviews with personnel who were in attendance during the performance of OCP FO-K-0021-1 (Plugs-Out Test) were undertaken to further describe the actual C/M nonmetallic configuration at the time of the accident. Cabin environment conditions, i.e., O_2 partial pressure, temperature, flow rate of circulating air were determined and plotted to display a profile of these parameters from the end of OCP FO-K0034a (Manned Sea Level Test) December 30, 1966 to 6:31 pm EST on January 27, 1967.

RESULTS

The tabulation of materials added by DR, DRS, and TPS action in January 1967 (Ref. 8-45, 8-62, 8-63 & 8-64) is shown below:

- Water/glycol (leakage)
- Pressure-sensitive adhesive-backed aluminum foil
- Freon (cleaning)
- RTV 560 (potting)
- Methyl-ethyl-ketone (cleaning)
- Sealing Compound (MBO 130-019) and primer (MBO 125-038)
- Napthalene - Carbon tetrachloride mixture (cleaning)
- White Paint (MBO 125-019)
- Epon 828 with Versamid 125 (potting)
- Glass fabric tape
- Epon 954 (bonding)
- Teflon tape
- Naptha (cleaning)
- PRC 1538 (potting)
- Teflon heat shrink sleeving
- RTV 577 (potting)
- Loctite Grade HV, primer (sealing)
- Isopropyl alcohol (cleaning)
- Leak check soap solution
- Acid paste

Review of these materials against the NAA control specification MC999-0058 showed that 6 were accepted, 4 were rejected but waived, and 10 did not appear (Ref. 8-55).

Solvent usage in S/C 012 is estimated as follows for this time period:

methyl-ethyl-ketone	2 quarts*
Freon	1 quart
Leak check soap solution	1 pint
Isopropyl alcohol	1 quart*
Acid Paste	0.1 pint

* Used as a basis for analysis reported in Section 6.a.

A graphic time line on solvent usage was prepared based on the preceding data. Pertinent excerpts are included in Enclosure 8-7, which depicts the last utilization of solvents, the detection of odors and the basic environmental parameters in the spacecraft cabin. (See "Materials Odor Evaluation", 6.5.). Although etchants were not used in the crew compartment a summary study of the potential effects of various etchants was compiled and is presented in References 8-52 and 8-53. Evaluation of the results reveals that many process materials were added in January, 1967. The process materials noted were either installed in such a manner or in such minute amounts that their contribution to the fire initiation even though possible is considered remote.

Approximately 4.5 quarts of solvent were used in the spacecraft through January, 1967. However, results of a cabin environment air sample taken at 10:15 pm EST on January 26, 1967, indicated less than 1 ppm total hydrocarbons. This result tends to reduce concern that solvent vapors could have been a fuel for the fire.

9. RESULTS OF SPECIAL INVESTIGATIONS AND TESTS -TECHNICAL DATA AND INFORMATION AVAILABILITY

This section deals with investigations of the feasibility of methods for improving technical information availability to primary activities having materials selection, installation and control responsibilities.

a. MATERIALS MAPPING AND CREW BAY DISPLAY OBJECTIVE

The objective of this analysis was to develop S/C 012 materials usage displays and to evaluate the feasibility of maintaining displays of nonmetallic materials usage with the LM and C/M crew bay. The purpose of this display was to locate the nonmetallic materials that may become flammability hazards due to their close proximity to ignition sources. The intent of this display was to graphically illustrate the individual materials, location, approximate amounts, identity of the materials and their status.

RESULTS

The types of displays that were considered are as follows:

- (1). Photographs for schematics.
- (2). Overlay on schematic.
- (3). Display board of actual material samples.
- (4). Scale model of crew compartment interior.

A system that worked well during the Apollo 204 accident investigation has been to photograph the interior of the crew bay exhibiting by color photographs the location of the various pieces of associated equipment. This system involved one overall crew bay enlargement with individual "closeup" color photos of pieces of equipment and localized areas (Ref. 8-65 and 8-68).

SUMMARY

Maintenance of spacecraft nonmetallic materials usage displays is feasible and useful.

Preparation of the full-scale mockup of S/C 012 revealed the continuous fire propagation path presented by the placement of Raschel Knit and/or Velcro in the crew bay.

b. MATERIALS INFORMATION CENTER

Objective

The activities of the Materials Panel illustrated the need for:

- (1) The rapid availability of materials information including usage and property data.
- (2) The availability in graphic form of location and usage of nonmetallic materials in manned spacecraft.
- (3) Increased awareness of personnel at all levels of characteristics of nonmetallic materials.
- (4) Provide test data and means for getting new materials tested to appropriate criteria.

The objective of this study was to evaluate the feasibility of implementing a more active information interchange system.

RESULTS

An objective review of the materials information program has resulted in a plan for its reorientation toward a more active role in acquiring and distributing vital materials information. The targets for receipt of this information are program management, contractors, and field sites.

Displays covering materials usage in S/C 012 have been prepared. A feasibility study of maintaining individual spacecraft usage data in graphical form has also been prepared.

The existing computerized materials file maintained at MSC was reviewed. The expansion of this system to accommodate test data, usage locations and spacecraft effectivity and material status, including waivers is feasible and is being implemented. The target date is June 1, 1967 (Ref. 8-68, 8-81 & 8-82).

SUMMARY

The results of this study indicate the feasibility of a central data source for acquisition, storage, display and distribution of materials information.

Materials configuration can be maintained in a centralized document. This can be accomplished on each vehicle and reviewed during each Customer Acceptance Readiness Review (CARR), and Flight Readiness Review (FRR). During fabrication and test of each vehicle, configuration control and status can be maintained. Materials information on the use and applications of hazardous materials can be distributed to Program Management, Apollo contractors and field sites. This can be accomplished through workshops, film strips and formal presentations.

10. UNFINISHED BUSINESS

The following items of unfinished business are open.

ITEM	SECTION	EST. COMP. DATE
Routine Materials Testing	5	May 26
Electrostatic Spark Ignition - Suited Man in Spacecraft Tests	6.c	April 15
Effect of Water/Glycol on Wire Bundles	6.g	June 23
Effect of Water/Glycol on Connector Assemblies	6.h	April 21
Effect of Burning Foam Insulation on O ₂ Lines	7.a	April 15
Command Module Mockup Tests	7.e	April 15
Theoretical Combustion Analysis	7.h	April 7

D. FINDINGS AND DETERMINATIONS

1. MATERIALS CONFIGURATION

a. FINDING:

Complete documentation which identified potentially combustible nonmetallic materials used in S/C 012 is not available in a single readily usable format. A total of 2,528 different potentially combustible nonmetallic materials which were probably used on S/C 012 were found by a review of available documentation.

DETERMINATION:

The program for identification and documentation of nonmetallic materials used in the S/C, including their weights and surface areas, was not adequate.

There is no system in effect through which nonmetallic materials configuration changes are tracked, reported, evaluated, and controlled in an integrated manner.

b. FINDING:

Test data providing individual combustion properties in environments of 5 psia to 21 psia oxygen were available for 550 of the potentially combustible nonmetallic materials identified as possibly being used. Data on higher pressure testing were available only on suit materials, Velcro and K-10 flight paper.

DETERMINATION:

Flammability test requirements were not standardized at the time the referenced tests were accomplished.

Large numbers of potentially combustible nonmetallic materials were used in the fabrication of S/C 012 without specific correlated combustibility test data. Test data were available at high O₂ pressures (to 21 psia) to define the combustion characteristics of some of the major materials which contributed heavily to the fire.

c. FINDING:

Installation records including photographs and redlined drawings were maintained at KSC which contained descriptions of materials added to S/C 012.

DETERMINATION:

Methods for identifying configuration changes related to materials were operational at KSC.

2. ROUTINE MATERIALS TEST

FINDING:

Raschel Knit, Velcro, Trilock and polyurethane foams burn about twice as fast (in the downward direction) in 16.5 psia as in 5 psia O₂.

DETERMINATION

The primary fuels for the fire burned over twice as fast in the early stages of the fire in accident conditions (16.5 psia) than in space flight atmosphere for which they were evaluated (5 psia).

3. FIRE INITIATION SPECIAL INVESTIGATION

a. Retention of Solvents

FINDING:

Laboratory analyses indicated that solvent retention by test specimens was significant. The analyses also indicate that the evaporation characteristics of the solvent is such that vapor concentration fell below the lean flammability limit after 1½ hours.

DETERMINATION:

The presence of significant volumes of concentrated vapor in the spacecraft is unlikely. However, the retention of solvents in the surface layers of solid flammable materials could possibly contribute to their ignitability.

b. Materials Odor Evaluation

FINDING:

Odors similar to that of sour milk and methyl-ethyl-ketone were reported before the fire during suit and cabin purge operations.

Thresholds of methyl-ethyl-ketone and isopropyl alcohol detection by smell are approximately .01 percent to .03 percent by volume and concentrations described as strong, irritating or sickening range from 1 percent to 4 percent by volume.

DETERMINATION:

There is no evidence that significant concentrations of organic vapors were present in S/C 012 at the time of the fire.

c. ELECTROSTATIC SPARK IGNITION

FINDING:

The maximum electrostatic spark energy generated and measured on a man suited in a space suit was about 4 millijoules.

FINDING:

Ignition of the more flammable S/C 012 solid materials tested required spark energies of 190 millijoules or greater.

FINDING:

Ignition of solvent vapors in oxygen can take place at spark discharge energies as low as 0.002 millijoules. Ignition of methane vapors in oxygen can take place at spark discharge energies as low as 0.004 millijoules. Ignition of solid materials damp with solvents can take place at spark discharge energies as low as 40 millijoules.

DETERMINATION:

Ignition of solid materials by electrostatic discharge is not a probable cause of the S/C 012 fire.

DETERMINATION:

It is possible from an energy consideration that methane and solvent vapor can be ignited by electrostatic discharge. Nevertheless, this is not believed to be a possible cause of the fire.

d. COBRA CABLE SPARK IGNITION

FINDING:

Connecting and disconnecting of spacecraft qualified Cobra connectors at normal loads did not create sufficient energy to ignite concentrations up to saturation (approximately 12 percent) of methyl-ethyl-ketone in 16.4 psia oxygen. An increase in loading to 2.5 times operating amperage in 4.0 percent of MEK yielded no ignition.

DETERMINATION:

Ignition of flammable concentrations of solvent vapors by connecting and disconnecting Cobra connectors is an unlikely ignition source for the S/C 012 fire.

e. IMPACT SENSITIVITY OF MATERIALS IN GOX

FINDING:

Preliminary high energy impact tests on Velcro and Raschel Knit in 16.5 psia oxygen produced ignition and burning.

FINDING:

A survey of similar spacecraft and mockup failed to disclose the possibility of any high impact conditions.

f. SPONTANEOUS IGNITION OF S/C 012 MATERIALS

FINDING:

Results of tests on S/C 012 materials considered to be most flammable with and without solvents (methyl-ethyl-ketone, isopropyl alcohol) and coolants (water/glycol) did not result in spontaneous ignition at or below 400°F in any case.

DETERMINATION:

Spontaneous ignition is an unlikely ignition source for the S/C 012 fire.

g. EFFECT OF WATER/GLYCOL ON WIRE BUNDLES

FINDING:

Conditions required for wet-wire fire ignition through electrolytic action are damaged wire insulation, presence of an electrolyte and electric potential between damaged wires and a flammable substance in the proximity. A test has shown that ECS coolant applied to a purposely damaged wire of a type used in the C/M caused a fire.

DETERMINATION:

The required conditions could have been present in S/C 012.

h. REVIEW OF KSC CONNECTOR TEST WITH WATER/GLYCOL

FINDING:

An unpotted connector with some unused pin channels subjected to water/glycol and placed under DC stress developed a short circuit.

DETERMINATION:

Water/glycol electro-corrosion products and residue are conductive and capable of acting as an electrolyte.

4. FIRE PROPAGATION SPECIAL INVESTIGATION

a. WATER/GLYCOL LEAKAGE IN SPACECRAFT

FINDING:

There have been 35 instances of water/glycol leakage on Block I Spacecraft involving approximately 320 ounces.

DETERMINATION:

The water/glycol distribution system requires corrective action to eliminate leakage.

FINDING:

Prior to the accident there had been no electrical system failures attributable to the water/glycol leaks.

DETERMINATION:

The electrical system has some tolerance to water/glycol spillage.

FINDING:

There is no standard cleaning procedure in effect to remove water/glycol spills or residue.

DETERMINATION:

There is a probability that water/glycol residue is present in areas of all Block I Spacecraft.

FINDING:

Six instances of water/glycol leakage were recorded for S/C 012. Of these, one soaked several SCS connectors and wire bundles. Some corrective action was taken to clean all known spills in S/C 012.

DETERMINATION:

Water/glycol residues may have been present in areas of S/C 012 including on wire bundles and connectors.

b. FLAMMABILITY OF WATER/GLYCOL RESIDUES

FINDING:

Tests in a 14.7 psia oxygen atmosphere on horizontal surface show films of C/M coolant will not propagate a flame before or after air drying for up to 48 hours. Films of coolant will propagate a flame after exposure to reduced pressure for periods of 60 to 80 hours. Pure ethylene glycol will propagate a flame in a similar atmosphere.

DETERMINATION:

Residues from previous standard coolant fluid spills in S/C 012 might have provided a path for flame propagation on materials that were wetted. Spills or leaks in the early stages of the fire would burn when heated.

c. TEMPERATURE MAPPING OF S/C 012

FINDING:

Surface and bulk damage of materials in S/C 012 varied from melting and blistering of aluminum alloys, combustion of Velcro and melting and burning of Teflon wire insulation to slight surface damage and melting of nylon fabrics.

DETERMINATION:

The fire filled the S/C interior. The most intense heat was in the lower left front area around the ECU. Surface temperatures in excess of 1000°F were reached in areas such as the front and left side of the spacecraft. Surface temperatures were less than 400°F in isolated pockets above the right-hand couch.

d. CORRELATION OF C/M MOCKUP TESTS

FINDING:

The condition and appearance of individual materials after the 16.5 psia oxygen boilerplate test approximated materials conditions observed in S/C 012. The pressure rise measured in the boilerplate test approximated that in the S/C 012.

DETERMINATION:

A reasonable simulation of the S/C 012 accident was achieved by the boilerplate tests.

FINDING:

The rate of flame propagation, the rate of pressure increase and the maximum pressures achieved and the extent of conflagration in 5 psia oxygen boilerplate tests was much less severe than observed in the 16.5 psia oxygen boilerplate tests. Burning or charring was limited to approximately 29 percent of the nonmetallic materials by oxygen depletion.

DETERMINATION:

The conflagration which occurred in S/C 012 at 16.5 psia would be far less severe and slower in a spacecraft operating with an environment of 5 psia oxygen if additional large quantities of oxygen are not fed into the fire.

DETERMINATION:

A fire in a spacecraft configured as S/C 012 operating with a 5 psia oxygen environment could be fatal.

FINDING:

The early stages of fire propagation in the boilerplate tests were observed to be dependent upon the combustion rate and location of the materials. The observed rates appeared to have been much greater than the factor of two increase measured downward in the laboratory tests when the oxygen pressure is increased from 5 psia to 16.5 psia. The additional increase in rate in the boilerplate tests most likely occurs because of the combined effect of burning upward and along the continuous paths provided by flammable materials. This is substantiated by preliminary results referenced in 8-106.

DETERMINATION:

The spread of fire at 16.5 psia operating pressures is too rapid for effective remedial action in spacecraft with combustible materials arranged as in C/M 012. The spread of fire at 5 psia operating pressures is probably too rapid for effective remedial action by an unsuited crewman.

e. THERMO-CHEMICAL ANALYSIS OF FIRE DEVELOPMENT

FINDING:

The energy available from about four ounces of Raschel Knit or Velcro could raise the pressure in a closed C/M from 16.5 psia to 36 psia in less than 14 seconds after ignition. (Calculations assume complete combustion and adiabatic conditions).

FINDING:

Teflon materials did not burn appreciably in S/C 012. Calculations based on laboratory data indicate that Teflon could not have contributed appreciably to the rate of pressure rise. The total energy available from the Raschel Knit, Velcro, foam, Trilock and polyurethane materials was much greater than necessary to raise the cabin pressure from 16.5 psia to 36 psia.

DETERMINATION:

Teflon provides an insignificant fire risk.

DETERMINATION:

There was considerable excess combustible material available with which to raise the C/M pressure to the estimated burst pressure.

5. MATERIALS INSTALLATION CRITERIA AND CONTROLS

a. NAA CRITERIA AND MATERIALS CONTROL PROCEDURE

FINDING:

The NAA materials selection specification MAO 155-008 requires only that a material pass a 400°F spark ignition test in 14.7 psia oxygen.

DETERMINATION:

The NAA criteria for materials flammability control were inadequate.

FINDING:

A system for control of nonmetallic materials usage existed at NAA during the design, fabrication and assembly of C/M 012. The NAA materials control system is design oriented.

DETERMINATION:

The system is permissive to the extent that controls over the installation or use of flammable materials are not adequate.

FINDING:

There were nonflight items containing combustible materials in C/M 012 during this test.

FINDING:

No flammability criteria or control existed covering nonflight items installed in C/M 012 for test.

DETERMINATION:

Lack of control of nonflight material could have contributed to the fire.

b. NASA-MSC CRITERIA AND MATERIALS CONTROL PROCEDURES

FINDING:

The NASA materials selection criteria MSC-A-D-63 and MSC-A-D-66-4 requires that a material pass a 400°F spark ignition test and a 0.5 in/sec combustion rate (measure downward in 5 psia O₂). Raschel Knit and Velcro (hook) pass this test.

DETERMINATION:

The NASA criteria for materials flammability control are not sufficiently stringent.

FINDING:

The system for control of nonmetallic materials usage at MSC during the design and development of government furnished equipment used in C/M 012 depended on identification of non-compliance with criteria by the development engineers.

DETERMINATION:

The NASA materials control system is permissive to the extent that installation or use of flammable materials were not adequately reviewed by a second party.

FINDING:

The NASA criteria were intended to limit the use of Velcro and Uralane foam to distances greater than 12 inches from wire bundles.

FINDING:

Nonmetallic materials selection criteria utilized by NAA and NASA are not consistent. The NASA criteria, although more stringent, were not contractually imposed on the S/C contractor.

DETERMINATION:

Materials were evaluated and selected for usage in C/M 012 using different criteria. Application of the NASA criteria to the C/M would have reduced the amount of the more flammable

materials (Velcro and Uralane foam).

FINDING:

Visual "walk-through" inspections had resulted in removal of combustibles in the proximity of wire bundles on C/M 012 before delivery and on C/M 008 before manned testing. Such inspection had not been made before OCP FO-K-0021-1.

DETERMINATION:

Visual inspections have resulted in removal of combustible materials from potential ignition sources (wire bundles).

c. AVAILABILITY OF ALTERNATE MATERIALS

FINDING:

Alternate materials which are nonflammable or significantly less flammable than those used on C/M 012 are available for many applications.

DETERMINATION:

The amount of combustible material used in Command Modules can be limited.

6. TECHNICAL DATA AND INFORMATION AVAILABILITY

MATERIALS INFORMATION CENTER

FINDING:

Current information and displays of the potentially flammable materials configuration of S/C 012 was not available prior to the fire.

FINDING:

A centralized source for materials data was established for the Board Panel 8 (Materials Review).

DETERMINATION:

Maintenance of data and displays at central locations and test sites for management visibility and control of flammable materials is feasible and useful.

E. SUPPORTING DATA

This section contains references to supporting data in the form of reports, lists and other documents. Also included are photographs, tables and graphs essential to provide completeness of this final report.

Items are numbered 8-1, et. seq., for those displays enclosed in this section. Supporting reports and references not included in this report are numbered consecutively.

Supporting data included are listed below:

Enclosure	Description
8-1	Not used
8-2	Sample page from C/M 012 Materials Configuration, March 6, 1967
8-3	C/M 012 Temperature Mapping and Materials Usage Display - Prior to Fire (Neg. No. 166-238C-2)
8-4	C/M 012 Temperature Mapping and Materials Usage Display - After Fire (Neg. No. 166-238C-3)
8-5	C/M 012 Temperature Mapping Overlay (Neg. No. 283-498C-1)
8-6	C/M 012 Pressure vs Burning Time - Velcro or Raschel Knit
8-7	C/M 012 Materials Time Line
8-8	Exposed Nonmetallic Materials Location - Velcro and Wire Bundles 12 Inches Apart on Floor (Neg. No. 329-713C-3)
8-9	Exposed Nonmetallic Materials Location - Velcro and Wire Bundles 12 inches Apart on Aft Bulkhead % Hatch (Neg. No. 329-713C-1)
8-10	Major Exposed Nonmetallic Materials in C/M 012 (Neg. No. 166-238C-1)
8-11	Exposed Nonmetallic Materials Location- Command Module Outline (Neg. No. 216-468C-1)
8-12	Exposed Nonmetallic Materials Location - Velcro (Neg. No. 216-468C-4)
8-13	Exposed Nonmetallic Materials Location - Velcro and Uralane Foam (Neg. No. 216-467C-6)

- 8-14 Exposed Nonmetallic Materials Location - Velcro and Uralane Foam and Raschel Knit (Neg. No. 216-467C-3)
- 8-15 Exposed Nonmetallic Materials Location - Velcro and Uralane Foam and Raschel Knit and Trilock/Raschel Covering (Neg. No. 216-467C-2)
- 8-16 Exposed Nonmetallic Materials Location - Suits Added (Neg. No. 216-466C-5)
- 8-17 Exposed Nonmetallic Materials Location - Aft Bulkhead Added (Neg. No. 216-466C-1)
- 8-18 Candidate Nonflammable Materials - Cushions Insulation, Velcro, Debris Net and Miscellaneous (Neg. No. 233-485C-3)
- 8-19 Candidate Nonflammable Materials - Felts, Coatings, Lubricants, Adhesives and Coolants (Neg. No. 238-487C-2)
- 8-20 Possible Equipment Attachment Substitutions (Neg. No. 233-485C-2)
- 8-21 Candidate Nonflammable Materials - Command Module Outline (Neg. No. 221-470C-3)
- 8-22 Candidate Nonflammable Materials - Velcro Substitutes (Neg. No. 221-470C-4)
- 8-23 Candidate Nonflammable Materials - Substitutes for Velcro, Foam, and Trilock/Raschel Covering (Neg. No. 221-470C-5)
- 8-24 Candidate Nonflammable Materials - Substitutes for Raschel Knit and Suits Added (Neg. No. 221-470C-2)
- 8-25 Candidate Nonflammable Materials - Substitutes on Aft Bulkhead (Neg. No. 221-470C-1)
- 8-26 List of References
- 8-27 Status of Major Nonmetallic Materials Used in C/M 012

SAMPLE PAGE FROM C/M 012 MATERIALS CONFIGURATION LIST

APOLLO CREWBAY MATERIALS

05 FABRIC

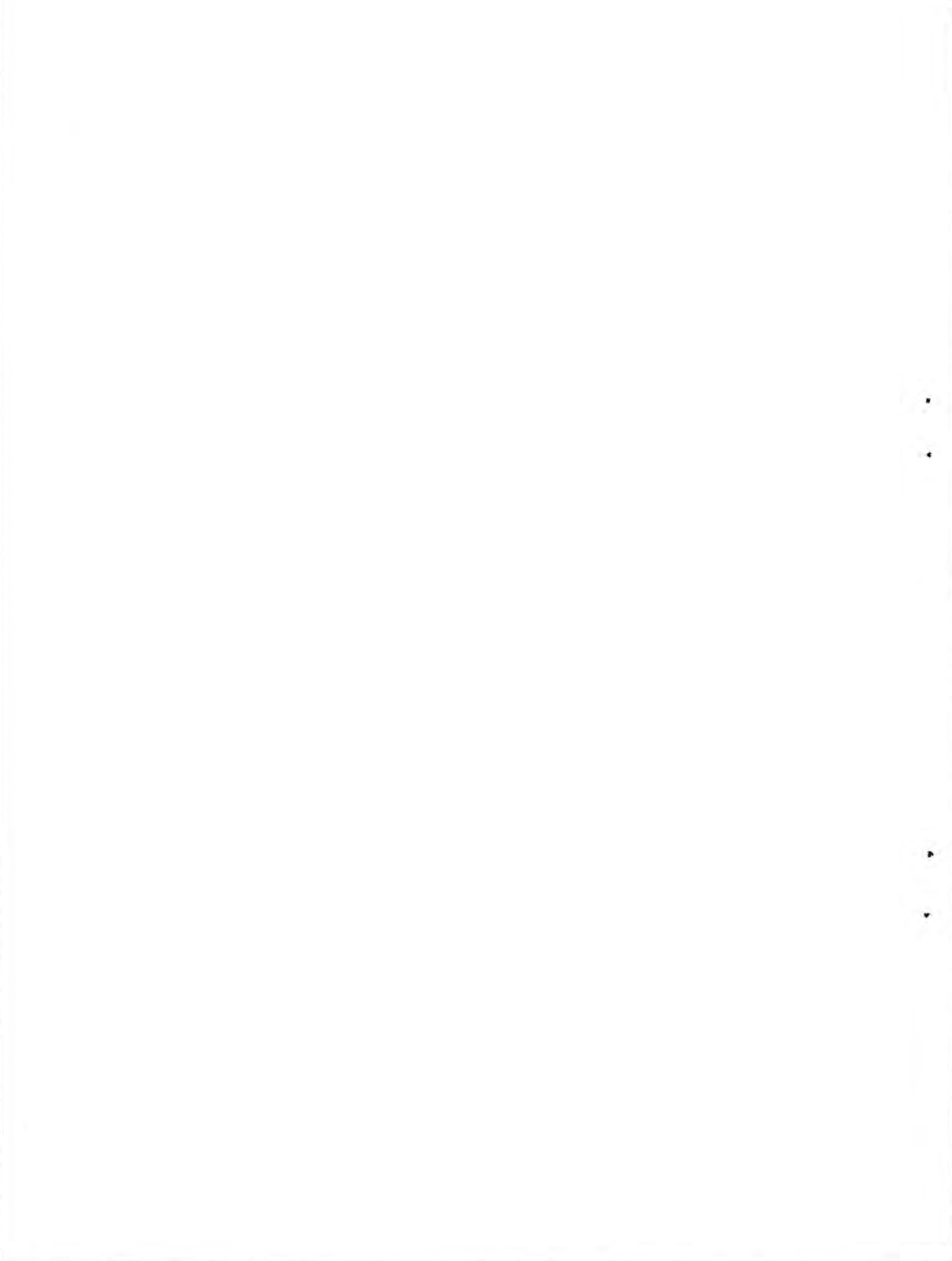
MATERIALS				LOCATION			TESTS			TEST RESULTS			QUANTITY USED		MATERIALS
NAME	MFR. DESIG.	MFR.	SPEC. NUMBER	SUB SYST.	CONTR.	SUB CONTR. SITE.	INSTL. USE	SPEC.	DATE	FIRE	FLASH	COMB. RATE	WGT. (LBS)	AREA (SQ FT)	
Nylon Lace (Ford, NY)	Class 3 Nylon	G.E.	MIL-T-713												
Textile Tape webbing	Kn	Geacel Moor	42011-000												
Polyprene Plyform Jersey	Stylin 11K-1 V.P.	Clon Rayon Mills	17-0092				5								
Dacron Trilaminar	Mylar	OT Schjeldahl	Schjeldahl OT-31	ME281-0023	NAA	R.E. Darling							.014	21.	
Thread Nylon	Unknown	Gudebrod Bros Silk	SDS-28			Whirlpool	5								
Untreated Nylon	Stylin 16	Gudebrod Bros Silk	1120137 210-0453				N								
Nylon Cord	Stylin 1K Treated	Gudebrod Bros Silk	MIL-T-713A Class 2					AS 516-1 (PA 20)	11/11/64	424	474	791			
Tape	18096	Gudebrod Bros Silk	1012507	G & M	ACED			MSCA-D-66-3	1967	500	500	500	.36	N.I.	
Tie Cord	Stylin-Lace 96	Gudebrod Bros Silk	MIL-T-713A	ME 450-0010 COM				MSCA-D-66-3	1967	500	500	500	.36	N.I.	
TEF Class Tie Cord	Gude-Class T Stylin 20T	Gudebrod Bros Silk	7821	MEB01-0040 SUP-1	NAA	Bennywell							.038	1.74	021
Tie-Lace Rubber	Tie-Lace M 202	Gudebrod Bros Silk	MIL-T-713A	ME 432-0129 FMS									.01	2.0	
Nylon Cord	Stylin 21	Gudebrod Bros Silk	MS6847				4								

REMARKS:

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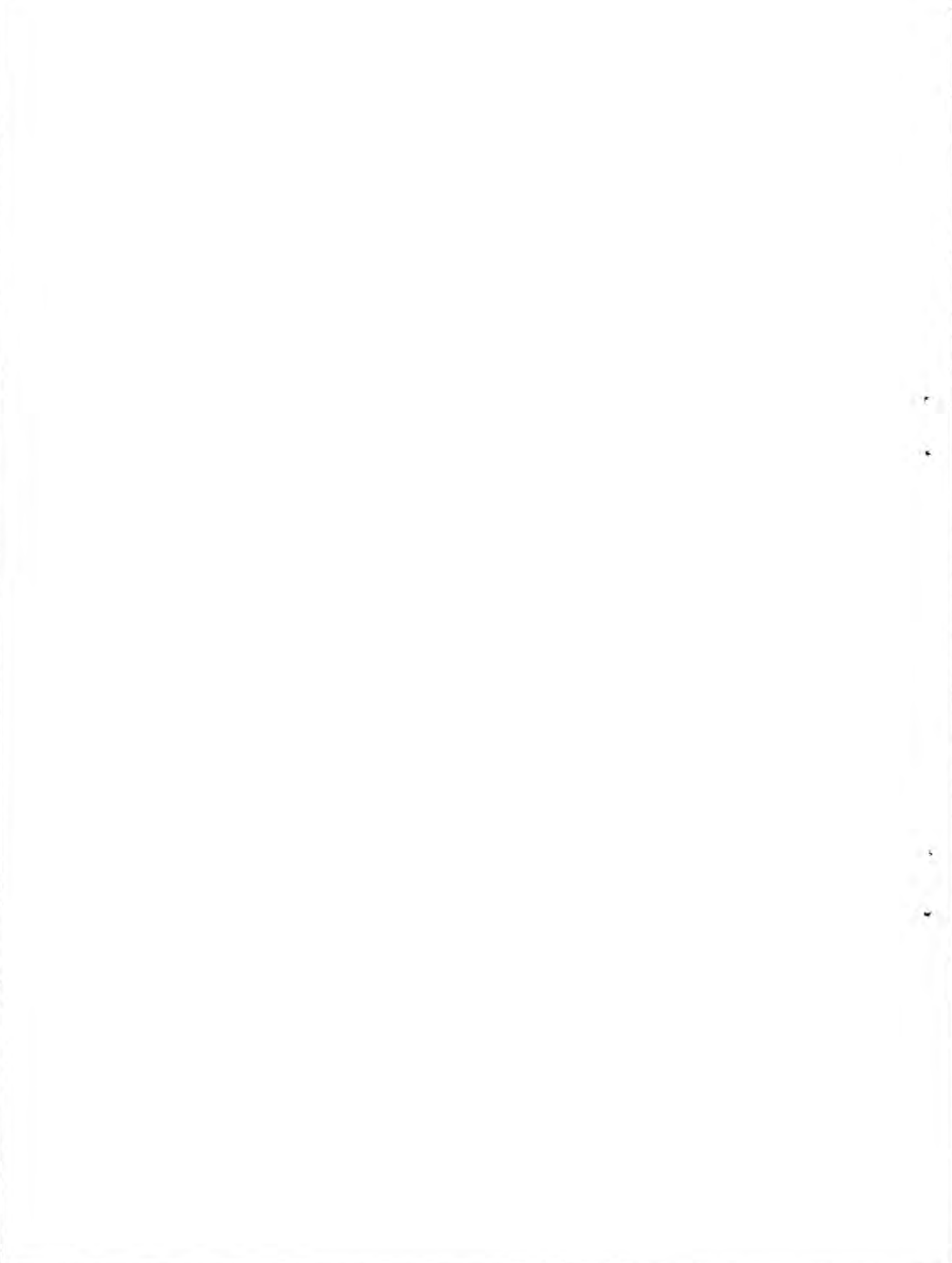


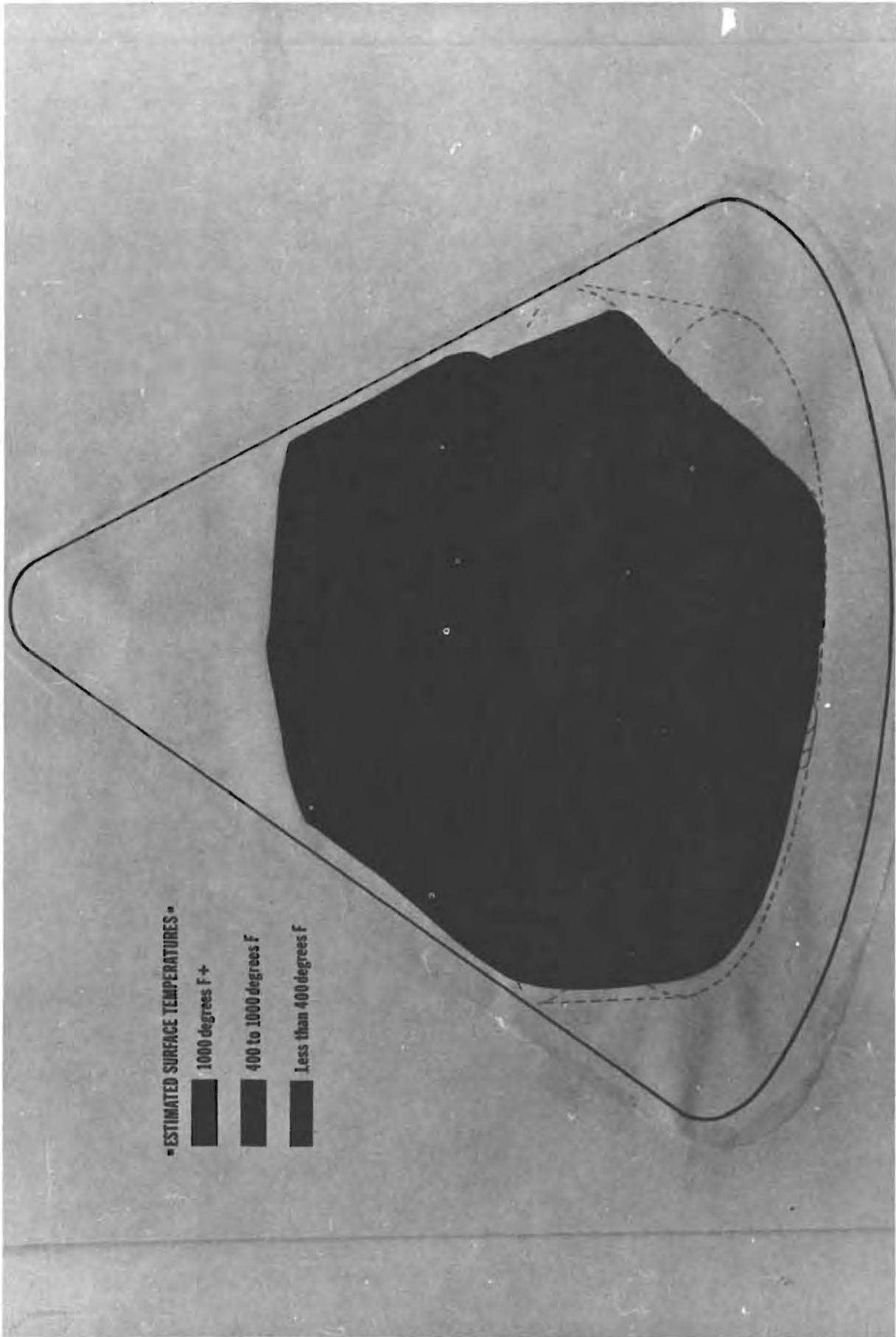
SPACECRAFT 012 TEMPERATURE MAPPING & MATERIALS USAGE DISPLAY - PRIOR TO FIRE



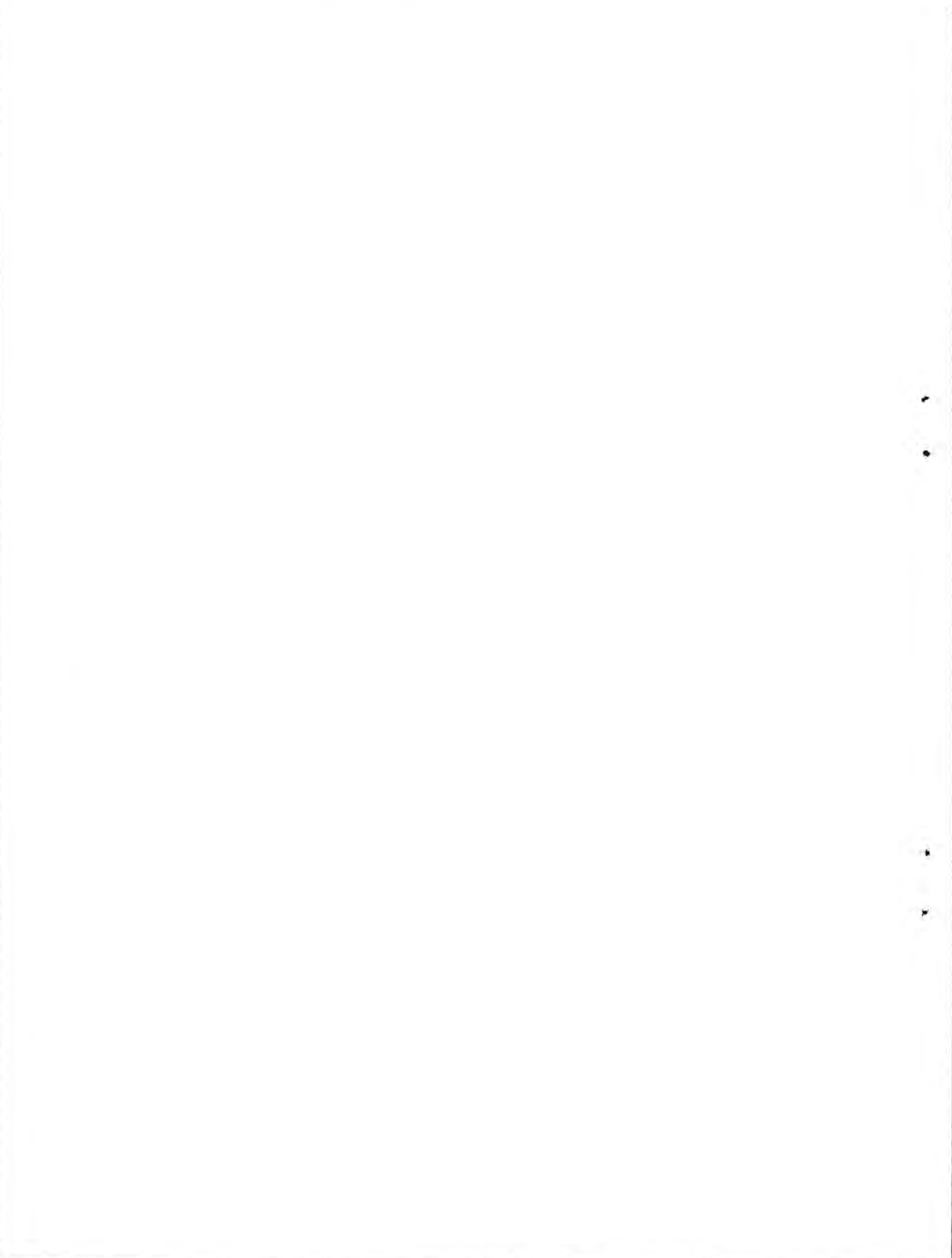


SPACECRAFT 012 TEMPERATURE MAPPING AND MATERIALS USAGE DISPLAY - AFTER FIRE

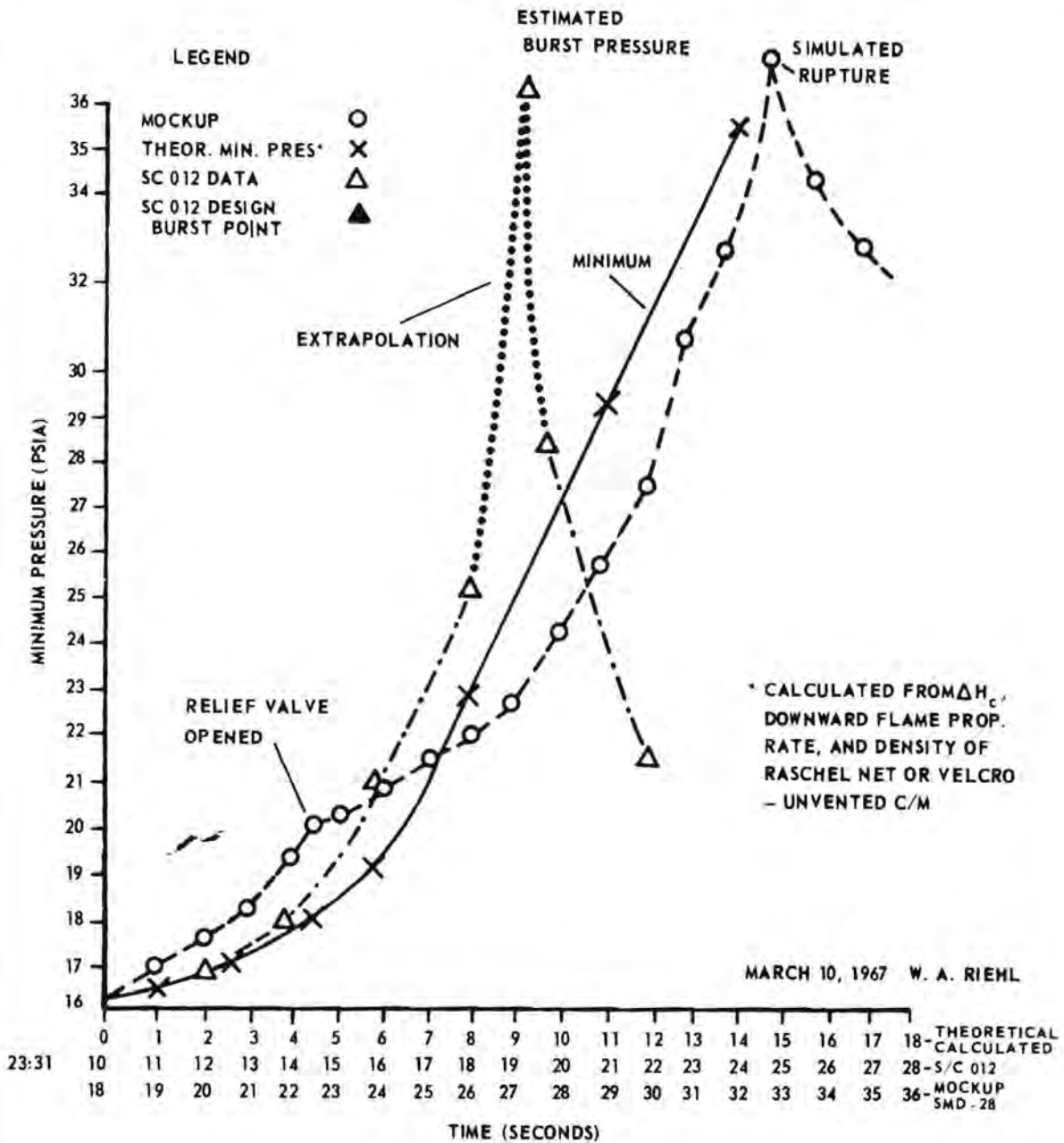




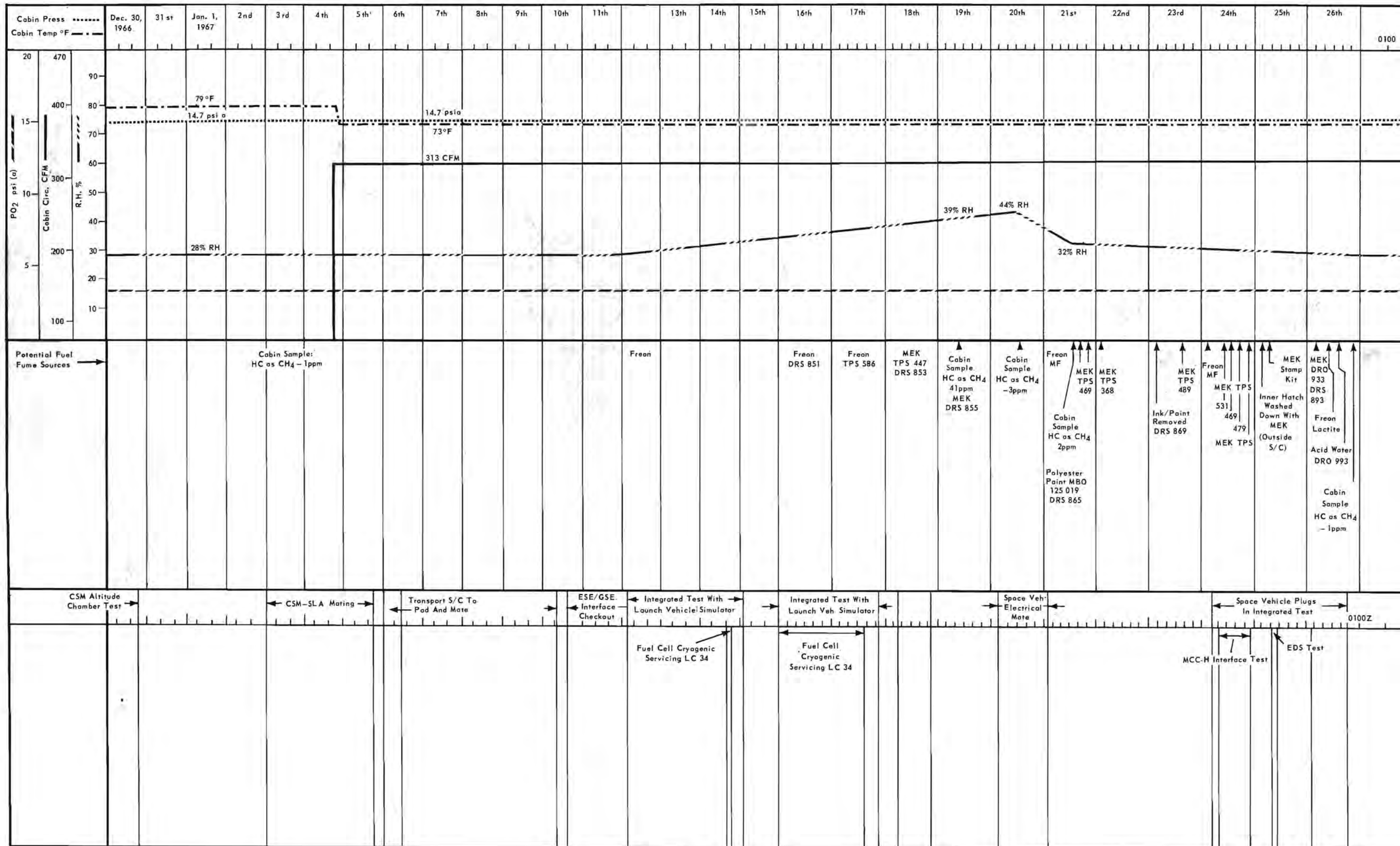
SPACECRAFT 012 TEMPERATURE MAPPING OVERLAY

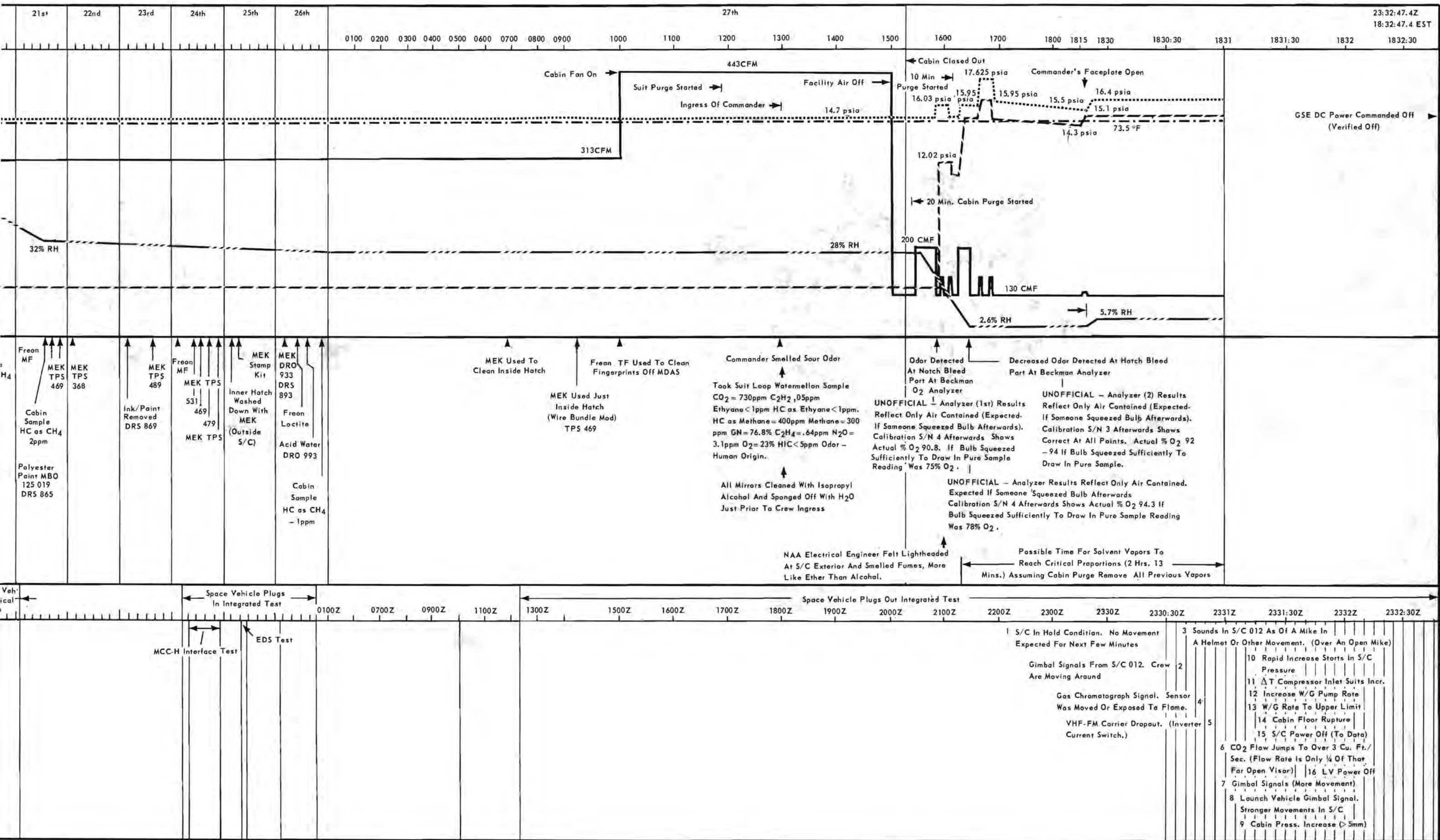


PRESSURE VS BURNING TIME

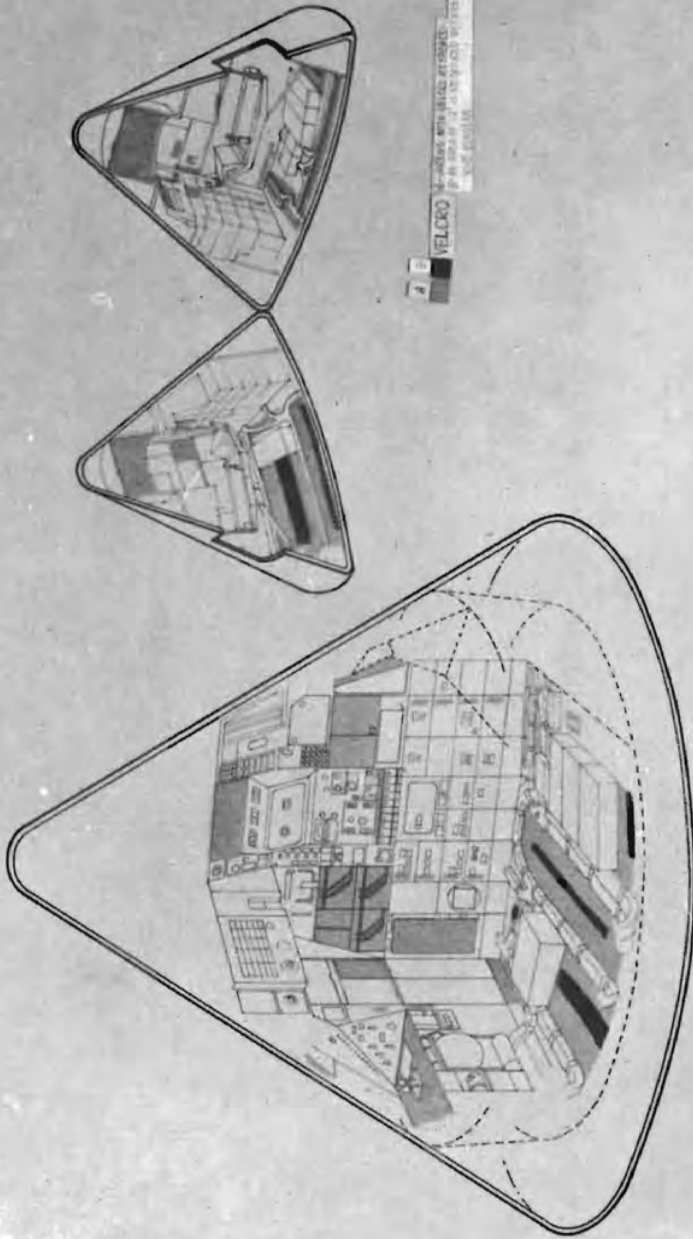


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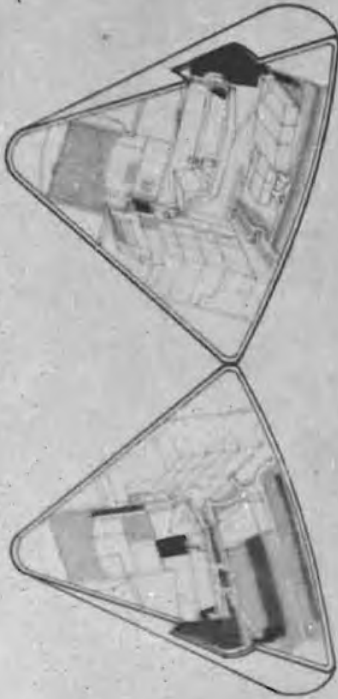
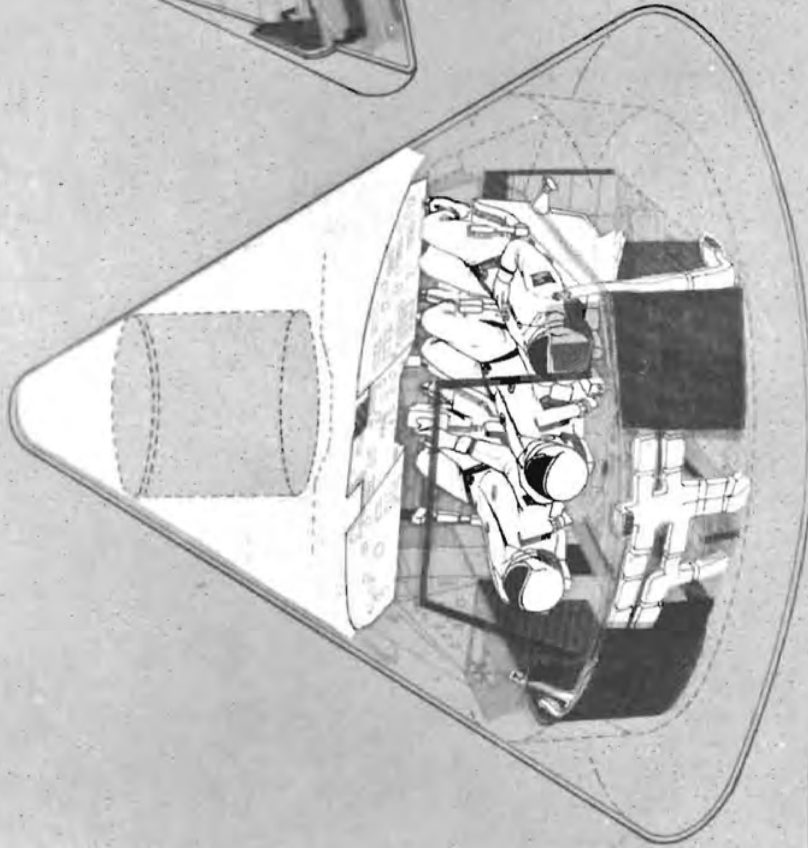
EXPOSED NON-METALLIC MATERIALS



EXPOSED NON-METALLIC LOCATION - VELCRO AND WIRE BUNDLES,
12 INCHES APART ON FLOOR

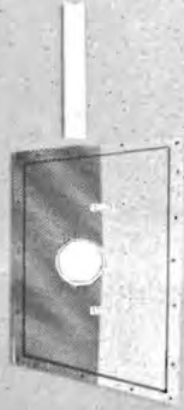


EXPOSED NON-METALLIC MATERIALS



VELCRO
URALANE
RASCHEL KNIT
TRILLOCK AND RASCHEL COVERING
RASCHEL KNIT (AFT BULKHEAD)

2/20/67
2/20/67
2/20/67
2/20/67



EXPOSED NON-METALLIC LOCATION - VELCRO AND WIRE HUNDLES,
12 INCHES APART ON AFT BULKHEAD AND HATCH



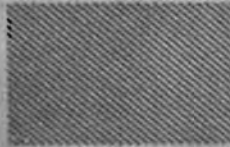
MAJOR NON-METALLIC MATERIALS IN S/C 012

HOOK



WEIGHT (LBS) 2.04

**VELCRO
(NYLON)**



FLASH POINT °F
FIRE POINT °F
COMB. RATE (IN/SEC)

AUTO IGN. °F

PILE



5PSI

16.5PSI

450
450
.57(HOOK) .73(HOOK)
2.77(PILE)

825



WEIGHT (LBS) 2.17

**URALANE
(POLYURETHANE FOAM)**



FLASH POINT °F
FIRE POINT °F
COMB. RATE (IN/SEC)
AUTO IGNITION °F

5PSI

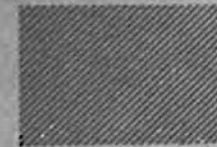
16.5PSI

302
302
.59 1.0
500



WEIGHT (LBS) 2.39

**RASCHEL KNIT
(NYLON)**



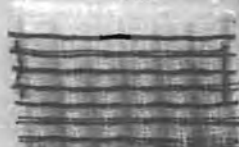
FLASH POINT °F
FIRE POINT °F
COMB. RATE (IN/SEC)
AUTO IGNITION °F

5PSI

16.5PSI

460
460
.47 1.38

PAD



WEIGHT (LBS) 6.91

**COUCH PAD
RASCHEL KNIT & TRI-LOCK**

USED



FLASH POINT °F
FIRE POINT °F
COMB. RATE (IN/SEC)
AUTO IGNITION °F

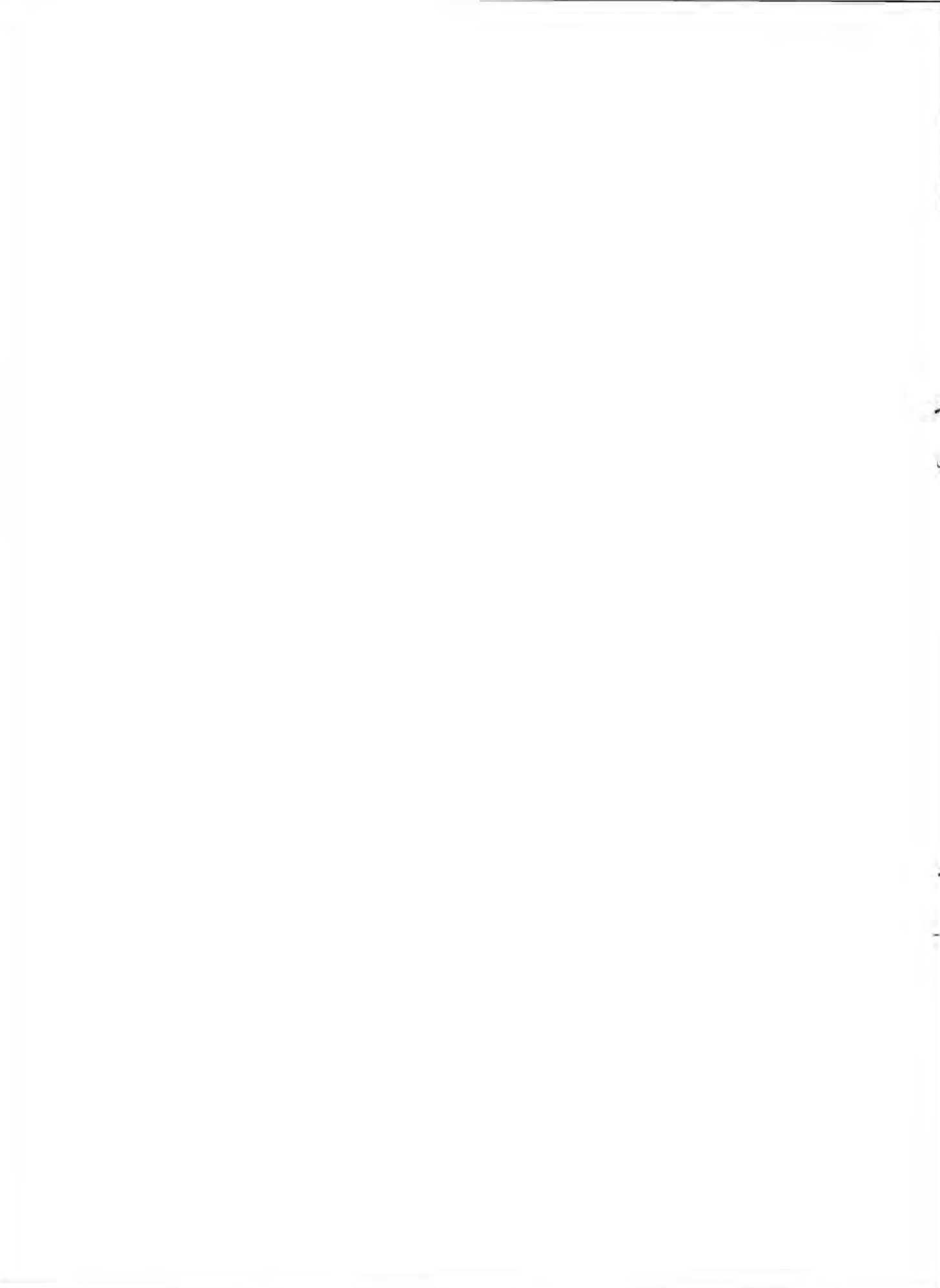
5PSI

16.5PSI

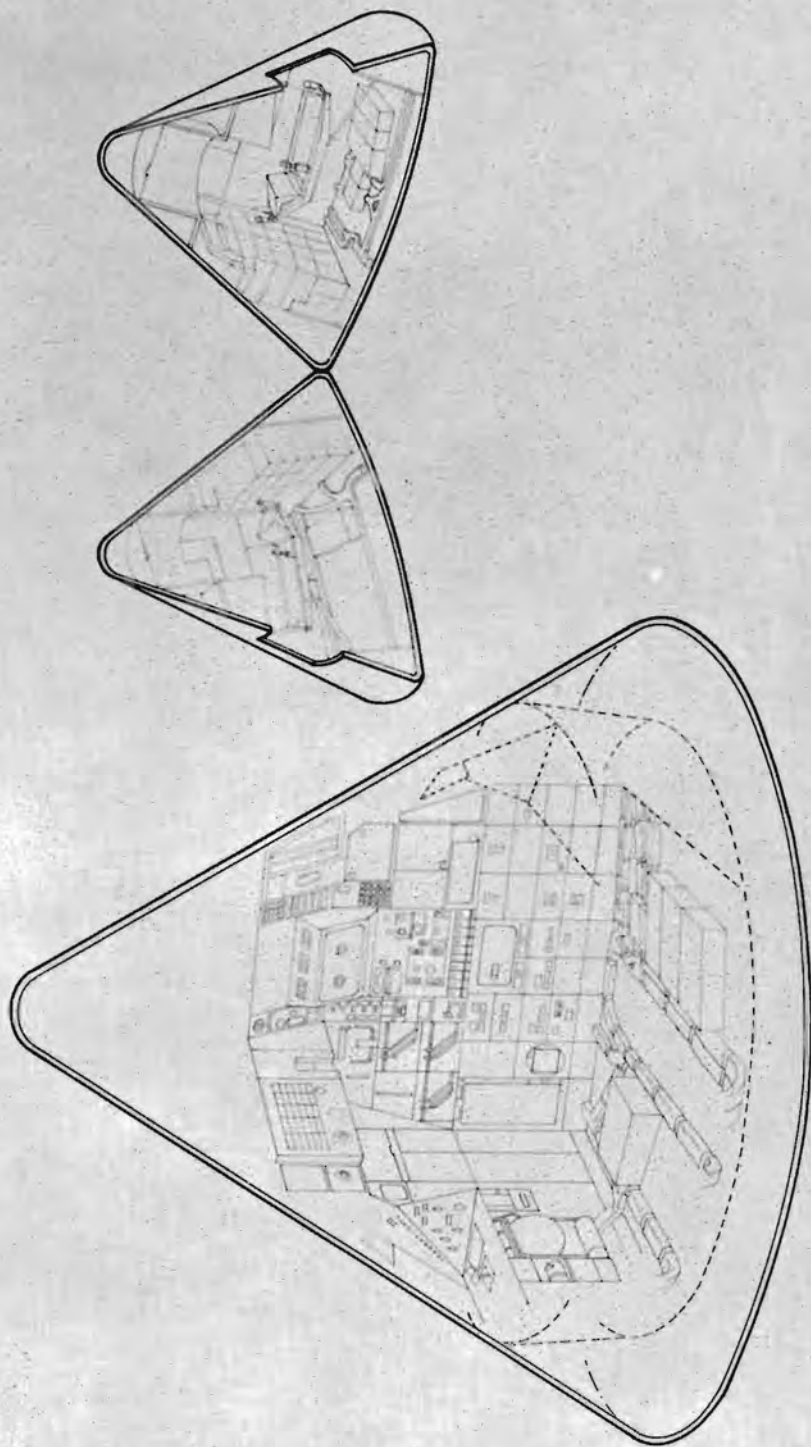
250
250
1.07 2.0

MAJOR EXPOSED NON-METALLIC MATERIALS IN SPACECRAFT 012

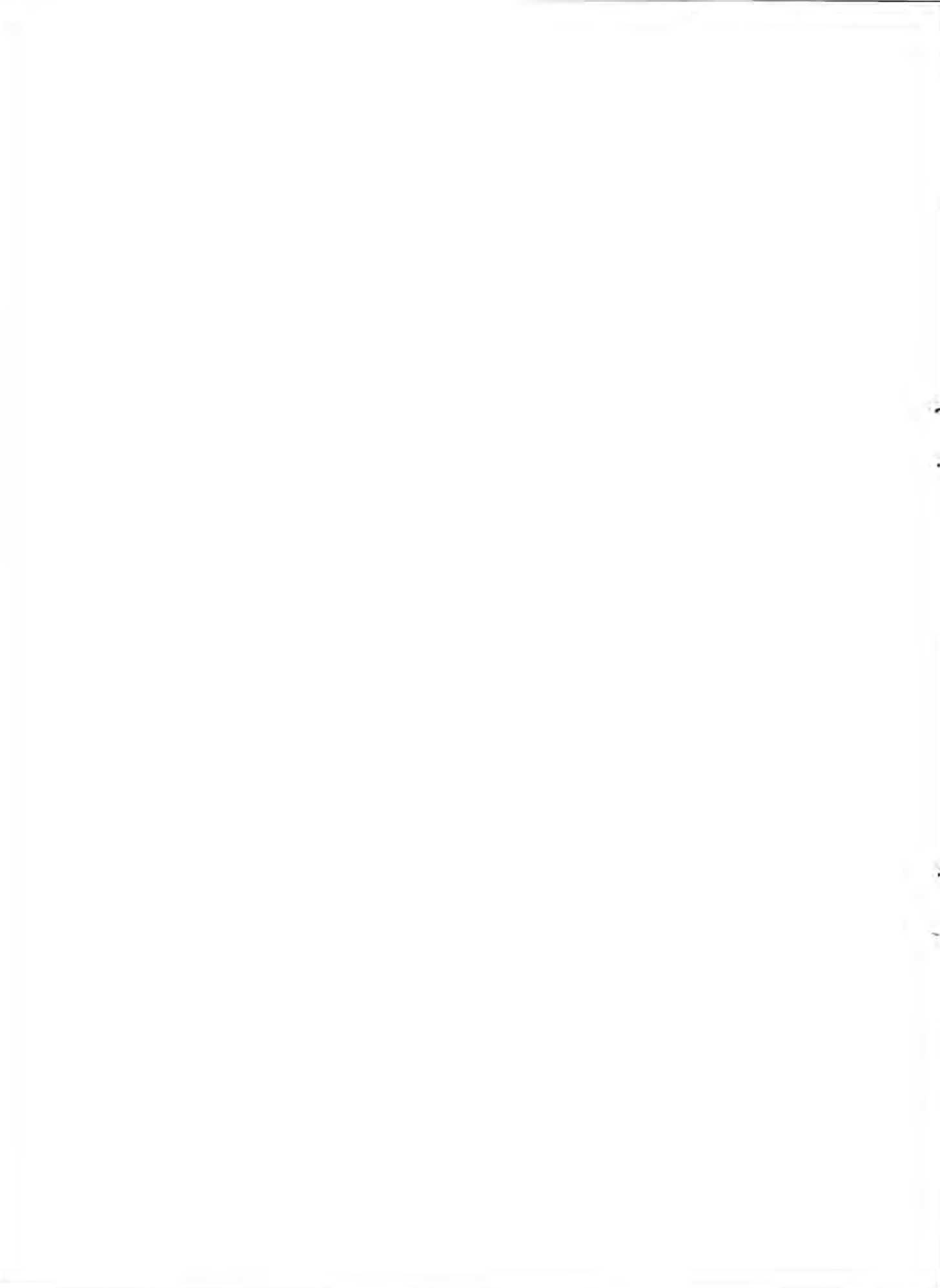
ENCLOSURE 8-10



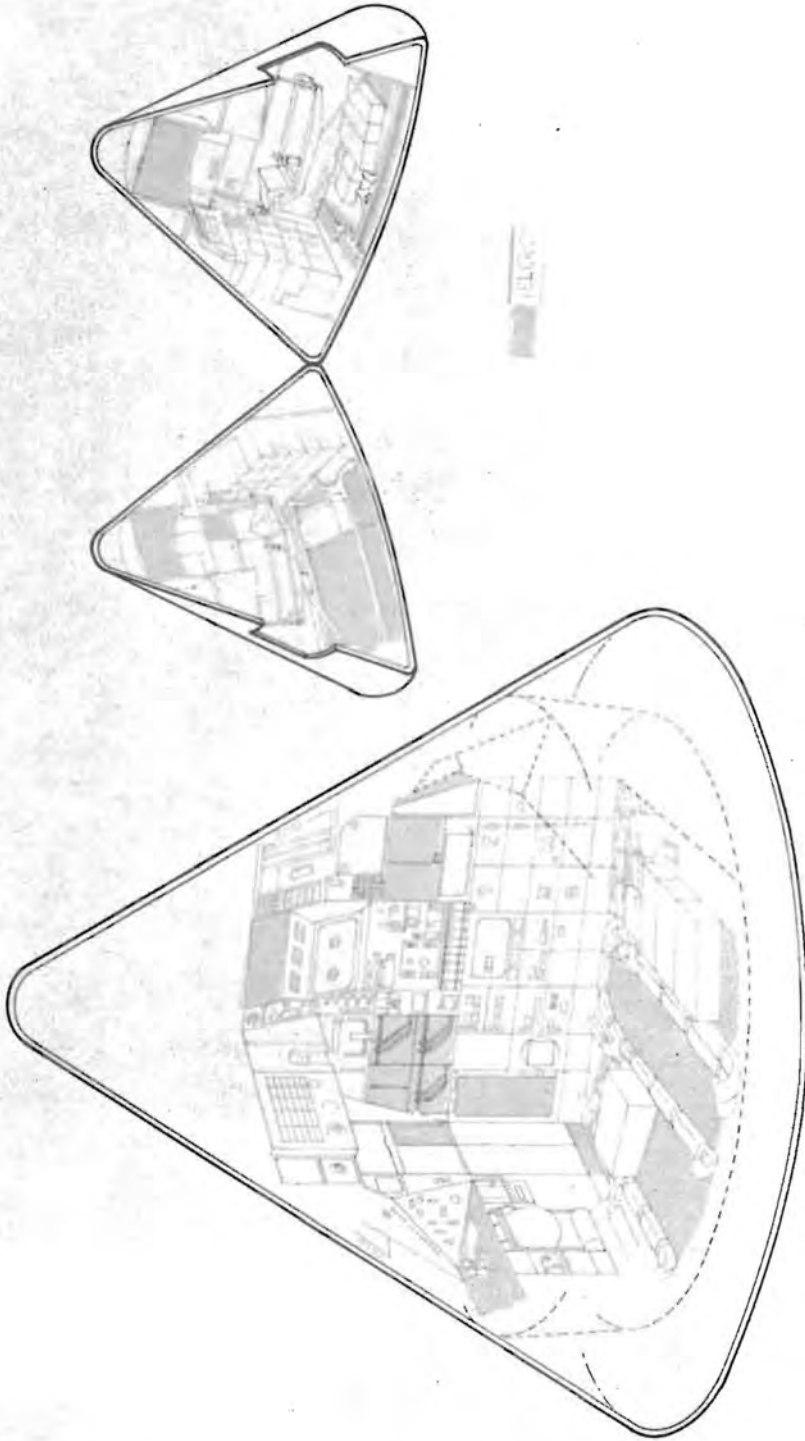
EXPOSED NON-METALLIC MATERIALS



EXPOSED NON-METALLIC MATERIALS LOCATION - COMMAND MODULE OUTLINE



EXPOSED NON-METALLIC MATERIALS

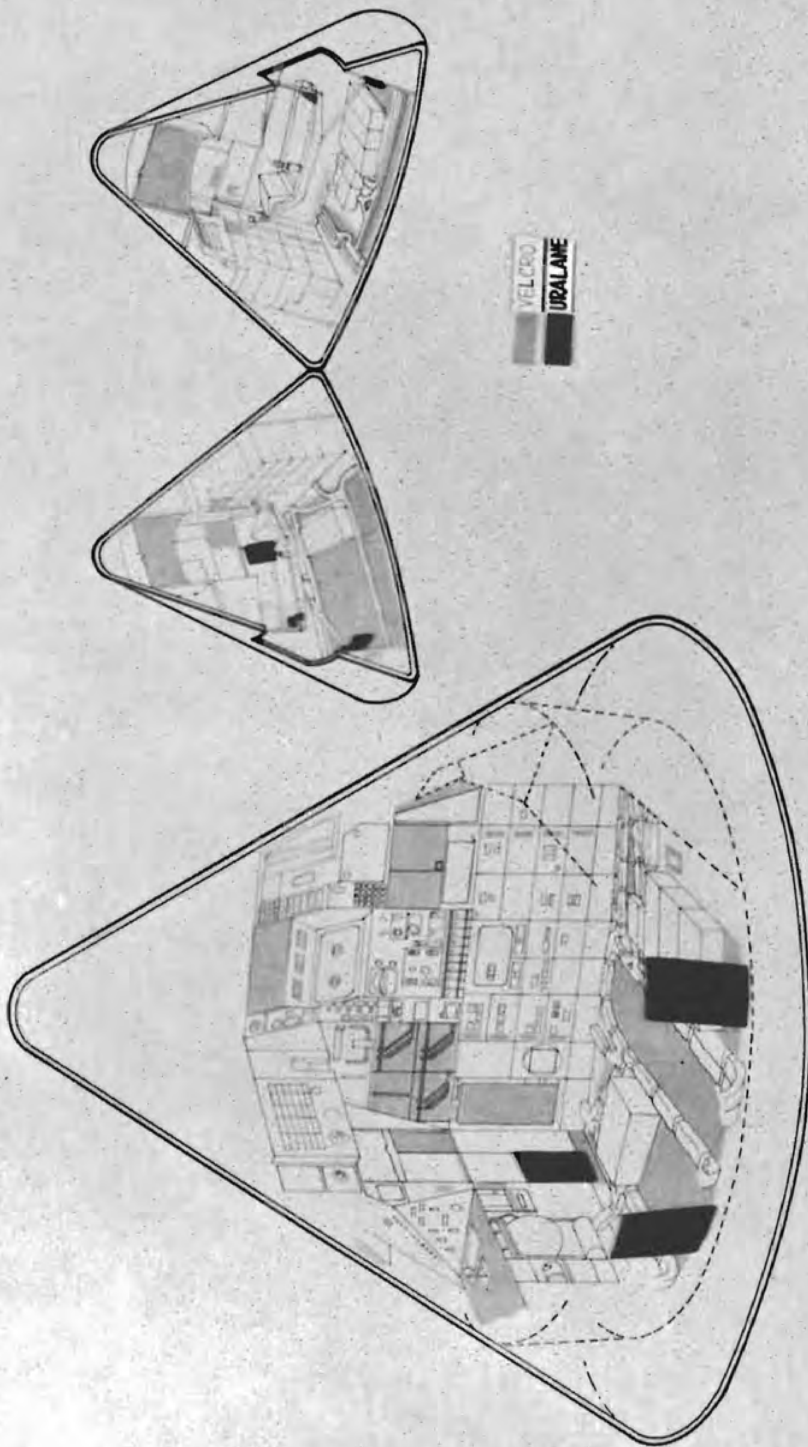


2/20/67

EXPOSED NON-METALLIC MATERIALS LOCATION - VELCRO



EXPOSED NON-METALLIC MATERIALS

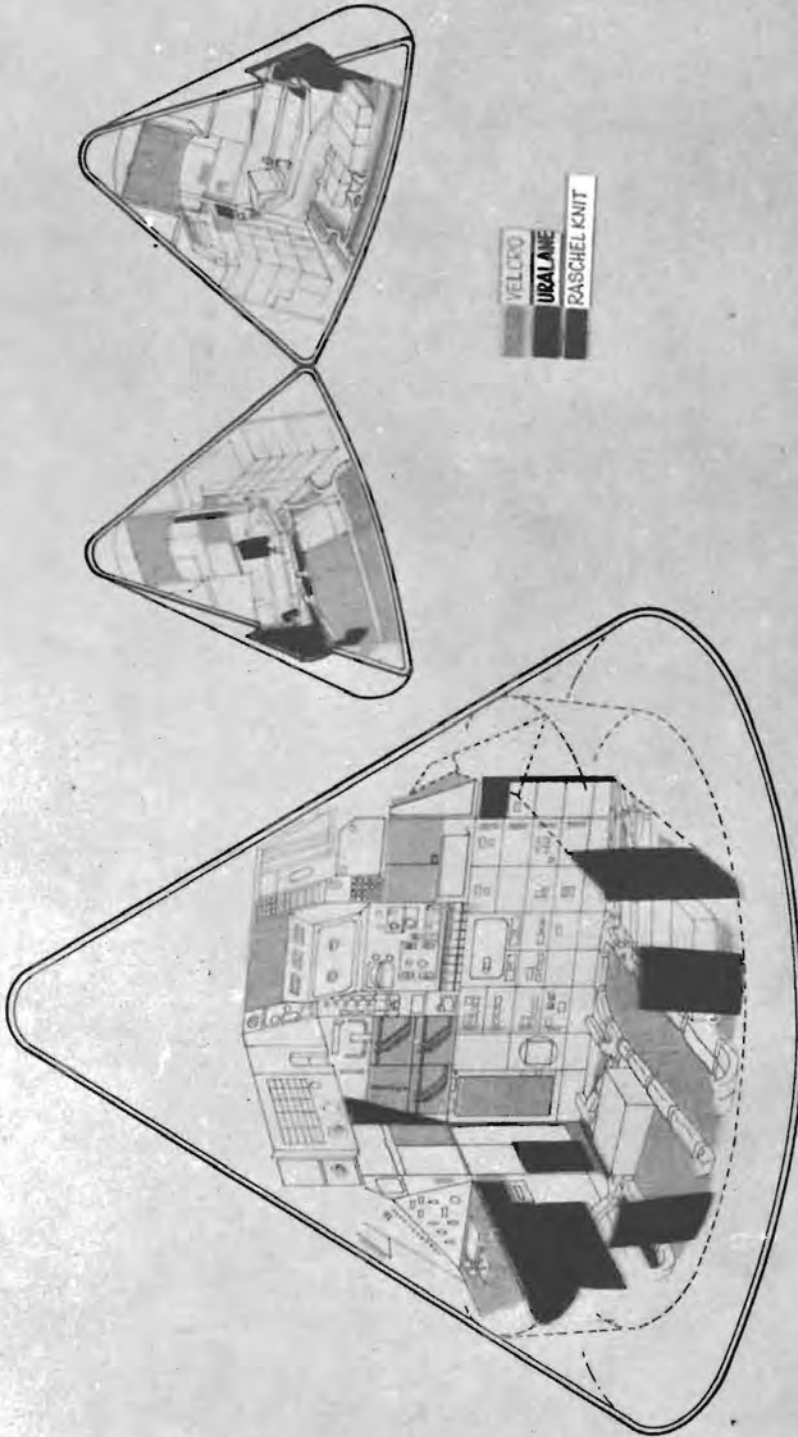


2/20/67
2/20/67

EXPOSED NON-METALLIC MATERIALS LOCATION - VELCRO AND URALANE FOAM



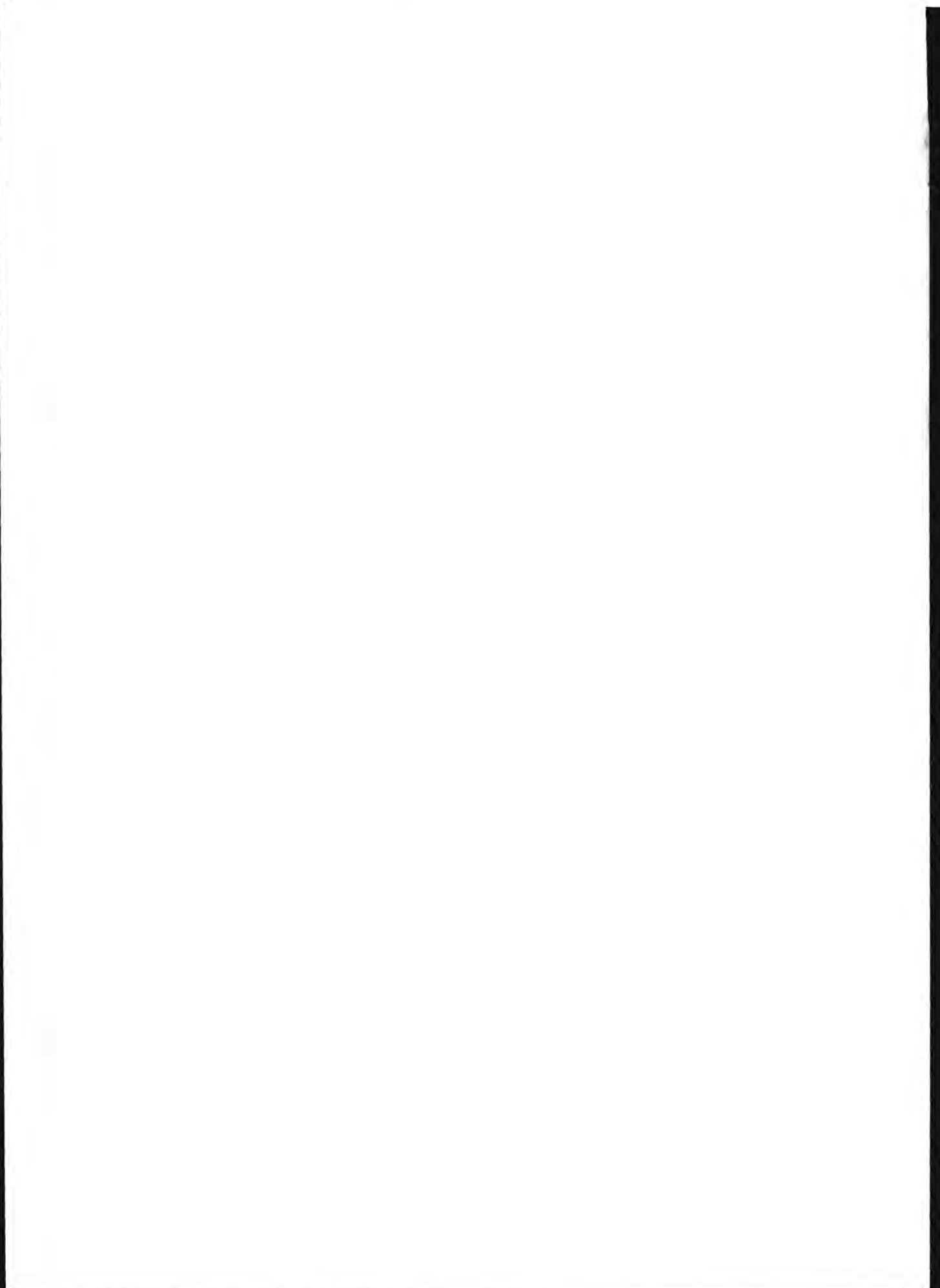
EXPOSED NON-METALLIC MATERIALS



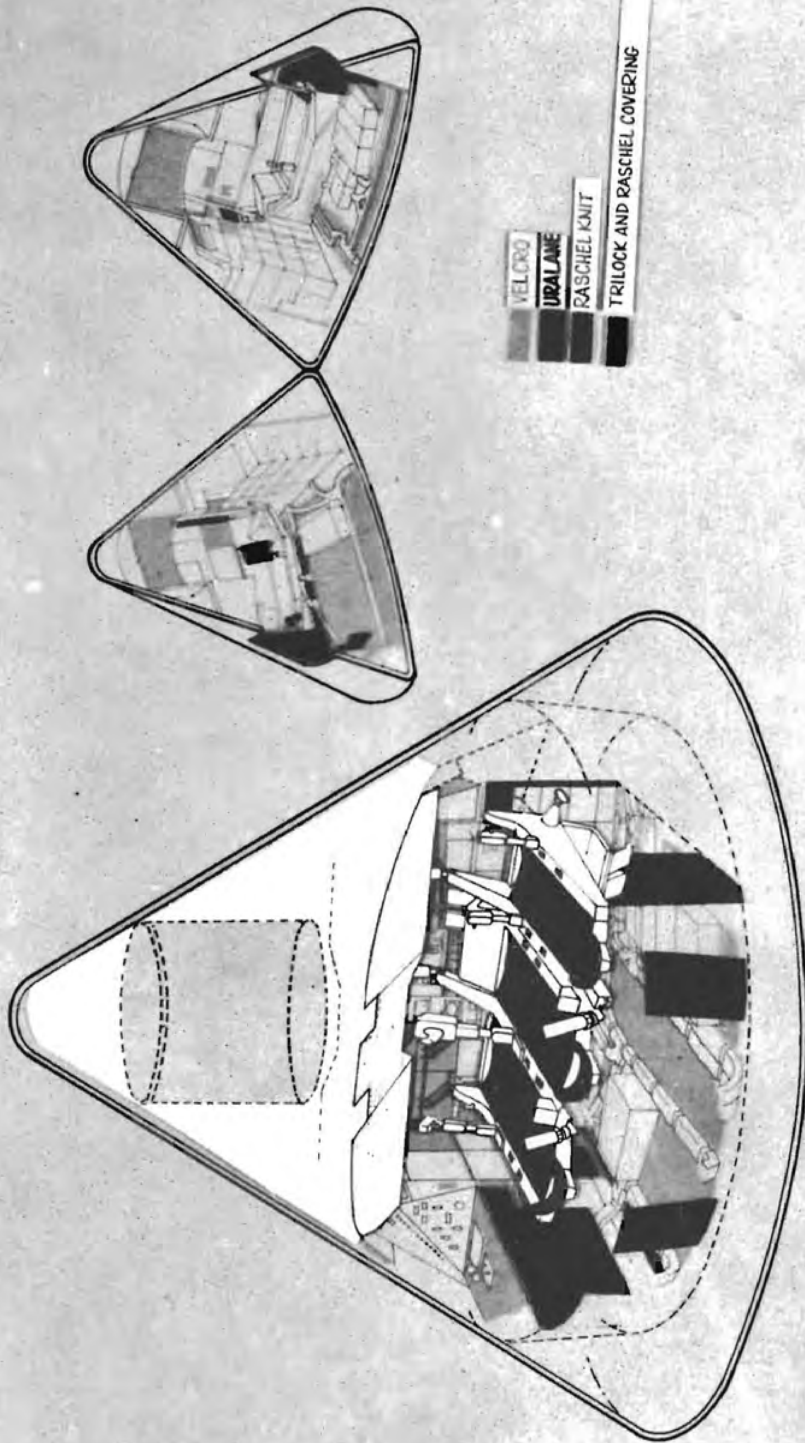
VELCRO
URALANE
RASCHEL KNIT

2/20/67
2/20/67
2/20/67

EXPOSED NON-METALLIC MATERIALS LOCATION - VELCRO AND URALANE FOAM
AND RASCHEL KNIT



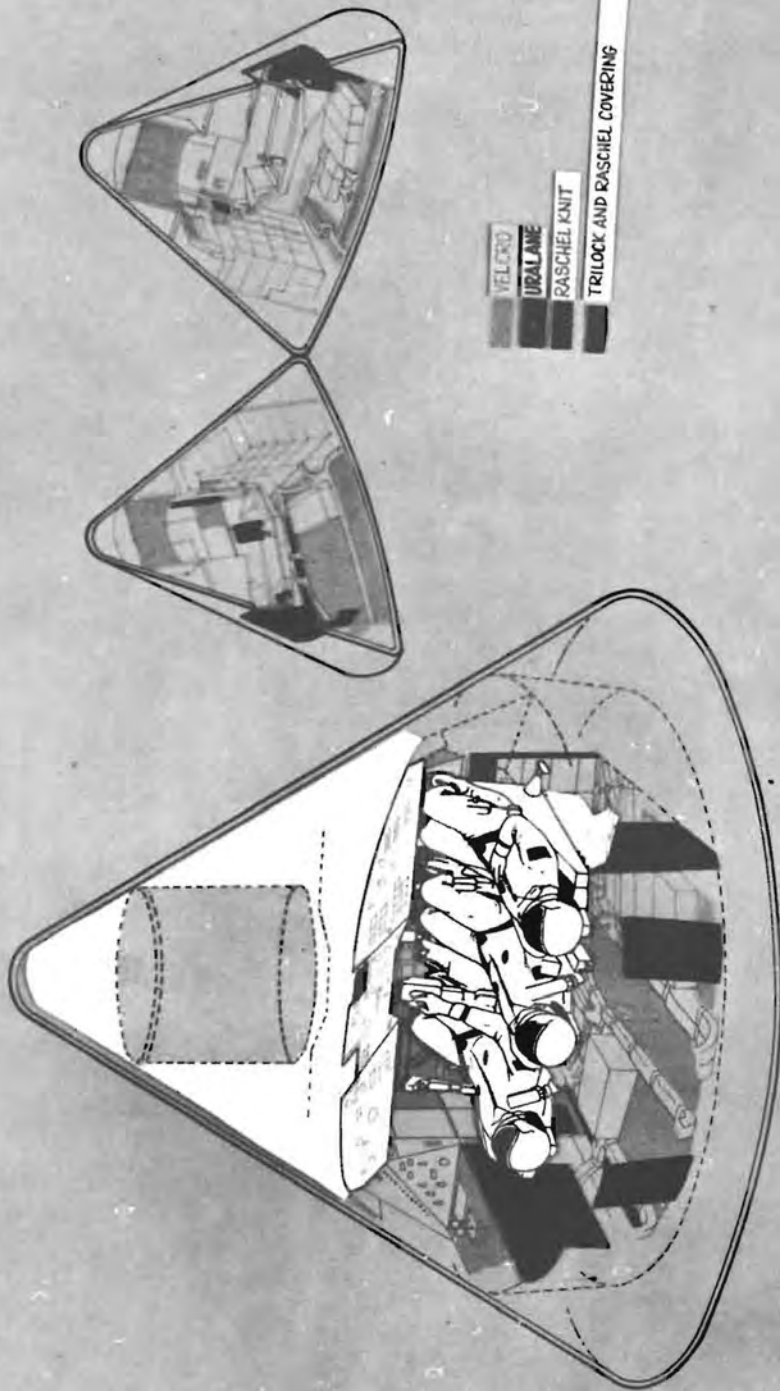
EXPOSED NON-METALLIC MATERIALS



EXPOSED NON-METALLIC MATERIALS LOCATION - VELCRO AND URALANE FOAM
AND RASCHEL KNIT AND TRILOCK/RASCHEL COVERING

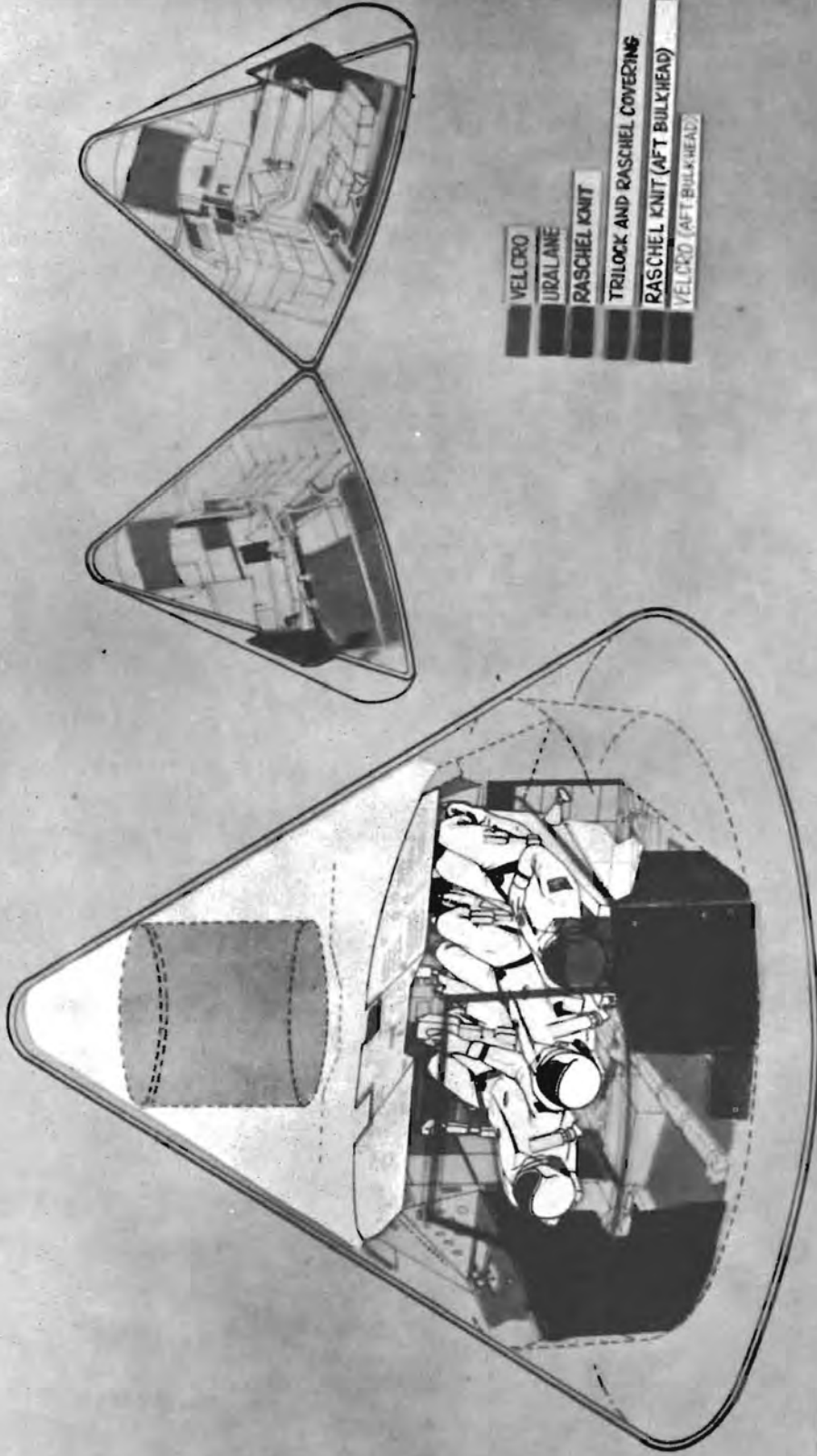
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EXPOSED NON-METALLIC MATERIALS





EXPOSED NON-METALLIC MATERIALS



- VELCRO
- URALANE
- RASCHEL KNIT
- TRILOCK AND RASCHEL COVERING
- RASCHEL KNIT (AFT BULKHEAD)
- VELCRO (AFT BULKHEAD)

2/20/67
2/20/67
2/20/67
2/20/67
2/20/67



EXPOSED NON-METALLIC MATERIALS LOCATION - AFT BULKHEAD ADDED







CANDIDATE NON-FLAMMABLE MATERIALS - FELTS, COATINGS, LUBRICANTS, ADHESIVES AND COOLANTS

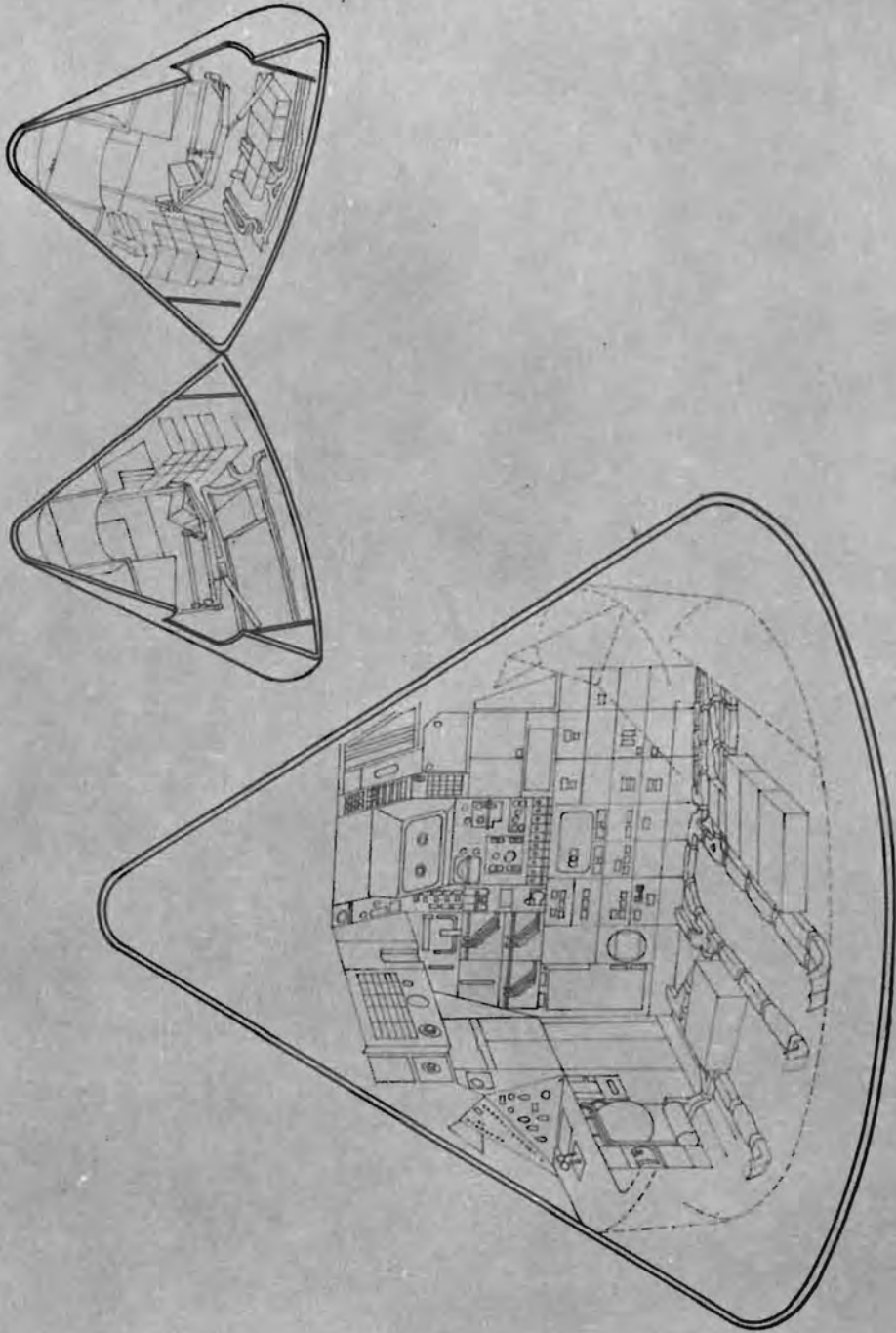




POSSIBLE EQUIPMENT ATTACHMENT SUBSTITUTIONS

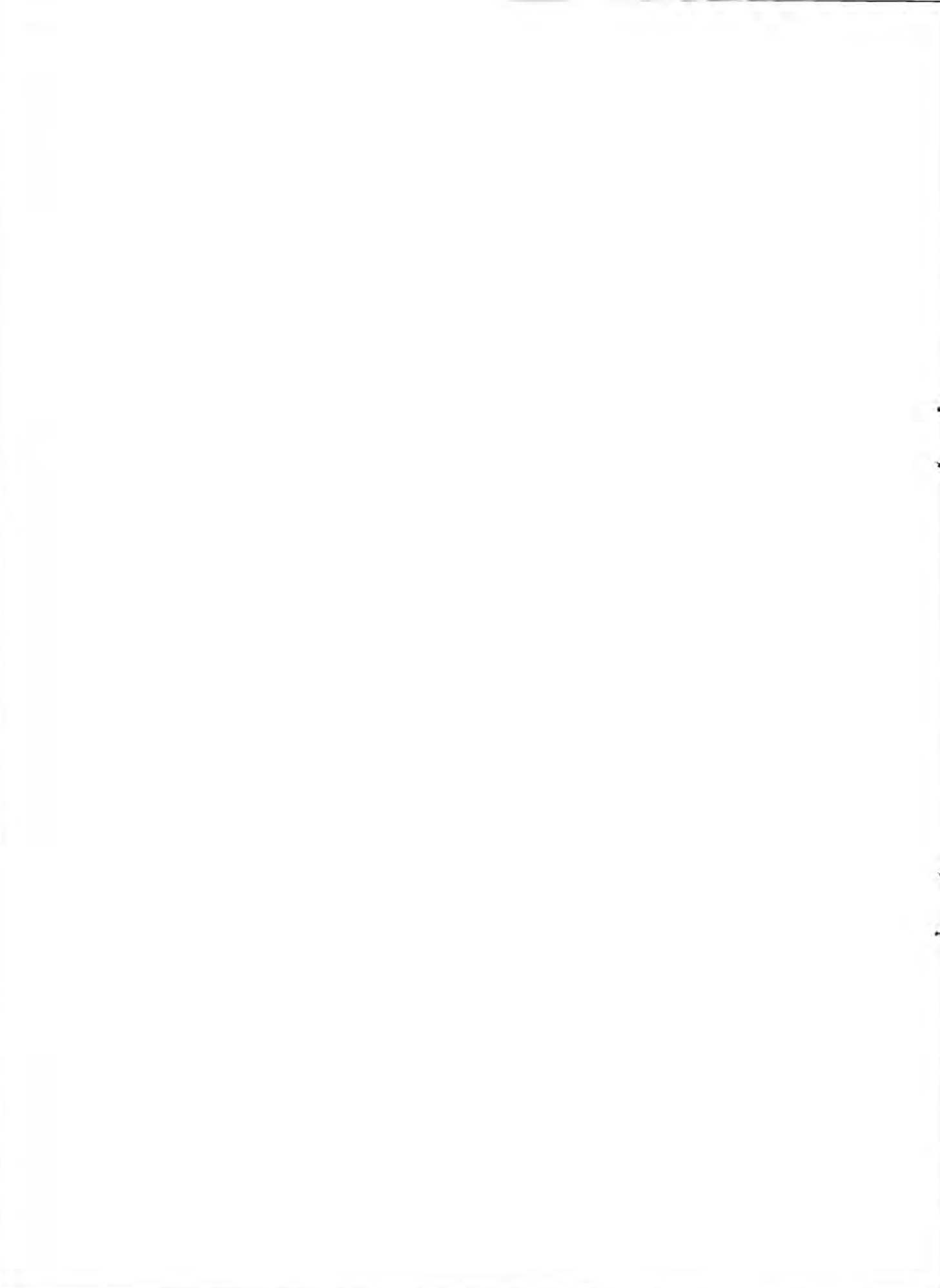


CANDIDATE NON-FLAMMABLE MATERIALS

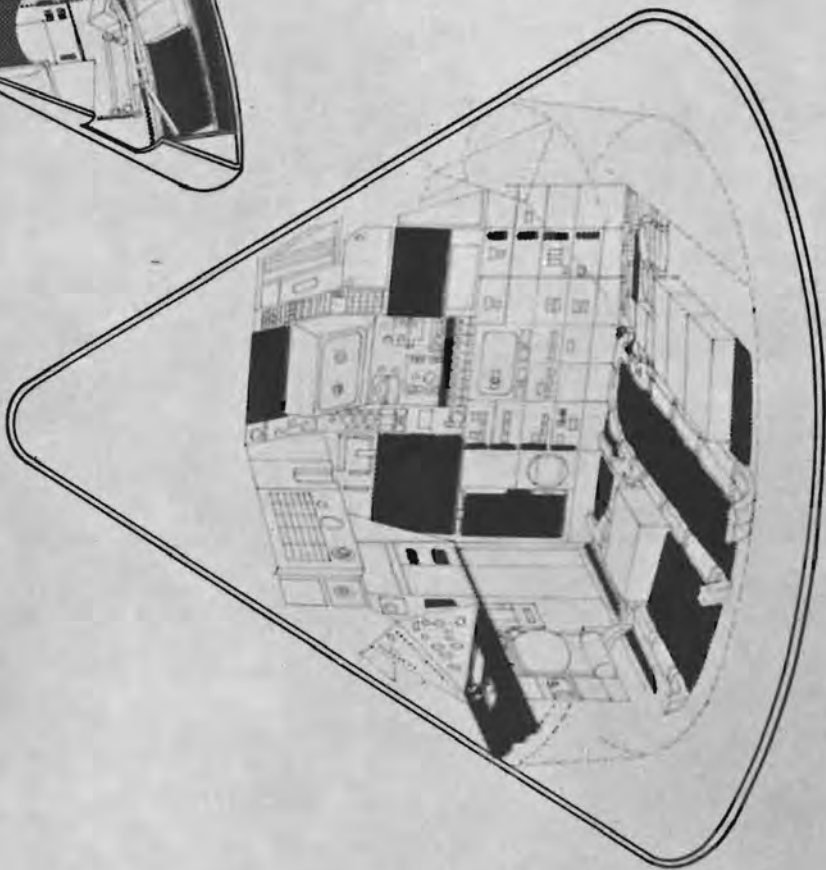
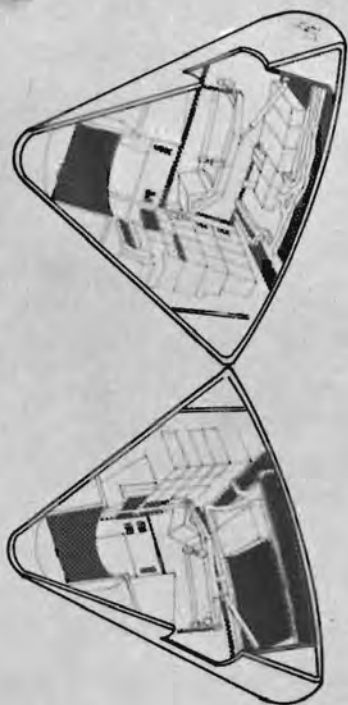


3/4/67

CANDIDATE NON-FLAMMABLE MATERIALS - COMMAND MODULE OUTLINE



CANDIDATE NON-FLAMMABLE MATERIALS

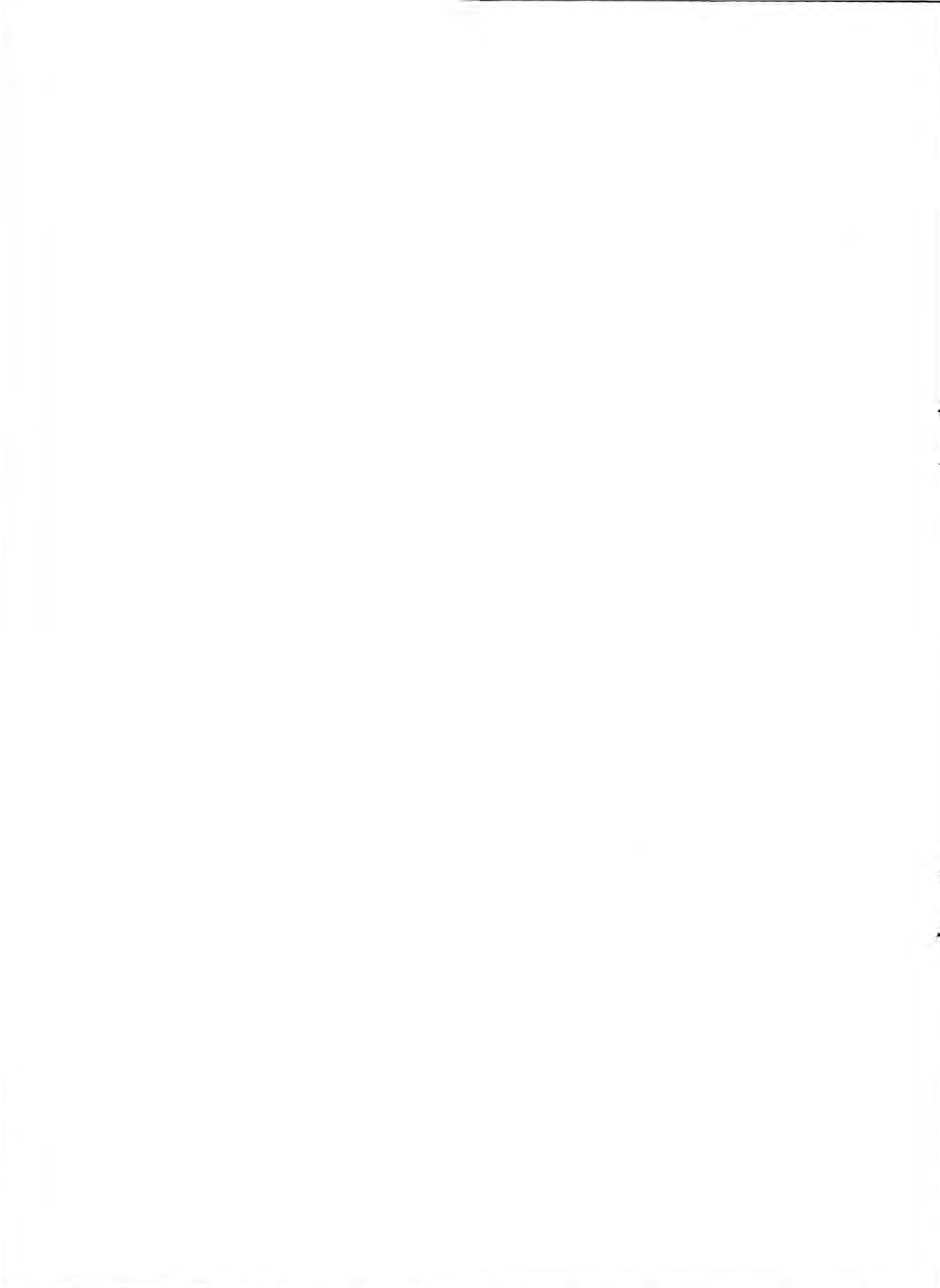


SUBSTITUTE MATERIALS FOR:
VELCRO, HOOK AND PILE

- 1. POLYESTER FIBRE VELCRO
- 2. RADIANT-TEMPERATURE PROTECTIVE COAT (RT-23)
- 3. STAINLESS STEEL AND ALUMINUM

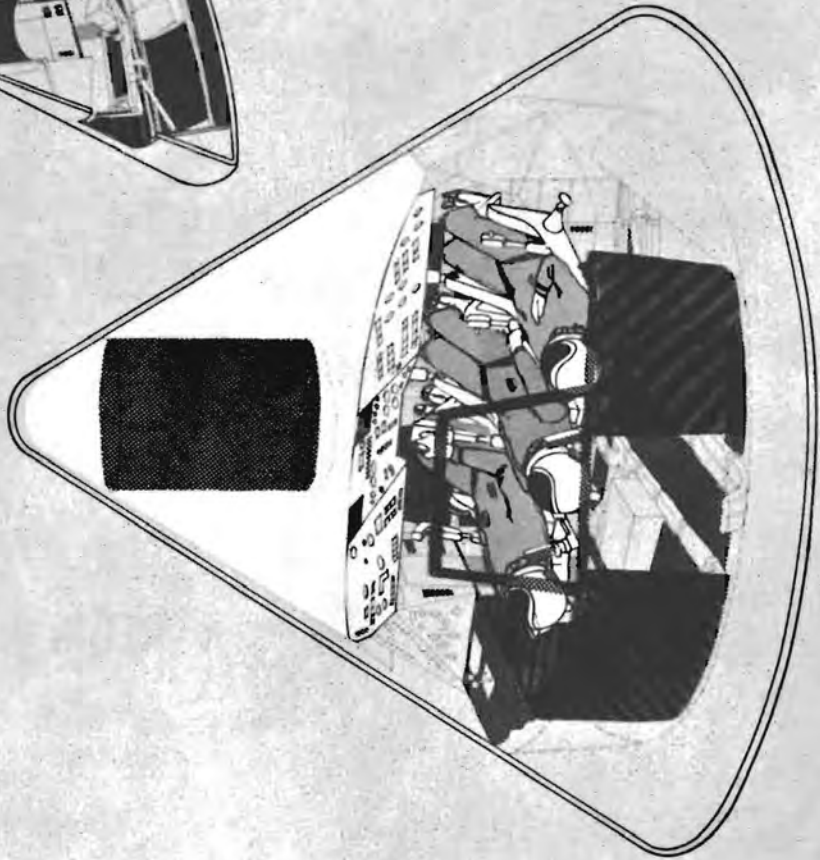
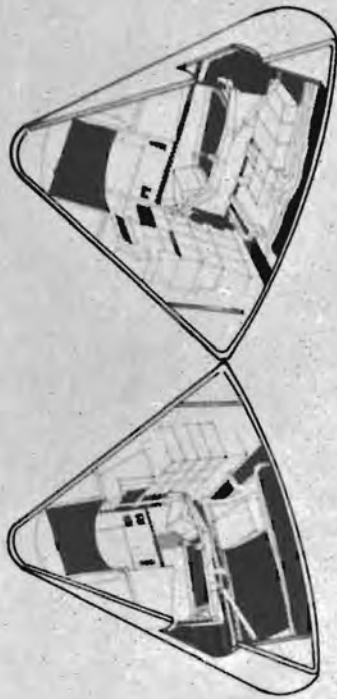
3/4/67

CANDIDATE NON-FLAMMABLE MATERIALS - VELCRO SUBSTITUTES





CANDIDATE NON-FLAMMABLE MATERIALS



SUBSTITUTE MATERIALS FOR:

HEAVY WOOD AND PLY

AS SPECIFIED UNDER WHICH
OF FEDERAL SPECIFICATION NUMBERS THAT IS APPLICABLE
TO THE ABOVE MATERIALS

SUBSTITUTE MATERIALS FOR:

URETHANE AND POLYURETHANE FOAM

AS SPECIFIED UNDER WHICH
OF FEDERAL SPECIFICATION NUMBERS THAT IS APPLICABLE
TO THE ABOVE MATERIALS

SUBSTITUTE MATERIALS FOR:

TEXTILES AND CLOTHING MATERIALS

AS SPECIFIED UNDER WHICH
OF FEDERAL SPECIFICATION NUMBERS THAT IS APPLICABLE
TO THE ABOVE MATERIALS

SUBSTITUTE MATERIALS FOR:

SKINNELEAVE

AS SPECIFIED UNDER WHICH
OF FEDERAL SPECIFICATION NUMBERS THAT IS APPLICABLE
TO THE ABOVE MATERIALS

SUBSTITUTE MATERIALS FOR:

ADHESIVES (OTHER THAN EPOXY)

AS SPECIFIED UNDER WHICH
OF FEDERAL SPECIFICATION NUMBERS THAT IS APPLICABLE
TO THE ABOVE MATERIALS

3/4/67

LIST OF REFERENCES

	TITLE	IDENTIFICATION SOURCE
8-1	Nonmetallic Materials Used in the Interior of the Apollo Command Module, September 1, 1966	Unidentified (30 pgs. 881 materials)
8-2	Subcontractor Material Use List	Unidentified (53 pgs)
8-3	Updated Tab Run of Nonmetallic Materials	NO ID Number
8-4	Stabilization and Control System, Honeywell Inc., Material List, October 25, 1964	A64769A (2)
8-5	Partial List of Materials on S/C 012 by Drawing Number	Unidentified (48 pgs)
8-6	Material Usage G&N 12/50, February 5, 1967	Unidentified (86 materials plus hand-written update of KSC added)
8-7	Apollo Materials Master File Index, December 28, 1967	RPT-X50-98-915
8-8	GFE Equipment - Nonmetallic materials (Addendum to TRIS 020580)	TRIS 020583
8-9	GFE - Flight Crew Support Division Hardware Onboard, January 27, 1967	Unidentified (Survey of cognizant FCSD personnel)
8-10	Acceptable S. C 012 GFE Materials List - Tab Run, February 6, 1967	TRIS 020585
8-11	Bills of Materials, Space Suit Assembly S987-000 Part I	TRIS 020590
8-12	Bills of Materials, Space Suit Assembly, S978-000 Part II	TRIS 020591
8-13	Bills of Materials, Helmet Assembly, A1920-000	TRIS 020592
8-14	Collins Test Data	AR-518-1, January 1965
8-15	Hamilton Std. Test Data	SVHSER 4024,3886
8-16	KSC Data	February 14, 1967
8-17	MSC Data	February 2-9, 1967
8-19	MSC Data	Tech. Note S136, 1966
8-18	MSC Data	February 7-8, 1967
8-20	WSTF Data	February 2, 1967
8-21	GAEC Data	LED-520-3A, January 1966
8-22	S. A. M. Data	TR-65-78, 1965
8-23	MIT G&N Data	Not published, 1967
8-24	NAA/Hughes Data	P64-53, June 1964
8-25	NAA/Hughes Data	P66-06, January 1966
8-26	NAA/Hughes Data	P67-32, February 1967
8-27	NAA/Hughes Data	2748, 06/56, February 20, 1967
8-28	S/C 012, Materials Configuration	Apollo 204 Review Board Panel 8 Materials Review March 6, 1967
8-29	Spark Ignition Tests	Apollo 204 Review Board Panel 8 Materials Task 2.1
8-30	Determination of Impact Sensitivity of Materials to GOX	Apollo 204 Review Board Panel 8 Materials Task 2.29
8-31	Material Cataloging and Routine Testing	Apollo 204 Review Board Panel 8 Materials, Tasks, 1.1, 1.2 and 1.3
8-32	Electrostatic Spark Generation in Selected Nonmetallic Materials	Apollo 204 Review Board Panel 8 Materials, March 8, 1967
8-33	Flammability of Materials in O ₂ (Preliminary)	Apollo 204 Review Board Panel 8 Materials Task 2.3
8-34	Temperature Mapping in S/C 012	Apollo 204 Review Board Panel 8 Materials Task 2.4
8-35	Preliminary Temperature Survey of S/C 012	Apollo 204 Review Board Panel 10, February 28, 1967

8-36	Temperature Changes in S/C 012	Apollo 204 Review Board Panel 3, February 28, 1967
8-37	Temperature Changes in S/C 012	Apollo 204 Review Board Panel 1, February 20, 1967
8-38	Wire Bundle Insulation Test Exposed to Water/Glycol	Apollo 204 Review Board Panel 8, Materials Task 2.5
8-39	Studies Underway on Water/Glycol Solutions	Apollo 204 Review Board Panel 8, Dr. A.A. Staklis
8-40	Flammability of Type II Water Glycol Coolant	Apollo 204 Review Board Panel 8, W. A. Riehl
8-41	Absorption - Evaporation Tests	Apollo 204 Review Board Panel 8, Materials Task 2.6
8-42	Data on Flammability Limits and Ignition Energies for Certain Substances	Datafax to A. Busch from W. T. Olson, Lewis Research Center February 2, 1967
8-43	Development of the Maximum Temperature Profile of C/M 012 Inner Cabin	Apollo 204 Review Board Panel 10, February 22, 1967
8-44	S/C 012 Temperature Profile	Apollo 204 Review Board Panel 10, February 18, 1967
8-45	Concentrations of MEK in S/C 012	Apollo 204 Review Board Panel 8, February 18, 1967
8-46	Autogenous Testing of Nonmetallic Materials in the C/M	Apollo 204 Review Board Panel 8, Materials Task 2.7
8-47	Updating of Thermochemical Plots of Pressures vs. Time for S/C 012	Memo to W. M. Bland, Panel 8, from W. A. Riehl March 10, 1967
8-48	Final Report - Preliminary Cobra Cable Spark Test, TPS-MA-014	Apollo 204 Review Board, Panel 8 March 7, 1967
8-49	Investigation Report - Preliminary Cobra Cable Spark Test (TPS-MA-014)	Submitted to Panel 8 by J. C. Van Hooser, March 1, 1967
8-50	Approved Nonmetallic Materials for C/M Interior	Apollo 204 Review Board, Panel 8 February 22, 1967
8-51	Materials Comparison and Reconciliation Between NAA Spec. 0058 and MSC Spec. 66-4, March 1, 1967	Apollo 204 Review Board, Panel 8 Materials Task 2.11
8-52	Deleterious Effects of Etchants in S/C and Wire Bundles	Apollo 204 Review Board, Panel 8 Materials Task 2.13
8-53	MSFC Tests of Teflon Etchant	Apollo 204 Review Board Panel 8, February 15, 1967 W. A. Riehl
8-54	Material Odor Evaluation for S/C 012 (Ref. Action Item no. 78)	Apollo 204 Review Board Panel 8, March 7, 1967, Materials Task 2.15
8-55	S/C 012 Crew Bay Configurations Time of Delivery to Time of Accident	Apollo 204 Review Board Panel 8, Materials Task 2.16
8-56	Thermochemical Analysis of Fire Development in S/C 012 Based on Materials Characteristics	Apollo 204 Review Board Panel 8, March 9, 1967
8-57	Estimates of the Mass of Materials in S/C 012 at Time of Accident	Apollo 204 Review Board Panel 8, Materials Task 2.18
8-58	Flammable Materials Substitution Program	Apollo 204 Review Board Panel 8, Unissued
8-59	Alternates for the More Prevalent Nonmetallic in the Cabin, March 1, 1967	Apollo 204 Review Board Panel 8, Materials Task 2.19
8-60	Comparison of Nonmetallic Distribution in S. C. 008 and 012	Apollo 204 Review Board Panel 8, Materials Task 2.21
8-61	Calorimeter Bomb Tests of Selected Materials to Determine Fuel Energy Available	Apollo 204 Review Board Panel 8, Materials Task 2.23
8-62	S/C 012 Materials Oriented Timeline Backup Material	Apollo 204 Review Board Panel 8, Materials Task 2.31
8-63	Summary of Solvents, Bonding Agents, Etchants, etc. Usage in S/C 012	Apollo 204 Review Board Panel 8, Materials Task 2.32
8-64	Quantities of Nonmetallic Materials Installed in CSM 012 at KSC	Memo to W. M. Bland, Panel 8, from A. Lorenz, March 9, 1967, re: Task 2.16

8-65	Reconciliation of Materials Usage Geometry in PIB Mockup and Panel 8 Display	Apollo 204 Review Board Panel 8, Materials Task 2.38
8-66	A Special Assessment on Materials Analysis Branch Report of 12/2/66 on Hughes Co. Connector Assembly	Apollo 204 Review Board Panel 8, February 28, 1967
8-67	Materials Evaluation, Connector Assembly Hughes Aircraft Co. P/N 1004250 and P/N 1004251 - MAB-1392-66	Materials Analysis Branch Technical Services Division
8-68	Materials Information Service Plan	Apollo 204 Review Board Panel 8, Materials Task 2.41
8-69	Alternate Materials Follow-up Information Display	Apollo 204 Review Board Panel 8, Materials Task 2.44
8-70	Water/Glycol Leakage History of S/C 009, 011, and 012	Apollo 204 Review Board Panel 8, Materials Task 2.50
8-71	NAA's Criteria and Materials Control Procedures Prior to Jan. 27, 1967	Apollo 204 Review Board Panel 8, Materials Task 2.51
8-72	Contractor Nonmetallic Materials Waiver Status	Apollo 204 Review Board Panel 8, Materials Task 2.52
8-73	GFE Nonmetallic Materials Waiver Status	Apollo 204 Review Board Panel 8, Materials Task 2.54
8-74	Interim Summary Report	Apollo 204 Review Board Panel 8, February 16, 1967
8-75	Responsibility and Schedule for Accomplishment of Panel 8 Materials Tasks, Rev. A	Apollo 204 Review Board Panel 8, February 28, 1967
8-76	Responsibility and Schedule for Accomplishment of Panel 8, Materials Tasks, Rev. B.	Apollo 204 Review Board Panel 8, March 2, 1967
8-77	Study of Flammability Properties of Water/Glycol Mixtures	Apollo 204 Review Board Panel 8
8-78	Testings of the Effect of Water/Glycol on Apollo S/C Wire Insulation.	Materials Task 2.27
8-79	Activity Report as of February 27, 1967, Spark Ignition Tests per February 6, 1967. Letter by A. Busch	Apollo 204 Review Board Panel 8, February 27, 1967 Dr. A. A. Staklis Memo to W. M. Bland from J. D. Jeter, Chief, Materials Analysis Branch, KSC. February 27, 1967
8-80	Input to Panel 8 - Materials Final Report. Routine Materials Test Status and Boilerplate Test Status	Memo to W. M. Bland, Panel 8, from J. N. Kotanchik, MSC. March 8, 1967
8-81	Selection, Control of Nonmetallic Materials in S/C (Preliminary Outline)	W. M. Bland, ASPO, R. Q&I, March 8, 1967
8-82	Materials Information Service Program Plan	Apollo 204 Review Board Panel 8, Materials, March 6, 1967
8-83	Testing of Water/Glycol Treated Wire Bundles (Connectors) at KSC	Apollo 204 Review Board, Panel 8, Materials, March 10, 1967 (Task 2.12)
8-84	Approved Materials for Use in the Apollo S/C, General Specifications	North American Aviation, Inc., Specification No. 99-0058

8-85	Procedures and Requirements for the Evaluation of Apollo Crew Bay Materials	NASA-MSC, R. Q&T Div. May 13, 1966, MSC-A-D-66-3
8-86	Crew Bay Nonmetallic Materials Status Report of Unacceptable/Acceptable Materials Rev. F	NASA-MSC, R. Q&T Div. December 30, 1966, MSC-A-D-66-4
8-87	Boilerplate Flammability Tests in 5 psia oxygen	NASA-MSC (Film)
8-88	Boilerplate Flammability Tests in 16.5 psia Oxygen	NASA-MSC (Film)
8-89	Hazardous (Nonmetallic) Materials Control Program	H. M. Lampert, GE-ASD February 17, 1967
8-90	Acceptable S/C 012 GFE Materials List, Tab Run, 2/16/67	TRIS 028075
8-91	Flammability Characteristics of Materials in Oxygen	Apollo 204 Review Board, Panel 8 Materials, February 22, 1967 Lockheed Film No. 3 (4-1963)
8-92	Investigation Report - Aircraft Wire Harness Fire	
9-93	Spontaneous Ignition of S/C 012 Materials	Apollo 204 Review Board, Panel 8, Materials Task 2.7
8-94	The Lockheed Aircraft Corporation Film on Wet-Wire Fire	Memo to PD/Chief, Systems Engineering, from PD4/Engineering Branch, February 9, 1967, PD4/M864
8-95	Materials Literature Survey of Wire Bundle Tests Having Application to Apollo 204 Accident Investigation	Apollo 204 Review Board, Panel 8, Materials Task 2.24
8-96	Flammability of the Higher Boiling Liquids and their Mists	Industrial and Engineering Chemistry, December 1947, p. 1607
8-97	Physical Properties of Ethylene Glycol	GLYCOLS. Curme and Johnston, ACS Monograph 114 Reinhold Publ. Co.
8-98	Test Activities by Structures and Mechanics Division, Manned Spacecraft Center	Apollo 204 Review Board, Panel 8, March 10, 1967
8-99	Boilerplate Flammability Tests in 16.5 psia Oxygen (1st Test)	
8-100	"Some Experiments on Coolant Mixture"	NASA-MSC (Film) Raychem Corp. Memo to R. M. Halperin from Heslop & Frisco dated March 11, 1967
8-101	List of Some Significant Correspondence Relative to Nonmetallic Materials Control at NAA	Apollo 204 Review Board, Panel 8 March 17, 1967
8-102	Contract NAS9-150, R&D for Project Apollo S/C Toxicity and Flammability Program	Letter to R. W. Williams, MSC from G. W. Jeffs, NAA, January 10, 1967
8-103	Final Report-Solvent Evaporation Rates from nonmetallic materials in an ambient environment	Letter to Panel 17 from Chairman, Panel 8, Material Review, Task 2.6
8-104	Results of Electrostatic Ignition Investigation, March 31, 1967	Memo from E. L. Litchfield to Chairman, Panel 18, with attachment

8-105	Summary of Suit Electrostatic Measurement Data	Memo to Chairman, Panel 8, from KB-6/ Whittaker
8-106	Results of Special Tests on Raschel Knit	Preliminary Report, March 31, 1967, W. M. Bland, Panel 8, Materials
8-107	Wet Wire Fire Test No. 1	Apollo 204 Review Board, Panel 8, March 31, 1967

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**STATUS OF MAJOR NONMETALLIC MATERIALS USED IN
S/C 012 CREW BAY**

Introduction

The objective of this evaluation was to determine the status of the major combustible materials used in the S/C 012 crew bay.

Results

The table below lists materials status as determined from a review of NAA MC 999-0058 and MSC-A-D-66-4 documents which list acceptable and unacceptable materials.

**TABLE
STATUS OF MAJOR NONMETALLIC MATERIALS USED IN
S/C 012 CREW BAY**

MATERIAL DESIGNATION	MATERIAL TYPE	STATUS PER NAA-MC-999-0058 Rev. D	STATUS PER MSC-A-D-66-4 Rev. F
Nylon Rachel Knit	Polyamide	Acceptable	Acceptable
Nylon Velcro	Polyamide	Acceptable	Restricted - 12 inches from electrical leads
Trilock Cushions	Woven Cushion. Rubber Based Thread.	Acceptable	Unacceptable
Uralane 577-1	Polyurethene Foam	Acceptable	Restricted - Not to exceed 18 inches lengths or closer than 12 inches from electrical leads

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**REPORT OF PANEL NO. 9
DESIGN REVIEWS PANEL
APPENDIX D-9
TO
FINAL REPORT OF
APOLLO 204 REVIEW BOARD**

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DESIGN REVIEW PANEL REPORT

A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Design Review Panel, 9. The task assigned for accomplishment by Panel 9 was prescribed as follows:

Conduct critical design reviews of systems or subsystems that may be potential ignition sources within cockpit or which might provide a combustible condition in either normal or failed conditions. Consider areas such as glycol plumbing configuration, electrical wiring and its protection, physical and electrical, as well as other potential ignition sources such as motors, relays, and corona discharge. Other areas of review include egress augmentation and basic cabin atmosphere concept (one versus two-gas). Document where applicable pro's and con's of design decisions made.

B. PANEL ORGANIZATION

1. MEMBERSHIP:

The assigned task was accomplished by the following members of the Design Review Panel:

- Mr. R. W. Williams, Manned Spacecraft Center (MSC), NASA, Chairman
- Mr. J. Janokaitis, Kennedy Space Center (KSC), NASA
- Mr. Aaron Cohen, Manned Spacecraft Center (MSC), NASA
- Dr. John F. McCarthy, North American Aviation (NAA), Downey, California
- Mr. R. Pyle, North American Aviation
- Mr. F. Sanders, McDonnell Company, St. Louis, Missouri

2. COGNIZANT BOARD MEMBER:

Mr. G. White, NASA Headquarters, Board Member, was assigned to monitor the Design Review Panel.

C. PROCEEDINGS

1. APPROACH:

Panel 9 effort has encompassed the four major sub-divisions as follows:

- a. Review of subsystems for sources of ignition or flammable materials.
- b. Review of the selection of the cabin atmosphere.
- c. Review of the egress process.
- d. Review of the flight and ground voice communications.

The object of the review was to:

- a. Identify problems and potential problem areas that may provide guidance in determining the cause of the fire.
- b. Identify potential problem areas in the design for which design changes may be required.

The review process has been expedited by informal assignment of subtasks to knowledgeable groups of people (Reference 1).

It must be noted that the contemplated spacecraft configuration for the next manned flight (Spacecraft 101, Block II) is different to a significant extent from spacecraft (S/C) 012 (Block I) in which the fire occurred. As a consequence both configurations are involved in the design reviews; the Block I configuration as an aid to determining possible sources for the fire, and the Block II to evaluate the system design characteristics and potential design change requirements to prevent recurrence of fire.

2. DETAILS OF INVESTIGATION

A description of the process leading to the results of the detailed analyses of each of the four major subdivisions listed in Item 1 is presented herein.

a. Ignition and Flammability

(1) SUMMARY

A team of NASA and NAA Subsystem Managers and Systems Engineers conducted a thorough review of the subsystems housed in Block I and II Command Module (C/M) crew compartments. The purpose of the review was (1) to ascertain if any of the subsystems con-

tained ignition sources that might have contributed to the Apollo 204 incident and (2) to identify similar anomalies that might exist in the Block II S/C and document them for input to the overall spacecraft design review activity.

This extensive review culminated in the compilation of a final report (Reference 2) to the Chairman of Panel 9 substantiated by the Design Review summary sheets (Reference 3). Results of the review delineate ignition sources (Blocks I and II) and contiguous non-metallic materials (Block II) for each subsystem. The type of packaging and qualification history was examined and is listed for each component (Block II). A summary of this review is included as Enclosure 9-1 to this report.

(2) CRITERIA FOR REVIEW

(a) IGNITION SOURCES

Search for and identify possible ignition sources of the following types:

Corona discharge

Electrical arcs or sparks from damaged insulation, motor brushes, exposed relay contacts, switches, etc.

Overheating caused by circuit failures

Overheating due to inadequate or improper lubrication

Chemical sources

Miscellaneous (impact, etc.)

(b) COMBUSTIBLE MATERIALS

Identification and location by subsystem of all flammable materials within the crew compartment.

(3) SYSTEM/SUBSYSTEMS FOR REVIEW

(a) Guidance and Navigation (G&N) (including Block II rendezvous radar)

(b) Stabilization and Control System (SCS)

(c) Electrical Power System (EPS) and Sequential Events Control System (SECS)

(d) Controls and Displays

(e) Caution and Warning System (C&WS)

(f) Environmental Control System (ECS)

(g) Emergency Detection System (EDS)

(h) Telecommunications (T/C)

Operational instrumentation

Spacecraft communication

Crew communication

Television (TV)

System instrumentation

(i) Experiments and Scientific Equipment

(j) Crew Personal Equipment

(4) METHOD OF OPERATION

The task was executed in two phases. The first phase consisted of concurrent independent reviews of the C/M subsystems by Subsystem Managers and Systems Engineers at Manned Spacecraft Center (MSC) and by contractor personnel at the North American Aviation (NAA) plant in Downey, California. These independent reviews were conducted in the time period February 6-16, 1967. The second phase consisted of working sessions, involving both MSC and NAA personnel, conducted at MSC during the period February 17-20, 1967. During these sessions, the MSC and NAA inputs were combined to constitute the subpanel report. The two-phase method of task execution was used for many reasons, the principal being optimum utilization of personnel and facilities at both the contractor's and MSC plants, and thoroughness afforded by two independent reviews of the subsystems which separately reflect the contractor and customer rationale.

(5) SPECIAL DESIGN CONSIDERATIONS

The configurations of both Block I and Block II vehicles were examined with a view

toward identifying deficiencies in design and compatibility of design with criteria (specified requirements). Many deficiencies in the design could be traced to criteria which changed in the course of the program. The deficiencies can be categorized into those affecting wiring and ECS plumbing.

A number of criticisms of the wiring and ECS plumbing joints for Block I vehicles have resulted from examination of S/C 012, 014, and 017. The criticisms include instances of:

- Interference with access for maintenance
- Insufficient physical protection
- Undesirable routing and terminating
- Lack of flexibility for change
- Frequent leakage of water/glycol joints
- Poor workmanship
- Lack of neatness and craftsmanship

The process of spacecraft manufacture, test, and maintenance, which results in the above criticisms, derives from the designs to which the spacecraft are built. The criteria establish the requirements for the design. These criteria continued to evolve after the design had been started and in some instances changed after release of design to manufacturing. Some significant examples follow:

(a) **WIRING**

(1) Unmanned flights were introduced which required retrofit of the Mission Control Programmer and associated wiring, and interconnecting with C/M flight control and other subsystem circuits. This additional complexity applies to S/C 017 but not to S/C 012 and 014.

(2) Because of the experience of water condensing on electrical equipment during the flight of a Mercury spacecraft, the electrical and electronic components were required to be qualified in a combined environment of water, oxygen and salt instead of oxygen alone. As a result, the environmental-seal concept was introduced which changed the packaging design of the electronic equipment.

(3) The in-flight maintenance concept, on which the initial design was based, was dropped in favor of built-in redundancy after design completion on Block I but prior to the initiation of the design of Block II.

(4) The requirements for in-flight scientific experiments were added after designs were released to manufacture or test.

(5) Additional development and operational instrumentation requirements were introduced after the wiring design was released and in manufacture or test.

(6) The design of displays and controls was based on requirements established by a flight-crew group. Subsequently, minor changes were made to meet the requirements of the assigned flight crew.

(7) The audio communication control equipment on S/C 012 suffered from a series of changes in performance requirements resulting in a number of fixes. The final configuration contained many changed and interrelated switch functions which resulted in a complex matrix of switch positions for proper selection of the different modes.

The initial design for the Block I vehicles failed to accommodate growth and changes typically experienced in research and development programs. The result was that the flexibility for change was quickly saturated, and it was necessary to improvise at the expense of the factors exposed by the criticisms above. (However, the initial design of Block II allowed for a 50 percent growth in wiring.) The Block I wiring runs were laid out without the use of an engineering mockup and wire harnesses were fabricated in two-dimensional rather than three-dimensional fixtures.

Post-fire inspection of S/C 012 revealed deficiencies in the wire installation demonstrating poor practices in design, manufacturing and quality control. The wiring in the spacecraft survived the fire with a small degree of damage overall. The Teflon insulation was found to be damaged only in localized hot spots. The majority of the damage consisted of insulation loss due to heat; however, in practically all instances there remained sufficient insula-

tion or distance between the affected wires, that shorting was not apparent. All enclosures pertaining to this section are photos of S/C 012 after the accident.

During the wire inspection, the following design deficiencies were noted:

(1) The wiring in the Lower Equipment Bay (LEB) was routed through narrow channels having many 90 degree bends. This could cause mechanical stress on the Teflon insulation. Some wiring in these areas was found with damage to the sleeve which covers the shielded wire (Enclosure 9-4).

(2) Wire color coding practices were not always adhered to as evidenced by Enclosure 9-5.

(3) Some areas of wiring exhibited what would be referred to as "rats nests" because of the dense, disordered array of wiring. In some instances excessive lengths of wires were looped back and forth to take up the slack. Also, there were instances where wires appeared to have been threaded through bundles which added to the disorder (Enclosures 9-6, 9-7, 9-8, 9-9 and 9-10).

(4) A circuit breaker panel was pressed so close to a wire harness, that wiring indentions were left in the circuit-breaker potting (Enclosure 9-11).

(5) There were wires routed across and along oxygen and water/glycol lines.

(6) The floor wiring and some connectors in the LEB were not completely protected from damage by test personnel and the astronauts. This is evidenced by mashed 22-gauge wires found in some of the wire harnesses.

The following Manufacturing and Quality Control deficiencies were noted:

(1) Lack of attention during manufacture and/or rework is evidenced by foreign objects found in the spacecraft harnesses. Enclosure 9-12 shows a wrench socket in one of the connector channels, and Enclosure 9-13 shows a metal washer inside a wire bundle.

(2) Some wiring did not have identification tags.

(3) A Hughes connector on communications equipment was broken prior to the fire as evidenced by soot in the crack, Enclosure 9-14.

(4) A chipped Hughes connector was found in a condition exposing female inserts (Enclosure 9-15).

(b) ECS PLUMBING JOINTS

(1) The ECS design criteria, emphasizing minimum weight, resulted in the selection of aluminum piping with soldered joints (Enclosure 9-3). The design approach utilized accounted for the normal operating stresses but failed to account for the loads and stresses introduced by handling and installation.

(2) The proper fabrication of joints requires that the initial alignment of the tubes to be soldered must be established without stress and without benefit of a holding tool. The tool provides support to the joint only during the heat-up and cool-down phase.

(3) The couplings were made too short to provide the joint with strength greater than the tubing. As a result, unanticipated axial, bending or torsional loads cause the joint to develop leak paths.

(4) The installation design does not permit adequate inspection and does not protect the plumbing and the joint from accidental damage, or from use as hand holds. In some areas access of tools is difficult without stressing or springing joints already made.

The development and qualification testing of the ECS extended beyond the original schedule. Units were produced and installed in spacecraft which required modification to eliminate problems later identified during qualification tests. The design failed to provide easy access for removal and replacement of components in the assembled condition. Consequently, the process of rework is difficult, and the design criteria for soldered joints is violated under rework conditions. The leakage of soldered joints in the C/M cabin is traceable primarily to these conditions.

b. CABIN ATMOSPHERE

(1) INTRODUCTION:

The process of selection of the cabin atmosphere has been reviewed and a comprehensive bibliography (Reference 4) of all material leading to the decision to use oxygen O₂ in space and at the pad has been compiled. A summary of this material is contained in Enclosure 9-2 to this report. The references contain a retracing of all the steps and considerations leading to the choice of the cabin atmosphere for the spacecraft. Pertinent data are included from cognizant NASA organizations, other government agencies, Mercury, Gemini, and Apollo contractors and subcontractors, other aerospace companies, the medical community, universities, and other research organizations.

(2) DISCUSSION:

Selection of a spacecraft cabin atmosphere involves human physiology constraints, spacecraft and space suit design considerations, flammability characteristics of materials, ground considerations, and considerations of fire extinguishing and suppression.

(a) HUMAN PHYSIOLOGICAL CONSTRAINTS

Human physiology imposes a requirement for a minimum partial pressure of oxygen for respiration, a minimum absolute-pressure environment for respiration and control of body water-vapor partial pressure, and limits to the rate of depressurization to prevent bends from gases emanating from solution in the body. A one hundred percent oxygen atmosphere is physiologically acceptable for continuous use up to thirty days.

NASA physiologists specify that a minimum oxygen partial pressure of 3.5 psia and a minimum absolute pressure of 5 psia be maintained as spacecraft cabin atmosphere. Reduced levels are acceptable for short periods of time (up to eight hours). One hundred percent oxygen pre-breathing is specified for a minimum of three hours prior to launch.

Dysbarism (bends) is avoided by a minimum partial pressure of diluent gas in the spacecraft. The desirable partial pressure of nitrogen in a mixed-gas spacecraft atmosphere has not been formally established. It has been established that the disadvantages will more likely exceed the advantages at nitrogen partial pressures greater than 3.5 psia.

Oxygen toxicity is prevented by avoiding oxygen partial pressures significantly greater than those experienced at sea level (3.5 psia).

Consequently, from the physiological standpoint, acceptable cabin atmosphere ranges from a 5 psia oxygen single-gas environment to a mixed-gas environment with 3.5 psia oxygen and 3.5 psia nitrogen partial-pressures.

(b) SPACECRAFT AND SPACE SUIT DESIGN CONSIDERATIONS

The design parameters for spacecraft involving cabin atmosphere are concerned with the strength of the structure to contain the cabin pressure and the varying complexities of atmosphere-control systems for one hundred percent oxygen or mixed gases. The design parameters for space suits are the same as for the spacecraft with the addition that the effort associated with movement increases with increasing differential pressure.

The Apollo spacecraft atmosphere control system design is based on providing a one hundred percent oxygen environment. Duplication of the atmosphere-control components as well as addition of a mechanism for oxygen partial-pressure control is required to provide diluent gases. These additions introduce additional crew-safety failure modes into the flight systems.

The state-of-the-art in space suit design establishes 3.8 psi as the desirable maximum differential pressure. Freedom of movement is constrained with further increases in differential pressure.

(c) FLAMMABILITY CHARACTERISTICS OF MATERIALS

The flammability characteristics of materials involve interrelationships with chemical and physical properties of the material, the total pressure of the atmosphere and partial pressure of atmospheric constituents, the temperatures of the material and the atmosphere, and the process of ignition utilized to initiate combustion.

There are three flammability characteristics that are generally measured to determine relative flammability of materials:

- (1) Linear burning rate in inches per second.
- (2) Temperature at which self-ignition occurs.
- (3) Temperature at which ignition by spark is achieved.

The tests are performed in the atmospheres of particular interest. These have included oxygen alone at various pressures and oxygen mixed with nitrogen at various pressures with various ratios of partial-pressure.

The linear burning rates and auto-ignition temperatures measured in tests are shown in the tables below:

Relative Propagation Rates (inches/sec, downward)

Atmosphere psia/gas	Material			
	Cotton	Velcro	Nomex	Teflon
3.5/O ₂	.49	.4	.3	
5.0/O ₂	.5	.48	.34	
16.0/O ₂	.55	.7	.43	.003
3.5/O ₂ 1.5/N ₂	.4	.33	.22	
Air	.1	.3	.1	

Auto-Ignition Temperature (°F)

Atmosphere psia/gas	Cotton
3.5/O ₂	1160
5.0/O ₂	1180
16.0/O ₂	1280
3.5/O ₂ 1.5/N ₂	1040
Air	1000

Downward burning rates of the same material are shown to vary over a range of only 1.4 to 1 with atmosphere changes from 5 psia oxygen to a 7 psia atmosphere of 3.5 psia oxygen and 3.5 psia nitrogen. Downward burning rates in a particular atmosphere vary over a range of 1000 to 1 with material changes from cotton to Teflon. Consequently, the potential for fire in the C/M is much more strongly influenced by the selection of materials than by acceptable variations in atmosphere.

It may be concluded that the selection of 5 psia oxygen as a cabin environment for space flight operations was a reasonable choice. The physiological requirements are totally fulfilled. The requirements on spacecraft structure and systems are minimized. Based on tests of downward-burning propagation, the difference in fire potential between various physically acceptable atmospheres is not large, particularly if easily combustible materials are eliminated.

(d) GROUND CONSIDERATIONS

At any pressure the suitloop must contain only oxygen to avoid the "bends". If cabin atmospheric constituents other than oxygen are used, they should be isolated from the suitloop and expelled from the cabin prior to crew emergency from the suited conditions to avoid anozia. These requirements were fulfilled for Apollo 204 by the use of oxygen without diluents.

Downward burning rates of some materials vary by a factor of 1.3 to 1 for an atmosphere of 16 psia oxygen compared to a 5 psia oxygen atmosphere. If the decision had been made to use the extreme atmosphere for space operation of 3.5 psia oxygen and 3.5 psia nitrogen partial pressures, the burning-rate ratio between 16 psia oxygen and this environment would be only 1.8 to 1.

Tests carried out subsequent to the Apollo 204 accident with full-scale mockups at both 16 psia and 5 psia, one hundred percent oxygen atmospheres have demonstrated that differences in downward burning rates of materials are not indicative of actual fire hazards. Propagation rates and overall fire damage were much greater at the higher pressure. Thus, it appears that the geometric arrangement of the combustibles in their actual installations are much more significant than tests on isolated samples.

If air were used instead of oxygen on the ground (recognizing that spacecraft design changes would be required) a ratio of burning rates of 1 to 2 over 5 psia or 1 to 4 over 16 psia oxygen would be achieved. This reduction in burning rate would provide a reduced hazard for ground operation over space operation, except within the suit loop where 15 psia oxygen is required. These relations are based on downward burning rates for isolated specimens under controlled conditions. The conclusions have not been verified by tests in air with full scale mock-ups.

It must be concluded that burning rates of materials are significantly reduced only when large amounts of diluent are used. The limited quantity of diluent acceptable by physiological criteria contributes very little to the reduction of burning rate over that in pure oxygen.

(e) FIRE EXTINGUISHING AND SUPPRESSION

The established process for extinguishing a cabin fire in space is to evacuate the cabin of oxygen by venting to space. Limited flammability tests indicate that burning generally ceases when oxygen pressure is reduced to a half (0.5) psia. The cabin-venting mechanism design results in cabin pressure reducing from 5.0 psia to 0.5 psia in approximately one minute forty-five seconds.

Cabin depressurization requires that the crew be in their space suits. The donning time is 10-15 minutes.

Alternative extinguishing techniques have been examined, but no really satisfactory technique has so far been found. Effort in this area is continuing. Recent experiments have shown only water to be effective. A better understanding of the burning and extinguishing phenomena is required to properly assess the adequacy of the present and alternative extinguishing processes.

Elimination of contaminants in the cabin by means such as suit purge and cabin venting must be provided. Prior to the venting process, crew protection should be provided by some means such as oxygen masks supplied by a separate fire-proof oxygen supply.

c. REVIEW OF THE EGRESS PROCESS

(1) INTRODUCTION:

A critical review of the egress situation investigated the elements of both Launch Com-

plex (LC) 39 and Launch Complex 34, including the environmental chamber, access arm, elevator, personnel carrier (M-113) (Launch Complex 34 only), escape chute and hardened room (Launch Complex 39 only), lighting, communications, and fire suppression. This review was supplemented by conferences and responsive written reports on suggested design criteria from the following permanent Apollo Saturn Inter-Center Coordination Panels: Apollo Launch Operations Committee (ALOC) Emergency Egress Working Group, Apollo Launch Operations Panel (ALOP) Emergency Egress Subpanel, and Crew Safety Panel, as well as the Ground Emergency Provisions Review Panel No. 13 of the Apollo 204 Review Board.

The Panel No. 9 review and the reports of these associated organizations are contained in the supporting data which has been transmitted to the Apollo 204 Review Board files (Reference 6). This review utilized time lines, simulations, review of drawings, inspection of the Ground Support Equipment (GSE), and a methodical analysis of the egress process all the way from C/M exit to safety.

(2) DISCUSSION:

Based on tests in mock-up configurations, the following times for crew egress were measured. (Average times are used; best times are in parentheses.) Sixty (41) seconds are required for unaided crew egress from the Command Module. Ten (7) seconds are required for all three crewmen to disconnect and for the center crewman to turn around and face the hatch prior to opening. Forty (26) seconds are required for the center crewman to release and stow the inner hatch and release and open the outer hatch and boost-protective-cover hatch. Ten (8) seconds are required for all three crewmen to exit. The hatch cannot be opened with positive cabin pressure above approximately 0.25 psi.

The access arm to the Command Module contains flammable materials, and the doors are not designed to accommodate rapid emergency egress. Correction of these conditions would significantly improve emergency egress capabilities.

Removal of the access arm to allow the escape mode changeover from crew egress to Launch Escape System (LES) pad abort is necessary for maximum flight-crew safety just prior to launch. In the event of a C/M fire in this time period, the access arm could be returned to the C/M in time for safe crew egress if reduced flammability characteristics of the Command Module would greatly increase the allowable time for the egress escape process.

d. REVIEW OF THE FLIGHT AND GROUND VOICE COMMUNICATIONS

(1) INTRODUCTION:

Since the Operational Checkout Procedure (OCP) Plugs-Out Test during the Apollo 204 accident (OCP FO-K-0021-1) experienced communications difficulties, an examination of the design and performance of the total communications network was undertaken. This effort included: a comprehensive review to establish the configuration and operating characteristics of the Apollo 204 system; a system and circuit analysis, a test of the total ground system utilizing detailed measurements (February 21-24, 1967), and analyses of recordings made during the OCP FO-K-0021-1 test.

The supporting data (Reference 7) transmitted to the Apollo 204 Review Board files contain: a description of the on-board system, its test performance, and a discussion of the problems encountered; description and conclusions concerning the ground network; and detailed findings and determinations.

(2) DISCUSSION:

During the OCP FO-K-0021-1 test (Plugs-Out Test during Apollo 204 incident), difficulties were experienced maintaining voice communications. These difficulties included the following:

- (a) Voice unintelligible due to very low levels at the listener's position.
- (b) Voice unintelligible due to distortion, or "garbling."
- (c) Syllables or words not received.

(d) Inability to contact another individual.

(e) Inability to communicate because of noise or other interference, including undesired voice.

These problems did not occur at all stations, or at any one station all the time; however, there were instances when several of the troubles occurred simultaneously. The source of the problems can be divided into two parts, viz., spacecraft and ground.

SPACECRAFT:

The spacecraft experienced a "live mike" situation, first noticed by the crew approximately one hour and five minutes before the accident. The records indicate that the VHF and S-band RF downlinks (exclusive of spacecraft audio and control circuit wiring) from spacecraft to ground operated satisfactorily during the OCP FO-K-0021-1 test.

GROUND:

The Communications Astronaut Console (CAST) on the ground was configured to patch the three voice links together (Astro 1 - Unified "S" Band, Astro 2 - VHF, and Astro 3 - Umbilical). With this configuration any downlink transmission is retransmitted back to the spacecraft on all three links.

The Spacecraft Test Conductor (MSTC) in the Automatic Checkout Equipment (ACE) Control Room in the Manned Spacecraft Operations Building (MSOB) was unable to contact the Command Pilot, Senior Pilot or Pilot at one time because of the Voice Operated Relay (VOX) in the ground link. The back-to-back VOX circuits lock out operation in the reverse direction when a signal appears in the unit.

Any signal coming from the Cape Kennedy Air Force Communications Terminal Building, Eastern Test Range, such as the MSTC or Superintendent of Range (AFETR) going into Launch Complex 34 has priority, with interrupt capability, over a signal originating in the Complex. However, even though it gets into the Complex Operational Intercommunication System (OIS) and the CAST console, it still has no priority to the spacecraft on any link.

System and circuit analyses showed that the difficulties experienced were due to system design deficiencies in the ground communications system, unfamiliarity with the system limitations and unsatisfactory procedures.

The ground communication system is one that has evolved during a series of modifications and additions. Rather than establishing an overall system design, hardware was merely added as new requirements were identified. The result was an overloaded system, with different types of subsystems which were inadequately interfaced.

D. FINDINGS AND DETERMINATIONS

1. A listing of findings and determinations from the information generated in the processes described in Section C above are listed in Section D.2.
2. To be compatible with Section C above, the findings and determinations are listed according to the major classifications; viz., Ignition and Flammability, Cabin Atmosphere, Review of Egress Process, and Review of the Flight and Ground Voice Communications.

a. IGNITION AND FLAMMABILITY

(1) FINDING:

Flammable, non-metallic materials are used throughout the spacecraft. In the Block I and Block II spacecraft design, combustible materials exist contiguous to potential ignition sources.

DETERMINATION:

In the Block I and Block II spacecraft design, combustible materials are exposed in suf-

ficient quantities to constitute a fire hazard.

(2) FINDING:

Malfunctions and failures can produce ignition sources in the Command Module.

DETERMINATION:

An ignition source in the presence of a combustible in the cabin atmosphere constitutes a fire hazard.

(3) FINDING:

Packaging design for Block II components differs from Block I in that nearly all components in Block II are hermetically or environmentally sealed.

DETERMINATION:

The Block II packaging design practice reduces the probability for the coexistence of an ignition source and flammable material.

(4) FINDING:

The space suit contains power wiring to electronic circuits; also, the astronauts could be electrically insulated.

DETERMINATION:

Both the power wiring and potential for static discharge constitute possible ignition sources in the presence of combustible materials. The wiring in the suit could fail from working or bending.

(5) FINDING:

Eighteen electrical circuits in Spacecraft 012 did not adhere completely to wire size/load/circuit protection design criteria.

DETERMINATION:

The condition was examined from the standpoint of overheating, and no problem was found to exist.

(6) FINDING:

Residues of RS89 (inhibited ethylene glycol/water solution) after drying are both corrosive and combustible. RS89 is corrosive to wire bundles because of its inhibitor.

DETERMINATION:

Because of the corrosive and combustible properties of the residues, RS89 coolant could in itself provide all of the elements of a fire hazard if leakage occurs onto electrical equipment.

(7) FINDING:

Water/glycol is combustible, although not easily ignited.

DETERMINATION:

Leakage of water/glycol in the cabin increases the risk of fire.

(8) FINDING:

Deficiencies in design, manufacture and quality control were found in the post-fire inspection of the wire installation.

DETERMINATION:

There was an undesirable risk exposure which should have been prevented by both the Contractor and the Government.

(9) FINDING:

The environmental control system is plumbed with aluminum tubing in both the water/glycol and oxygen circuits. Joints in the plumbing are made by nickel plating the aluminum and joining the nickel-plated surfaces with a tin-lead solder. Leakage of ECS coolant from these joints has been experienced in the Apollo spacecraft.

DETERMINATION:

The design of the soldered joints is inadequate to cope with all the conditions experienced in the spacecraft.

b. CABIN ATMOSPHERE

(1) FINDING:

NASA physiologists specify that a minimum oxygen partial pressure of 3.5 psia and a minimum absolute pressure of 5 psia be maintained as spacecraft cabin atmosphere.

DETERMINATION:

Acceptable cabin atmosphere ranges from a 5 psia oxygen single-gas environment to a mixed-gas environment with 3.5 psia oxygen and 3.5 psia nitrogen partial pressure.

(2) FINDING:

The spacecraft atmosphere control system design is based on providing a pure oxygen environment.

DETERMINATION:

The complexity of the technology is such that, to provide diluent gases, duplication of the atmosphere-control components as well as addition of a mechanism for oxygen partial-pressure control is required. These additions introduce additional crew-safety failure modes into the flight systems.

(3) FINDING:

Flammability characteristics of non-metallic materials are varied by only a factor of 3 or 4 by diluents in atmospheres containing oxygen at 3 to 5 psi partial pressure.

DETERMINATION:

Previous analyses leading to the decision to use 5 psia pure oxygen cabin environment in space are still valid.

c. REVIEW OF THE EGRESS PROCESS

(1) FINDING:

Sixty seconds are required for unaided crew egress from the Command Module. The hatch cannot be opened with positive cabin pressure above approximately 0.25 psi. The vent capacity was insufficient to accommodate the pressure buildup in the Apollo 204 Spacecraft.

DETERMINATION:

Even under optimum conditions emergency crew egress from Apollo 204 Spacecraft could not have been accomplished in sufficient time.

(2) FINDING:

The access arms to the Command Module in Launch Complexes 34 and 39 contain flammable materials, are removed thirty minutes prior to launch, and their doors open the wrong way for easy egress.

DETERMINATION:

The access arm could constitute a fire hazard and imposes delays to emergency crew egress.

d. REVIEW OF THE FLIGHT AND GROUND VOICE COMMUNICATIONS

(1) FINDING:

The control circuit from the Command Pilot developed a condition of continuous keying during the test.

DETERMINATION:

An anomaly existed in the spacecraft communication system.

(1) FINDING:

During the Apollo 204 test, difficulty was experienced in communicating from ground to Spacecraft and among ground stations.

DETERMINATION:

The ground system design was not compatible with operational requirements.

E. SUPPORTING DATA

The following is a list of enclosures to this section of the report.

Enclosures

9-1	Summary of Ignition and Flammability Review
9-2	Spacecraft Atmospheres
9-3	Examination of Soldered Joints for Aluminum Tubing
9-4	Wiring Assessment
9-5	Wiring Assessment
9-6	Wiring Assessment
9-7	Wiring Assessment
9-8	Wiring Assessment
9-9	Wiring Assessment
9-10	Wiring Assessment
9-11	Wiring Assessment
9-12	Wiring Assessment

9-13	Wiring Assessment
9-14	Wiring Assessment
9-15	Wiring Assessment
9-16	List of Reference Material

ABBREVIATIONS USED IN APPENDIX D-9

ALOC	Apollo Launch Operations Committee
ALOP	Apollo Launch Operations Panel
AS	Apollo Saturn
C&WS	Caution and Warning System
CM	Command Module
ECS	Environmental Control System
ECU	Environmental Control Unit
EPS	Emergency Detection System
ECP	Electrical Power System
EVA	Extravehicular Activity
G&N	Guidance and Navigation
T/C	Telecommunications
KSC	Kennedy Space Center
LC	Launch Complex
LES	Launch Escape System
LH ₂	Liquid Hydrogen
MC	McDonnell Company
MSC	Manned Spacecraft Center
NAA	North American Aviation
O ₂	Gaseous oxygen
OCP	Operations Checkout Procedure
OCP - 0021	Space Vehicle Plugs Out Overall Test
RF	Radio Frequency
RS89	Inhibited Ethylene Glycol/Water Solution (AiResearch Specification)
S/C	Spacecraft
SCS	Stabilization and Control System
SECS	Sequential Events Control System
SM	Service Module
TV	Television
VHF	Very High Frequency

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SUMMARY OF RESULTS OF IGNITION AND FLAMMABILITY REVIEW

This enclosure contains the significant findings of the Ignition Source Review Team for both Block I and Block II equipment installed in the Command Module interior. The possible ignition sources are grouped by subsystem. The information which follows was derived from a detailed review of the approximately 2000 pages contained in the basic ignition source report.

It is important to bring out the fact that neither the MSC, nor the NAA review teams nor the integration team were able to locate any possible sources of ignition in the subsystems under normal operating conditions. In all cases in order to have an ignition source, there must first be some type of failure of the component in question.

When a single failure mode for each component was postulated, twenty-one and fourteen potential ignition sources were identified for the Block I and Block II crew compartment subsystems, respectively. The number of ignition sources noted above does not represent a tally of total individual compartment subsystems, respectively. The number of ignition sources noted above does not represent a tally of total individual components that are suspect because all identical components such as switches and indicators on the display and control panels, all electrical connectors, and all harnesses or cable runs, etc., were treated generically; i.e., each group of suspect items in a category was considered as one potential ignition source. Delineation of ignition sources identified in Block I and II subsystem follows.

BLOCK I ELECTRICAL POWER SUBSYSTEM

The following components of this subsystem are considered possible sources of ignition under a failure condition:

- General Usage Connectors
- Special Purpose Connectors
- Modular Terminal Boards
- Electrical Wiring

The above listed possible sources are generally generated by procedural and human error problems such as broken wires, damaged insulation, bent connector pins, damaged or lack of, conformal coating on terminal boards, etc. Evaluation of the detailed data in the basic report revealed that there were several cases on S/C 012 where there were deviations taken to the basic criteria for circuit-breaker compatibility with wire size. The basic ignition source report contains an analysis of each of the cases of deviation, and evaluation of these analyses reveals a very low probability that these deviations could have been contributory to the S/C 012 accident.

DISPLAYS AND CONTROLS SUBSYSTEM

The following components of this subsystem are considered possible sources of ignition under a failure condition:

- Main Display Console (MDC) Panels
(Wiring and Terminal Strips)
- Lower Equipment Bay (LEB) Panels
(Wiring and Terminal Strips)

Excessive handling and human error problems associated with these components can lead to damage of wiring and conformally coated terminal strips. This damage could, in turn, lead to an arcing or shorting failure mode.

CAUTION AND WARNING SUBSYSTEM

The following component of this subsystem is considered a possible ignition source under a failure condition:

- Elapsed Time Indicator

This device is removed prior to flight and is, therefore, only a potential ignition source during ground operations. The Block I program has experienced one problem with this indicator on S/C014 during Downey checkout that could have led to it being an ignition source. Smoke was observed in this particular case when over-heating of a spike-suppression capacitor occurred.

ENVIRONMENTAL CONTROL SYBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Glycol Evaporator Back Pressure Controller
- Cable Assemblies
- Waste Management System Blower
- Valve Seats in Oxygen Lines

The Controller was considered as a potential source only in that there is some probability that overheating of the controller under an internal failure condition could ignite the encapsulating material. It is not known, whether such a condition could result in ignition of the insulation, so it must be classified as suspect.

The cable assemblies are listed since breakage or abrasion could provide a source of ignition in that some harnesses are in direct contact with the Environmental Control Unit (ECU) foam insulation. The foam insulation was not covered with silicone rubber and thus did not meet the Apollo criteria for ignition temperature characteristics of nonmetallic materials.

The Waste Management System Blower is considered suspect because failures of a shorting or arcing nature within the blower motor have been experienced during the program.

Overheating of regulator and valve seats can occur in high-pressure oxygen lines due to compression waves. Because of this phenomenon, ignition of flammable plastic seats is possible.

GUIDANCE AND NAVIGATION SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Display and Keyboard (DSKY) Electroluminescent Panels
- Guidance and Navigation (G&N) Interconnecting Harness
- Inertial Measuring Unit (IMU) Control Panel Switches
- Eye-piece Heaters

A failure of the sealing for the Electroluminescent lights on the DSKY Panel could allow moisture to provide a shorting path for 250 volts used to excite the luminescent material. These seals did experience failure in qualification testing during low-temperature storage.

Breakage or abrasion of the G&N harness could lead to a possible ignition source.

The IMU Control Panel pushbutton lighted switches which contain bulbs do not constitute an hermetically or environmentally sealed device. These are possible ignition sources in the case of cracked bulbs or poor contact due to corrosion.

An equipment or component is considered hermetically sealed if it is sealed, either via a bonded-metal cover, or a gasketed cover (a molded-in-place elastomer gasket) which is designed to be capable of remaining pressurized or evacuated for the specification life of the equipment or component.

An equipment or component is considered environmentally sealed if it is not hermetically sealed, and is potted, foamed and/or conformally coated such that it will withstand the Apollo qualification environments, particularly with regard to the humidity and salt fog environments. This type of packaging generally "breathes" and is normally enclosed in a metal package.

The Eyepieces contain resistance heaters which operate at 28 volts and 0.1 amps. These eyepieces are subject to much handling before and during flight and are therefore subject to a greater probability of damage than fixed electrical components. Such damage could result in arcing or shorting.

STABILIZATION CONTROL SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Rotational Control
- Velocity Change Indicator (Delta V)

These two components of the Stabilization Control Subsystem contain non-hermetically sealed switches. If a failure occurs in the arc-suppression diodes, there could be a short to ground causing arcing of the contacts.

SPACECRAFT COMMUNICATIONS SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure condition:

- Radio Frequency (RF) Connectors
- Overheating of Equipment due to Loss of Cooling
- Elapsed Time Indicators (See Caution and Warning Subsystem)
- Hughes Connectors

Arcing of RF connectors and pin-to-pin shorting of the Hughes connectors are potential ignition sources under a failure condition. There is a general concern with regards to potential ignition sources if all communications system cooling should be lost. Whether or not ignition temperatures of adjacent non-metallics could be attained is not known.

TELEVISION SUBSYSTEM

The following components of this subsystem are considered possible ignition sources under a failure (procedural) condition:

- Television Bulkhead Connectors and Cable Assemblies

If the TV power switch is left in the "on" position during connection or disconnection of the TV power cable, arcing could occur thereby providing an ignition source.

SUBSYSTEM CONTAINING NO PROBABLE IGNITION SOURCES

Based on the ground rules established for this evaluation, the following subsystems are considered non-suspect from a probable ignition source standpoint:

- Sequential Events Controller
- Mission Control Programmer
- Crew Communications
- Instrumentation
- Experiments and Scientific Equipment

BLOCK II

The number of Block II components considered to be possible ignition sources under failure conditions is fourteen. This is seven fewer components than were listed in the Block I subsystems. The reduction in number is due in all cases to either one of two conditions:

- (a) The Block I component is not used in Block II or
- (b) The Block II components have been redesigned to eliminate the problem that existed in the Block I component. In many cases non-hermetically sealed components in Block I had been previously redesigned to incorporate hermetic seals due to concern over moisture penetration.

The following is a listing by subsystem of the Block II components that are considered possible ignition sources under failure conditions. The reasons that these are suspect can be found under the previous Block I subsystem discussion of the component.

ELECTRICAL POWER SUBSYSTEM

- General Usage Connectors

Special Purpose Connectors
Modular Terminal Boards
Electrical Wiring

DISPLAYS AND CONTROLS SUBSYSTEM
MDC and LEB Panels (Wiring and Terminal Strips)

ENVIRONMENTAL CONTROL SUBSYSTEM
Glycol Evaporator Back Pressure Controller
Cable Assemblies

GUIDANCE AND NAVIGATION SUBSYSTEM
G&N Interconnecting Harness
Eyepiece Heaters

STABILIZATION CONTROL SUBSYSTEM
Rotational Control

SPACECRAFT COMMUNICATION SUBSYSTEM
RF Connectors
Overheating of Equipment due to Loss of Cooling

TELEVISION SUBSYSTEM
Television Bulkhead Connectors and Cable Assemblies
The following lists subsystems in which there exists no probable source of ignition:
Caution and Warning
Sequential Events Controller
Entry Monitor
Crew Communications
Instrumentation
Experiments and Scientific Equipment

Table I of this Enclosure is a convenient listing of the ignition sources and identifies changes from Block I to Block II.

The type of packaging and qualification history was examined for the components which were reviewed for possible ignition services. The components were treated categorically so the total number portrayed is greatly reduced from the total number actually reviewed (i.e., switches, circuit breakers, terminal boards, etc.)

Total number of components	-	188
Number environmentally sealed	-	95
Number hermetically sealed	-	78
Number not protected by either hermetic or environmental packaging	-	15

Table II of this Enclosure is a listing of all the Block II components which are neither hermetically nor environmentally sealed.

Table III of this Enclosure is a listing by subsystem of non-metallic materials contiguous to the components in Block II which have been identified as possible single-failure ignition sources.

TABLE I OF ENCLOSURE
SUMMARY OF POSSIBLE SOURCES OF IGNITION UNDER A FAILURE CONDITION
- BLOCK I & BLOCK II -

BLOCK I ITEM	DESCRIPTION	STATUS IN BLOCK II
General Usage Connectors	Cabling	Same
Special Purpose Connectors	Cabling	Same
Modular Terminal Boards	Cabling	Same
Electrical Wiring	Cabling	Same
Main Display Console (MDC) Panels (Wiring and Terminal Strips)	Cabling	Same
Lower Equipment Bay (LEB) Panels (Wiring and Terminal Strips)	Cabling	Same
Elapsed Time Indicator	Component	Eliminated
Glycol Evaporator Back Pressure Controller	Component	No Change
Cable Assemblies	Cabling	Same
Waste Management System Blower	Component	Fixed
Display and Keyboard (DSKY) Electroluminescent Panels	Component	Fixed
Guidance and Navigation (G&N) Interconnecting Harness	Cabling	Same
Inertial Measuring Unit (IMU) Control Panel Switches	Component	Fixed
Eyepiece Heaters	Component	No Change
Rotational Control	Component	No Change
Velocity Change Indicator (Delta V)	component	Fixed
Radio Frequency (RF) Connectors	Cabling	Same
Overheating of Equipment due to Loss of Cooling	Condition	Same
EIapse Time Indicators	Component	Eliminated
Hughes Connectors	Cabling	Eliminated
Television Bulkhead Connectors and Cable Assemblies	Cabling	Same

TABLE II OF ENCLOSURE I
BLOCK II COMPONENTS NOT HERMETICALLY OR ENVIRONMENTALLY SEALED

COMPONENT	SUBSYSTEM	TYPE OF PACKAGING	REMARKS
D&C Panel Assemblies (Twenty-eight for Block I) (Fifteen for Block II)	Displays & Controls (D&C)	Conformal Coating	Terminals are potted or conformally coated. All current-carrying contacts are within sealed enclosures. Incandescent filaments are doubly sealed within glass bulbs inside sealed envelopes.
Eyepiece Stowage	Guidance & Navigation	Stowage	Qualified
Video Coaxial Connector/Cable Assemblies	Communications	No seal	These assemblies have been qualified. Voltage and power levels are not considered to be high enough to pose a threat of fire. There are no known failures which have indicated that a fire hazard exists in the video connector/cable assemblies.

TABLE II OF ENCLOSURE I (Continued)

COMPONENT	SUBSYSTEM	TYPE OF PACKAGING	REMARKS
Bulkhead Receptacle	Communications	Metal housing with plastic dielectric around terminals- No scat	The receptacle has been tested in 100% O ₂ at 14 psia with simulated camera load. No failure has occurred.
Stadiometer	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Data Reduction Tables	Experiments & Scientific Equipment	Not packaged	Non-electrical component
D009 Container	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Ultraviolet (UV) Stellar Spectrograph Support Structure	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Lens Cover	Experiments & Scientific Equipment	Not packaged	Non-electrical component
UV/X-Ray Solar Spectrograph Cable	Experiments & Scientific Equipment	Connectors Potted	No history of failure
Scientific Airlock	Experiments & Scientific Equipment	Not packaged; provides spacecraft seal	Non-electrical component
Film Magazine for Camera	Experiments & Scientific Equipment	Combustible film is totally enclosed, but not sealed, in metal magazine	No history of failure
1.2 Litre Contingency	Experiments & Scientific equipment	Not packaged	Non-electrical component
Urine Receiver	Experiments & Scientific Equipment	Not packaged	Non-electrical component
Scientific Junction Box	Experiments & Scientific Equipment	Potted internally	No history of failure

TABLE III OF ENCLOSURE 9-1

BLOCK II NON-METALLIC MATERIALS CONTIGUOUS TO COMPONENTS IDENTIFIED AS POSSIBLE SINGLE-FAILURE IGNITION SOURCES

SUBSYSTEM	NON-METALLIC MATERIALS
Electrical Power	Teflon Tetrafluoroethylene (TFE) Silicone Rubber

TABLE III OF ENCLOSURE 9-1 (Continued)

SUBSYSTEM	NON-METALLIC MATERIALS
Stabilization & Control	Phenolic Molding Compound Diallylisophthalate (DAMP) Molding Compound Epoxy Primer Acrylic Enamel Epoxy-Syntactic Foam Polyurethane Varnish Silicone Lubricant Silicone Rubber
Sequential Events Control	No Ignition Sources
Mission Control Programmer	Not Applicable
Entry Monitor	No Ignition Sources
Communications	Class A Foamed Polypropylene Irradiated Polyolefin Irradiated Polyvinylidene Fluoride Teflon
Instrumentation	No Ignition Sources
Experiments and Scientific Equipment	No Ignition Sources

TABLE III OF ENCLOSURE 9-1 (Continued)

SUBSYSTEM	NON-METALLIC MATERIALS
Displays & Controls	Teflon Tetrafluoroethylene, Fluoro Ethylene Propylene (TFE FEP)
	Polyvinylidene Fluoride
	Nomex Acrylic Coated
	Nylon
	Epoxy Polyamide Resin
	Epoxy Adhesive Epon 929
	Silicone Rubber Grommets
	Room Temperature Vulcanized (RTV) Conformal Coating
	Teflon
	Polyvinylide Fluoride
	Nomex Acrylic Coated
	Nylon
	Polyurethane
	Fiberglass
	Neoprene
Epoxy Polyamide Resin	
Caution & Warning	No Ignition Sources
Environmental Control	Compounds, Aircsearch SPEC Nos. 219-081-9001, 219-049-9001, S8471E22, S8952-20-9-008 223-022-9047 219-109-9001
Guidance & Navigation	Polyurethane Foam
	Viton
	Irradiated Polyethylene
	Polytetrafluoroethylene

SPACECRAFT ATMOSPHERES

BACKGROUND

The use of 100% oxygen for spacecraft atmosphere in the U. S. manned space program has been based on extensive research and development in both the fields of biomedical science and engineering. The selection of a pure oxygen atmosphere at a pressure of 5 psia for the Mercury, Gemini, and Apollo Programs resulted from careful consideration of the physiological, safety, and reliability requirements of manned space flight.

The engineering, medical, and safety aspects of the one-gas (100% oxygen) atmosphere have been the subject of widespread investigation in the United States and abroad, by government, university, and industrial research. While the bulk of the research has been over the past ten years, considerable work relating to the use of 100% oxygen in aircraft was done much earlier. Probably one of the most authoritative compilations of this research is contained in a four-part series on "The Selection of Space-Cabin Atmospheres," prepared for NASA by Dr. E. Roth of the Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico. The series, which was prepared under NASA contract, is comprised of four volumes: (1) "Oxygen Toxicity," (2) "Fire and Blast Hazards," (3) "The Physiological Factors of Inert Gases," and (4) "Engineering Trade-offs of One-Versus-Two-Gas Systems." Volumes (1) and (2) have been published; Volumes (3) and (4) are in the publication process. These studies have been further expanded by the work of the Douglas Company for NASA contained in, "Engineering Criteria for Spacecraft Cabin Atmosphere Selection," Douglas Missile and Space Systems Division, Douglas Report DAC-59169, November 1966.

GENERAL CONSIDERATIONS IN THE SELECTION OF SPACECRAFT ATMOSPHERE

Before discussing the specific aspects of the spacecraft atmospheres used in Mercury, Gemini, and Apollo, the general considerations relating to spacecraft atmosphere should be reviewed. Selection of the atmosphere must consider at least the following factors:

1. Sufficient oxygen content to support life. This requires a minimum partial pressure of oxygen equal to or greater than 3.5 psia.

2. Dysbarism (bends) caused by pressure decreases in a multi-gas system, or in transitions from normal atmosphere to pure oxygen environment at reduced pressures.

3. Total operating pressure, which affects spacecraft structural design as well as dysbarism potential in event of spacecraft decompression in normal or emergency operations.

4. Space suit operating pressure (gauge) which has significant effects on suit design, crew mobility in unpressurized cabin and extra-vehicular activity (EVA) physiological stress levels. In general, suit pressure levels exceeding 3.5 psia result in increasingly severe space suit rigidity.

5. Difference in cabin atmosphere constituents and suit atmosphere constituents which affect the possibility of dysbarism in decompression, or would dictate extended time for crew purging for EVA activities as well as potential leakage problems between suit and cabin atmospheres in redundant operating modes.

6. Pulmonary atelectasis (collapse of lung tissue), which could be caused by inhalation of pure oxygen for extended periods of time which is a function of absolute oxygen pressure level.

7. Differences between cabin atmosphere and suit atmosphere constituents which could produce the possibility of hypoxia! lack of sufficient oxygen! in the event of minor system malfunction or interaction.

8. The hardware complexity of the environmental control system design which is a function of its atmosphere constituents. This extends to consideration of oxygen uses for purposes other than life

its atmosphere constituents. This extends to consideration of oxygen uses for purposes other than life support.

9. The reliability of measuring and controlling the partial pressures of constituent elements of a multigas system. In general, more complex measurement and control systems must be used for a two-gas atmosphere as compared to simply controlling the pressure of an oxygen atmosphere.

10. Crew comfort on a long mission which is significantly affected by continued suit operation in either a pressurized or an unpressurized cabin. This consideration is also a function of confidence in cabin integrity and expected emergency decompression rates.

11. Effect of the atmosphere chosen on ignition temperatures of cabin materials. In general, the ignition temperatures for solids vary only slightly with oxygen partial pressure.

12. Effect of the atmosphere on combustion propagation rates after ignition has begun. Again, in general, the propagation rate is affected by oxygen partial pressure. However, at the relatively low pressures used in spacecraft, this effect appears to be of no significance.

MERCURY AND GEMINI FLIGHT ATMOSPHERES

The guideline for the selection of the atmosphere used in the Mercury Spacecraft was to employ the least complex and lightest approach consistent with reasonable safety. The 5 psia, 100% oxygen environment was selected as the best compromise to preclude anoxia and oxygen toxicity. Another consideration was the selection of a pressure level which, in the event of a cabin decompression, would result in a minimum decrease to the suit pressure, and therefore, the least incidence of dysbarism [bends]. It should be noted that prior to the inception of the Mercury Program, aviators flying high-performance aircraft were breathing 100% oxygen. This aircraft experience was the natural predecessor to the Mercury environment; in effect it constituted the "state of the art" within the aerospace medical community.

Early in the Mercury Program, a NASA Life Sciences Committee, chaired by Dr. W. R. Lovelace, II, reviewed the medical requirements and approved the approach taken by the program.

As a part of the development of the Mercury Environmental Control System (ECS) manned altitude chamber tests were conducted in a boilerplate spacecraft. The first of these manned tests was conducted at McDonnell Aircraft Corporation on April 21, 1960, with Mr. G. B. North, a McDonnell test pilot, as the test crewman.

Mr. North was prepared for the test by pre-breathing oxygen before ingress to the test vessel. The pressure suit circuit had already been purged with oxygen. After the ingress operation was completed, the suit circuit was again purged with oxygen for a time period and rate previously determined to assure an essentially pure oxygen environment in the suit circuit. The hatch was closed and sealed. No oxygen purge of the cabin was conducted, since the space suit was isolated and the Environmental Control System design provided an 80% cabin purge during spacecraft ascent by adding oxygen to the cabin as the cabin relief valve permitted total pressure to reduce from one atmosphere to space operating level.

The altitude chamber was evacuated to 27,000 feet equivalent altitude, and the Environmental Control System operation during the chamber pump down (simulating launch ascent) was as planned.

After approximately forty (40) minutes of operation at 5 psia, the test was aborted because Mr. North became unconscious. This condition was attributed to hypoxia (lack of sufficient oxygen).

Subsequent investigations revealed that leakage of nitrogen from the spacecraft air into the pressure suit circuit had gradually decreased the partial pressure of oxygen below physiologically acceptable limits. This decrease in oxygen partial pressure could occur since certain portions of the suit circuit were at negative pressures relative to the cabin pressure.

Three additional manned tests were conducted on June 2, 2, and 6, 1960. All three tests were aborted because of rapid decreases in the suit circuit oxygen levels.

As a result of these incidents, the prelaunch procedure for all Mercury spacecraft, both astronaut and chimpanzee, was changed to require that the cabin be purged with oxygen prior to launch. This change eliminated the possibility of nitrogen concentration in the suit circuit.

The requirement for purging the cabin with pure oxygen at approximately 15 psia during the

prelaunch period of several hours has been continued for all manned spacecraft launched in this country. This same procedure has been used also on all manned spacecraft vacuum chamber tests in the Mercury, Gemini and Apollo Programs.

The Gemini spacecraft atmosphere was selected to be the same as Mercury (5 psia, 100% oxygen). This selection allowed the Gemini program to develop an environmental control system largely based on the Mercury design, and to benefit from the years of previous experience in procedures, specifications, and standards. The Gemini system proved extremely reliable, and performed successfully in 10 manned flights, and in a large number of manned and unmanned altitude chamber tests and prelaunch operations.

APOLLO FLIGHT ATMOSPHERE

Early studies based on NASA's own research and also on a large body of other experimentation on artificial atmospheres, e.g., aircraft and submarine, resulted in a recommendation for a 7 psia oxygen-nitrogen atmosphere for Apollo. This first recommendation was in 1961. The primary reason for this recommendation was concern by physiologists that two-week Apollo missions in a 5 psia 100% oxygen environment (used in the Mercury Program) could cause pulmonary atelectasis (collapse of lung tissue). This condition had been observed after extended inhalation of pure oxygen prior to that time. However, a counter-balancing physiological question concerned dysbarism (bends) in the recommended two-gas system if a rapid cabin decompression should occur.

An extensive test program was, therefore, initiated to resolve these physiological questions for both the Apollo and Gemini atmosphere selections. (5 psia, 100% oxygen) atmosphere was planned for the Gemini spacecraft). The tests showed that a preoxygenation period of at least three hours was required to prevent bends in the event of cabin decompression during, or immediately following launch. Testing in the 5 psia 100% oxygen atmosphere indicated that atelectasis would not be a problem in the two-week Apollo or Gemini missions. (Satisfactory crew performance has not been demonstrated for 30-day periods in 5 psia 100% oxygen atmosphere, including dynamic and static conditions). Based on the results of this test program, NASA decided in 1962 that the Apollo spacecraft would also use the 5 psia 100% oxygen atmosphere used in the Mercury and Gemini Programs. This selection of cabin atmosphere in space has enabled:

1. Continuation of the Mercury and Gemini experience.
2. Avoidance of potential dysbarism problems in various modes of space operation.
3. Relatively simple environmental control system hardware with attendant high reliability.
4. A "shirt-sleeve" cabin environment which has enhanced crew comfort and effectiveness.
5. Minimum operational restraints to EVA initiation.
6. Maximum crew mobility within the constraints of present space suit design by utilizing lowest practical absolute pressure.

FLIGHT ATMOSPHERE FOR THE APOLLO APPLICATION PROGRAM

The Apollo Applications Program (AAP) presently plans to use a 5 psia two-gas atmosphere (60% oxygen; 31% nitrogen) only in the airlock module (S-IVB spent stage workshop) for planned mission durations in excess of 30 days. The 5 psia pressure level selected for the long duration missions was dictated by present Apollo pressure vessel capability and system compatibility considerations.

Present program plans continue the utilization of the standard Apollo pure oxygen environment in the Command/Service Module and Lunar Modules, which may be associated with AAP missions. While the airlock module will have the capability for a two-gas system on the first AAP mission, present plans are to utilize the two-gas system for the second mission (45 days). Pure oxygen atmosphere would be used on the first mission (30 days).

The primary consideration in utilization of the two-gas system for long duration missions is a desire to avoid physiological uncertainties and the possibility of atelectasis.

FIRE HAZARDS IN THE SPACECRAFT ATMOSPHERE

The possibility that fire could occur in any atmosphere capable of life support has been understood throughout the program. In general, neither ignition temperature nor combustion rate is a strong function of oxygen partial pressure in the range from 3.5 psia to perhaps 7 psia. Mixed gas systems operating with a minimum of 3.5 psia oxygen partial pressure apparently do not have significantly different fire hazard potentials as compared to a pure oxygen atmosphere at the same pressure.

Limited zero-G aircraft testing has indicated that there is a tendency for combustion in a low-pressure pure-oxygen environment at zero-G to be self-limiting. This may occur because of the lack of natural convection to remove products of combustion which no longer contain oxygen from the vicinity of the flame source. However, forced convection in the cabin could nullify this effect.

In orbit, fire on board the spacecraft could be extinguished by venting the cabin to space. This mode of operation would require the crew to be suited prior to the decompression period because physiological constraints dictate that a minimum body pressure of 3.5 psia be maintained. Suit-donning times are on the order of 10-15 minutes. Since the probability of fire was considered sufficiently remote, this mode was not given strong consideration because crew comfort and crew effectiveness in long-duration missions require that the suits be off for extended periods.

Attempts to design fire extinguishers for cabin deluge systems have not been particularly successful. The "fire pockets" between instrument panels and structures complicate the design of any effective fire-extinguishing system for spacecraft use. In addition, there is the potential interaction with crew safety, e.g., toxic fumes. The difficulty of timely detection of a fire and reliable operation of an extinguishing system must be carefully weighed against the potential dangers when considering such a system for spacecraft use.

SUMMARY REMARKS

In summary, the selection of a 100% oxygen atmosphere for manned spacecraft has resulted from the careful consideration of all factors relating to crew safety and mission success. This choice has been based on extensive research, which has included single and multi-gas atmospheres with their attendant advantages and disadvantages.

The 100% oxygen atmosphere has been used successfully in all U.S. manned flights to date, and is considered suitable for missions of 30 days or less.

EXAMINATION OF SOLDERED JOINTS FOR ALUMINUM TUBING

A. Design Selection Rationale

The decision to use aluminum tubing in the Environmental Control System (ECS) for both the water/glycol and oxygen circuits was made on the basis of stringent mission requirements and design limitations (weight, vibration, fluid compatibility, pressure, ect.). These required that:

- (1) All joints were to be essentially leak free. The maximum leak rate allowed was 5.6×10^{-6} std. cc of helium/sec.
- (2). The joints were to be compatible with the various spacecraft fluids without a loss in strength, particulate formation, or fluid degradation.
- (3). The joints, and the lines, were to withstand an acoustic environment sustained at a sound pressure level above 143 decibels for 150 seconds.
- (4). The joints were to sustain a dynamic in-flight environmental stress of 17,000 psi for 5,000 cycles.
- (5). The maximum design pressure was not to exceed 900 psi in the ECS aluminum lines.

Another consideration was that the plumbing system be of minimum weight. The aluminum tube wall thickness was established at .035 inch for strength and to facilitate handling, 304L stainless steel lines would also require 0.035 inch tube wall. On this basis, assuming the various joint configurations would be similar for both steel and aluminum, the steel system would weigh approximately 3 times the aluminum system, a weight penalty of approximately 103 pounds.

Welding of the aluminum joints was also considered, but early in the program it was evident that an extensive and costly development program would be necessary. Therefore, aluminum tube welding was limited to manual welding on the bench and in readily accessible areas on the spacecraft.

Mechanical fittings were utilized, but limited in number for obvious reasons. Mechanical fittings are susceptible to loosening under vibration, and generate the greatest amount of particulate matter during tightening. Therefore, these joints (B-nuts and quick disconnect fittings) were limited to dissimilar metal joining, closeout lines, equipment connectors, etc.

Based upon these considerations, a metallurgical joint was indicated and a soldered union for joining aluminum tubing was considered. The soldered tube-union joint permits the assembly of a plumbing system of minimum weight generates the minimum contamination, has adequate strength to withstand system pressures, is compatible with system fluids, and will sustain spacecraft environments.

When the decision to use solder joints was made in 1962, a program was immediately initiated to select a soldering alloy. This alloy was required to be compatible with the spacecraft fluids, readily available, and applicable to existing processing techniques. This phase of the program involved an intensive literature search, mechanical property determinations, flow and compatibility testing.

The literature survey resulted in 31 candidate alloys from which twenty were selected for fluid compatibility testing. These tests screened out all but two potential alloys. These two alloys were subjected to the following tests:

- [1]. Compatibility with N₂O₄
- [2]. Alloy wetting and flow characteristics
- [3]. Optimum plate thickness (nickel base for solder)
- [4]. Optimum gap for capillary flow
- [5]. Peel resistance
- [6]. Metallurgical analysis (diffusion, erosion of tube)
- [7]. Mechanical properties (shear, stress rupture)
- [8]. Effects of reheating

Subsequent to these tests, containment of N₂O₄ was not required by the aluminum tubing. This

necessitated a re-evaluation of the soldering alloy. Based upon prior development testing, production experience, strength, availability and exceptionally good corrosion resistance, it was decided to test and use the 60 Sn - 40 Pb solder alloy. This solder conformed to Federal Specification QQ-S-571, Type SN 60 RARP2 (activated rosin cored flux). This alloy was subjected to the following tests:

[1]. System and Material Compatibility Tests

- a. Exposure and weight loss
- b. Metallographic examination
- c. Salt spray - 240 hours at 95°F in 20% NaCL
- d. Humidity - 240 hours at 120°F in 95% humidity
- e. Simulated system exposure to water-glycol for periods up to 8 months
- f. Leak tests prior to and subsequent to exposure
- g. Joint strength change prior to (control specimen) and subsequent to exposure.

[2]. Mechanical Property Tests

- a. Joint shear strength
- b. Stress rupture under tensile loading (38% to 90% of joint shear strength).
- c. Creep (35% to 95% of joint shear strength)
- d. Burst pressure (Hydrostatic)
- e. Flexure - Impulse fatigue - Impulse fatigue (pressure 40-60 psi, 17,000 psi fiber stress for 5,000 cycles minimum).

[3]. Structural Environmental Tests

- a. Acoustic vibration (143 decibels minimum for 150 seconds).
- b. Vibration-flow (Sinusoidal and random vibration - time 5 minutes, Orientation: Both orthogonal axis perpendicular to the longitudinal axis of the tube).

[4]. Leak Testing

a. Mass Spectrometer

1. Internally pressurized joints
2. Evacuated lines and joints

[5]. Effect of Resoldering Joints

PROCEDURE

- a. Solder up to 3 times (joints pulled apart between each resolder operation).
- b. Check joint by X-Ray for presence of voids.
- c. Leak rate with mass spectrometer
- d. Determine change in joint strength.

[6]. Alignment

Where required, a tube alignment fixture shall be attached in such manner that the tubes are held together with a maximum allowable gap of 0.060 inch. The maximum permissible axial misalignment shall be three degrees, and displacement of either tube end from the center of the union shall not exceed 0.060 inch.

TEST RESULT SUMMARY

[1]. Corrosion and Compatibility Testing

- a. No evidence of deleterious corrosion or corrosion products were noted in simulated partial ECS systems with inhibited water/glycol after eight months exposure. Aluminum soldered joints removed from SC 011 after flight and recovery revealed only a slight white deposit in

the joint area, but no evidence of tube or solder alloy corrosion. The white deposit is believed to be an anhydrous $Al(OH)_3$, but is not considered detrimental in an active system as it is present as a gel and does not clog the system.

b. No deleterious corrosion was evident due to the salt spray and humidity testing. The leak integrity of the joint was maintained with no appreciable loss of strength as measured by the burst tests.

[2]. Mechanical Property and Environmental Stress Testing

a. The joint shear strength (tensile) is more than adequate for the low pressures used on the Apollo. The tensile load applied by the system pressure is only a fraction of the joint strength. Avg joint strength [1/4 dia.] - 681 pounds Axial load due to pressure [900 psi] - 36 pounds

b. The vibration, flexure-impulse, and burst-test results indicate that the joints do withstand the environmental stresses by at least a factor of 10.

(3). Structural Environmental Testing (Spacecraft Test Sections)

Several test sections of the service module containing numerous soldered joints of all sizes and configuration were acoustically tested with only one leak (out of 51 joints) in a water/glycol tube tee assembly. This test was part of the auxiliary plumbing and not a test item. This joint was repaired and the test repeated successfully.

[4]. Leak Testing

The leak tests were performed with a mass spectrometer sensitive to 10^{-6} std. cc of helium/second using helium as the detectable gas. The leak checks were performed prior to and subsequent to vibration, flexure-impulse, and resoldering tests. Out of 47 joints tested, five leaks were observed. Two of the leaks were in the tubes at the fixture, two did not exceed the allowable limits (3.54×10^{-7} and 1.27×10^{-7} st. cc of helium/sec.) and the fifth had a leak rate of 8.9×10^{-6} std. cc of He/sec.

(5). Burst Testing

The average hydraulic fluid pressure required to burst the aluminum soldered joints ranged from 13,000 psi for the 1/4 inch lines to 5,300 psi for 5/8 inch lines. These fluid pressures are more than adequate for the maximum system pressure of 900 psi. Based on these results the factor of safety at operating pressure is at least six.

(6). The selection of solder for joining aluminum tubes was evaluated further by establishing the magnitude of the midspan deflection of a simply-supported tube specimen stressed in bending to 17,000 psi. This stress was considered to be a minimum safe allowable value. The span was selected by assuring that the natural frequency would be greater than 120 cps. Based on the outer fiber stress of 17,000 psi achieved during the test, the following midspan deflections were obtained.

Tube Diameter (In.)	Span (In.)	Midspan Deflection (In.)
1/4	13.5	0.239
3/8	16.5	0.226
5/8	22.0	0.232

It was assumed that in normal manufacturing and assembly handling these deflections would permit assembly without any undue problems in tube alignment and line movement during equipment installation and removal. These deflections were substantiated by the vibration test which imposed a fiber stress of 17,000 psi for a minimum of 61,200 cycles.

Based upon the foregoing data, the implementation of soldering for joining aluminum tubing is considered to a sound decision provided the procedures for alignment are met, good design practice is exercised, and appropriate criteria for system installation and field maintenance are generated.

B. Program Experience

(1). Union on coupling design.

The union, as presently used in the program, has been designed to minimize weight. In practical use and especially in conjunction with the use of the 6061-T6 hardened aluminum tubing, these unions have proven to be unsatisfactory. Considerable number of leaking joints have been found on all spacecraft. Substantial improvement of this union is required in order to accept normal handling associated with spacecraft checkout and field repairs.

(2). Joint Assembly

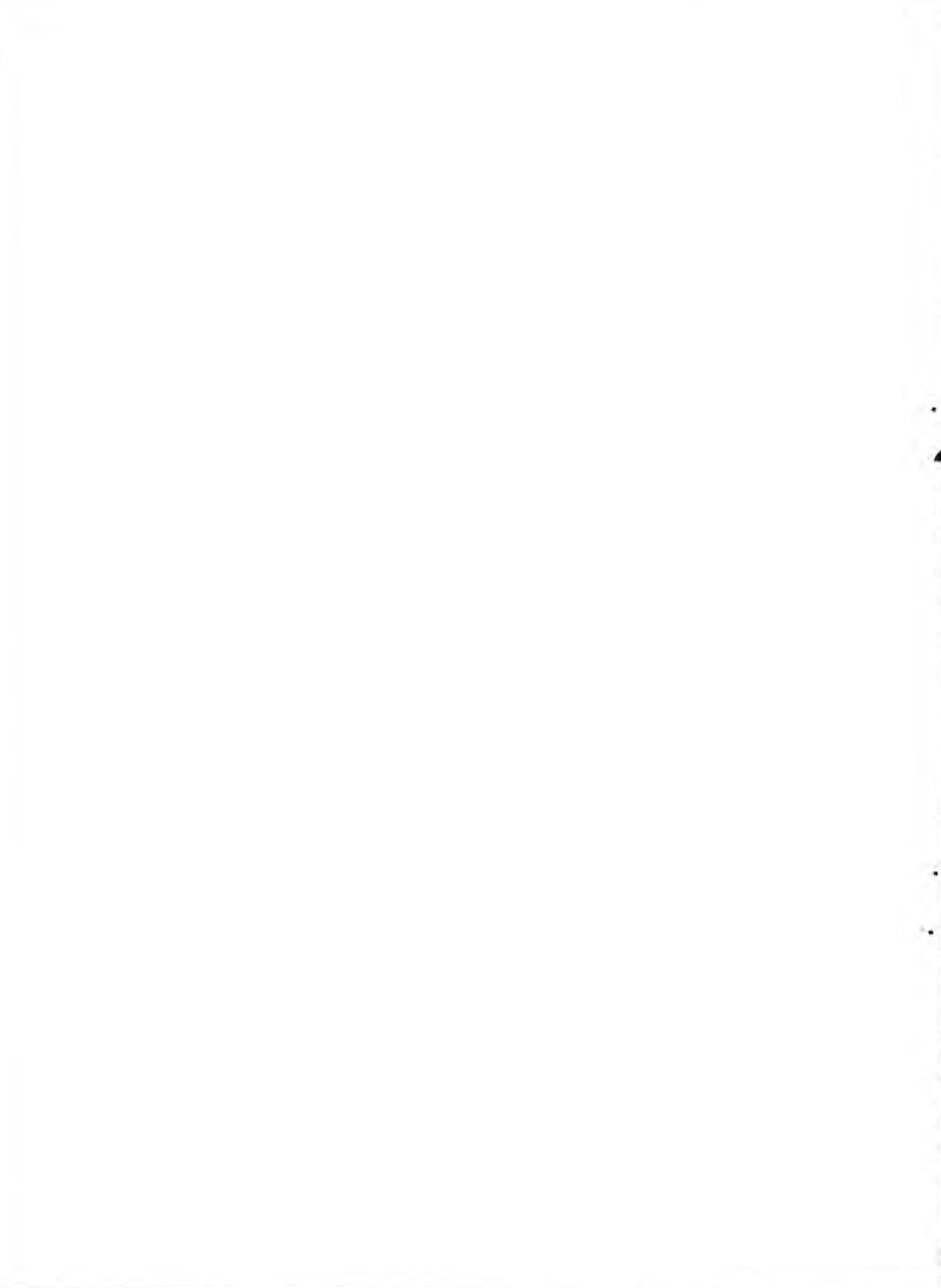
Initially, considerable difficulty was experienced in the nickel plating process; however, this problem has apparently been resolved by establishing and maintaining rigid cleaning process specifications.

The present specification allows an additional heat if the joint is unsatisfactory. Criteria for a satisfactory joint has been reduced to leakage only. Joints not meeting the other criteria are often accepted as a result of engineering action if they meet the leakage requirements.

In spite of the allowable reheat and reduced criteria, a ten percent rejection rate still exists.

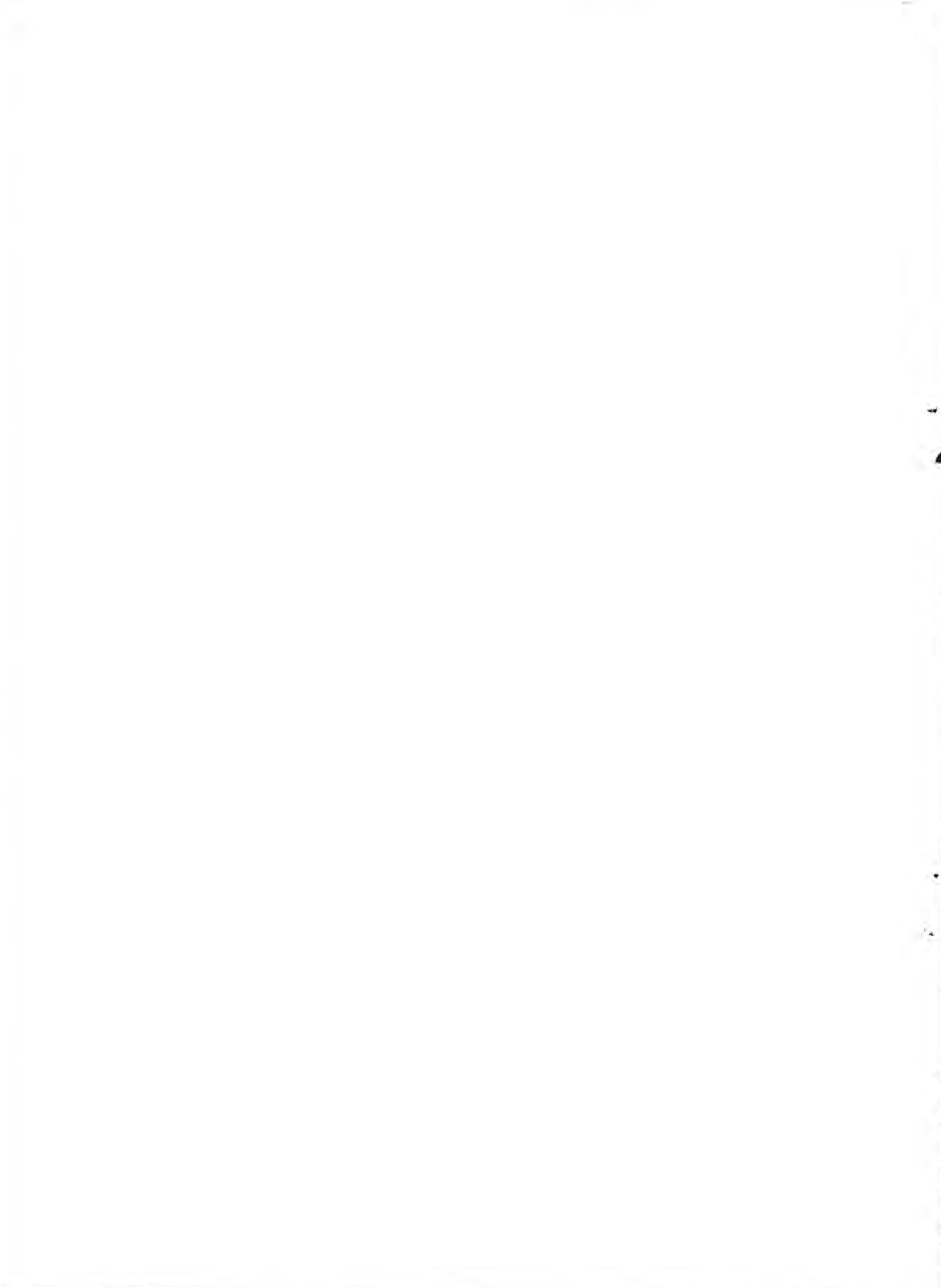


WIRING ASSESSMENT





WIRING ASSESSMENT

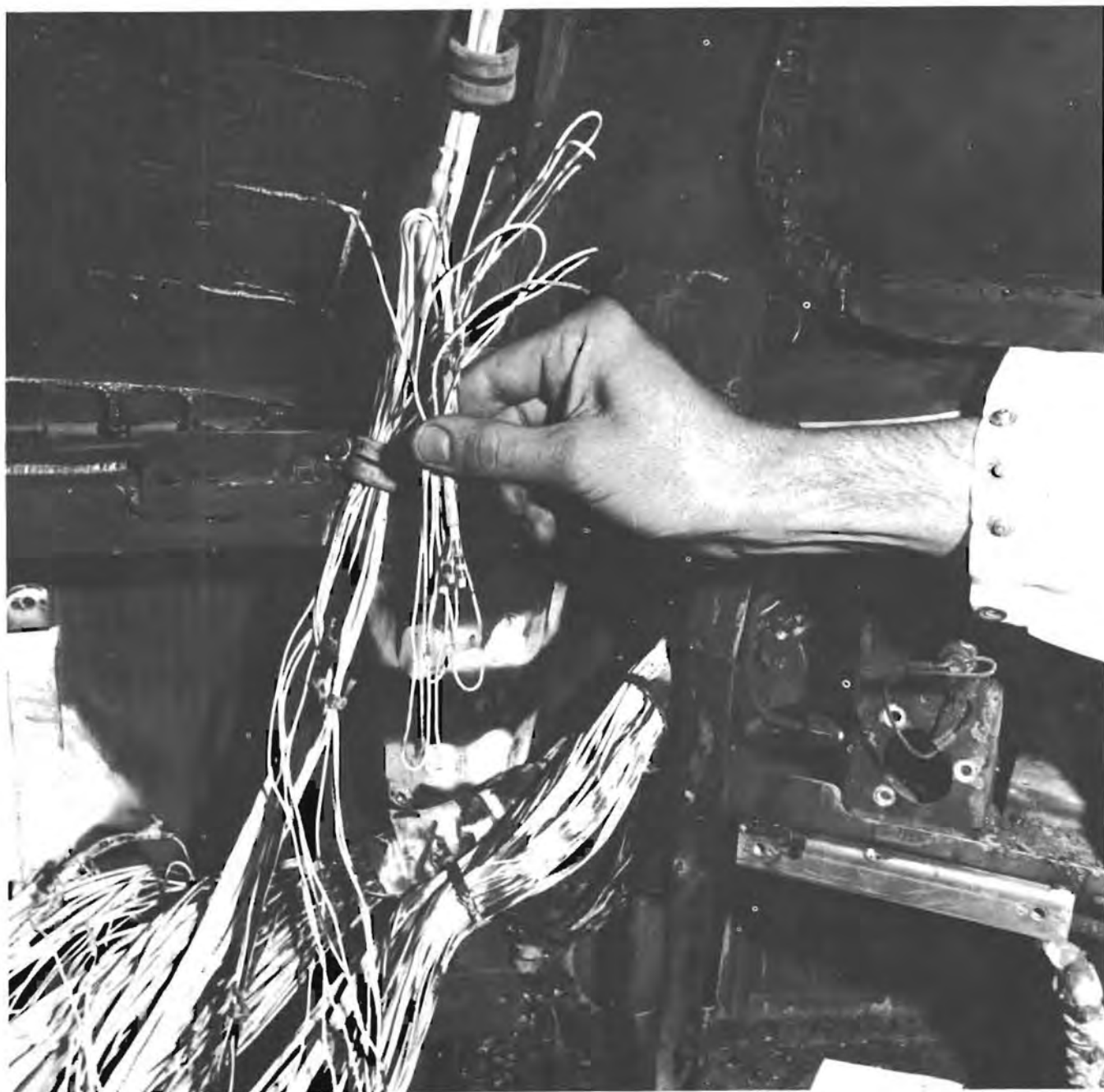




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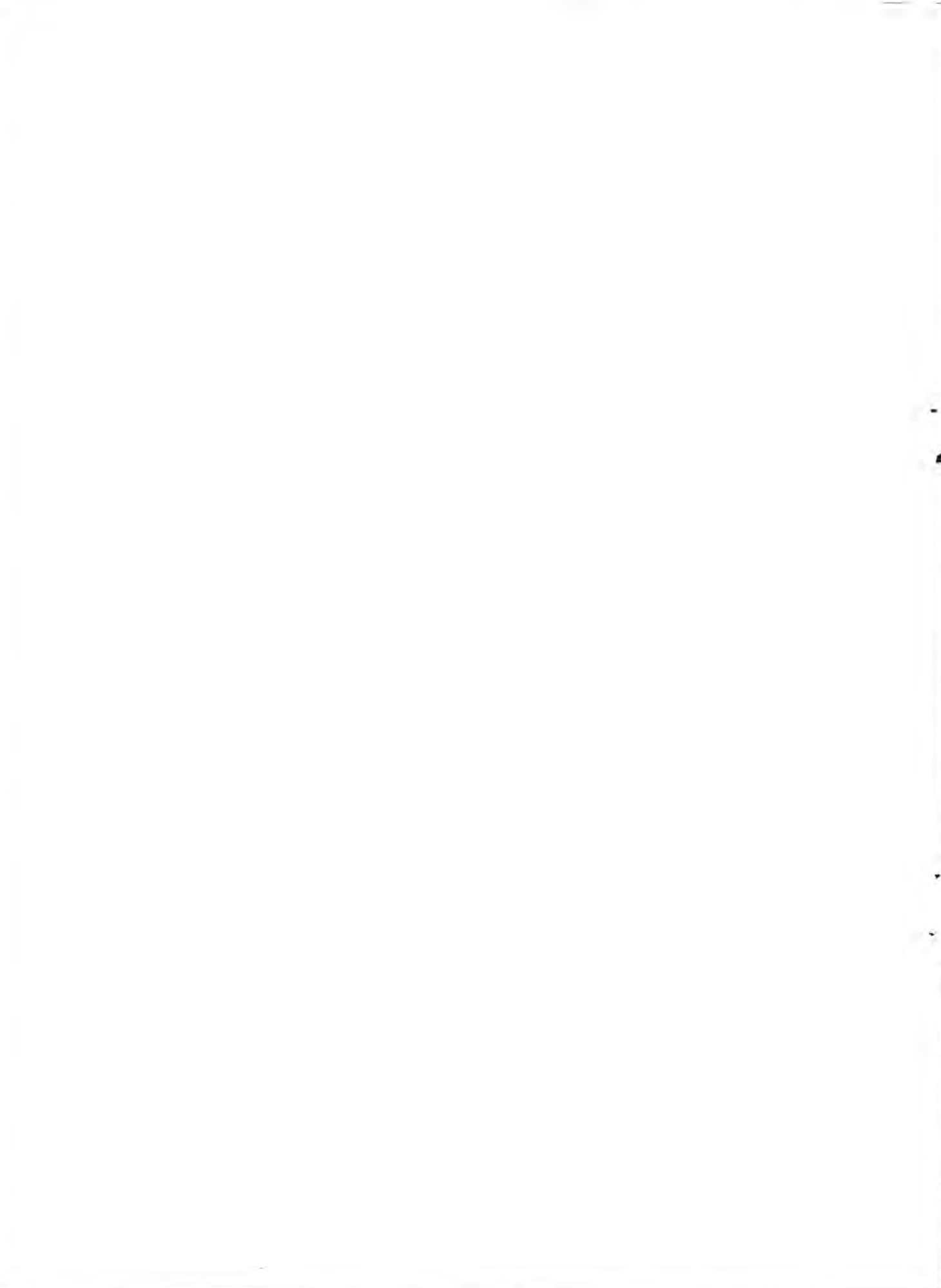
ENCLOSURE 9-6





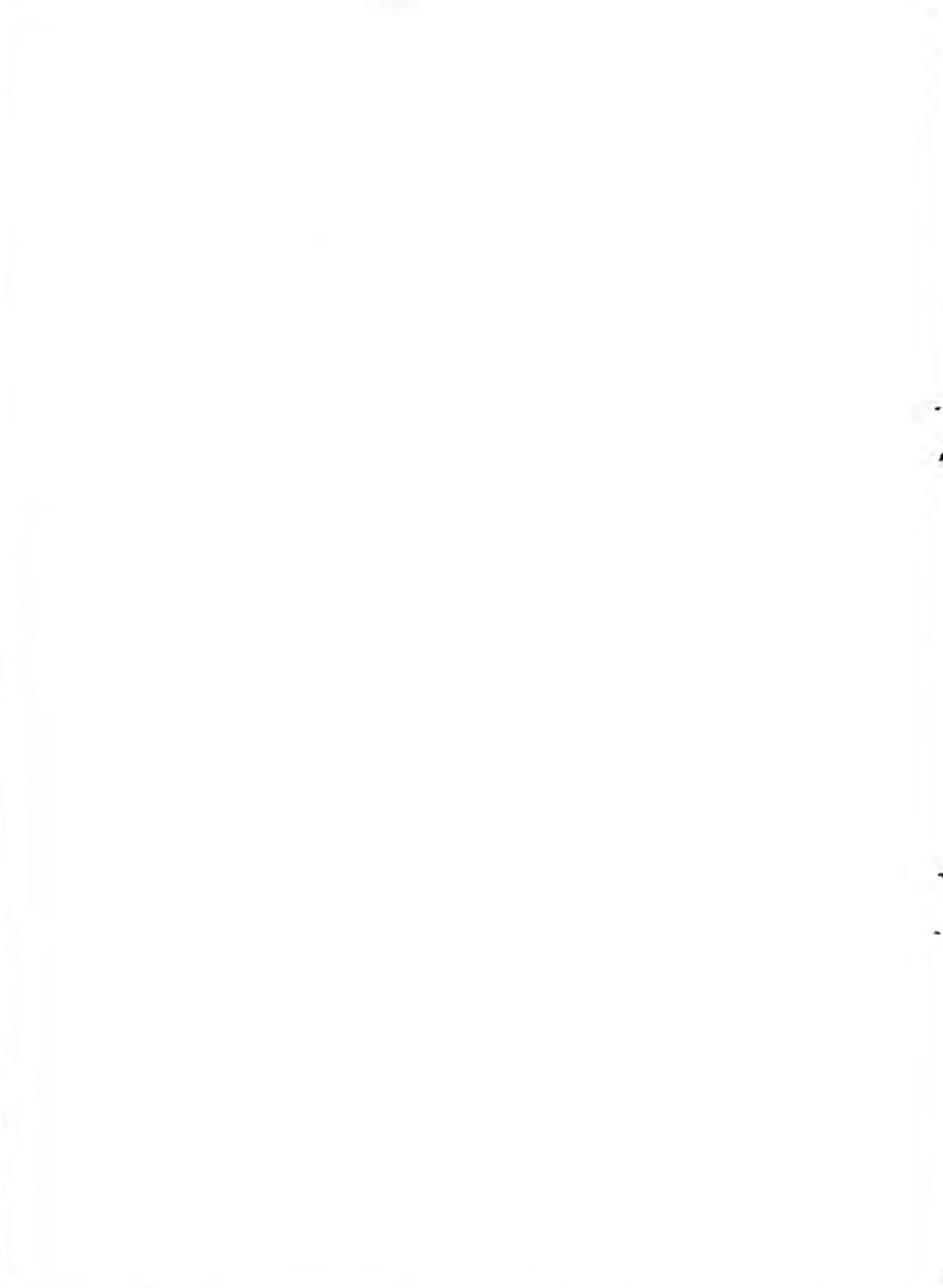
WIRING ASSESSMENT

ENCLOSURE 9-7





WIRING ASSESSMENT





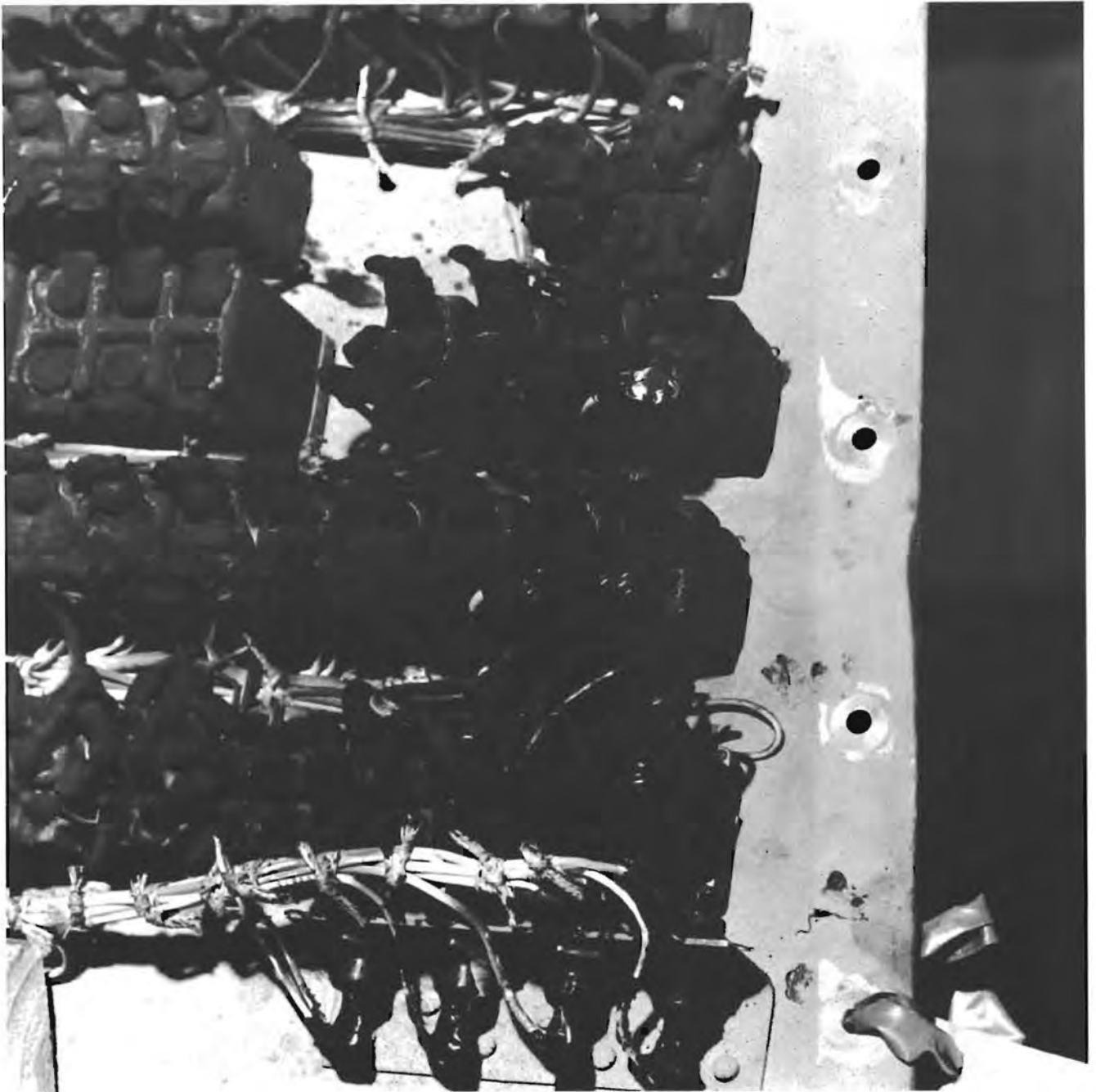
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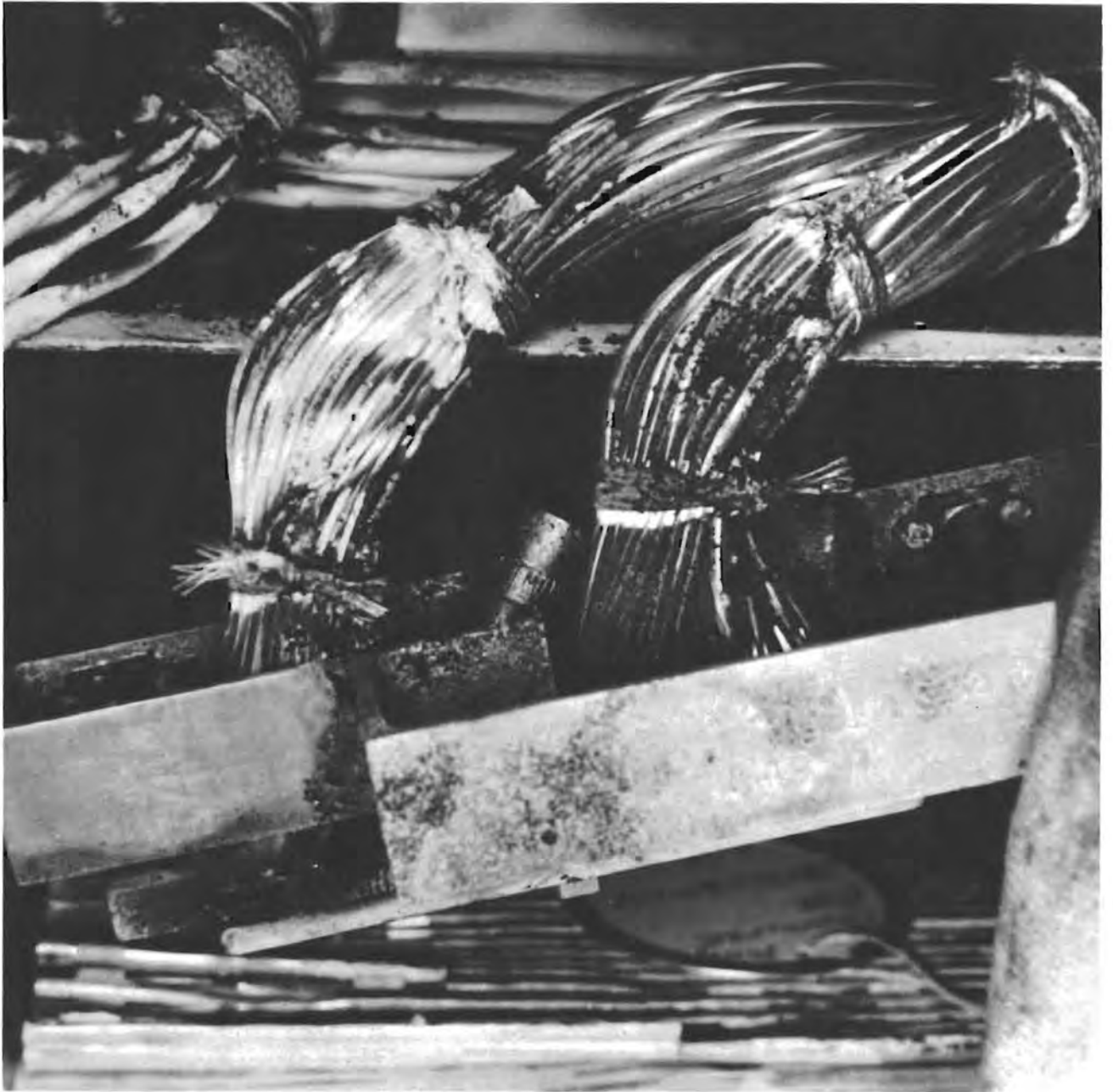


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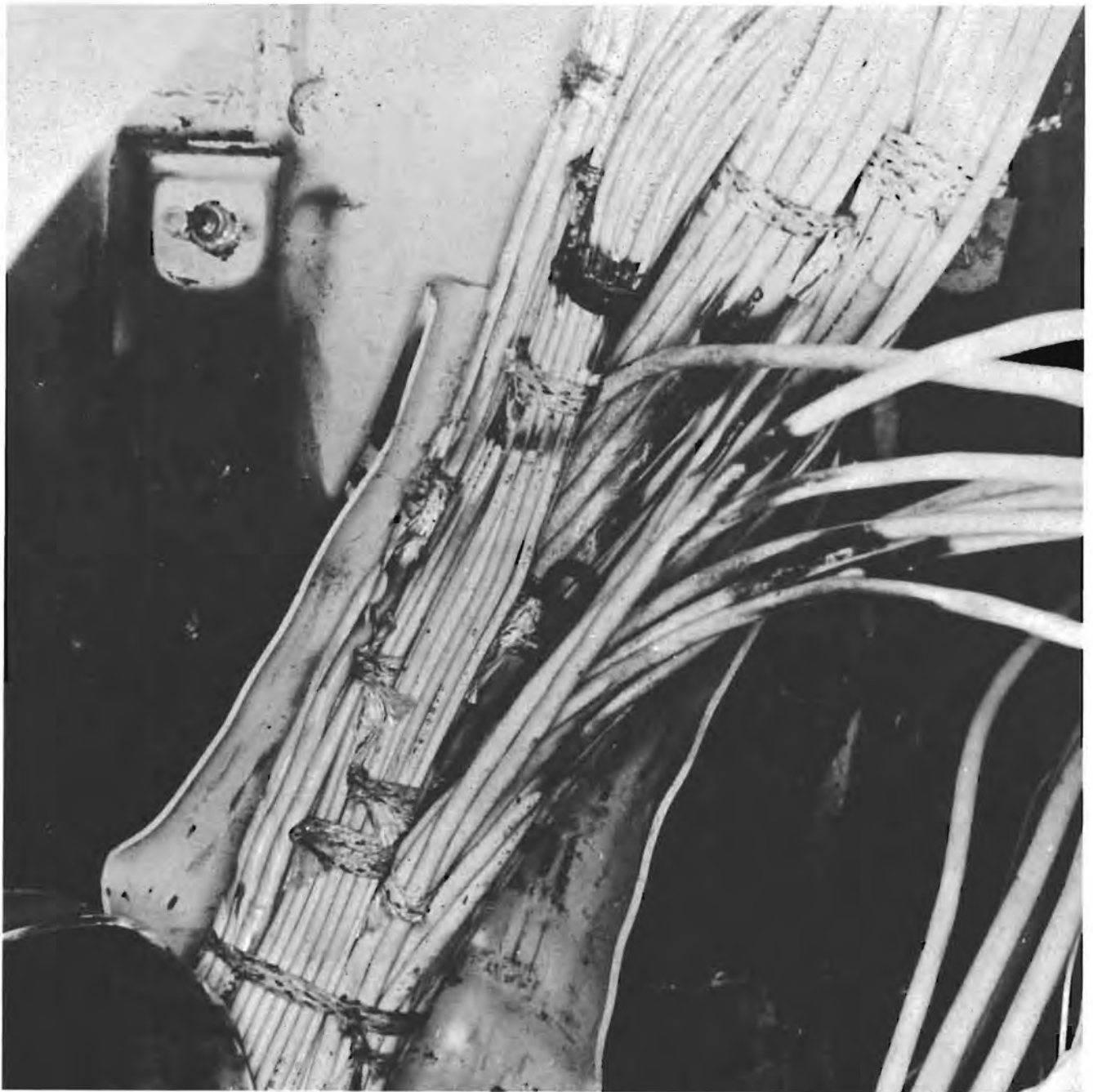
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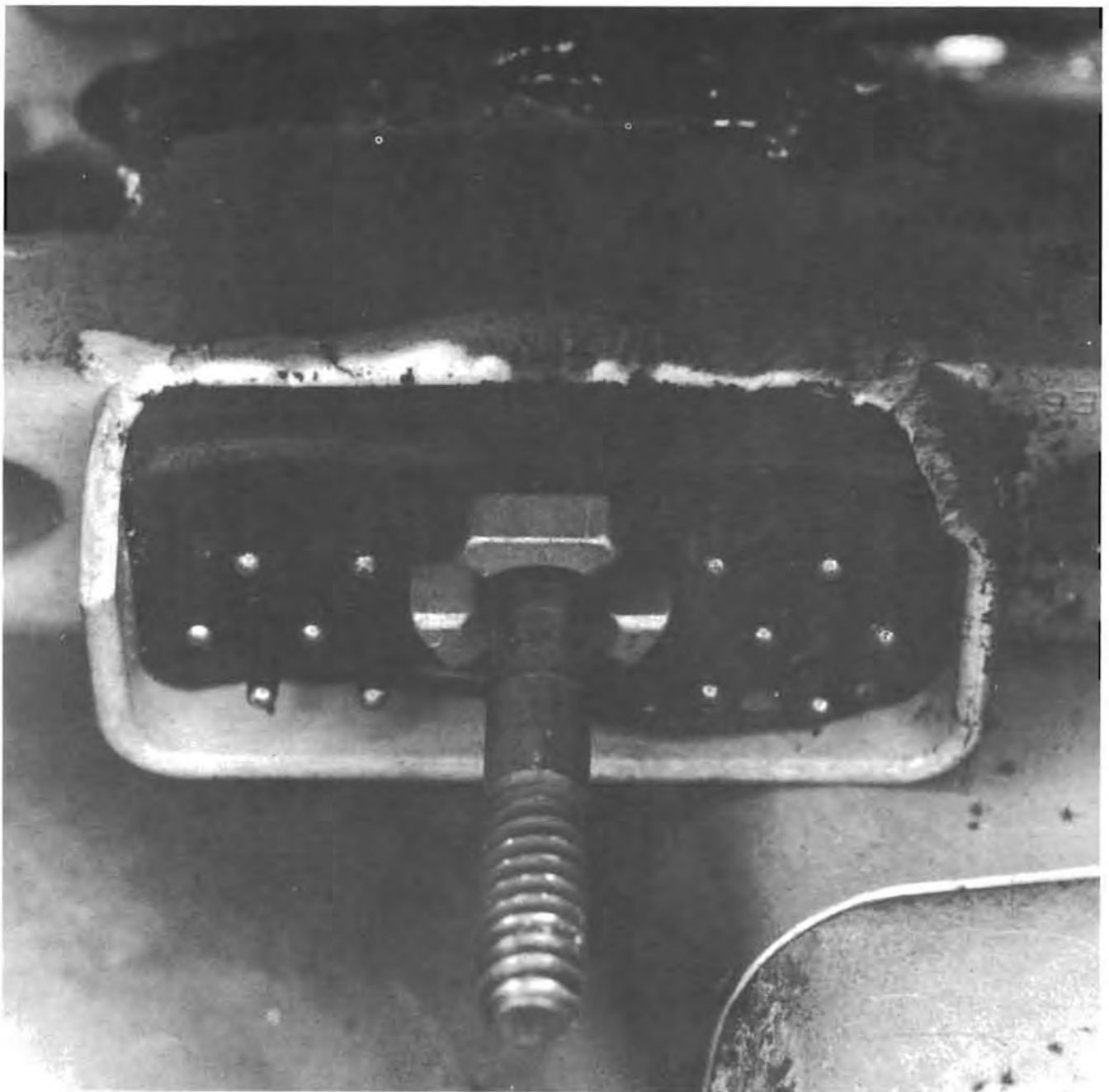
ENCLOSURE 9-12





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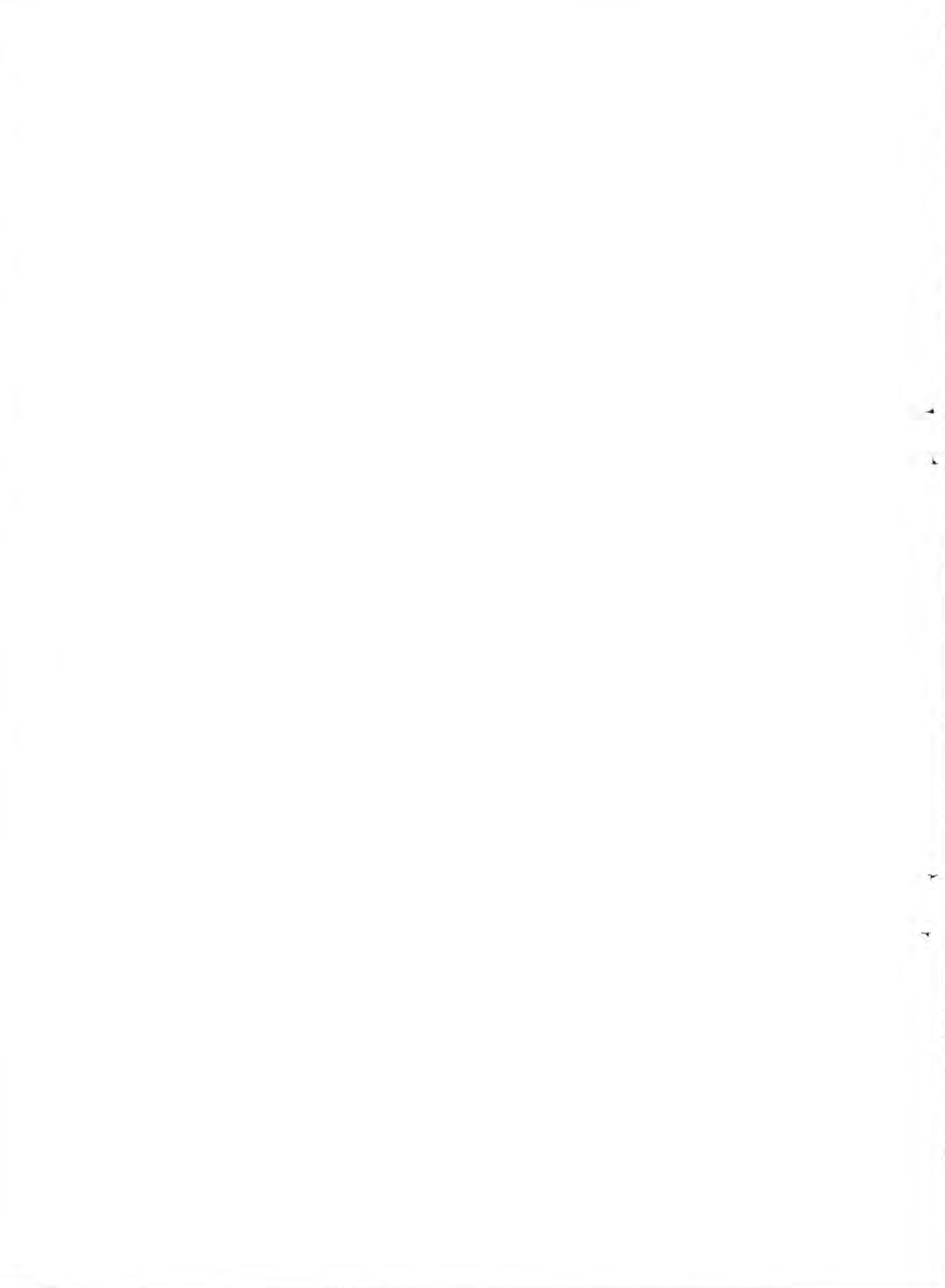


WIRING ASSESSMENT





WIRING ASSESSMENT



LIST OF REFERENCE MATERIAL

The supporting data for this report have been transmitted to the Apollo 204 Review Board files. These data are contained in the following references:

REFERENCE

- 9-1. Williams, R. W., DETAILED INSTRUCTION TO WORKING GROUPS, February 5, 1967.
- 9-2. Hamblett, E. B., et. al., COMMAND MODULE CREW COMPARTMENT IGNITION SOURCES AND CONTIGUOUS NON-METALLIC MATERIALS, March 15, 1967.
- 9-3. Hamblett, E. B., et. al., DATA SHEETS, BLOCK I AND BLOCK II COMMAND MODULE IGNITION SOURCE AND CONTIGUOUS NON-METALLIC MATERIAL REVIEW.
- 9-4. CABIN ATMOSPHERE, SUMMARY AND BIBLIOGRAPHY.
- 9-5. Joslyn, A. W., et. al., OXYGEN SUMMARY, March 15, 1967
Hazards Evaluation, Bibliography
Engineering Tradeoffs [State of the Art] - General, Bibliography
Material Selection, Bibliography
Physiological Considerations - General, Bibliography
MSC Supporting Data [Atmospheric Selection, Safety Considerations], Bibliography
New Releases, Bibliography.
- 9-6. Jaderlund, W. W., et. al., APOLLO 204 PANEL 9 REPORT ON PAD EGRESS, March 10, 1967.
- 9-7. Beers, C. A., et. al., VOICE COMMUNICATIONS ANALYSIS REPORT, PANEL 9, APOLLO 204 REVIEW BOARD, March 21, 1967.

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**REPORT OF PANEL 10
ANALYSIS OF FRACTURE AREAS
APPENDIX D-10
TO
FINAL REPORT TO
APOLLO 204 REVIEW BOARD**



A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Analysis of Fracture Areas Panel, 10. The task assigned for accomplishment by Panel 10 was prescribed as follows:

Inspect spacecraft for structural failures resulting from the fire. Analyze these failures from standpoint of local pressure, temperature levels, direction of gas flow, etc.

B. PANEL ORGANIZATION

1. MEMBERSHIP:

The assigned task was accomplished by the following members of the Analysis of Fracture Areas Panel:

Mr. P. C. Glynn, Chairman, Manned Spacecraft Center (MSC), NASA
Mr. N. Koenig, Kennedy Space Center (KSC), NASA
Mr. R. E. Johnson, Manned Spacecraft Center (MSC), NASA
Mr. S. Glorioso, Manned Spacecraft Center (MSC), NASA
Mr. L. J. Korb, North American Aviation, Inc. (NAA)
Mr. D. Root, North American Aviation, Inc. (NAA)

Technical support was provided by the Manned Spacecraft Center (MSC) Structures and Mechanics Division (SMD) and North American Aviation structural analysis personnel. The major portion of the on-site task consisted of detailed metallurgical inspection and laboratory analysis. Metallurgists Korb, Glorioso, Root, and Johnson performed the majority of the inspection while Koenig monitored or performed all the laboratory analyses.

2. COGNIZANT BOARD MEMBER:

Mr. E.B. Geer, Langley Research Center (LaRC), NASA, Board Member, was assigned to monitor the Analysis of Fracture Areas Panel.

C. PROCEEDINGS

In response to the direction of the Apollo 204 Review Board, the Panel derived detailed objectives. These objectives were:

Inspect the spacecraft structures to determine the extent, origin, mode, and failure sequence of significant structural damage.

Estimate the cabin environment during the fire. Analyze all applicable data and examine the spacecraft for evidence of local temperature and pressure extremes.

Provide metallurgical support to the systems engineers during spacecraft disassembly. Define metallurgical test requirements to determine the cause of system damage.

1. PANEL ACTIVITY

The inspection of the spacecraft structures was conducted in a systematic manner starting with the Command Module (C/M) and Service Module (S/M) while located at Launch Complex 34 and continued through C/M heat shield removal. Structural damage reports were made coincident with the spacecraft disassembly phases. As major sub-systems were removed from the spacecraft, they were visually inspected. Buckles, fractures, cracks, melted areas, localized arcing or pitting in metal components, and obvious direct wire shorts were noted and documented. Those items which required laboratory analyses were identified and detailed test requirements were defined. Equipment removed from the spacecraft following heat shield removal was inspected in detail at the request of the applicable system engineer. Analyses of results of the monitored laboratory work were provided to Panel 18 Integration Analysis. Metal degradation due to extreme structural temperatures was documented and analyzed. An estimate of the temperature attained in local areas as determined from examination of the metallic components was provided to Panel 8 Materials Review. Support concerning the spacecraft strength and structural configuration was provided to Panel 4, Disassembly Activities Panel. Structural and mechanical subsystem support was provided to the Equipment Screening Committee.

2. INTRODUCTION

The crew compartment of C/M 012 was a pressurized shell fabricated of bonded aluminum honeycomb sandwich structure. The cabin structure was pressurized to a positive pressure of approximately 2 pounds per square inch differential (psid) pressure at the time of the fire. As a result of the fire, portions of the interior and exterior were burned and the primary cabin structure was ruptured.

At the time of the accident, all components of the structural and mechanical subsystem were inactive. No evidence was found which would support a hypothesis of mechanically induced ignition of combustibles within the C/M. The crew equipment subsystem contained combustible material which burned. Examination of film and data from the SMD-2B boilerplate fire simulation test (Reference 10-1) verified that the rupture of the C/M cabin accelerated the propagation of the fire by inducing forced convection.

3. INVESTIGATIVE ACTIVITIES

a. CABIN RUPTURE

(1) TIME OF RUPTURE

The time of cabin rupture was concluded to be between 6:31:19.3 pm EST (23:31:19.3 GMT) and 6:31:19.5 pm EST. This conclusion is supported by analysis of aft heat shield thermocouple data and Stabilization and Control System (SCS) spacecraft angular rate data. The thermocouple data indicated an open circuit at approximately 23:31:19.5 GMT. Inspection of the measurement wire leads near the origin of cabin rupture verified that the leads had been burned through. The indicated structural motions at rupture, indicated at 23:31:19.3 GMT by the SCS rate measurements, were analyzed and correlated with the origin of the fracture.

(2) CABIN PRESSURE HISTORY

Atmospheric pressure at the time of the accident was 14.68 pounds per square inch absolute (psia). Direct measurement of the cabin pressure was valid until approximately 6:31:16 pm EST at which time the cabin pressure measurement indicated full scale. However, the Guidance and Navigation System did respond to cabin pressure as discussed in Reference 10-2. AC Electronics Division analyzed the applicable data from OCP FO-K-0021-1 as well as data from a previous C/M 012 cabin pressure test. This and supporting test data obtained by simulation using Spacecraft 008 (Reference 10-3) verified the cabin pressure measurement and provided the additional data points shown in Enclosure 10-2.

An estimate of the minimum cabin pressure history for the time period 6:31:16 to 6:31:19.4 pm EST was calculated. The heat absorbed by the cabin gas was calculated up to the time of pressure transducer saturation. The rate of heat absorbed by the cabin gas was linearly extrapolated and the resulting pressures and average gas temperatures were calculated. Venting of the cabin pressure relief valve and the addition of oxygen to the cabin were included in the analysis (Reference 10-4 and 10-5). Operation of the cabin pressure relief valve was shown to have negligible effect upon the time until cabin rupture. The method of analysis used was judged to yield a minimum pressure history. The estimated minimum pressure at rupture was 29 psia.

Enclosure 10-2 presents the estimated cabin pressure from 6:31:06 to 6:31:22 pm EST. Pressure values plotted for the time of rupture are:

- Design ultimate pressure 12.9 psi differential (27.6 psia)
- Estimated minimum pressure at rupture 14.3 psi differential (29 psia)
- Estimated maximum pressure at rupture (discussed in Section C3c(1))
23 psi differential (37.7 psia)

Average gas temperature at the time of rupture was estimated to be in excess of 700 degrees Fahrenheit (°F). The SMD-2B fire simulation test data (Reference 10-1) and analyses estimate a structural temperature at the time of rupture in the vicinity of the origin of fracture of less than 130° F.

b. C/M PRIMARY STRUCTURAL DAMAGE

(1) C/M EXTERIOR

Inspection of the C/M exterior indicated extensive primary structural damage to the +Y, -Z quadrant exterior structure. Evidence of degradation of the external thermal control coating was most severe in this region. Evidence of C/M crew compartment exterior structural damage was noted in the region between access panels 15 and 17, (Enclosure 10-3) and of the helium pressurization panel bracketry as illustrated in Enclosures 10-4 and 10-5. Inspection following heat shield removal indicated burned and melted secondary structure in this region.

(2) C/M CREW COMPARTMENT

Inspection of the interior of the C/M cabin determined that the primary structure was damaged in several locations. Burned penetrations of the bonded aluminum honeycomb sandwich cabin structure were observed in the aft bulkhead beneath the Environmental Control Unit (ECU) and Water Control Panel and in the aft sidewall behind the Water Control Panel. Rupture of the aft bulkhead was observed as illustrated in Enclosures 10-6 and 10-7. Melting and erosion of the fracture surfaces was evident and is illustrated in Enclosure 10-8.

Much of the fracture surface was not initially visible from the interior of the C/M due to equipment and secondary structure installations. The fracture surfaces are defined in detail in Enclosures 10-9 and 10-10. Exterior definition of the fracture is illustrated in Enclosure 10-11a, 10-11b, and 10-11c.

(3) C/M AFT HEAT SHIELD

The aft heat shield brazed stainless steel honeycomb sandwich structure was melted and eroded in the +Y, -Z quadrant as shown in Enclosures 10-12a, 10-12b, and 10-12c. Evidence of high temperatures and high velocity gas flow is further illustrated by the charred and missing insulation which is installed between the aft heat shield and cabin aft bulkhead. Evidence of impinging hot gas through penetrations in the cabin aft bulkhead in the +Z quadrant was observed. Little evidence of impinging gas was observed at the location of the burned-through area beneath the ECU and Water Control Panel.

c. ANALYSIS OF PRIMARY FAILURES

(1) BACKGROUND

Nondestructive pressure testing of the C/M crew compartment structure performed during the qualification tests of the Apollo Spacecraft structure predicted the observed mode of aft bulkhead rupture. The aluminum sheets forming the inner surface of the cabin are welded to form a pressure tight compartment. Thicker chemically milled sections at the circumferential joint of the aft bulkhead (Enclosure 10-7) are provided to facilitate the welding process and allow for the reduced unit strength of the weld. The junction of the aft sidewall aft bulkhead forms a discontinuity in the shell surface. The critical region of the cabin structure for internal pressure loading occurs in the aft bulkhead inner face sheet at the transition of the weld land to the thinner inner face sheet near this discontinuity.

The predicted failure mode is rupture due to meridional tensile stress of the inner face sheet. Calculation, using strain gage data from the qualification test, yields an estimated upper limit of burst pressure of 37.7 psia.

(2) ORIGIN

Detailed inspection of the bulkhead was correlated with the observed aft heat shield and cabin exterior structural damage. The motion of the structure due to cabin rupture, deduced from the Stabilization and Control System rate data, was consistent with the observed evidence. It was concluded that the cabin ruptured at point A shown in Enclosures 10-9 and 10-10 at the junction of the weld land to the inner face sheet. Enclosures 10-8, 10-9, 10-10, 10-11a, 10-11b, and 10-11c define the total fracture. Most of the fracture surfaces were burned and melted; little metallurgical analysis was attempted.

(3) FAILURE SEQUENCE

It was concluded that the tensile failure of the inner face sheet at point A (Enclosure 10-9) was followed immediately by tensile failure of the outer face sheet at point A (Enclosure

10-10). Rupture then propagated to points B and C. Failure of the inner face sheet to point H and failure of the outer face sheet along lines IJKL and CIJ were deduced from inspection and structural analysis to have occurred following the initial rupture and to have been of secondary significance. The bonded doubler at point K was added as a result of manufacturing process control testing performed during structural assembly. Failure of the inner face sheet along DEFG and delamination of the outer face sheet from the core with burn-through holes in the -Y, +Z quadrant occurred subsequent to the initial rupture at a pressure-structural-temperature combination less than that required to cause failure of the outer face sheet. Burn-through in the area beneath the ECU did not occur until the late stages of the fire at a time when cabin pressure was approximately ambient. Face sheet defects adjacent to this area are a result of the structural temperatures attained in this vicinity. The penetration in the aft sidewall, shown in Enclosure 10-13b, was concluded to be a result of locally impinging hot gas behind the Water Control Panel, occurring in the late stages of the fire.

(4) SECONDARY DAMAGE

Detailed inspection of the C/M inner secondary structure revealed buckled aluminum panels and burned and delaminated aluminum honeycomb sandwich panels. Typical damage is illustrated in Enclosure 10-14 and 10-15.

Aluminum melts at approximately 1200°F. With the exception of the aft bulkhead fracture, melting of aluminum was confined to the left hand (-Y) side of the inner cabin. Melted aluminum was observed in close proximity to plastic which was unmelted, indicating local flame impingement in specific areas.

Damage to the inner face sheet of the aft sidewall adjacent to the melted and deformed CO₂ Absorbers is shown in Enclosure 10-16. The structure shown is located in the -Y, +Z quadrant of the C/M. Significant structural damage was noted to plumbing beneath the ECU and in back of the Water Control Panel. The lines are identified and shown in Enclosures 10-13a, 10-13b, 10-13c, and 10-13d. Aluminum and stainless steel lines were melted in this area. It was also observed that soldered joints at couplings on the aluminum lines had parted.

Melted nickel-plated copper wire was observed in the vicinity of the ECU. Copper melts at approximately 1980°F whereas stainless steel and nickel melt at approximately 2600°F. These materials are distributed throughout the spacecraft and are unmelted at other locations.

d. SERVICE MODULE DAMAGE

The Service Module (S/M) structure was inspected for evidence of structural damage. No evidence of structural failure was observed. Nondestructive tests were defined to determine any degradation in design strength. It was recommended that these tests be accomplished within the normal Apollo program activity.

D. FINDINGS AND DETERMINATIONS

1. FINDING

The structural and mechanical subsystem was inactive at the time of the fire.

DETERMINATION

The structural and mechanical subsystem did not cause the fire.

2. FINDING

Visual inspection of the Service Module structure revealed no structural failures.

DETERMINATION

Verification of the structural adequacy for the design loads would require non-destructive testing.

3. FINDING

The crew compartment structure was a pressurized shell structure during the fire.

a. The resulting fire environment initiated the following sequence of major structural damage:

(1) Rupture of the C/M cabin aft bulkhead.

(2) Melting and erosion of C/M cabin and heat shield honeycomb sandwich face sheets adjacent to the origin.

(3) Penetration of the cabin structure beneath and adjacent to the ECU.

b. Minor structural damage resulting from the fire included:

(1) Honeycomb sandwich delamination

(2) Panel buckling

(3) Melting of metallic components

4. FINDING

Spacecraft data acquired during the OCP-FO-K-0021-1 test gave indications from which a spacecraft cabin pressure history could be estimated.

DETERMINATION

a. The C/M cabin structure ruptured at 6:31:19.4 (± 0.1) pm EST at an estimated minimum cabin pressure of 29 psia.

b. The C/M cabin structure sustained cabin pressure in excess of its design ultimate pressure of 12.9 psi differential (27.6 psia). It is probable that the cabin pressure at rupture reached a range of 29 to 37.7 psia.

c. The estimated average gas temperature at rupture exceeded 700°F.

5. FINDING

The C/M cabin ruptured in the aft bulkhead adjacent to its juncture with the aft sidewall.

DETERMINATION

The failure occurred due to excessive meridional tensile stress in the inner face sheet at the weld land to thinner face sheet junction. The fracture was determined to have originated on the right-hand side of the C/M in the vicinity of coordinates $Y=+45$ inches $Z=-30$ inches.

6. FINDING

Penetrations of the C/M cabin structure occurred in the aft bulkhead beneath the ECU and in the aft sidewall.

DETERMINATION

a. The loss of structural integrity at these penetrations occurred after the primary rupture.

b. Failure of the water glycol and oxygen lines in the vicinity of the ECU resulted in local burning and melting of the adjacent structure.

7. FINDING

The aft heat shield stainless steel face sheets were melted and eroded.

DETERMINATION

The flame and gas temperature exiting from the fracture origin exceeded 2500°F.

8. FINDING

With the exception of the aft bulkhead fracture surfaces, melting of aluminum was confined to the left-hand side of the C/M. Melting of copper wire, stainless steel and aluminum occurred in the vicinity of the ECU and Water Control Panel on the left side and at the foot of the left-hand couch. These materials are distributed throughout the spacecraft and (excluding aluminum) are unmelted at other locations.

DETERMINATION

- a. The left-hand side of the inner cabin attained the maximum temperatures.
- b. The hottest part of the C/M cabin occurred in the vicinity of the ECU and Water Control Panel.

9. FINDING

Melted aluminum was observed on the left-hand side of the C/M inner cabin in very close proximity to plastic which was unmelted, although the plastic had a much lower melting point than the aluminum.

DETERMINATION

A "blow torch" effect occurred where narrow "tongues of flame" impinged on certain areas at the same time as the general burning.

10. FINDING

Several aluminum tubes were parted at soldered joints at couplings.

DETERMINATION

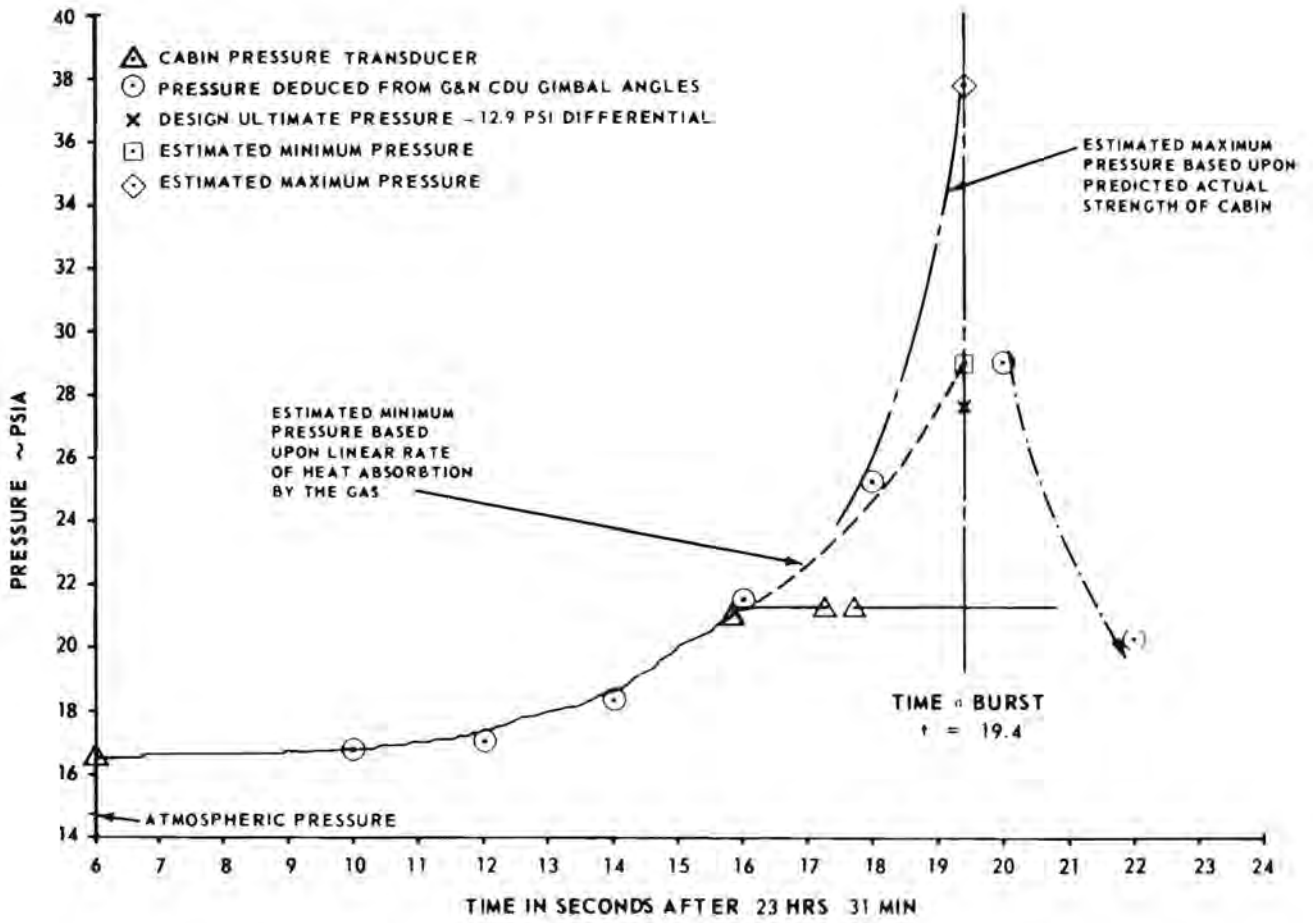
The soldered aluminum joints at unions will fail if the solder is raised to its melting point of approximately 360°F. The soldered aluminum joints at couplings were not adequate for the temperatures attained during the fire.

E. SUPPORTING DATA

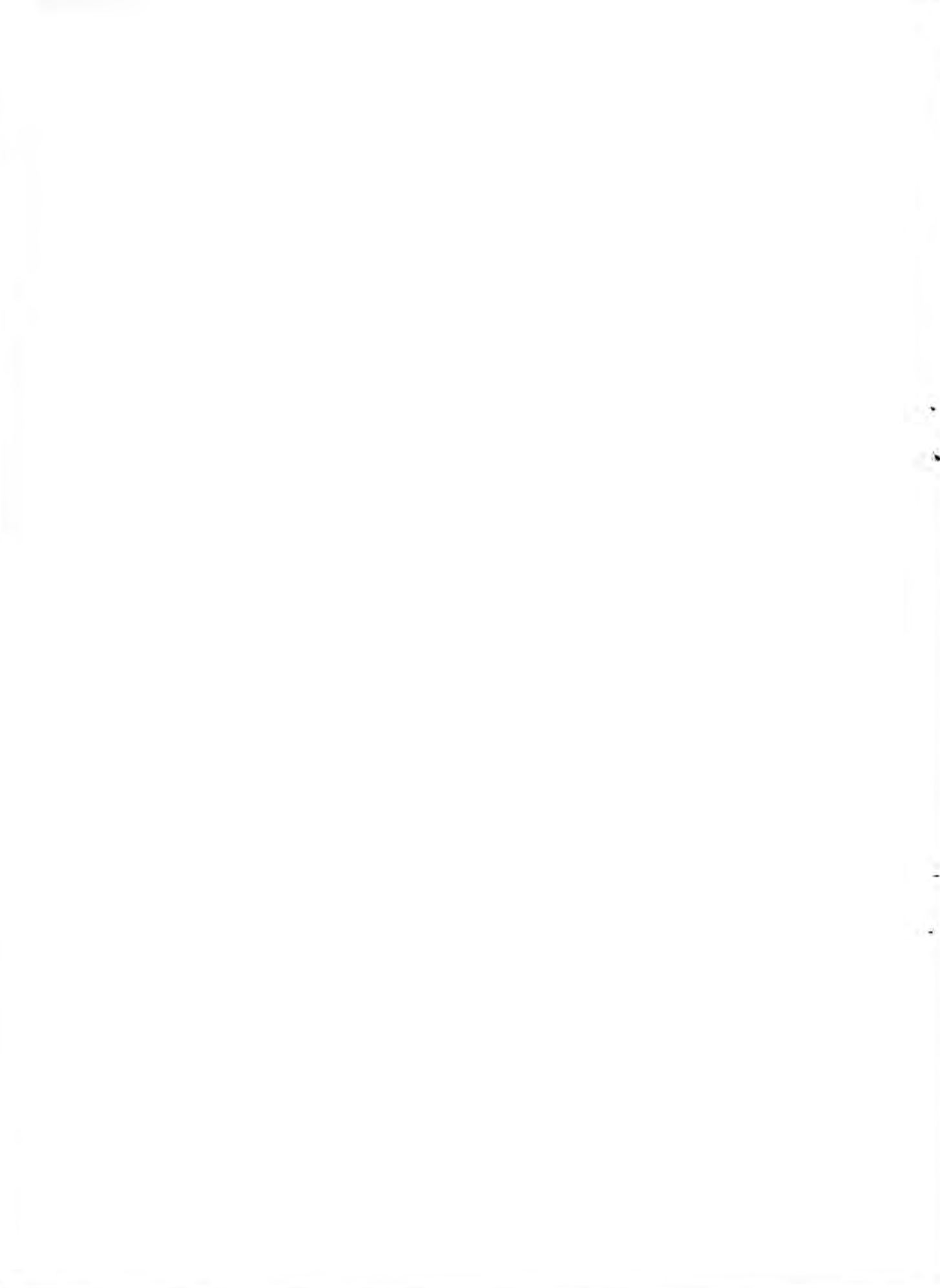
LIST OF ENCLOSURES

10-1	Not Used
10-2	Cabin Pressure
10-3	Heat Shield Access Panels
10-4	Helium Access Panel Number 15, +Y, Axis
10-5	Crew Compartment Structure, +Y Axis
10-6	Location of Cabin Fracture
10-7	Origin of Cabin Failure
10-8	Inner Fracture of Crew Compartment in Vicinity of Point B
10-9	Inner Face Sheet of Aft Bulkhead
10-10	Outer Face Sheet of Aft Bulkhead
10-11a	Aft Bulkhead of Crew Compartment, +Y View
10-11b	Aft Bulkhead of Crew Compartment, +Y Axis
10-11c	Aft Bulkhead of Crew Compartment, -Y Axis
10-12a	Aft Heatshield Damage, View I
10-12b	Aft Heatshield Damage, View II
10-12c	Aft Heatshield Damage, View III
10-13a	Tubing Codes for Use with Enclosures 10-13b, 10-13c, and 10-13d
10-13b	Inner Sidewall Penetration Behind Water Control Panel
10-13c	Tubing Beneath ECU
10-13d	Melted Tubing Beneath CO ₂ Absorbers
10-14	Buckled Food Storage Compartment Doors
10-15	Damaged Food and Garment Storage Locker Doors
10-16	Damaged Inner Sidewall Below CO ₂ Absorbers
10-17	List of References

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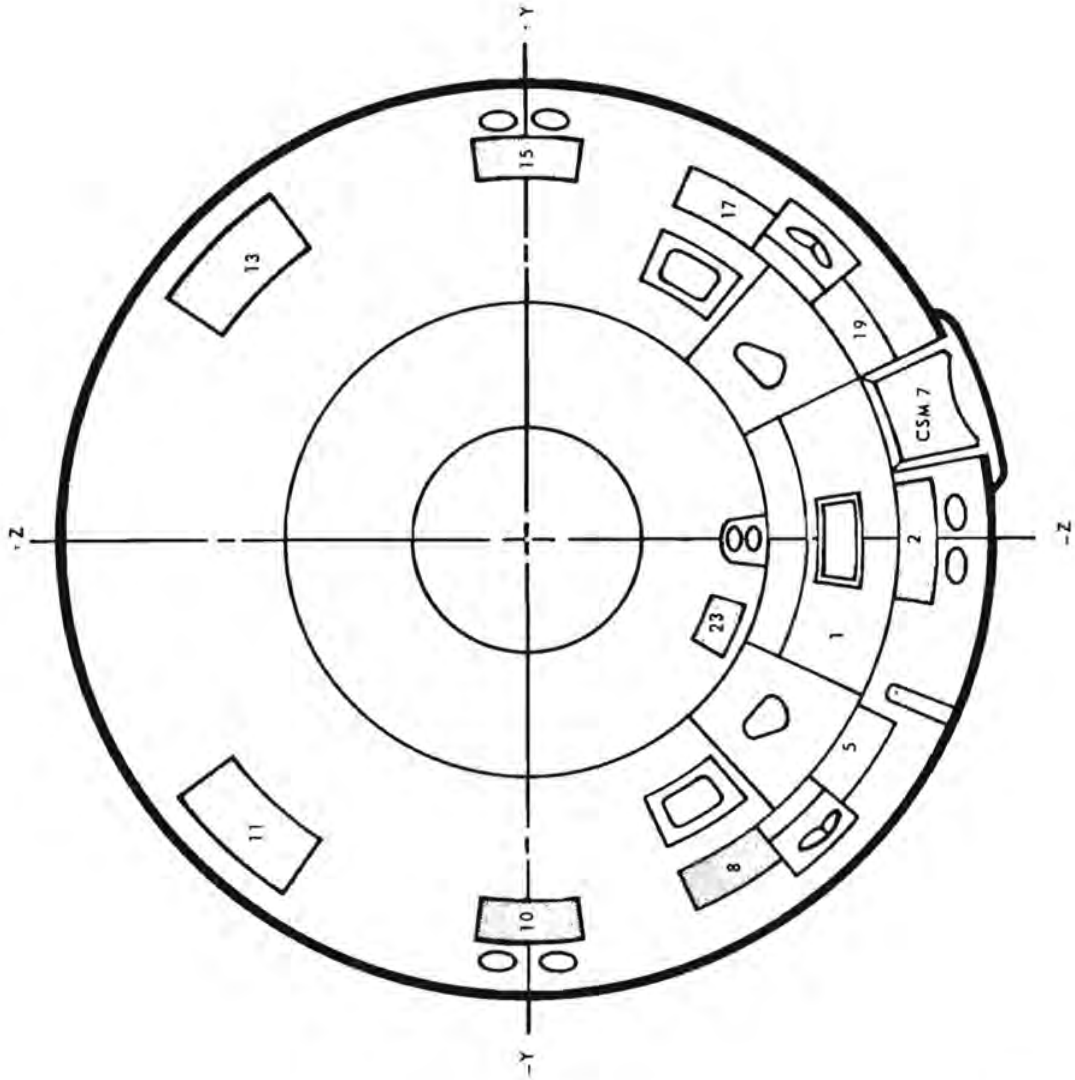


CABIN PRESSURE



ACCESS PANEL NOMENCLATURE

- CM 1 CREW HATCHES
- CM 2 PITCH ENGINE ACCESS
- CM 5 ROLL ENGINE & URINE DUMP PANEL
- CM 8 ROLL ENGINE ACCESS
- CM 10 YAW ENGINE & He FILL ACCESS
- CM 11 FUEL PANEL ACCESS
- CM 13 OXYGEN PANEL ACCESS
- CM 15 YAW ENGINE & He FILL ACCESS
- CM 17 ROLL ENGINE ACCESS
- CM 19 ROLL ENGINE ACCESS
- CM 23 PITCH ENGINE ACCESS
- CSM 7 CM TO SM UMBILICAL



NOTE: SHADED PANELS REPRESENT AREAS OPEN AT THE TIME OF THE ACCIDENT

HEATSHIELD ACCESS PANELS





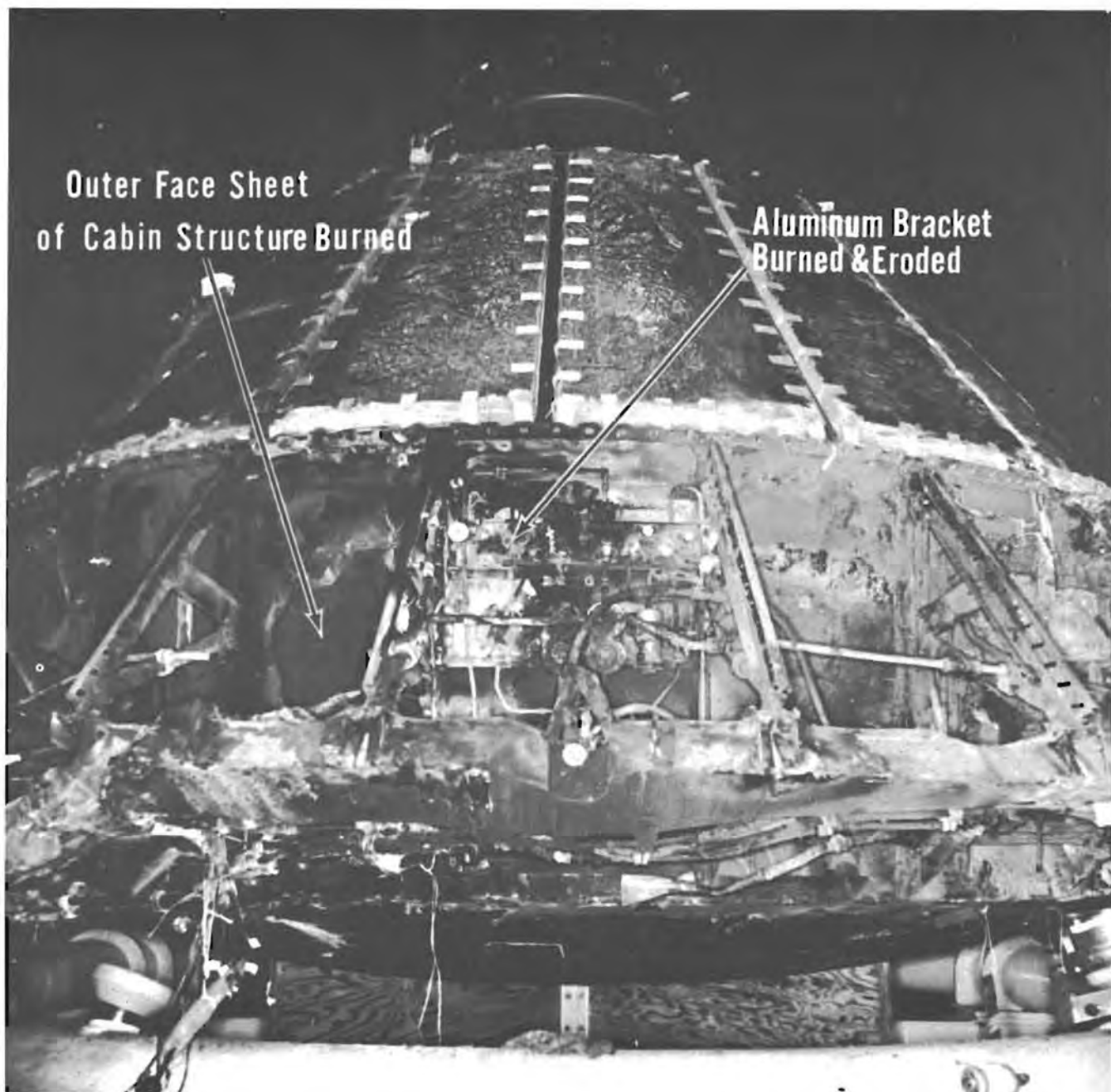
Degradation of Heat Shield
Ablator

AFT Sidewall Face Sheet
Burned & Eroded

Helium
Panel Bracket
Burned & Eroded

HELIUM ACCESS PANEL #15 +Y AXIS

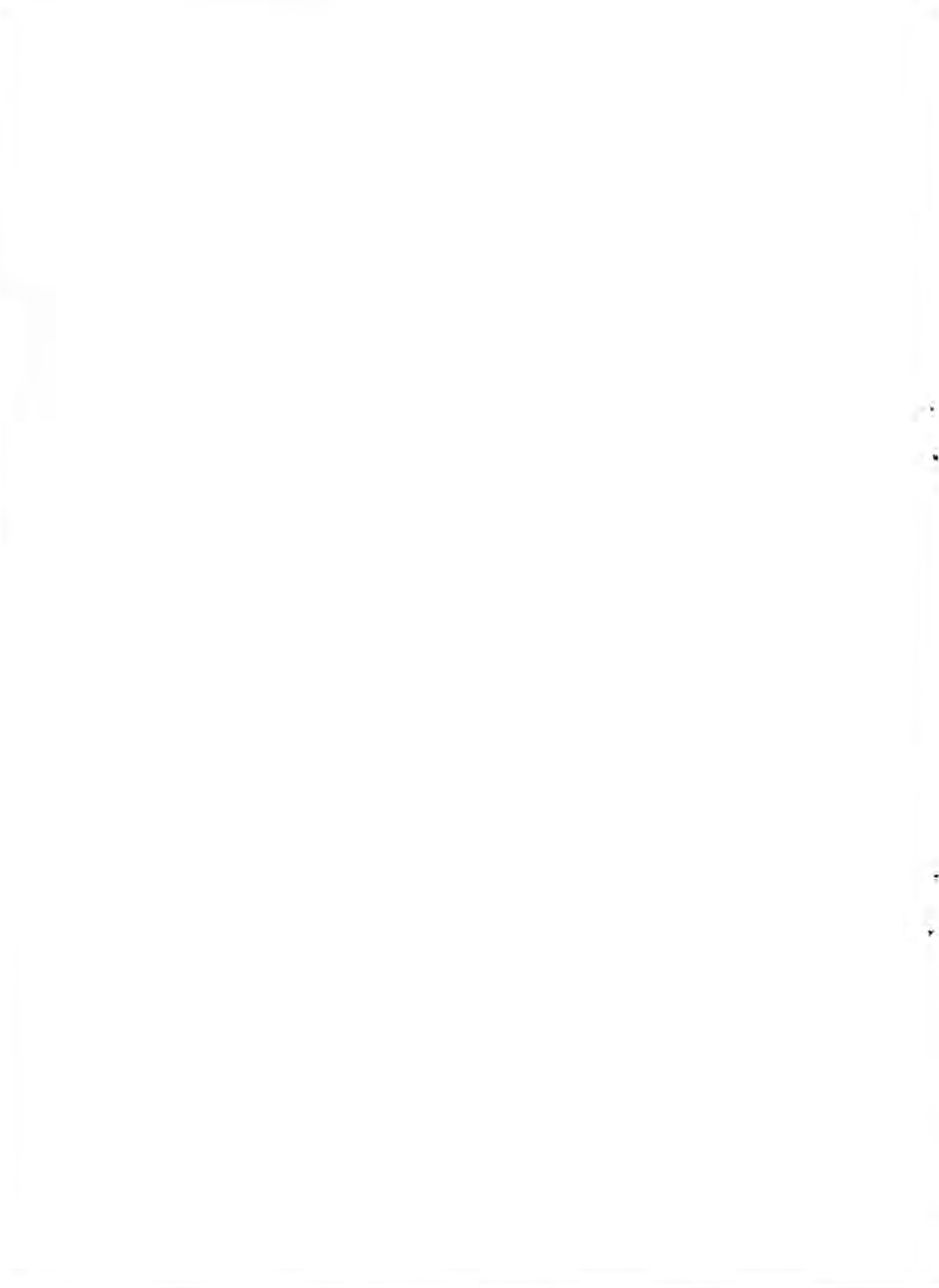


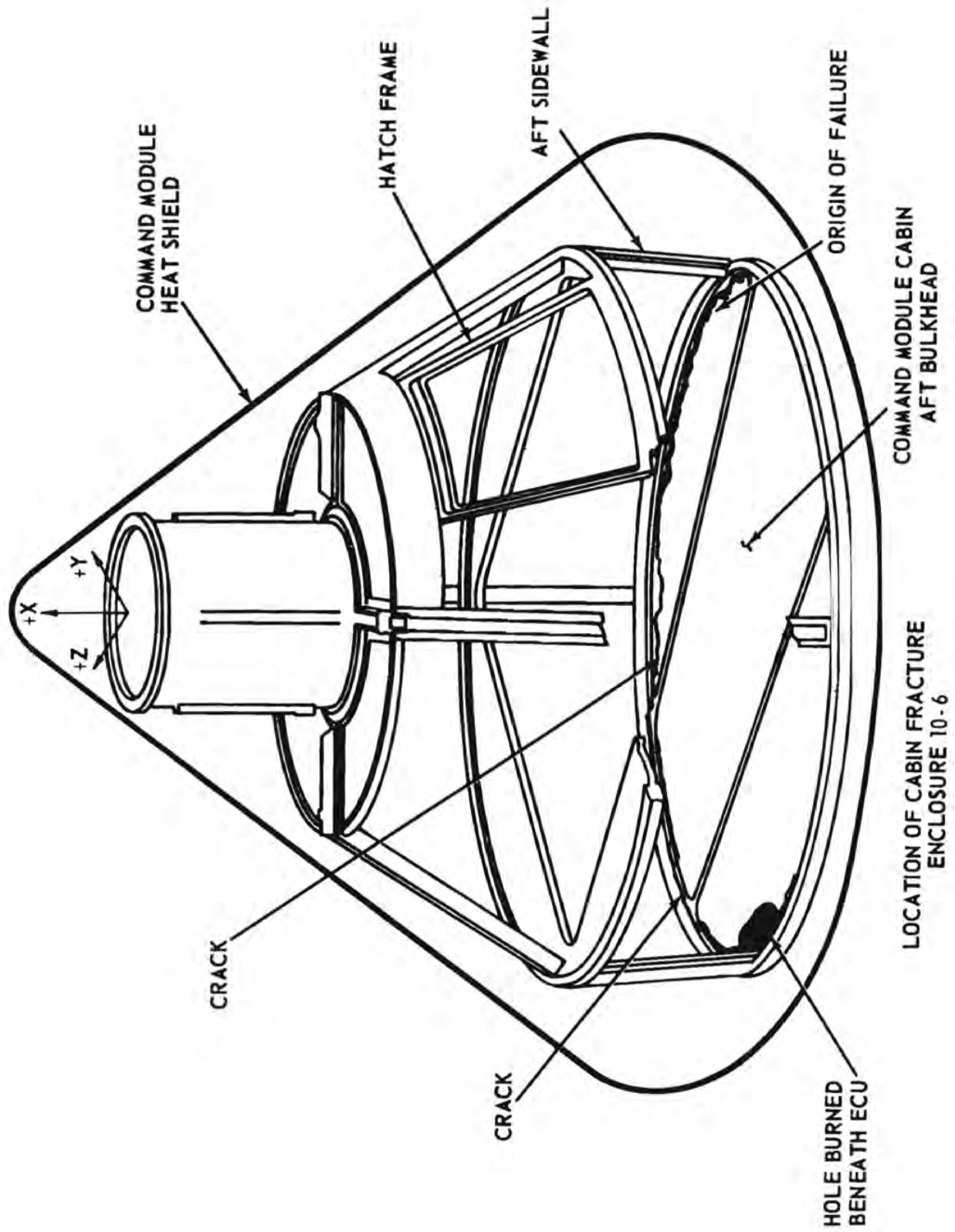


Outer Face Sheet
of Cabin Structure Burned

Aluminum Bracket
Burned & Eroded

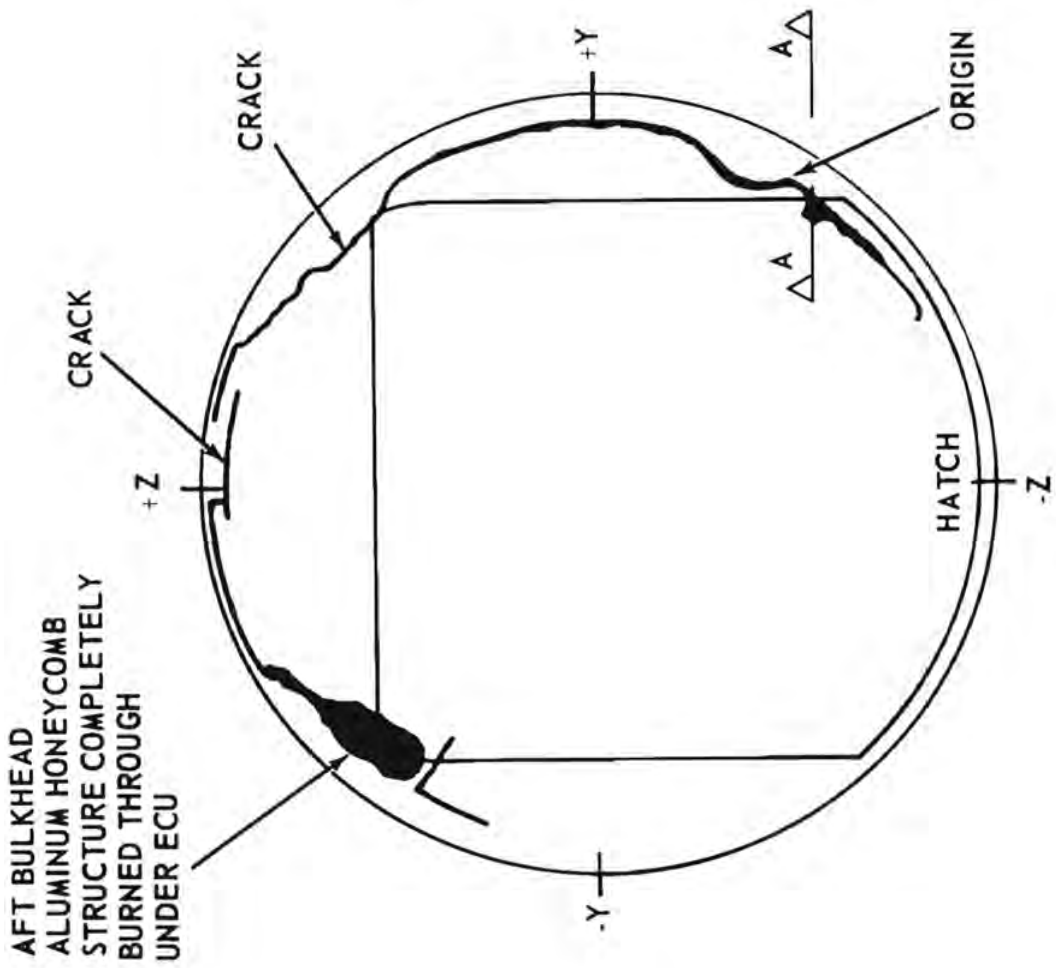
CREW COMPARTMENT STRUCTURE +Y AXIS





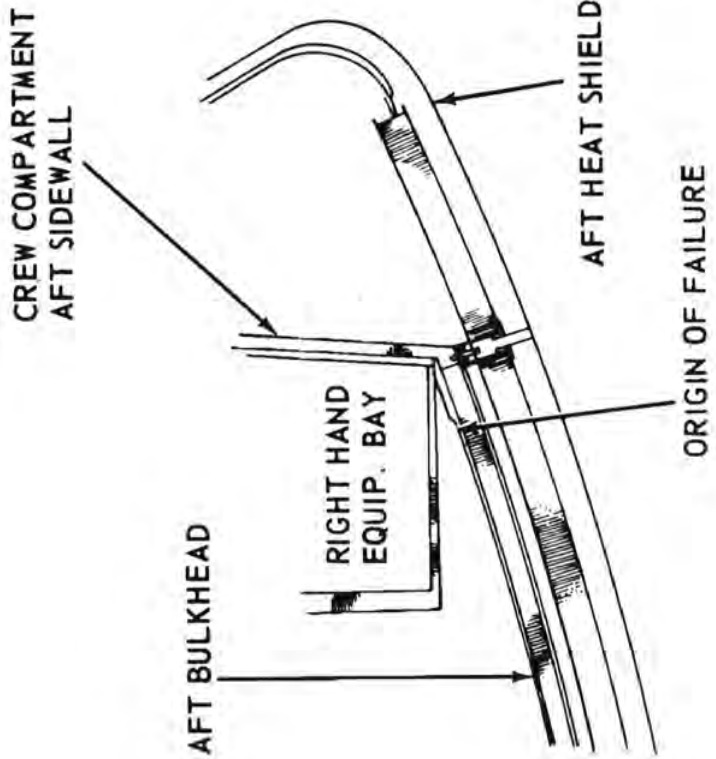
ENCLOSURE 10-6



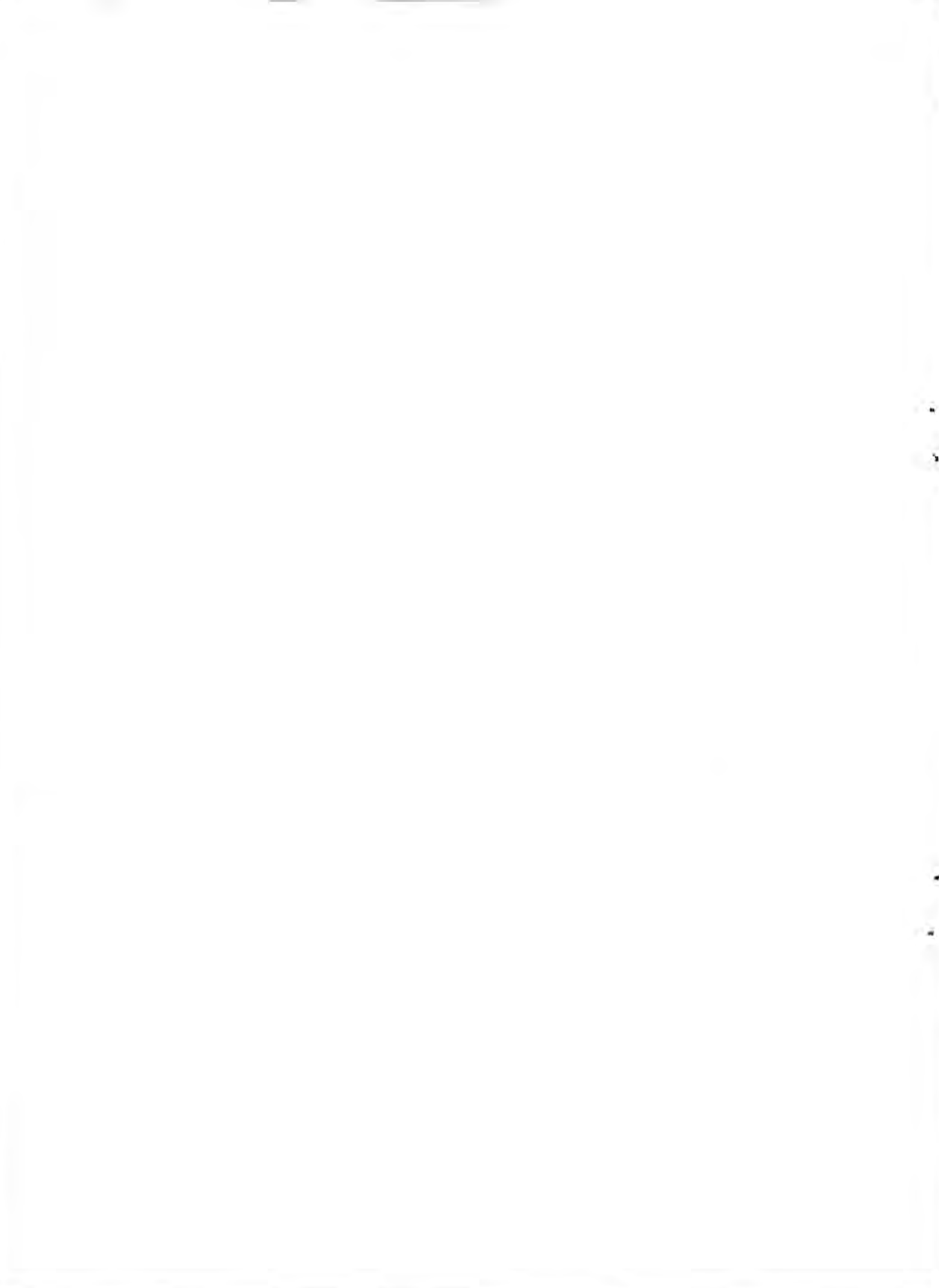


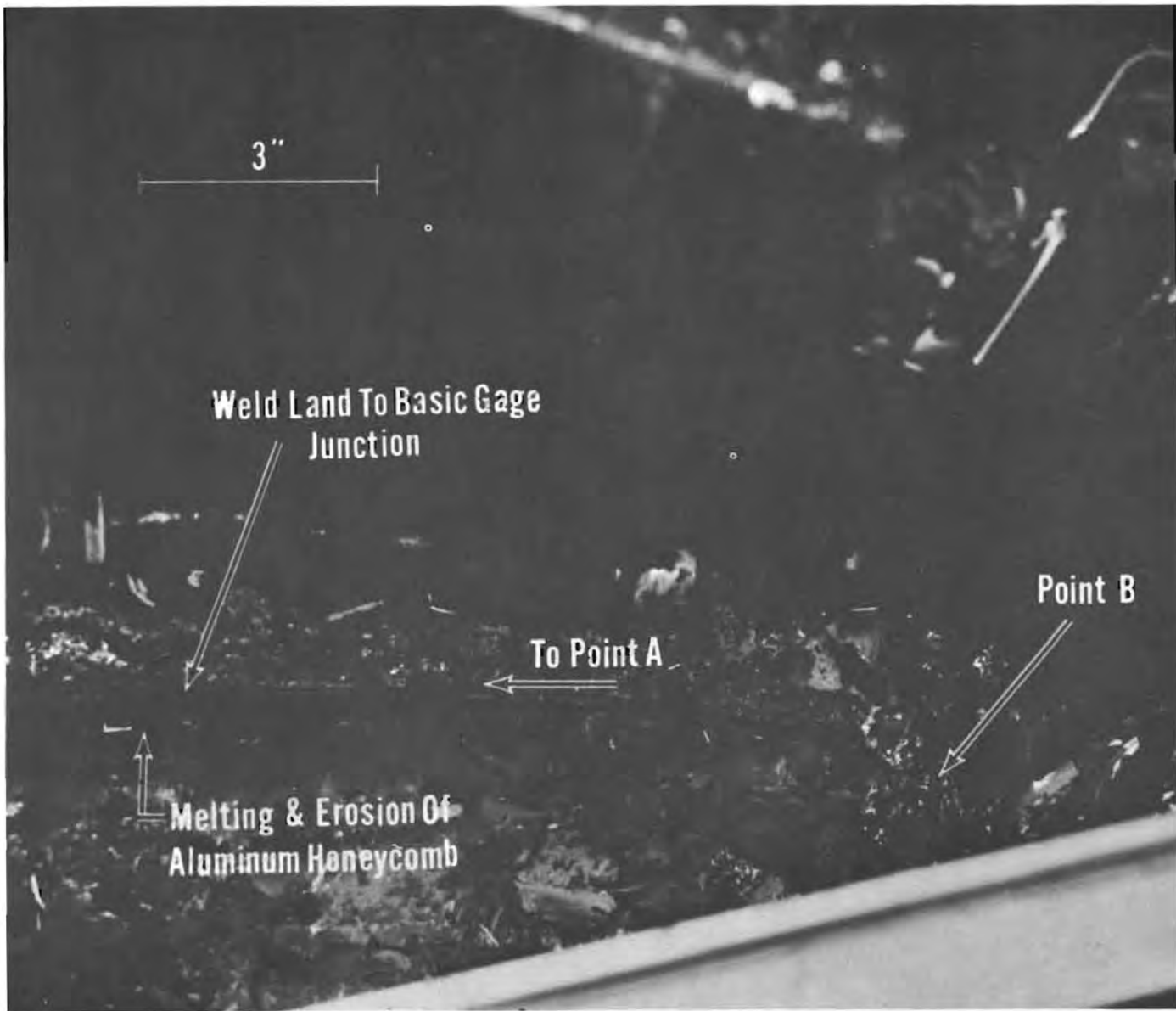
AFT BULKHEAD

ORIGIN OF CABIN PRESSURE



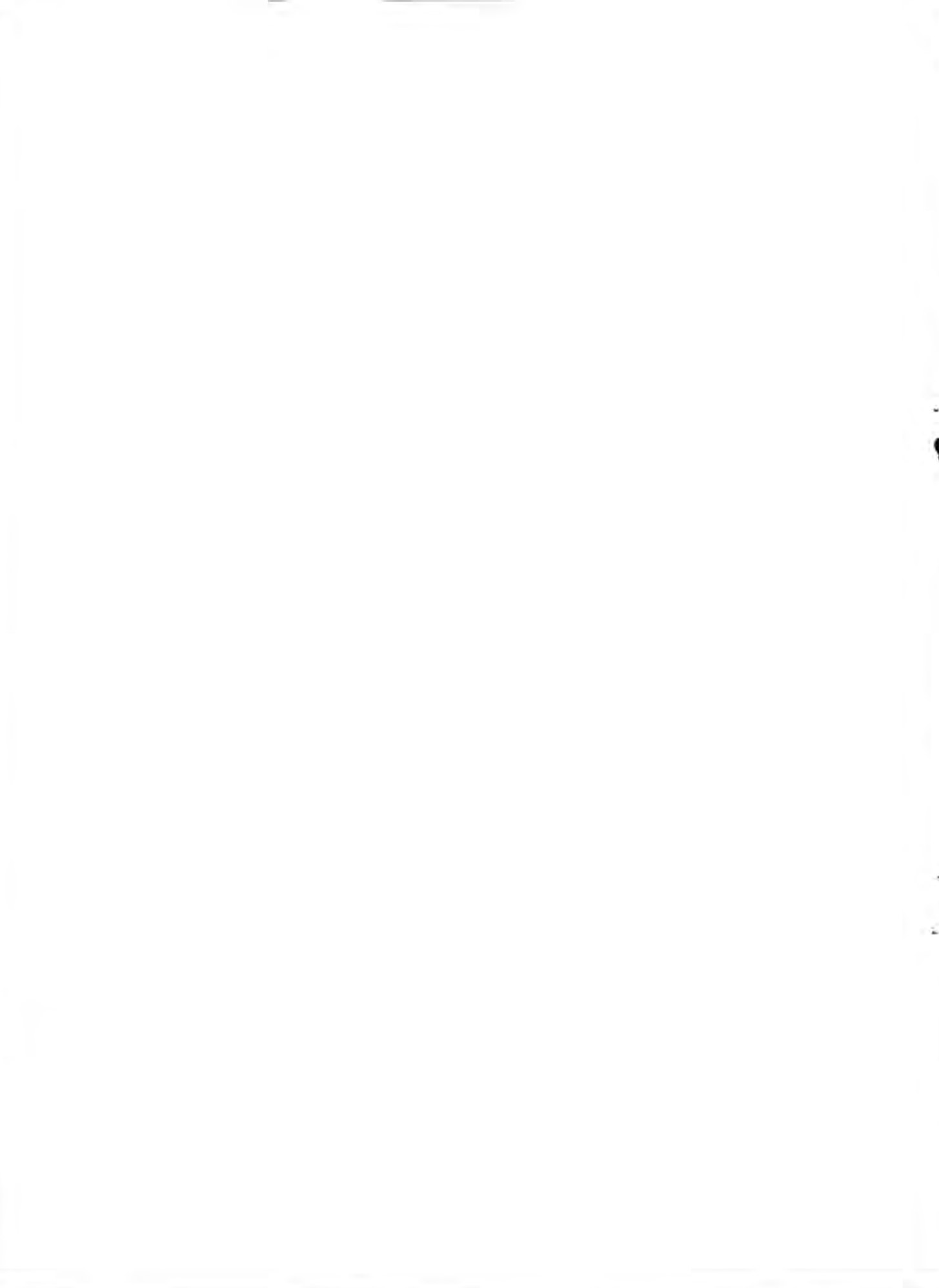
VIEW A

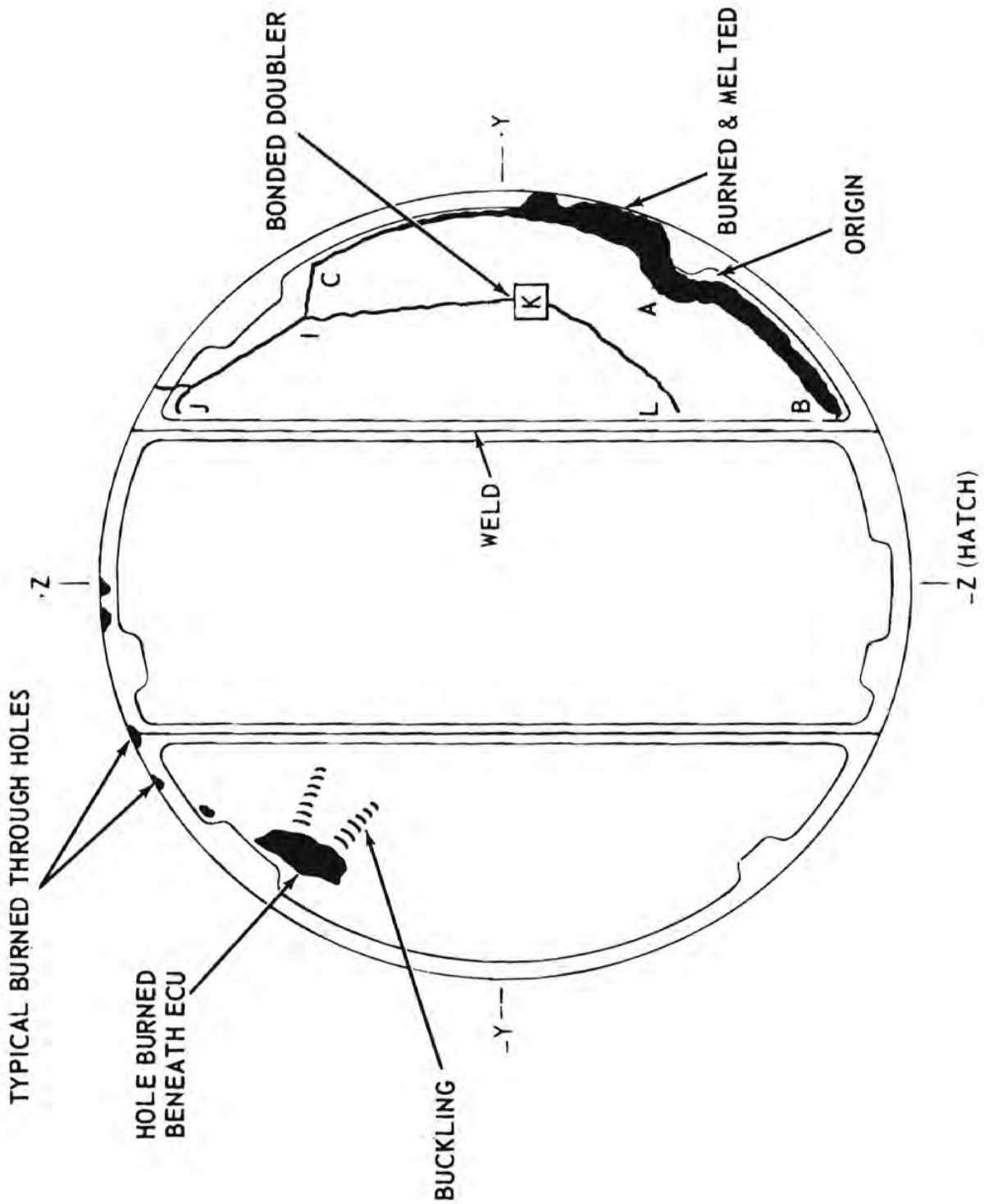




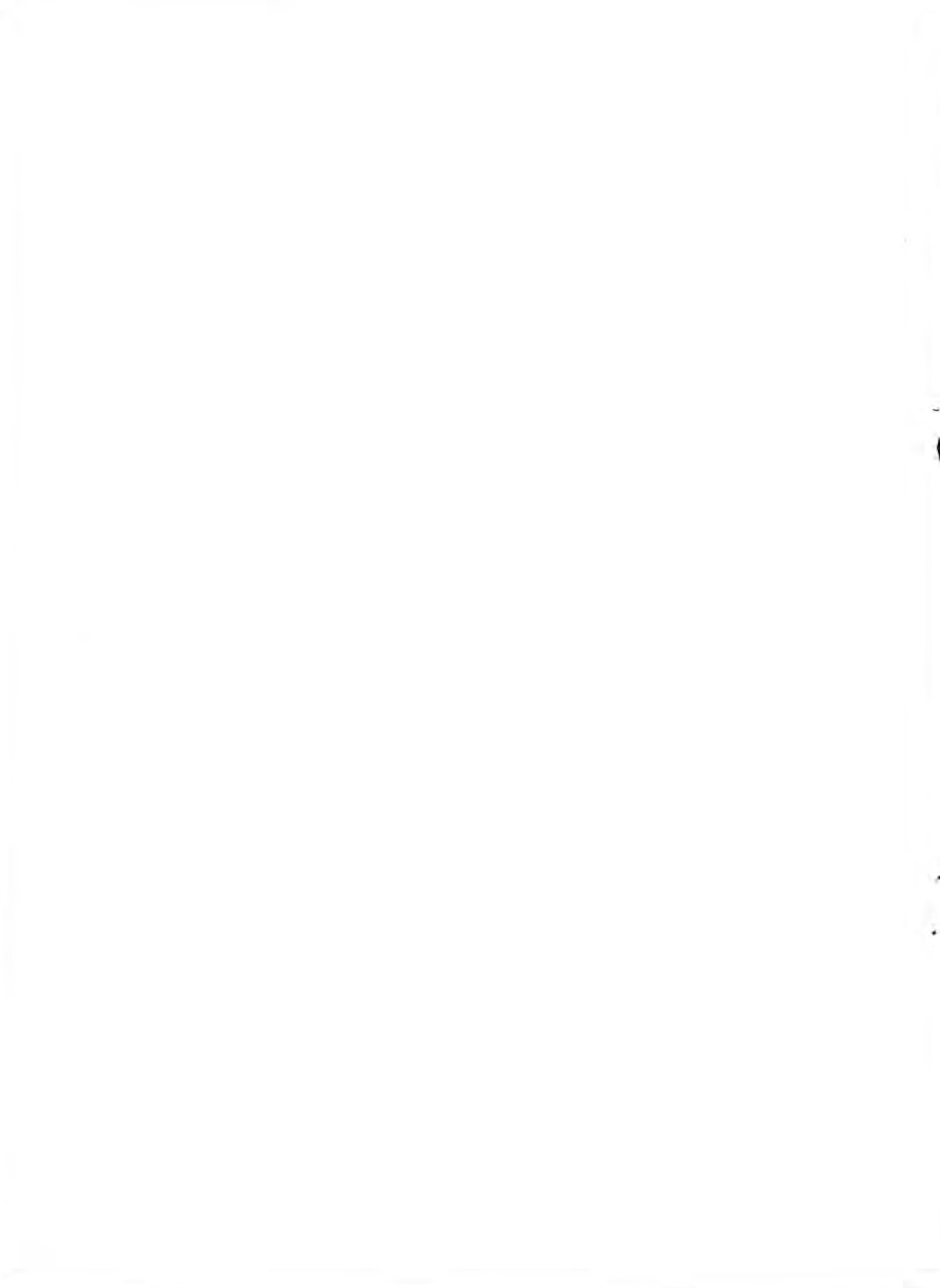
INNER FRACTURE OF CREW COMPARTMENT IN VICINITY OF POINT B

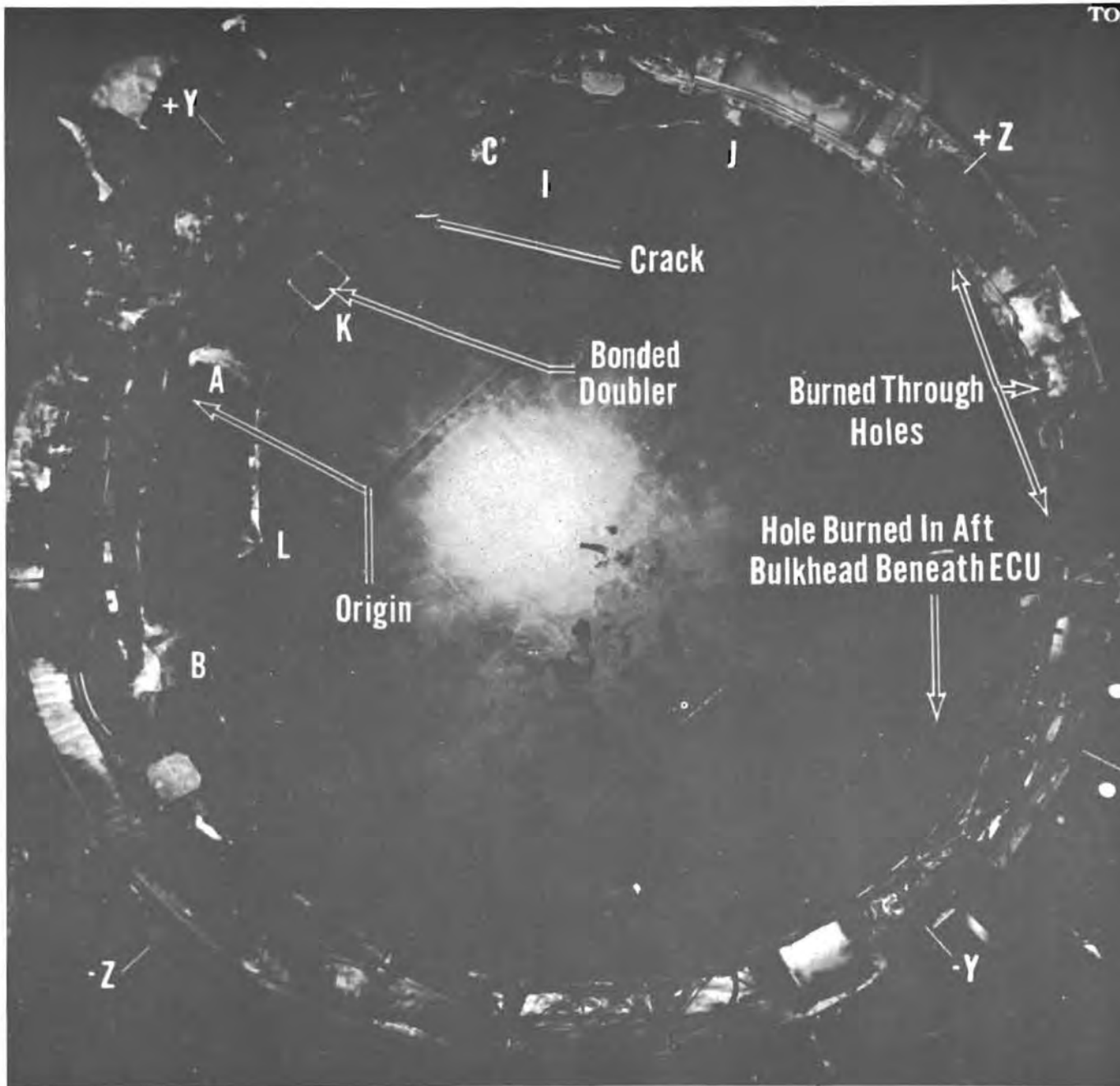






OUTER FACE SHEET OF AFT BULKHEAD

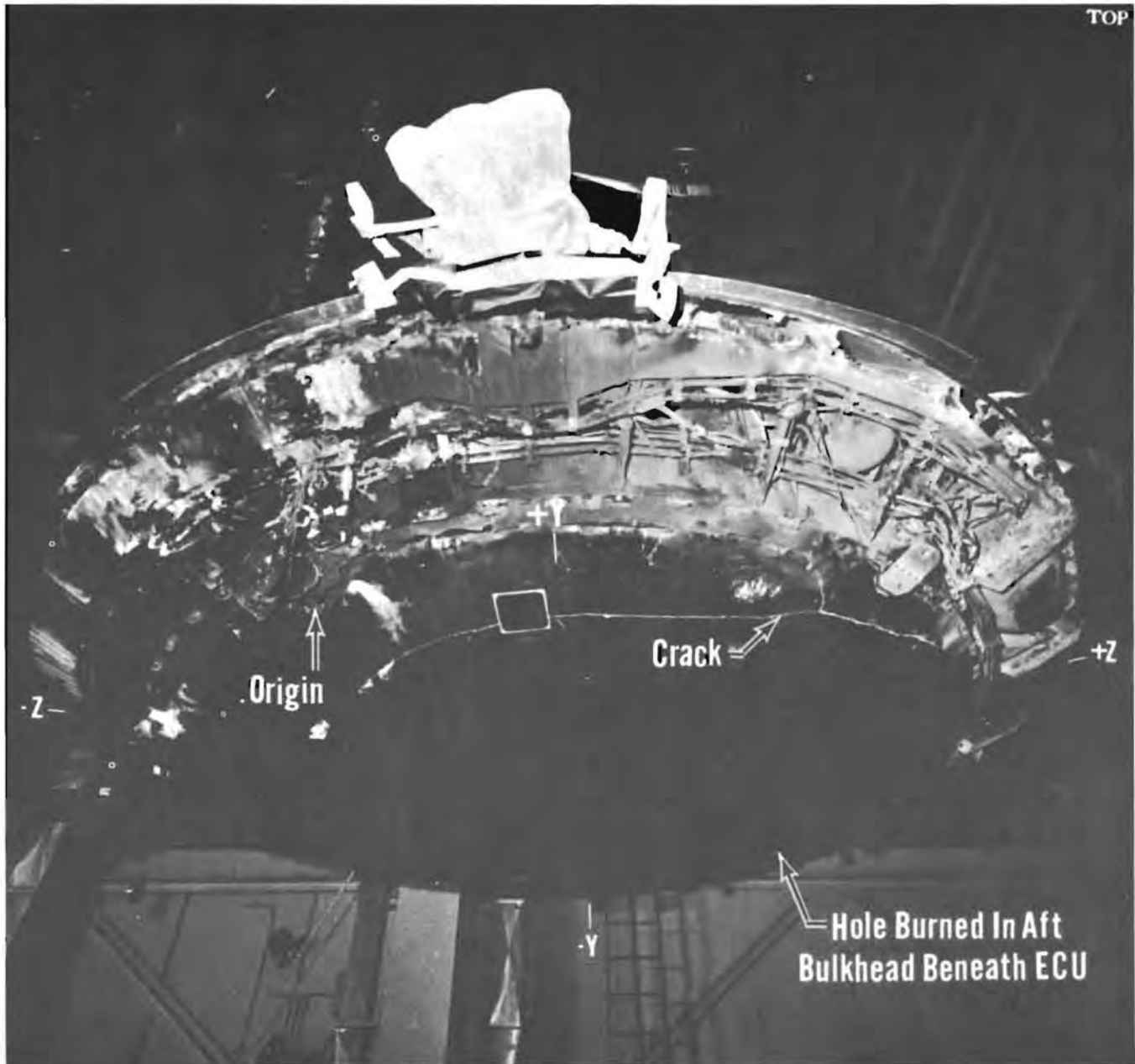




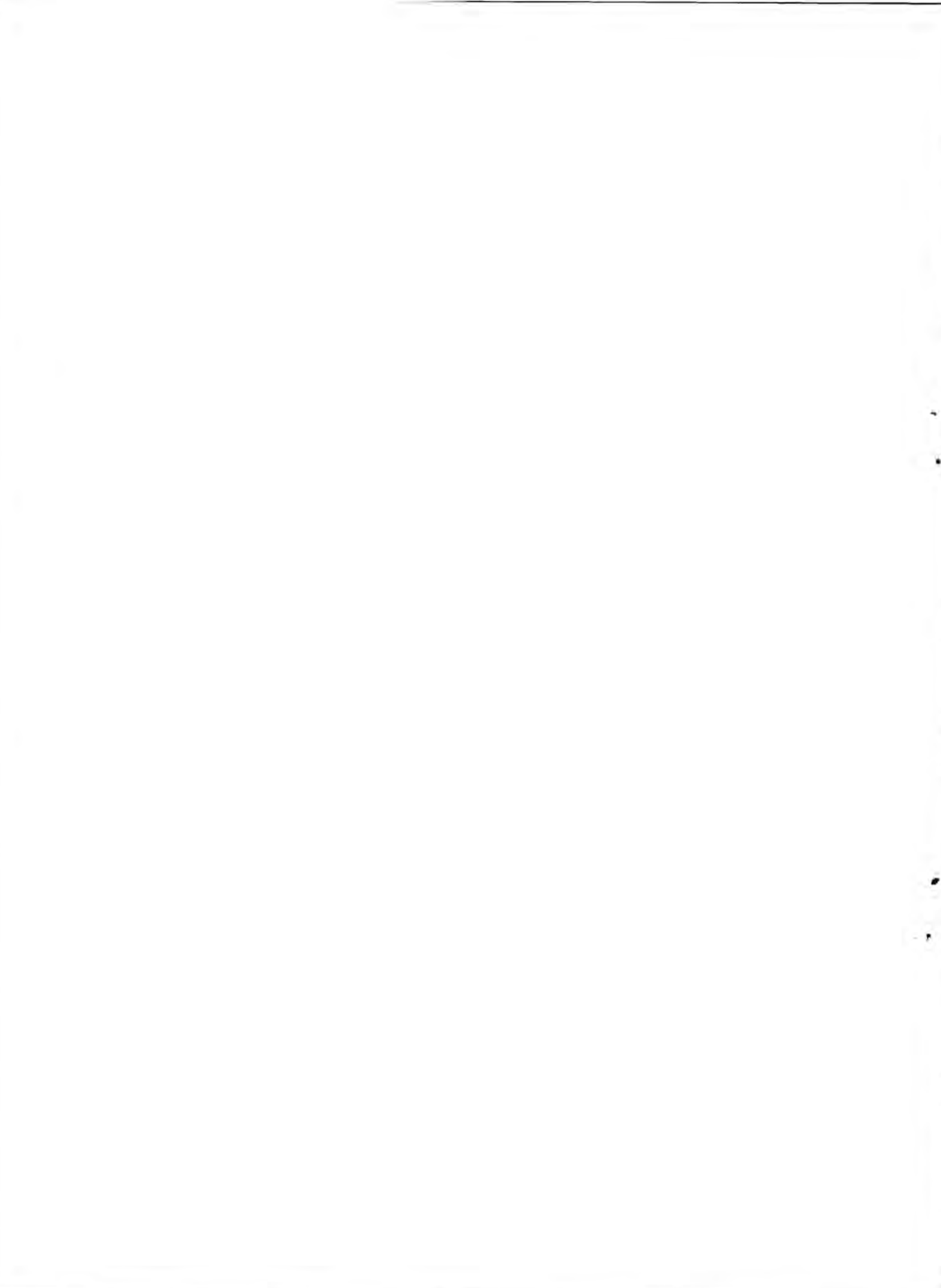
AFT BULKHEAD OF CREW COMPARTMENT +X VIEW

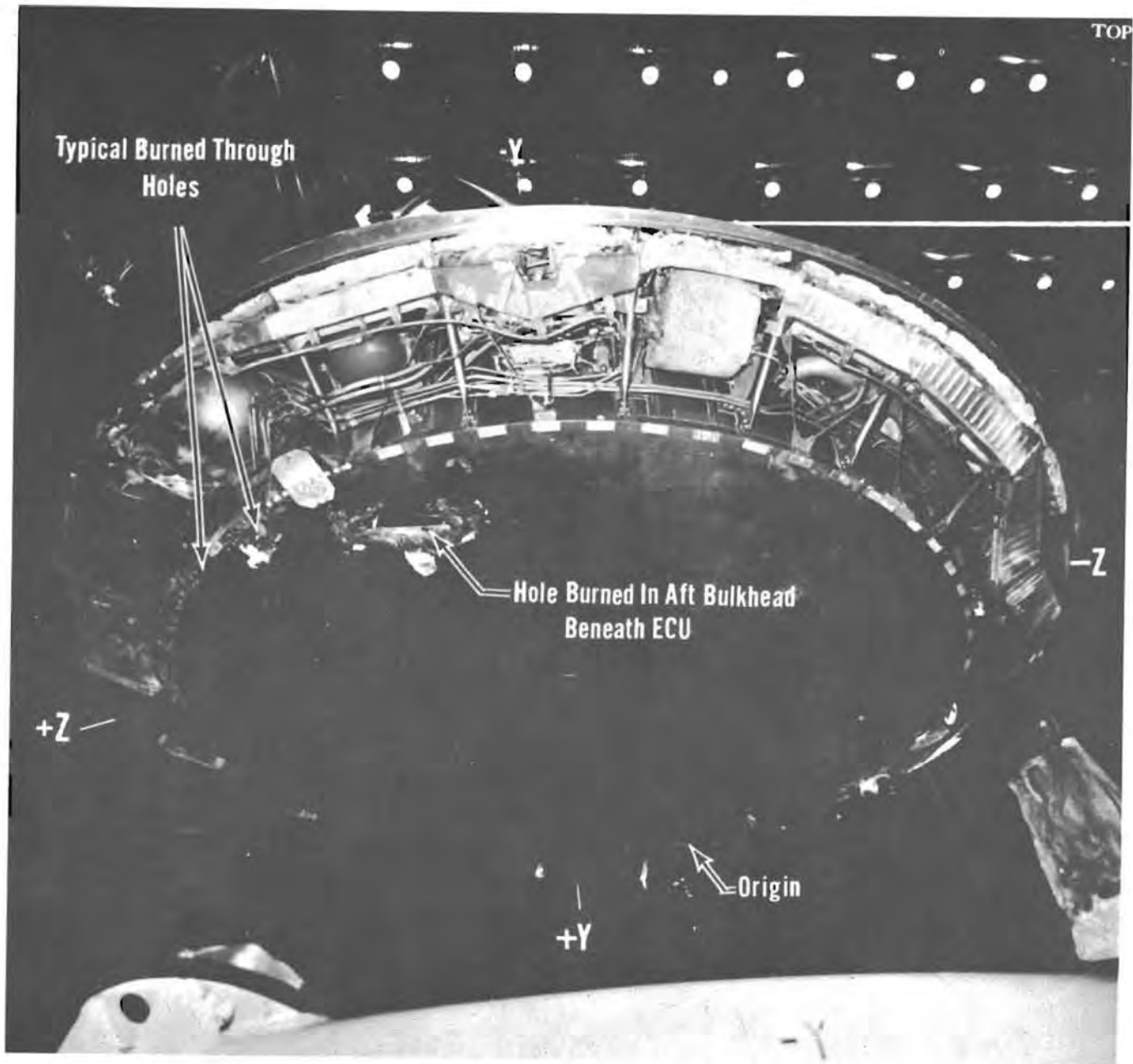


TOP



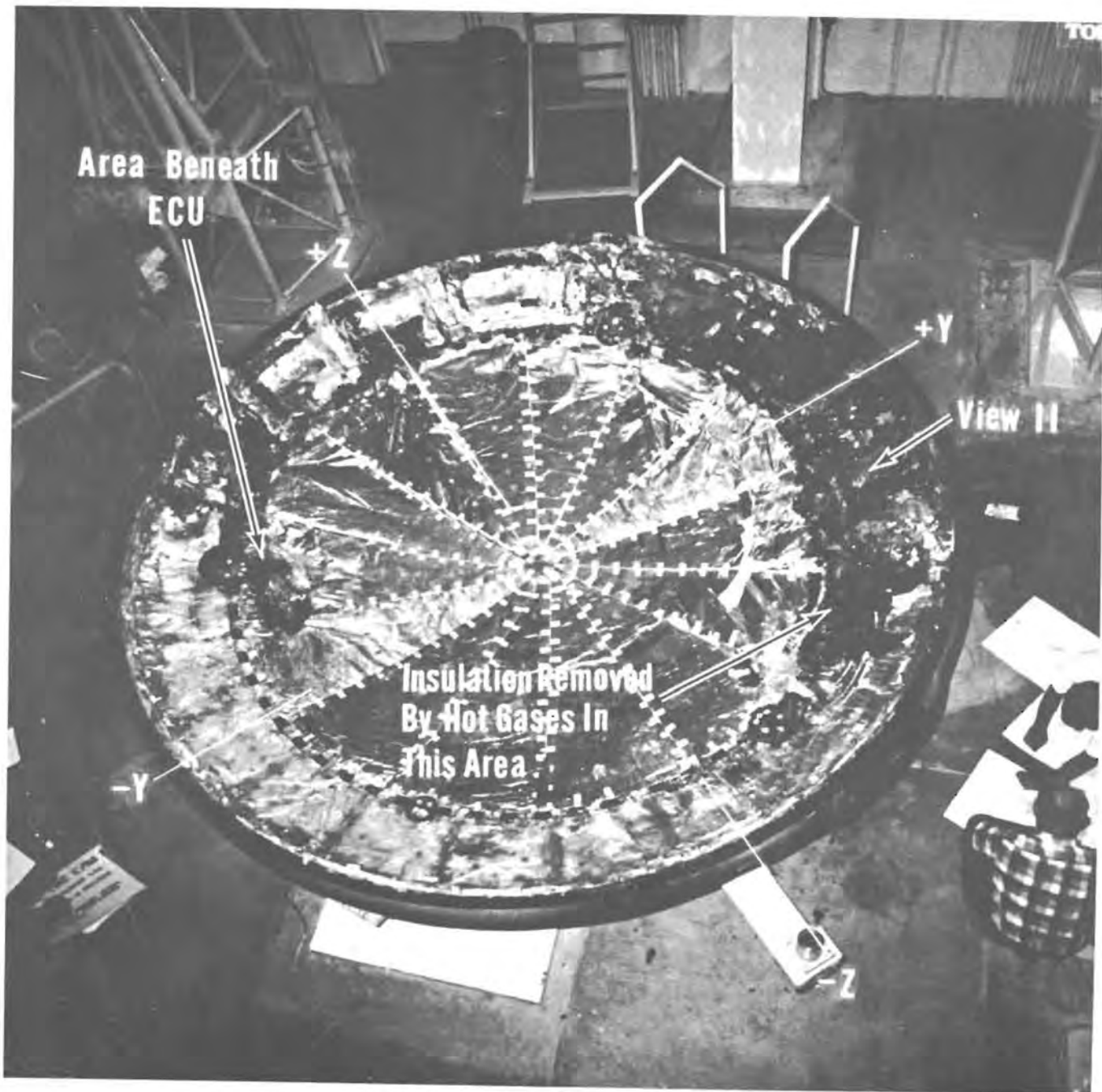
AFT BULKHEAD OF CREW COMPARTMENT +Y AXIS





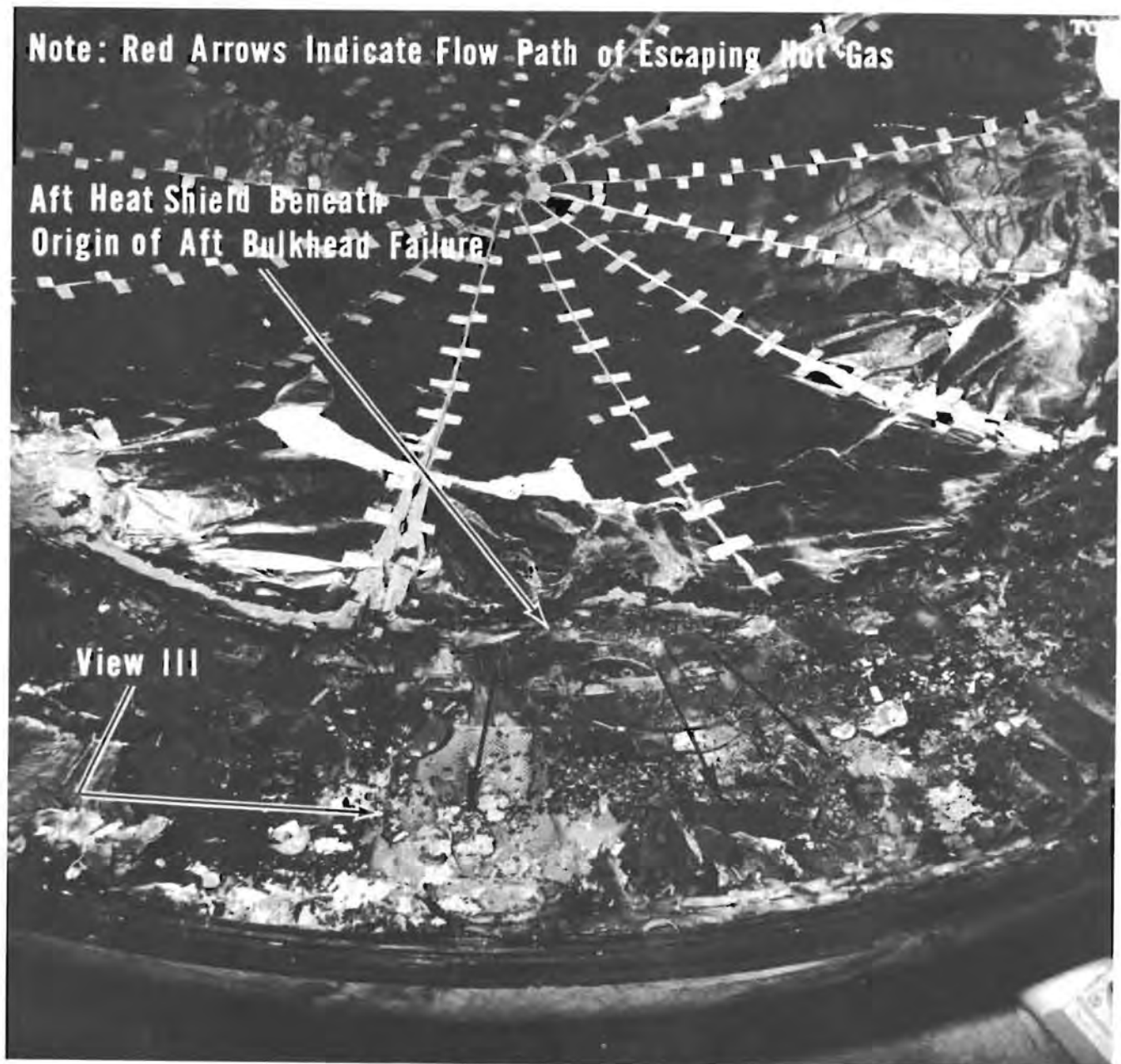
AFT BULKHEAD OF CREW COMPARTMENT -Y AXIS





AFT HEATSHIELD DAMAGE VIEW 1





AFT HEATSHIELD DAMAGE VIEW II





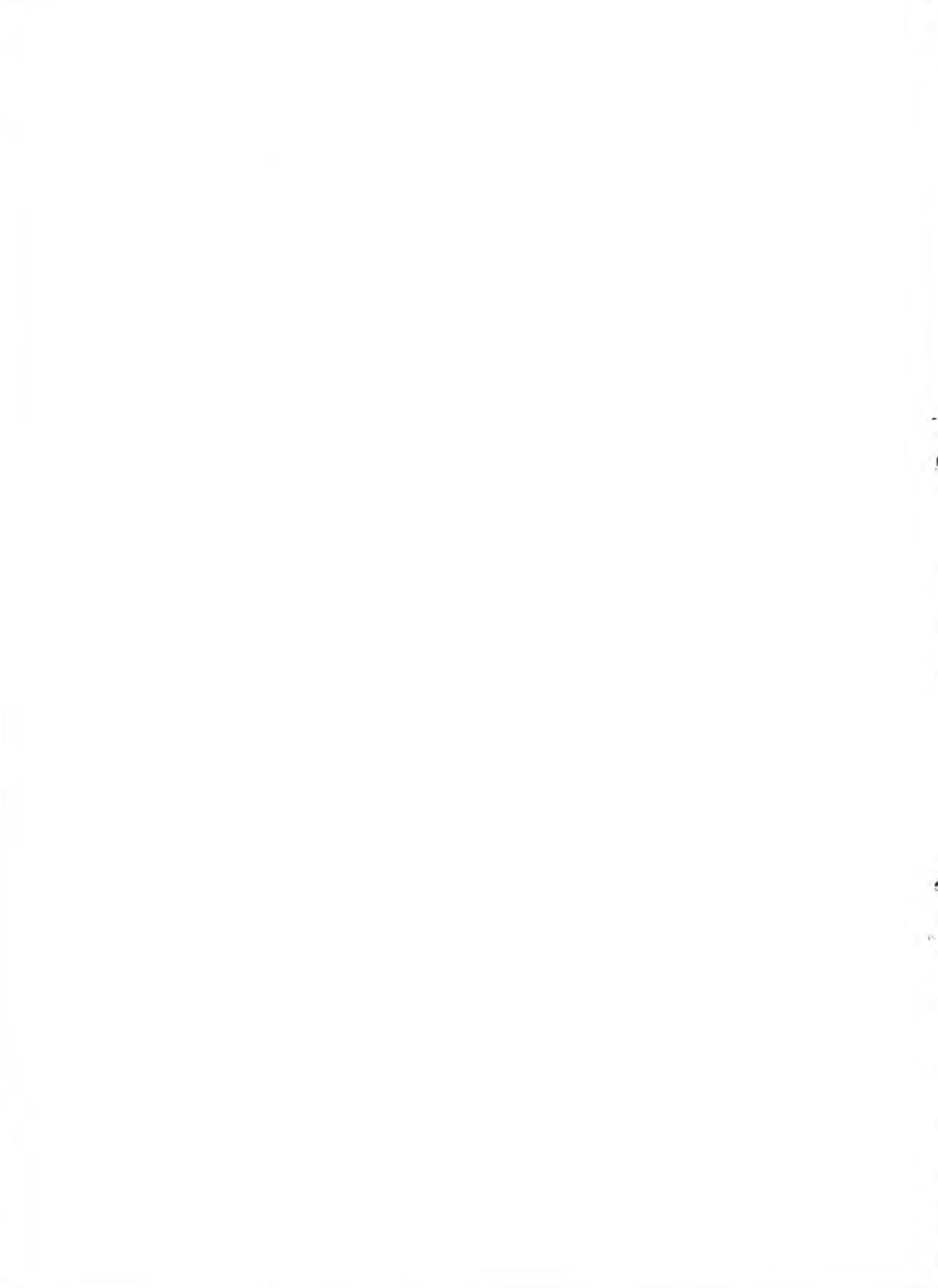
AFT HEATSHIELD DAMAGE VIEW III

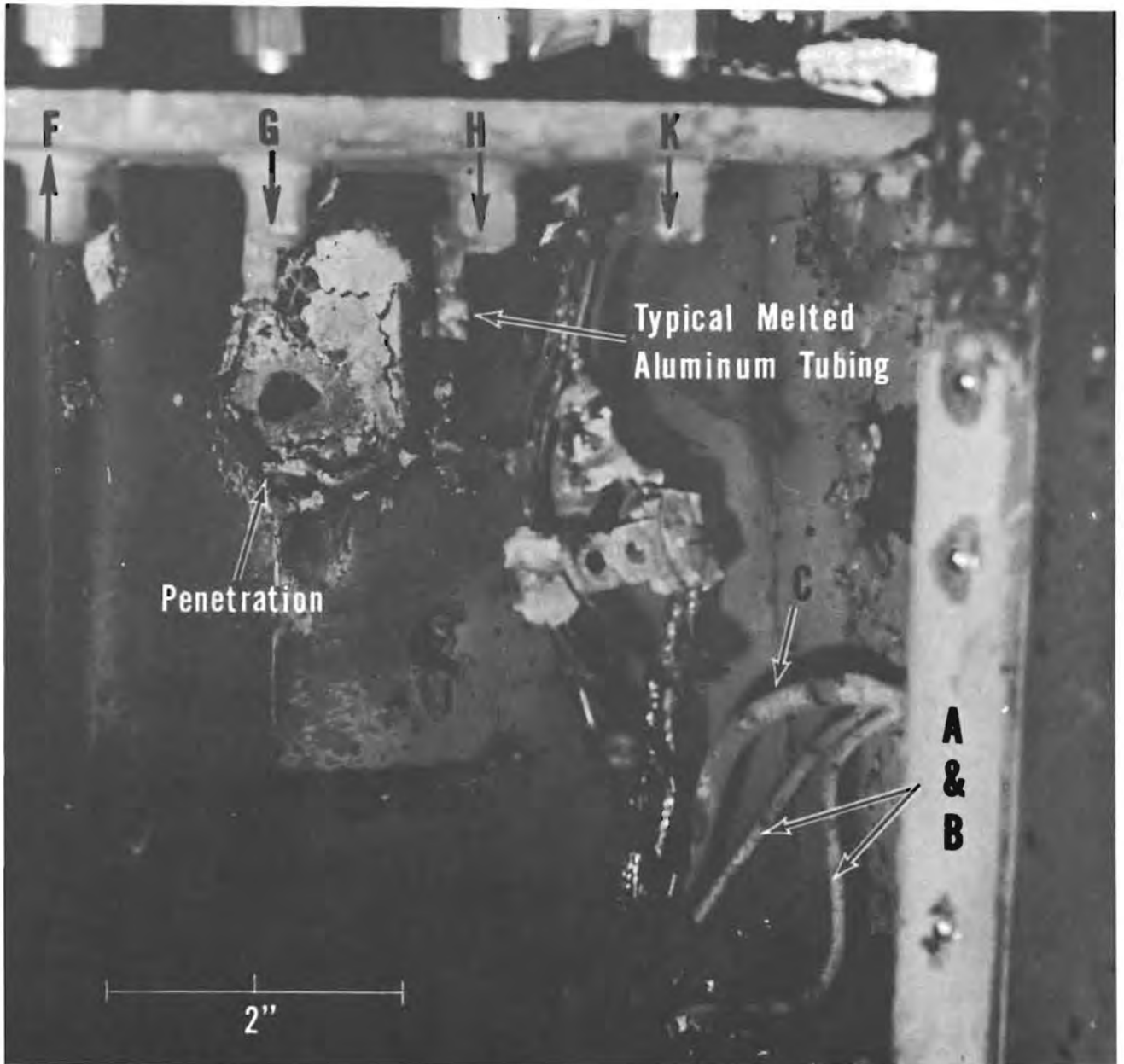


CODE	GAS OR FLUID CONTAINED	PRESSURE
A	OXYGEN	SAME AS CABIN
B	OXYGEN	SAME AS CABIN
C	AIR	AMBIENT
D	AIR	AMBIENT
E	NITROGEN	AMBIENT
F	OXYGEN	700 PSI
G	OXYGEN	700 PSI
H	OXYGEN	100 PSI
I	NITROGEN	AMBIENT
J	WATER GLYCOL	50 PSIG
K	OXYGEN	20 PSIG

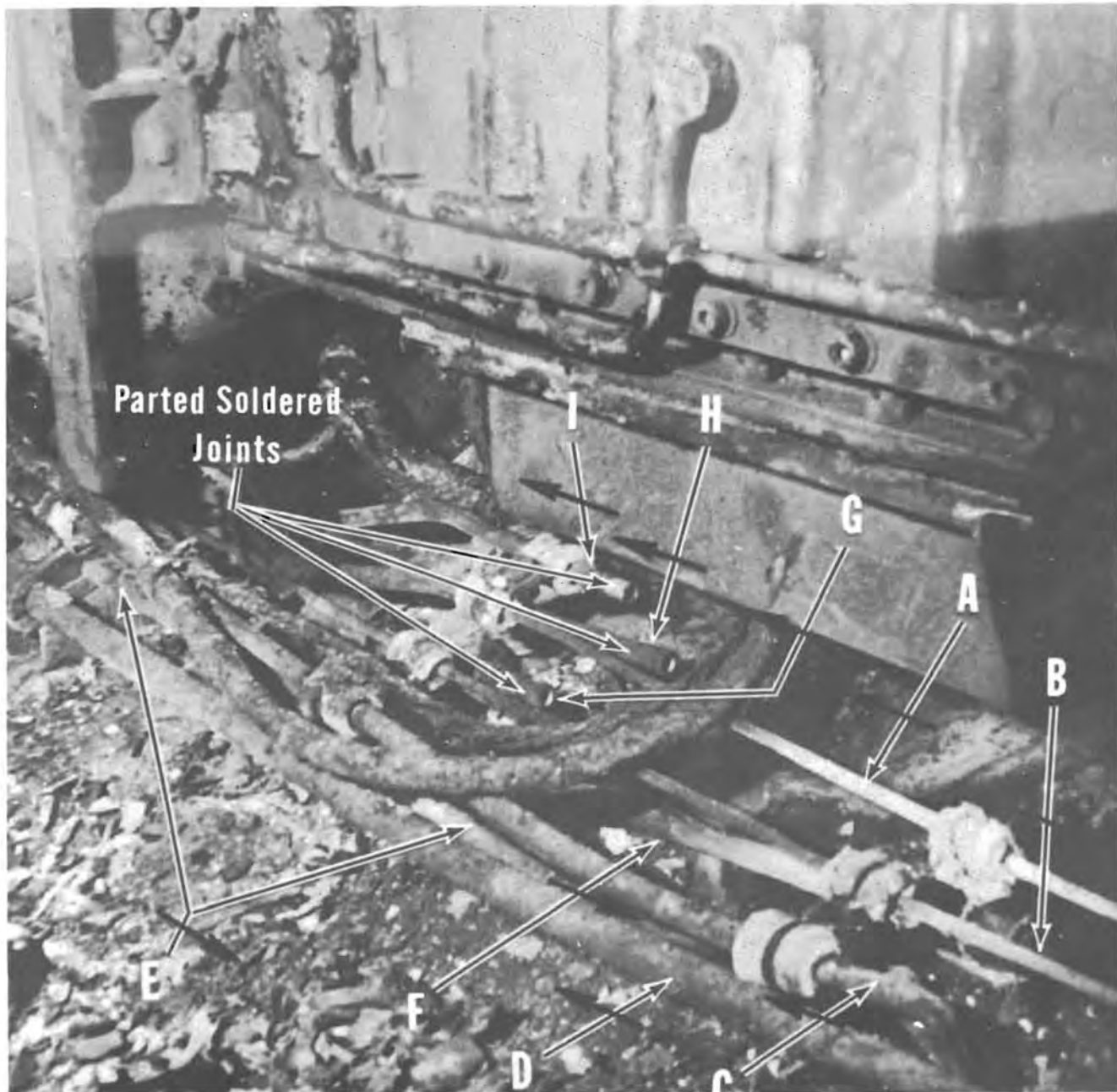
NOTE: RED ARROWS ON ENCLOSURES 10-13b, 10-13c, AND 10-13d INDICATE DIRECTION OF FLOW IN TUBE

TUBING CODES FOR USE WITH ENCLOSURES 10-13B, 10-13C, & 10-13D

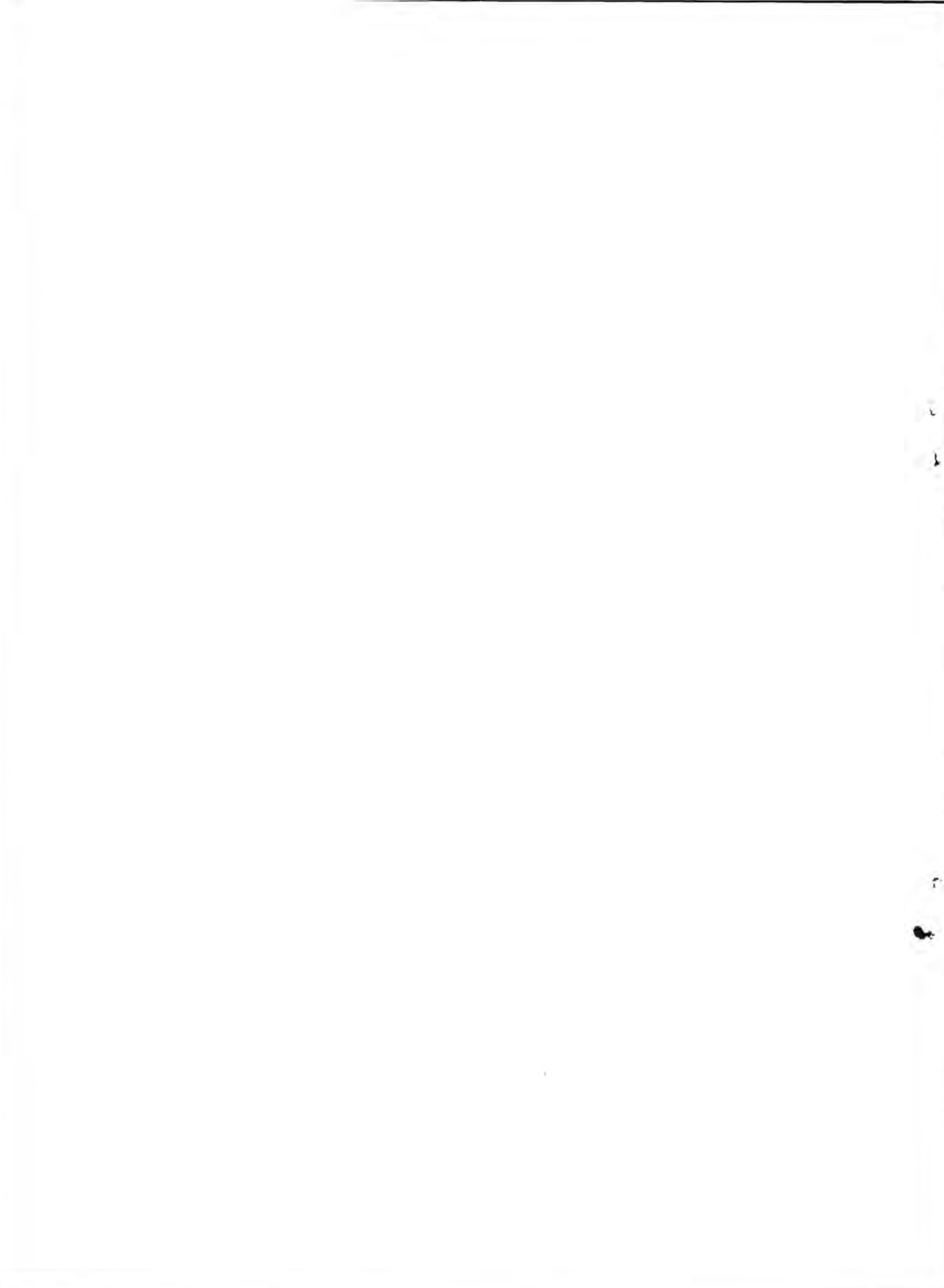


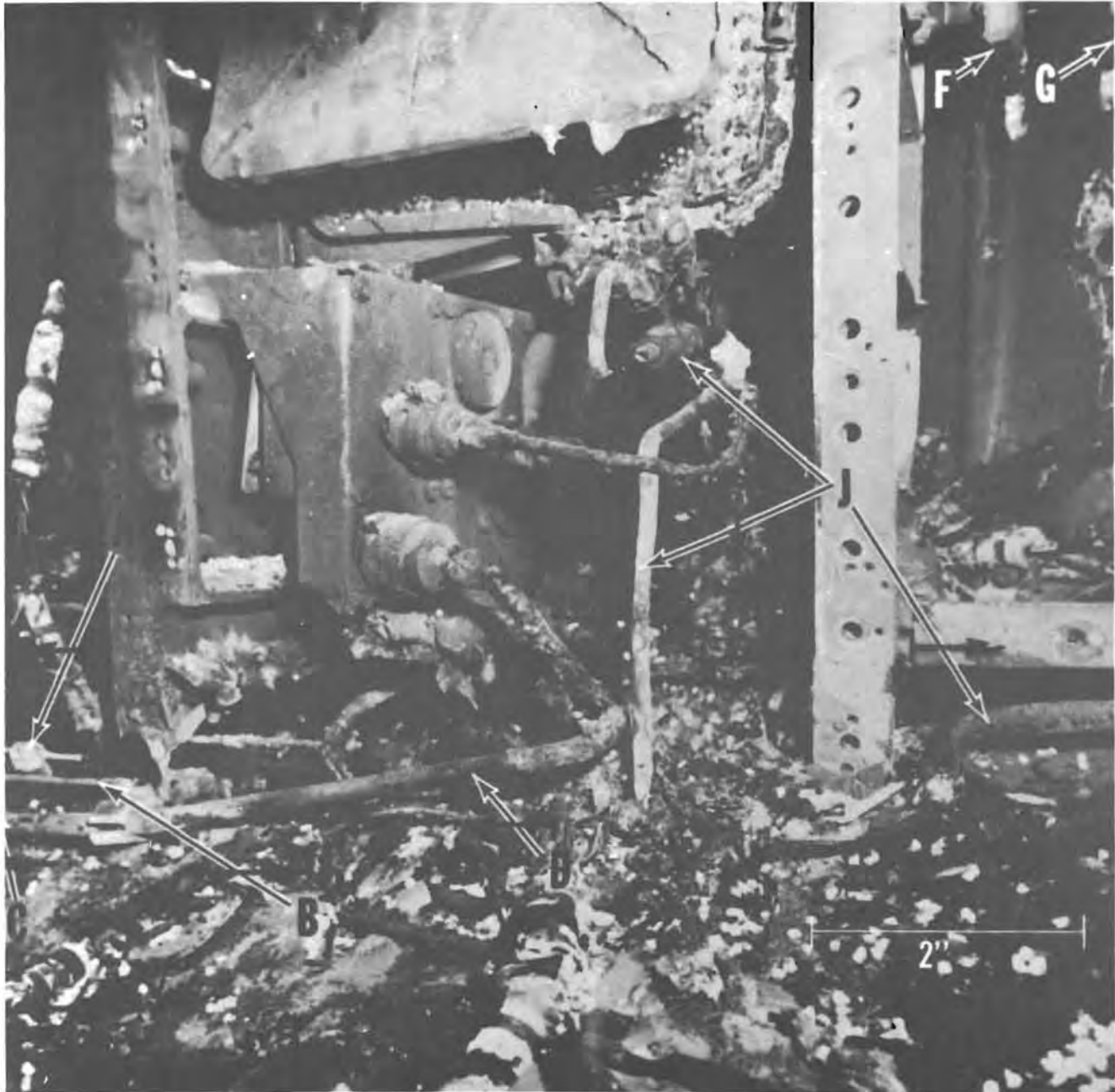


INNER SIDEWALL PENETRATION BEHIND WATER CONTROL PANEL



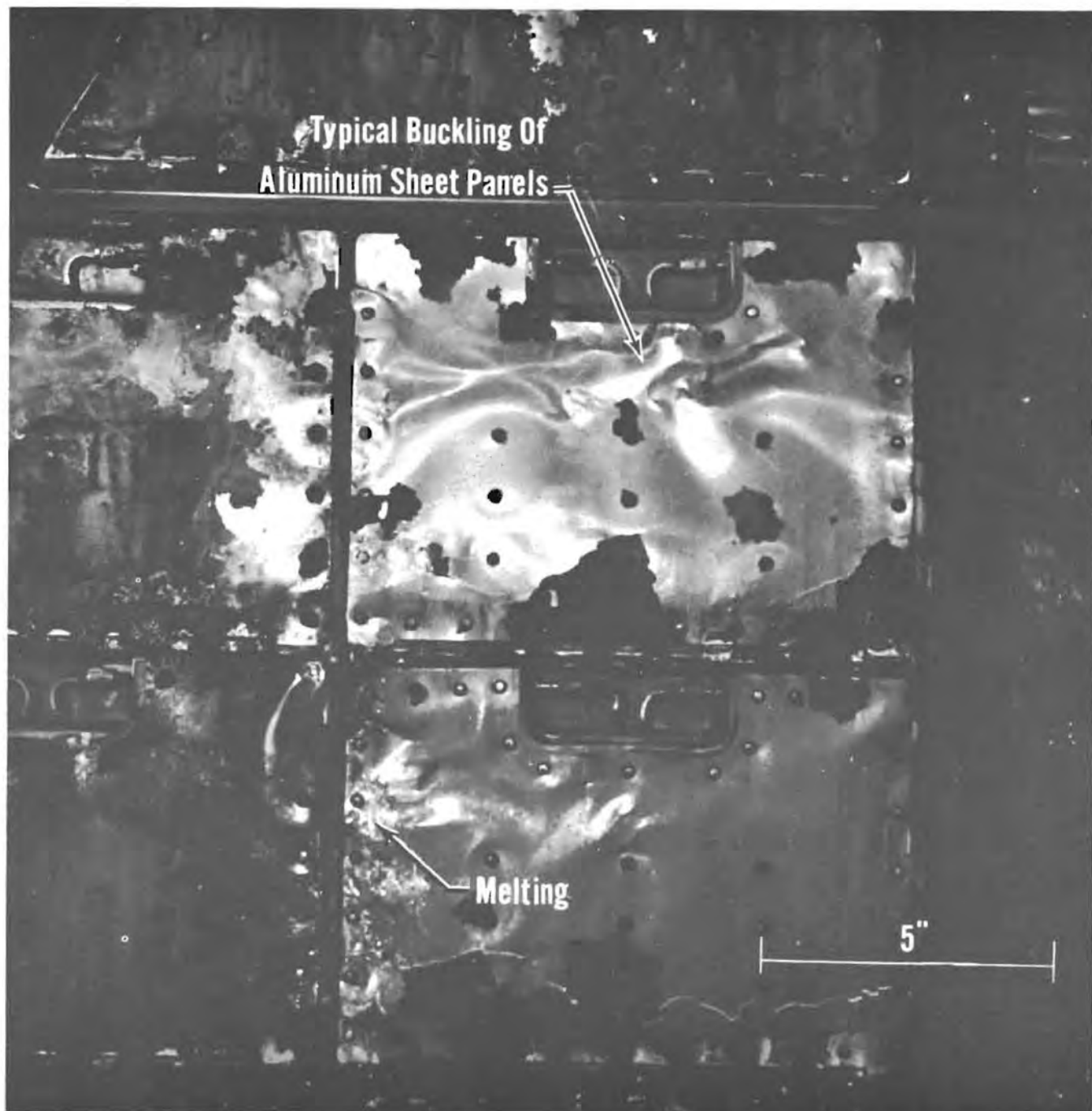
TUBING BENEATH ENVIRONMENTAL CONTROL UNIT





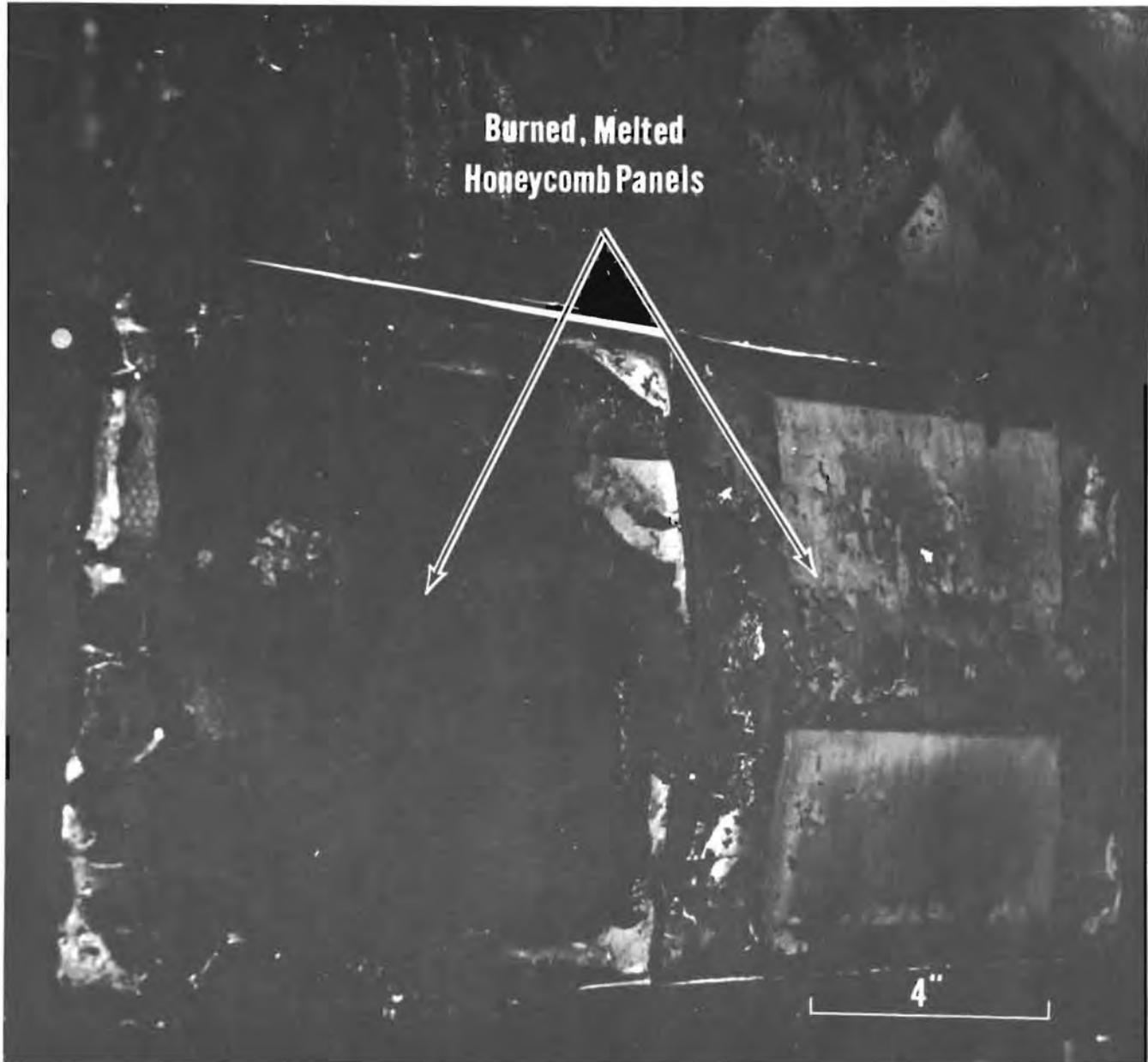
MELTED TUBING BENEATH CO₂ ABSORBERS



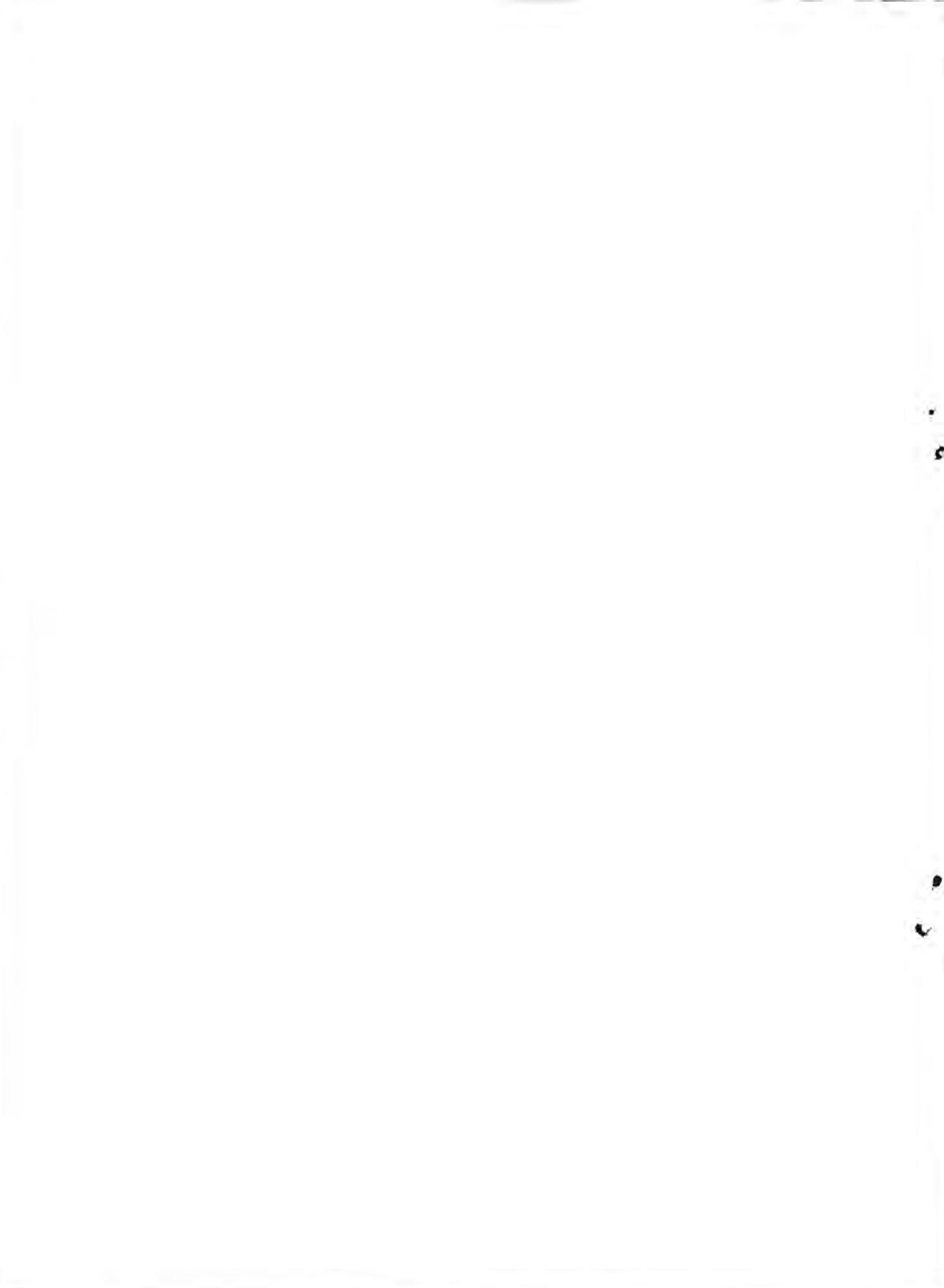


BUCKLED FOOD STORAGE COMPARTMENT DOORS



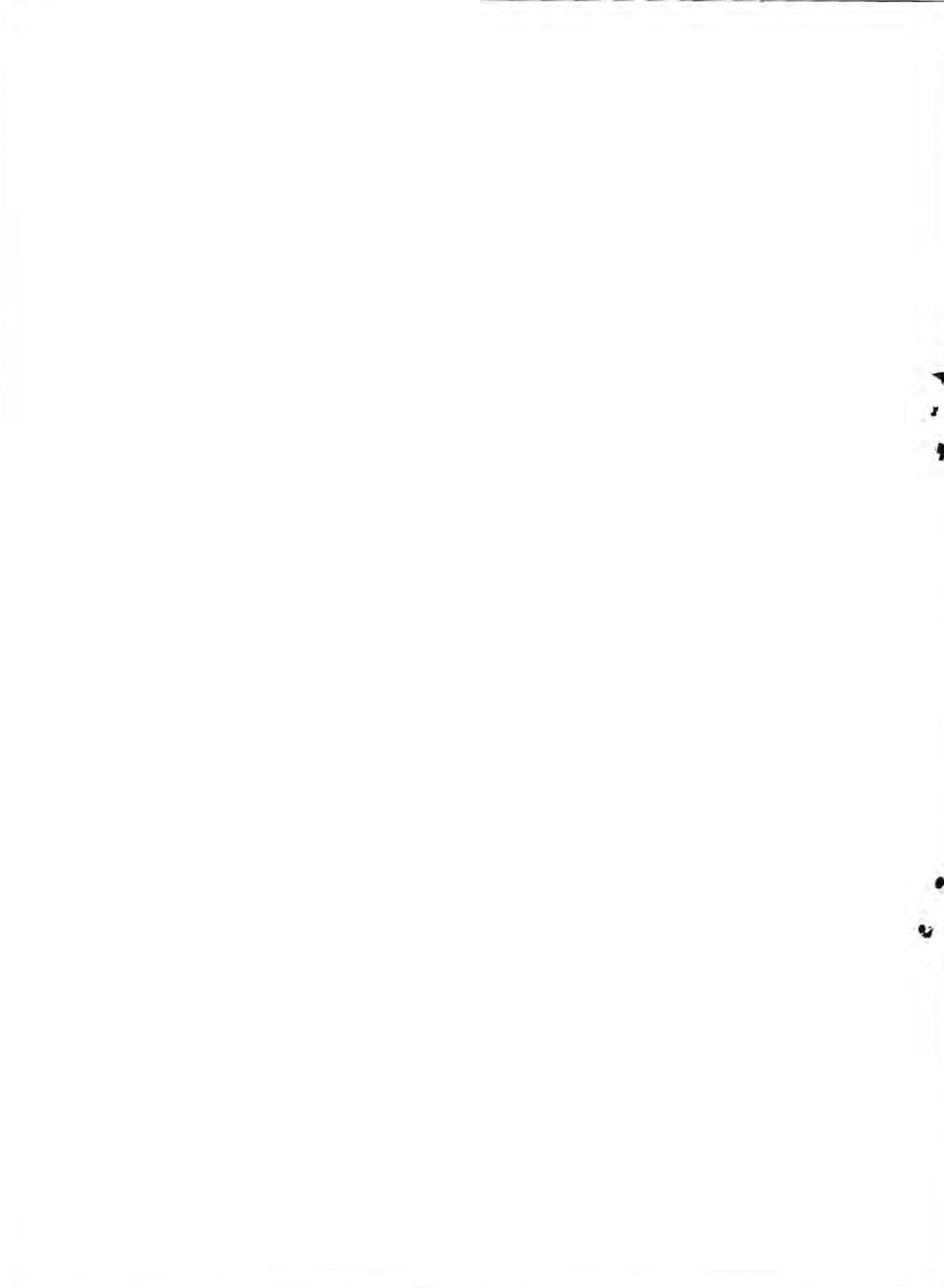


DAMAGED FOOD AND GARMENT STORAGE LOCKER DOORS





DAMAGED INNER SIDEWALL BELOW CO₂ ABSORBERS



LIST OF REFERENCES

- 10-1 "Apollo Mockup SMD-2B Plots, 0-60 Sec. 12 Window" Manned Spacecraft Center, NASA, March 6, 1967.
- 10-2 Panel Number 18, Integration Analysis (Appendix D-18) For Final Report to AS-204 Review Board
- 10-3 STN 43 - Delta P vs CDU Gimbal Angles
- 10-4 STN 42 - Cabin Pressure Relief Valve and Vent Line Flow Characteristics
- 10-5 STN 37 - Soot Comparative Analysis (Test results will be contained in Appendix G of the Apollo 204 Review Board Final Report)

ENCLOSURE 10-17