REPORT OF APOLLO 204 REVIEW BOARD

TO

THE ADMINISTRATOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APPENDIX D

PANEL 18

REPORT OF PANEL 18

INTEGRATION ANALYSIS PANEL

APPENDIX D-18

TO

FINAL REPORT OF

A P O L L O 2 0 4 R E V I E W B O A R D

A. TASK ASSIGNMENT

The Apollo 204 Review Board established the Integration Analysis Panel, 18. The task assigned for accomplishment by Panel 18 was prescribed as follows:

> This task involves the review of inputs from all task groups, the correlation of all pertinent information, feedback for further study, and the final technical integration of the evidence.

B. PANEL ORGANIZATION

1. Membership

The assigned task was accomplished by the following members of the Integration Analysis Panel:

Mr. A. D. Mardel, Chairman, Manned Spacecraft Center, NASA
Mr. R. W. Pyle, North American Aviation, Kennedy Space Center
Mr. C. B. Mars, Kennedy Space Center, NASA
Mr. D. S. Levine, North American Aviation, Downey, California

2. Cognizant Board Member

Dr. M. A. Faget, Manned Spacecraft Center, NASA, Board Member, was assigned to monitor the Integration Analysis Panel.

3. Panel Consolidation

Panel 16 and 3 served as separate Panels from January 31, 1967, through February 23, 1967. These Panels were dissolved on February 23, 1967, and merged with Panel 18.

C. PROCEEDINGS

1. General

In response to the direction of the Board, the Panel discharged its responsibilities to the Board by planning and executing the following major activities:

a. Coordination of all phases of hardware inspection, disassembly, test and analysis requirements, and presentation of periodic status and summary of results to the Board.

b. Correlation, validation, and determination of each significant finding, and presentation of periodic status and summary of results to the Board.

2. Hardware Inspection, Disassembly and Analysis

Inputs were solicited from all Panels with respect to hardware inspection, disassembly, test and analysis requirements. A special form, "Disassembly and Post-Disassembly Requirements," (Enclosure 18-1), was used for the logging of all requirements.

In keeping with the analysis activity, priorities for the various requirements were established. Items were then selected twice daily to be approved by the Board for proceeding with that activity of work. Board approval information was fed by the Panel back to the systems engineers so that a "Test Preparation Sheet," TPS, (Enclosure 18-2) would be originated to accomplish this work. This Panel approved all TPS's, kept current TPS files, and reported on the status of all approved requirements by means of a "Board Action Summary" prepared each Wednesday. A sample page of the latest "Board Action Summary" is attached as Enclosure 18-3. All three enclosures relate to the same item: "Removal of a cover over the junction box in the lower left-hand equipment bay."

Significant findings from hardware inspection were then correlated with the analysis effort to determine further courses of activity so as to culminate all research and work on an item and enable a determination to be made. This hardware activity was completed on March 27, 1967. All of the equipment has been removed from the spacecraft.

An examination of the electrical wiring harnesses remaining in the spacecraft in the most probable zone of fire initiation was completed on March 24, 1967. The most probable zone of fire initiation is defined as the area on the Command Pilot side of the Command Module. Looking forward through the main hatch, this area starts at the Environmental Control Unit (ECU) and progresses forward to the gas chromatograph compartment, and covers the volume from the floor to the top of the ECU and to the top of the gas chromatograph compartment. All wiring in the lower equipment bay was also examined. The ECU wiring has been examined while the unit was in the spacecraft and after removal from the spacecraft.

Electrical Power System wiring inspection and analysis is still continuing. Work items that are active are as follows:

a. Determination of the cause for each circuit breaker and fuse that was found open or blown after the accident. All open circuit breakers have been identified. The identity of all blown fuses has not yet been established. All circuit breakers that were to be closed but were found open after the accident are listed in Enclosure 18-4.

b. Conduct of additional continuity checks to establish that suspect wiring was installed as required by manufacturing drawings.

The only evidence of arcs, shorted and suspicious wiring that has been found is listed below:

(i) DC wiring completely burned through in harnesses providing power to Environmental Control System instrumentation.

(ii) Arc between a DC wire and the cover of J-Box C15-1A52.

(iii) Shorted AC wires providing power to the gas chromatograph connector.

(iv) Shorted DC wires providing power to scientific equipment bay 2.

(v) Two shorted AC phases in cabin air fan 1 wiring.

(vi) Crushed DC harness in Environmental Control Unit providing power for instrumentation.

(vii) Shorted DC wires providing power to the biomed recorder.

(viii) Shorted AC wires in Environmental Control Unit providing power for suit compressor 2.

(ix) Command Pilot suit wiring shorted.

(x) Arc on structure by side of switch S11 in back of panel 8.

All removed parts and assemblies were thoroughly reviewed by NASA and Contractor design engineers, metallurgists and Panel 5 members. Based on these reviews, they were classified either as a possible or as an improbable ignition source. A written justification was required for each item, and each item was approved by three design engineers representing NASA KSC, NASA MSC, and NAA, by the three members of the Screening Committee, by the Head of the KSC Materials Analysis Branch, and by a member of Panel 5 before it could be classified as an improbable ignition source.

The listing of all equipment totals 299 parts and assemblies. No attempt was made to list or to remove from suspicion as a possible ignition source the spacecraft wiring or devices integrally a part of that wiring such as terminal boards.

The 299 parts and assemblies were categorized as follows:

System	Number of Parts and Assemblies	Improbable Ignition Source (Cat. B)	Possible Ignition Source (Cat. A)	Remarks
Communications	17	17		
Instrumentation	22	12	10	9 ECS related transducers 1 harness assembly
Guidance and Navigation	16	16		
Stabilization and Control	14	14		
Environmental Control System	48	3	45	
Electrical Power System	32	30	2	Static Inverter 2 Panel C15-1A52 (LEB J-Box Cover)

Continued

System	Number of Parts and Assemblies	Improbable Ignition Source (Cat. B)	Possible Ignition Source (Cat. A)	Remarks
Displays and Controls	30	29	1	Switch 11, Panel 8
Sequencers	6	6		
Reaction Control System	12	12		
Structure	18	18		
Earth Landing System and Recovery Aids	5	5		
Crew Equipment	61	59	2	Command Pilot Cobra Cable, Command Pilot Torso Harness
Experiments	4	3	1	Octopus Cable
Pyrotechnics	14	14		
TOTALS	299	238	61	

The details of the Screening Committee review are contained in the "Screening Committee Final Report," dated March 24, 1967 (Reference 18-1). Analyses of the remaining Category A items are contained in other sections of this report. Special laboratory investigations of spacecraft wiring, the ECS and Static Inverter 2 are reported in this document.

3. Correlation, Validation and Determination of Investigation Items

Inputs were received periodically from daily Panel meetings, daily Panel reports, special Panel reports, hardware inspection and disassembly, brainstorming sessions, technical discussions, etc.

The more significant inputs, defined as those that (a) could possibly contribute to the cause of ignition, or (b) could contribute to the propagation of the fire, were listed as investigation items. Each investigation item was correlated with other items, studied to establish validity and meaning, and finally a determination was made as to whether the item did not cause the accident or whether it may have contributed to the accident.

To better illustrate the mechanics, the process for one investigation item will be summarized:

Investigation Item 42 - Elapsed Time Indicator burned on Spacecraft (S/C) 014. This unit was associated with the Caution and Warning System. Data were received from Panel 6 that an Elapsed Time Indicator (a non-flight item) for the Caution and Warning System was overheated as a result of a noise suppression capacitor short during factory checkout on S/C 014 at North American Aviation, Downey, California. The Command Module filled with smoke during this incident.

The following validation actions were taken:

(a) Action to Panel 1 to determine the exact configuration of the Elapsed Time Indicator installed on S/C 012 and compared to the S/C 014 installation, and knowledge on whether this unit was installed during the accident.

(b) Action to Panel 2 to determine the level of qualification with respect to oxygen and pressure environments. Because this unit was to be removed before flight, it was believed that the unit would not have been qualified, but this still had to be confirmed.

(c) Action to Panel 3 to review all data from S/C 014 during the time that the incident occurred to determine if there were any electrical transients or if any circuit breakers opened, for correlation with indications during the accident.

Closure of these actions disclosed that no changes were made to the unit following the incident on S/C 014, that the unit installed on S/C 012 during the accident was of the identical configuration, and that the unit was not qualified for the environment during the time of the accident. A Board action was then requested to examine the installation on S/C 012 (Board Action No. 0035). A TPS was written (TPS 053) and an examination of the unit was made the next day. The physical examination disclosed that the unit was in a satisfactory condition with no evidence of burning or damage. The item was then closed in the category of "did not cause the accident."

A "Status of Investigation Items" was prepared for the Board each Wednesday. The latest "Status of Investigation Items" is attached as Enclosure 18-52. Whenever an item was closed, an "Integration Analysis Summary" was prepared and presented to the Board (all are attached as Enclosure 18-53).

Output data from selected Panel activities were reviewed in detail. Examples of these outputs were discrepancy reports and open difficulties provided by Panel 6, and incomplete work or open "Engineering Orders" (EO's) and configuration differences provided by Panel 1. These outputs were reviewed by NASA and Contractor system engineers to determine which could be related to the cause of the accident. Those that could have some bearing on the cause of the accident were entered as investigation items.

4. Special Reports to the Board

Formal and informal reports were prepared and presented to the Review Board. The more significant of these included:

Review of Spacecraft Power Status
Supplement to Review of Spacecraft Power Status
Structural Assessment Report
Explanation and Discussion of ECS Water/Glycol Circuit Prior to and After the Fire Report
Spillage of Ethylene Glycol/Water (RS89-a) as a Possible Cause of Fire in S/C 012
ECS Oxygen System Description and Interim Data Evaluation
Communications Analysis Report
Mock-up 2 Mobility Evaluation Test Results

These reports are briefly summarized below.

Review of Spacecraft Power Status

This is a summary of internal and external power descriptions and configurations applicable to S/C 012. It contains a sequential history of the DC power system. The sequential history is fully verified by data indications and S/C and Ground

Support Equipment (GSE) switch and control positions. This report was used to establish the DC power system configuration at the time of the accident, and to show that it was proper. (Enclosure 18-54a)

Supplement to Review of Spacecraft Power Status

This is a summary of minor internal and external power supplies applicable to S/C 012 in addition to the main DC supplies. (Enclosure 18-54b)

Structural Assessment Report

This is the first summary of the visual inspection of the interior of the S/C to determine the extent of damage to the structure, plastic control knobs and glass dials. (Reference 18-2).

Explanation and Discussion of ECS Water/Glycol Circuit Prior to and After the Fire Report

This is a summary of the internal and external water/glycol system configuration throughout the test. It also contains a sequential history of significant system parameters. (Reference 18-3)

Spillage of Ethylene Glycol/Water (RS89-a) as a Possible Cause of Fire in S/C 012

This report presents laboratory results on the properties of water/glycol and its inhibitor agents. It points out that the residue remaining from any spillage or leakage is hygroscopic and corrosive. It postulates a theory that fire can be produced from electric short circuits caused by glycol/water residue in electrical insulations. (Reference 18-4)

ECS Oxygen System Description and Interim Data Evaluation

This is a summary of the internal and external oxygen system configuration throughout the test. It also contains a sequential history of significant system parameters. (Reference 18-5)

Communications Analysis Report

This report covers the configuration of the complete voice communications system - the Spacecraft, Spacecraft/Ground Interfaces and Ground Systems. It includes detail transmission information during the last ten minutes of the test. (Reference 18-6)

Mock-up 2 Mobility Evaluation Test Results

This report presents the results of a crew mobility test conducted at KSC. This test was conducted to determine the capability of a crew to see certain areas of the spacecraft and to perform certain actions with respect to time. (Reference 18-7)

5. Brainstorming Meetings

When the initial review of data and hardware failed to disclose an obvious source of the fire, a series of brainstorming meetings was held with participation by test engineers, design engineers, astronauts, etc. The purpose of these meetings was to initiate and critique possible fire initiation and propagation theories.

A large number of potential fire initiation and propagation theories were proposed and evaluation sheets were established to build up the supporting factors for the theory, negative factors to refute it, and to delineate additional physical examinations or tests required to support or to eliminate the theory. A total of 47 potential initiation theories have been proposed and evaluated. All of these are attached as Enclosure 18-55.

Of the 47 potential initiation theories, 46 are closed as not considered likely ignition sources, and one is closed as a probable potential ignition source.

The one probable ignition source is the DC wiring completely burned through in harnesses providing power to Environmental Control System instrumentation. Two potential initiation theories of a more general nature were also considered. These are described below.

a. Cold flow characteristics of Teflon insulated wire.

Teflon wire was selected for the spacecraft because of excellent resistance to high temperature, good dielectric properties, lightweight characteristics, etc.

It has, however, in common with other plastic materials, cold flow characteristics which permit the insulation to flow away from localized high pressure points over long periods of time. It is possible that localized high pressure points, either between wires or between a wire and structure, could ultimately result in breakdown of the insulation. All wire bundles in the spacecraft which showed damage were carefully inspected for signs of arcing. Only those locations delineated in other sections of this report showed such signs.

b. Failure of electrical connectors due to water/glycol spillage:

The characteristics of the inhibitor used in the coolant water/glycol fluid leaves a residue that is electrically conductive, hygroscopic, and flammable. Leaks of water/glycol occurred in the lower equipment bay and Environmental Control Unit area during earlier tests on S/C 012. These leaks were mopped up and connectors and accessible wire harnesses were washed with distilled water and alcohol, and dried with nitrogen.

After the accident, all connectors were carefully disconnected, photographed, and inspected for any signs of internal burning or arcing. No evidence of internal arcing or burning was found which indicated a fire source. A few isolated cases of pin arcing were found, but these appeared unrelated to the fire since all surfaces in the vicinity were clean and without any indication of a combustion path.

6. Data Indications

The purpose of this section is to summarize briefly the recorded data indications that were unusual and unexpected prior to the crew report of fire, and significant data indications following the crew report of fire.

a. Gas Chormatograph Telemetry Indication

Gas chromatograph channel output variation occurred at 23:30:50 GMT. The gas chromatograph was not installed for this test and the connector that carries the telemetry data signals and the required AC power was placed on the gas chromatograph shelf prior to the test. Power to the AC line in the connector was turned on during the test, as required by the test procedure.

A careful examination of records showed activity on this channel seven times prior to 23:30:50 GMT.

Following is a summary of the seven periods of activity (see Enclosure 18-7):

Trace A - 22:04:45 GMT - Gas Chromatograph (GC) trace changed in exact correlation with a rise in the VHF/FM RF output when transmitter was turned on. GC output change was 2 to 3 per cent.

Trace B - 22:06:54 GMT - This trace correlates with middle gimbal angle stabilization loop, responding to fine align mode.

Trace C - 22:19:23 GMT - This change in the gas chromatograph trace correlates to the Guidance and Navigation System (G&N) going to coarse alignment.

Trace D - 22:20:09 GMT - Change correlates with G&N going to fine align. The large current drawn by this change in the G&N mode also caused transients on DC bus A and DC bus B.

Trace E - 22:34:46 GMT - Pilot turned updata link to UHF.

Trace F - 22:53:13 GMT - Environmental Control System monitor reported high oxygen flow. He asked crew if the face plates were opened. Crew said "No." Much noise in background of Spacecraft.

Trace G - 22:55:40 GMT - Command Pilot changed cobra cable and was in process of communication check at this time. Location of Pilot was not known. Pilot did get cobra cable and may have still been in the lower equipment bay.

Trace H - 23:30:50 GMT - Variation just prior to the accident.

The telemetry data line in the connector has the characteristics of an antenna, and consequently can detect changes in the electromagnetic field within the spacecraft.

b. AC Bus 2 Voltage Variation

A momentary increase in AC bus 2 voltage was noted at approximately nine seconds before the crew report of fire, and at the same time the recorded parameters monitoring the equipment powered from AC bus 2 showed abnormal indications. Enclosure 18-3 shows the parameters and changes, with the times of sampling by the telemetry system. These were:

(1) Rise in AC bus 2 voltage phases A, B and C

(2) 1.7 second dropout of C-band decoder and transmitter outputs

(3) Momentary dropout of VHF-FM carrier

(4) Fluctuation of rotation controller null outputs

(5) Gas chromatograph telemetry signal transient

Other equipment connected to AC bus 2 at this time had no telemetry monitoring capability that would detect effects of voltage variation.

The associated changes which occurred at the time of the AC bus variation are individually discussed:

(1) The C-band beacon parameters dropout occurred for approximately 1.7 seconds. The 1.7 second dropout observed is the minimum recovery time of the protective circuit internal to the beacon to prevent magnetron damage. Possible causes of the C-band beacon dropout are:

(a) Interruption of AC bus 2 power would cause the C-band beacon dropout as verified by special tests on a C-band beacon similar to the one used in S/C 012.

The test indicated that interruptions of the AC power, all three phases, or phases A and B, or phases B and C, for 10 milliseconds or more created a dropout.

(b) Momentary drop of range interrogation; however, the range C-band station log shows no report of interrogation dropout at this time.

The most probable cause of the beacon dropout was a momentary loss of AC input power to the beacon, particularly since the transponder dropout was coincident with the variation of the AC bus and the beacon performed normally after the recovery from the dropout until loss of the data.

(2) VHF-FM transmitter signal dropout occurred for approximately 30 milliseconds. A dropout of this nature has been duplicated by special tests conducted by Collins Radio Company with a transmitter under similar conditions. These tests show that the received video signal during the noted time can be matched very closely by a momentary dropout on the AC supply (all three phases) to less than 50 volts, or a dropout of DC supply to less than 6.5 volts for a period of 15 to 20 milliseconds. Since the VHF-FM transmitter recovered, as did the C-band beacon, the most likely cause of the dropout was a momentary interruption of the AC input power.

(3) Rotation controller null outputs showed momentary transients in each of the three control axes. The rotation controller outputs which were reading slightly off null just prior to the voltage variation (the controller was pinned) are supplied by phase A of AC bus 2. Special tests have shown that the null

output transients can be duplicated by a momentary interruption of AC bus 2 phase A input power.

(4) The gas chromatograph telemetry signal showed a sharp transient coincident with the voltage variation. The character of the transient is indicated in Enclosure 13-7.

The AC bus 2 voltage increase appeared on all three phases momentarily. The AC bus voltages are sampled ten times a second by the instrumentation system. It is, therefore, impossible to determine the actual variation of AC bus 2 voltages for 100 milliseconds prior to or after the observed voltage increase. In addition, special tests indicate that there is an inherent delay and stretching of the AC voltage signal conditioner output due to rectification and filtering. Consequently, an AC voltage transient occurred several milliseconds prior to the time indicated in the S/C 012 data. However, the AC bus voltages are connected to an overvoltage and undervoltage sensor which will trip if the voltage on any phase exceeds 135 volts AC or drops below 90 volts AC for 32.5 $\pm$ 7.5 milliseconds. Main bus A and B voltages are also monitored by an undervoltage sensor which will trip if the voltage drops below 26 volts DC for 70 $\pm$ 30 milliseconds. Any one of these conditions would cause a master alarm. The master alarm did not occur during the period of the AC bus 2 voltage variation.

c. High Oxygen Flow Rate

At 23:30:59 GMT the oxygen flow rate measurement went to a saturated condition of 1.03 pounds per hour. Fifteen seconds later the caution and warning system master alarm was triggered. The oxygen (O_2) flow stayed in a saturated condition until loss of signal (LOS). Oxygen flow rate and associated data are shown in Enclosure 18-9.

There were 10 other periods during this test in which an unexplained saturated flow rate condition existed. A correlation of relevant data for these unexplained periods is shown in Enclosure 18-10. The actual flow rates for several of the times listed were computed using measured surge tank pressure.

Four possible conditions can cause a high oxygen flow indication. These are:

(1) H_2O Cyclic Accumulator Activation - The cyclic accumulator is actuated every 10 minutes for a ten second duration by the Spacecraft Central Timing Equipment (CTE). The diaphragm pump is actuated when the CTE triggers the circuit. During the 10 seconds in which the solenoid is open, the O_2 flow transducer will saturate and energize circuitry which could trigger the Caution and Warning System high-O_2 flow indication; the system is, however, equipped with a 15 second time delay to prevent the 10 second high flow condition from triggering the system.

(2) Suit Leakage - Crew suits are not designed for the very low delta pressures that were present during this test. The joint seals, etc., are not adequately effective at low differential pressures and therefore crew movements can induce suit leakages which result in high-O_2 flow rates.

(3) Open Helmet Visor - Enclosure 18-12 shows that with an open helmet visor (23:19:13 GMT), Surge Tank Pressure responds within about 5 seconds. For this condition the surge tank pressure decayed from 739 to 480.6 psig (see Enclosure 13-13 which shows the history of surge tank pressure for the entire test). During the last high-O_2 flow condition the surge tank does not start decreasing for 12 seconds.

(4) Crew Movement - During five of the ten unexplained high oxygen flow rates, listed in Enclosure 13-10, the voice tapes indicate the crew was troubleshooting the communications problems. During the last three high-O_2 flow rates the Guidance and Navigation System gimbal angle movements have been correlated with crew motion and biomed data. Of particular interest is the time period of 23:24:03 to 23:24:06 GMT. Five seconds prior to start of high-O_2 flow the biomed data indicates a deep breath and possible talking by the Senior Pilot. Biomed data are available from the Senior Pilot only. The slope at the start of high-O_2 flow correlates with the characteristics of the data when the Command Pilot opened his face plate at 23:19:13 GMT. Another significant period is at 23:30:59 to LOS, where the middle gimbal torque motor input shows response to motion at 23:30:24 GMT. At this time the O_2 flow starts a gradual rise. At 23:30:39 GMT the gimbal torque motor inputs reflect a distinct vehicle motion. The biomed data from the Senior Pilot, shown in Enclosure 18-14, show the start of motion which is

also reflected in the continued increase of O_2 flow. At 23:30:59 GMT the O_2 flow rate reached saturation with motion still being indicated on the inner gimbal.

d. Live Microphone Condition

Voice tape analysis and instrumentation data records show that a live microphone constant-keying condition existed from the Command Pilot position during a considerable portion of the final test period.

The live microphone condition was evidenced in a real time during the test at 22:25:53 GMT, when the crew selected the VHF/AM T/R mode. Data analysis using the Merritt Island Launch Area Open-Loop Communication (MOLC) tape (S-band and VHF/AM voice) showed that the first indication of the live microphone was at 22:18:49 GMT.

However, a review of the Mission Control Center-KSC (MCC-K) tape showed that the MOLC tape recorder was stopped between 20:57:19 and 22:13:49 GMT. Further analysis of the MOLC tape established no evidence of the live microphone condition prior to 20:57:19 GMT. It is concluded therefore that the live microphone condition began between 20:57:19 and 22:13:49 GMT.

The crew became aware of the live microphone condition at 22:26:48 GMT, and started a series of trouble-shooting exercises. These exercises, plus voice tape analyses and data records, indicated that the live microphone condition existed in the Command Pilot communication system. The known exercises were:

(1) The Command Pilot switched from the "normal" connector to the "emergency" connector of his cobra cable.

(2) The Command Pilot and Senior Pilot interchanged cobra cables.

(3) The Command Pilot and Senior Pilot placed their cables back in the original configuration.

(4) The Command Pilot replaced his cobra cable with a flight spare.

(5) Various audio control panel modes were tried.

The live microphone condition continued to exist after the above exercises and was in evidence through the crew report of fire.

e. Crew Movement

Crew activity was evident for about the last 30-second period just before the crew report of fire. The data that indicates movement is shown in Enclosure 18-14 where several parameters support the indications. The crew was not required to perform any operation or function during this time. The Enclosure shows changes in the torquing voltage to the gimbal torque motors indicating significant spacecraft motion.

Activity of the Senior Pilot was interpreted from respiration rate, heart rate and phonocardiogram data. The Senior Pilot was essentially at a resting baseline until 23:30:21 GMT, when slight increases in pulse and respiratory rate was noted. At 23:30:30 GMT, there was a 4.5 second burst of noise on the electrocardiogram trace indicating some muscle activity. A similar burst occurs at 23:30:39 GMT accompanied by maximum noise on the phonocardiogram. The data are consistent with increased activity, but are not indicative of an alarm response. By 23:30:45 GMT all biomed parameters have begun to revert toward baseline levels.

The Command Pilot's live microphone condition on the S-band voice loop indicated considerable amounts of brushing and tapping-type noises during the 30 second time period prior to the crew report of fire. Noises on the S-band voice loop prior to this time were not of this magnitude or density.

Additional indication of crew activity was the onset of increasing oxygen flow to the suit circuits during this relative time span.

f. Cabin Pressure Rise

A determination of the pressure the cabin attained and the approximate time of structural rupture is included in this section. The analysis is based on observations from previous tests and certain known facts of the hardware design.

The installation of the optics system and INERTIAL MEASUREMENT unit on the navigation base is shown in

Enclosure 18-15. The navigation base is shock mounted on the Command Module structure. The optics system penetration through the pressure vessel is a set of bellows which forms the crew compartment seal. Navigation base displacement is most significant in the spacecraft pitch axis. The inertial reference and spacecraft axes are not coincident, therefore, gimbal angles must be transformed to reflect navigation base motion (refer to Enclosure 18-16).

A finer detail of the navigation base is shown in Enclosure 18-17. The single lower shock mount acts as a pivot point. The optics bellows mounted at the upper extreme end of the navigation base allows motion of the base about that pivot. A pressure differential across the optics and bellows assembly results in a force which will tend to rotate the upper end of the navigation base outboard. Any rotational motion or angular displacement of the navigation base will be reflected in the Inertial Measurement Unit (IMU) gimbal torque motor currents and gimbal angles. Deflection of the navigation base has been correlated with differential pressure across the optics and bellows assembly through data acquired during the altitude chamber test of S/C 012. The results are shown in Enclosure 18-18. With the cabin pressurized to 5.5 psig, the upper navigation base was deflected outboard. An approximate linear movement of the navigation base was noted as a function of decreasing cabin pressure.

Variations of temperature on the Command Module RCS "A" engine, CR 4561T, and on the Aft Heat Shield thermocouple, CA 5493T, are displayed in Enclosure 18-19 during the time of the accident. Cabin pressure and the three gimbal angles are also included for correlation. The variation of cabin pressure is shown from telemetry data which reached saturation at 21.3 psia. For comparison a second curve is shown which was developed from results of a digital simulation performed at AC Electronics, Milwaukee, Wisconsin, which determined the cabin pressure required to attain the gimbal angles observed during the accident.

The gimbal angles in Enclosure 18-19 change with the cabin pressure and reach an apparent maximum at 21:31:20 GMT, then reverse direction, indicating a decrease in cabin pressure. Because of the low sample rate of these measurements, the actual peak deflection and time of gimbal angle reversal is unknown. The RCS thruster chamber temperature CR 4561T displays a sharp rise in temperature starting at 23:31:19.86 GMT. Assuming the sharp rise in temperature is the result of hot gas impingement, a rupture in the pressure vessel must have occurred prior to start of temperature rise because of the insulation surrounding the RCS thruster transducer and the response time of the transducer. Therefore, the rupture must have occurred between 23:31:18 and 23:31:19.86 GMT. The time of rupture was estimated at 23:31:19.4 GMT by Panel 10. The time of 23:31:18 GMT was the last gimbal angle data point prior to the sharp temperature rise at 23:31:19.86 GMT. Following the rupture, the cabin pressure would decrease allowing the navigation base to move toward its initial position. Results of a digital simulation indicate the cabin pressure reached at least 29 psia.

g. Suit Flow Dropout

At 23:31:09.62 GMT the suit flow rate of the Senior Pilot was at the upper limit of the transducer (saturated) of 25.27 lb/hr. The flow rate per man was actually higher and was approximately 64 lb/hr per man. One-tenth of a second later, at 23:31:09.72 the flow rate had dropped to the lower limit of the transducer (6.15 lb/hr) and stayed there until 23:31:11.82 GMT. It then returned to the upper limit at 23:31:11.92 GMT. The other two suit flow rates remained at the upper limit during this period (see Figure 18-18).

There are three possibilities that could explain the suit flow drop-off. These are:

(1) A momentary short in the suit flow transducer wires would explain the suit flow transducer going to the lower limit and returning to saturated flow again. However, the suit delta pressure and compressor delta pressure show a marked change coincident with the drop in suit flow, indicating that the suit flow in fact changed.

(2) If the suit outlet hose was disconnected, the suit outlet has a check valve in the suit which stops the flow to the suit giving an indication of no flow. The suit delta pressure and suit compressor delta pressure should increase and, in fact, did as shown in Enclosure 18-20. The decrease in these parameters within about 2 seconds after the increase can only be interpreted as suit burn-through

and/or subsequent reconnection of the outlet hose. Disconnection and reconnection of the outlet hose within a 2 second time period is highly unlikely. If this argument is to hold, the suit must have burned through to re-establish flow and sometime later the outlet hose was reconnected to the suit. The outlet hose was found connected after the accident, which tends to weaken the argument in light of possibility (3) which follows.

(3) The suit inlet hose was found disconnected from the Senior Pilot's suit. An explanation of this could be that the Senior Pilot disconnected his suit inlet for emergency egress.

h. Water/Glycol System Integrity

Pressure and temperature measurements in the water/glycol system were examined to determine if any line rupture or leak might have occurred prior to or during the early phase of the fire.

No indications of a leak were found. It should be recognized that very slight leakages (less than about 0.5 cubic inches) could not reliably be determined with the information available.

7. Data Analysis and Correlation

The purpose of this section is to treat each data indication prior to the crew report of fire in combination with engineering tests and analyses, and correlate with other available information to provide an integrated technical evaluation.

a. Gas Chromatograph Data Interpretation

In the preceding section it was reported that the gas chromatograph measurement output varied seven times in the 22:00 to 23:00 GMT time period. It then remained totally quiescent for approximately 35 minutes, and at 23:30:50 GMT approximately 14 seconds prior to the crew report of fire, it again produced an output.

The last output is considered to have a special meaning with respect to the accident, because the trace was quiet for so long a period, and because an output occurred within seconds of the fire.

Tests were conducted at MSC and at the Contractor's facility to determine what physical phenomena can cause an output to be produced from a powered and open gas chromatograph electrical connector. Enclosure 18-21 shows the variations from two of these tests compared with the output from S/C 012. Trace A shows the output from a S/C 008 test at MSC, during the period of time when a plastic bag was being removed from the connector, where the wiring and connector were touched with bare hands. Trace C shows the output from a North American Aviation, Downey, California, test during the period of time when the wiring and the connector were subjected to an external flame. The composite data from all special test indicate that an output from the connector can be produced by the following:

(1) Physical movement or disturbance of the wiring and/or the connector

(2) Application of external heat to the wiring and/or the connector

(3) Changes in the electro-magnetic field, affecting the antenna characteristics of the wiring and/or connector

Tests are being conducted in which a wire will be sparked with a gas chromatograph connector nearby to determine if any output can be produced.

b. AC Bus 2 Transient

The AC bus 2 over-voltage condition observed at approximately nine seconds before the crew report of fire is a characteristic inverter response attributable to one of the following conditions:

(1) Momentary short or interruption of DC bus B input power to inverter 2

(2) Momentary short on one or more phases of inverter 2 output

(3) Removal of a major portion of the load from inverter 2

Enclosure 18-22 shows the basic AC and DC power distribution system configuration at the time of voltage variation. Power was in a standard configuration at the time.

Special tests have been conducted on S/C 008 at MSC and at the Contractor facilities to reproduce the telemetry voltage characteristic and the associated changes in C-band beacon, VHF-FM transmitter and rotation controller outputs. These tests show that the time relationship between the over-voltage indication and associated changes can only be duplicated by a momentary short or interruption of DC bus B input power to inverter 2. The results for all three conditions are shown in Enclosure 18-23. In this figure test AC bus 2 voltages versus time have been plotted with zero time as the time of VHF-FM transmitter and C-band beacon changes. The time that AC bus 2 voltages were sampled on S/C 012 is also indicated for each test condition. The data for the output of the AC bus 2 voltage signal conditioner was available only for the inverter DC input shorting test, but the plot of the bus voltages for the other conditions shows that the over-voltage occurs earlier and for a shorter time duration.

Voltage regulation tests were run on the ground power supply at Launch Complex 34. These tests were run under similar load conditions (30 amps) to that existing on DC bus B in S/C 012 at the time of the accident

Short circuits of 0.25 ohm resistance were applied across the bus for periods of 5 to 25 milliseconds. Measurements of voltage at the umbilical interface, voltage and current at the power supply were made using a CEC recorder with response characteristics good to 5000 cps. In addition, the ACE equipment was set up to monitor power supply voltage and current in a similar manner to that used for OCP FO-K-0021-1.

These tests indicated that a short circuit in the range of 5 to 25 milliseconds drawing approximately 75 amps caused an immediate drop in bus voltage of 13 to 15 volts, recovering to about 3.6 volts below steady state conditions after 1 to 1.5 milliseconds. The voltage remained constant until the short cleared at which time it overshot steady state conditions by about 10 volts recovering to steady state by 1 to 1.5 milliseconds.

The ACE indications of voltage and current were sporadic, depending on the time of the short relative to the ACE sample time (sample rate 1 per second). Several current measurements were obtained for the 20 and 25 milliseconds duration shorts. These current indications were quite low, from 1 to 6 amps, apparently because of the transient response characteristics of the current measurement system.

It is concluded that the probable cause of the AC bus 2 transient and associated indications was a momentary short (2 to 25 milliseconds) of DC bus B affecting the input voltage to inverter 2.

c. <u>High Oxygen Flow Rate</u>

Telemetered data indicate that the high oxygen flow rate conditions for the last 30 seconds before the crew report of fire can be attributed to the apparent high level of prime crew suit leakage at low suit-to-cabin differential pressure, magnified by apparent crew activity. An analysis of S-band audio data also indicates that a face plate may have been open. An analysis was also conducted to determine if the high flow could be indicative of a sensor and/or associated wiring difficulty.

It was considered improbable that any short circuit between the signal lead and a 28 volt DC supply lead could occur.

Single failures could exist within the bridge circuitry controlling the flow sensor which would indicate high flow rates on both the PCM output and the signal to a high flow alarm relay. A preliminary examination disclosed shorts to ground in the flow sensor; shorts to ground will produce a zero or no flow output indication. It should also be noted that the location of the oxygen flow sensor was a high fire damage area, and that the sensor would be expected to be damaged by the fire.

Based on the above, it is concluded that the high oxygen flow data indication was valid, and that there was no malfunction of the sensor prior to the crew report of fire.

d. Command Pilot Live Microphone

The live microphone connotation means that the microphone amplifier in the audio center has received a ground, allowing 28 volts DC to energize the amplifier electronics, and the diode gates in the audio center on the S-band audio output have been grounded, allowing audio signals to modulate the S-band transmitter. These two conditions are normally effected by a crewman pressing his Push-to-Talk (PTT) button on the cobra cable, or in the Command Pilot's case, by pressing his translation controller PTT or his cobra cable PTT button. The PTT button, in addition to the above function, provides a ground for the VHF/AM Transmitter keying relay through the audio control panel VHF/AM T/R select switch. These VHF/AM T/R switches are connected together for all three astronaut positions which would cause a ground to be transferred among all positions in VHF/AM T/R mode. See Enclosure 18-24 for logic detail.

An analysis of this problem has isolated the cause to the PTT or keying line that runs between the cobra cable, translation controller, Command Pilot audio control panel, and the audio center (circuitry shown in Enclosure 18-24). The following has been determined:

(1) The separate components have been checked for resistance to ground. All lines measured open which is correct.

(2) The S/C wiring was checked and a 3000 ohm resistance was measured to ground. This 3000 ohm resistance could account for the keyed microphone. However, this resistance could be a result of the fire damage to

wire bundles. Later, when an attempt was made to locate the cause of the 3000 ohm resistance, a recheck did not produce the same results. The circuit now measures open, which is normal.

(3) The translation controller PTT button was pushed and released ten times. On the fifth try the button stuck down. If the button had stuck during the S/C 012 test the microphone would remain keyed.

The audio center has successfully completed qualification testing with this line grounded for twenty-eight days.

A review of switch positions in the Command Pilot audio control panel indicates that all switches were in the positions expected. When in this configuration, current drawn by the keying line is limited to 20 milliamps at 28 volts. Tests run with a cobra cable show that no sparks were generated with 28 volts and 150 milliamps.

Based on all of the above, it is concluded that the live microphone condition was probably not a source of ignition.

e. Crew Movement

Crew movement was indicated during the last minute preceding the crew report of fire, most prominently by the torquing voltage to the gimbal torque motors. An attempt was made to determine what type of activity by the crew could produce these torquing signals by reviewing all available data from previous tests with the proper guidance mode selected. There was no consistency in the effects of crew activity such that repeatability could be shown for presumably similar activities. This may be expected since the combination of crew actions for a particular operation may never be the same. Similarly, the vigor with which an action is performed can vary. Even though the crew activity cannot be defined, the fact remains, crew motion can be detected.

f. Analysis of Tape Recorded Transmissions

The voice transmissions shown in Enclosure 18-5 were analyzed with the use of MOLC RF voice recorder tapes, oscillographs of the MOLC tapes and PCM data. This enclosure shows the VHF/AM and S-band voice tracks oscillograph readout from 23:29:42.5 GMT to LOS.

(1) 23:29:42.5 to 23:30:14 GMT

(a) The Command Pilot was transmitting on S-band. The Senior Pilot made a voice transmission on S-band and VHF/AM. There was no voice transmission by the Pilot.

(b) The ground personnel were transmitting to the S/C on S-band. The voice of the Command Pilot was being turned around by the CAST (Astro Communicator Console) system and retransmitted to the S/C on VHF.

(c) The live microphone noises were not evident, probably because of the higher noise level caused by the uplink S-band being patched to the MOLC RF recorder.

(2) 23:30:14 to 23:31:00 GMT

(a) There were no voice transmissions from the S/C.

(b) The ground personnel were not transmitting to the S/C on VHF.

(c) There was no change in the live microphone condition. Considerable amounts of noise similar to those obtained when a microphone is brushed or tapped, including breathing sounds, were evident. Some of the louder noises appear to have had sufficient amplitude to trigger the uplink VHF/AM via CAST.

(d) There is evidence of an open visor.

(3) 23:31:00 GMT to LOS

(a) There were two series of voice transmissions on S-band. The times for these two transmissions are detailed in Enclosure 18-5. No voice communications on VHF were made from the S/C during this time period.

(b) The ground personnel were not transmitting to the S/C on VHF. The voice transmissions from the S/C were being turned around by the CAST system and were retransmitted to the S/C on VHF.

(4) Analysis of Voice Tapes During the Period of Fire

The tape transcripts of the voice tapes from the C/M during the time period of the fire (referred to as the first and second transmission, on Enclosure 18-6), have been extensively analyzed. This analysis included a review of all transmissions prior to the fire that were made by the crew during the test in an attempt to aid in the determination of who made these last two transmissions and what was said. This analysis was made by NASA personnel familiar with the communication systems, the crew and their voice characteristics, the sequence of events before, during and after the fire as determined during the accident investigation. Experts at the Bell Telephone Laboratories performed extensive analysis of the tape record. The Board also reviewed these transmissions. Review by other experts is currently in progress. Any new findings from these additional reviews will be included in Appendix G of the Final Report.

Except for a portion of the first transmission, which is quite clear, it is impossible to define exactly what was said by the crew. Two points made by the Bell Telephone Laboratory experts, however, should be noted:

(a) The present state-of-the-art of analyses of voice records is such that little, if anything, can be determined as to what was said if the recording is not sufficiently clear to be intelligible by listening alone. Analyses under these circumstances can provide some clues to determine which crew member initiated the transmission. These clues cannot however establish definite identity.

(b) When the recording of the transmission is not clear, there will be nearly as many interpretations of what was said as there are qualified listeners. Many interpretations of what was said have been made. A summary of these interpretations is made in the following paragraphs.

The analysis of the first voice transmitted is as follows:

This transmission began at 23:31:04.7 GMT with an exclamatory remark. This transmission is not clear. Most listeners believe this initial remark was one of the following:

"Hey"

"Fire"

"Break"

Most listeners believe, and laboratory analysis supports this belief, that this transmission was made by the Command Pilot. This remark is followed by a short period of noise (bumping sounds, etc.).

The second portion of this first transmission begins at 23:31:06.2 GMT with an unclear word. Most listeners believe the first to be one of the following:

"I've"

"We're"

The remainder of this transmission is quite clear and is: "....Got a fire in the cockpit", followed by a clipped word sounding like "vheh", which ended at 23:31:10 GMT. Many listeners believed this transmission to have been made by the Pilot. Some believe it could have been made by the Command Pilot or the Senior Pilot. However, laboratory analyses indicate the greatest probability that it was made by the Pilot, but the results of the analyses do not negate the possibility that one of the other crew members could have made the transmission.

The analysis of the second voice transmission is as follows:

Following a 6.8 second period of no transmission, the second transmission began at 23:31:16.8 GMT and ended at 23:31:21.8 GMT.

The entire second transmission is somewhat garbled. This second transmission, therefore, is subject to wide variation of interpretation as to content and as to who was making the transmission or transmissions. The general content is what appears to be three separate phrases and it has been interpreted several ways by many listeners. The following is a list of some of the interpretations that have been made:

1. "They're fighting a bad fire - Let's get out....Open'er up."

2. "We've got a bad fire - Let's get out .... We're burning up."

3. "I'm reporting a bad fire....I'm getting out....Oh, aah."

Many listeners believe this transmission was made by the Pilot. It should be noted that:

a. The total time duration of these two transmissions was brief, lasting 17.1 seconds; the first lasted 5.3 seconds and the second lasted 5.0 seconds, with a 6.8 second period of no transmission between.

b. The transmissions provide evidence only of the time the crew first transmitted a report of the existence of the fire and do not provide any direct information as to the cause of the fire.

Two analyses of tape recorded transmissions were completed. The detailed findings are contained in references to this document. The first, Reference 18-8, is a report prepared by Bell Telephone Laboratories. The second, Reference 18-9, is a report prepared by NASA MSC.

g. Related Tests and Analyses

The purpose of this section is to cover special tests. analyses, additional data and other information that is essential to complete the investigation of the accident.

A brief summary of significant special test results is attached as Enclosure 18-56.

(1) Onboard Records Analysis

Items of onboard procedures, log books, switch lists, etc. found in S C 012 after the accident were delivered to the Federal Bureau of Investigation for reconstruction and spectrographic examination. All of the items have been positively identified. Written remarks were either changes to the OCP switching lists or crew comments in the crew log books. None of the comments are significant with respect to the accident and no other information was found pertinent to the cause of the fire.

(2) Status of Inverter 2 Investigation

Inverter 2 (Part No. ME 495-0001-0004, serial No. 88) was returned to Westinghouse facility in Lima, Ohio, for investigation relating to the S C 012 accident.

The results of the initial electrical tests conducted on the inverter disclosed that a pair of transistors in the booster stage was shorted and a fuse was open. The other four transistors in the inverter's booster stage were removed and checked out satisfactorily. The good transistors and new replacements were reinstalled. The inverter was again electrically checked and operated satisfactorily. Replacement of the fuse was not required for this check.

It is concluded that the inverter was not the source of the fire and that the transistors failure was due to thermal stresses induced by high temperatures external to the inverter. The fuse was probably damaged during the effort to remove the foam in order to gain access to the internal test points. It is also concluded that the inverter could not have caused the AC bus 2 transient at 23:30:54:86 GMT for had the transistors failed at that time the inverter would have dropped out and stayed out.

(3) Status of ECS Parts and Assemblies Investigation

The Screening Committee Report listed 54 Environmental Control System parts and assemblies as possible ignition sources. Further investigative work has placed 52 of these into the improbable ignition source category. The two remaining suspect items are still being analyzed and are identified as follows:

Electrical Cable Assembly P/N 836599-1-1
Electrical Cable Assembly P/N 836602-1-1

The two cables assemblies are connected in series. Both carry DC power to an instrumentation temperature sensor power supply. The power supply then provides power to five signal amplifiers.

Both DC bus A and DC bus B power wires were contained in these cables and both were protected by 5 amp circuit breakers. The circuit breakers were found open after the accident. Anomalies were not observed on the data from the five measurements. A short in one of the above cables would not show an anomaly on the data since the redundant power would continue to supply power necessary to maintain the integrity of the measurements.

Post-fire tests did establish a grounded condition in both harnesses and visual inspection revealed that a considerable amount of one of the cables was completely consumed by fire. These harnesses are covered in more detail in section 8-A of this report.

8. Technical Discussion of Possible Ignition Sources

The specific cause or the trigger that initiated the fire in S C 012 has not been determined. A number of potential causes have been identified and actions have been implemented to validate each one, so as to determine which will remain as likely possibilities.

The family of possible sources of ignition that apply to the Command Module includes:

(a) Spacecraft electrical power
(b) Overheating of mechanical equipment
(c) Electrostatic spark discharges
(d) Spontaneous combustion

The most likely cause of ignition is in the Spacecraft Electrical Power System. This may provide an ignition source from electric arcs that can be produced by making or breaking electric circuits, or by physical failure of a current-carrying wire. This most likely supposition is supported by the fact that the AC bus 2 power system exhibited a transient ten seconds prior to the crew report of fire, indicating an electrical power abnormality just prior to any awareness of fire by the crew.

Spontaneous combustion has been considered extensive series of test involving all know combustible materials in the spacecraft in combination with all known contaminants has been completed. The spontaneous ignition temperatures of these materials were all found to be in excess of the maximum test temperature of 400°F. All areas in the S/C should be well below this temperature unless there is a malfunction or electrical short. Therefore, the possibility of spontaneous combustion is ruled out.

Chemicals that are highly reactive can produce sufficient heat to start a fire. There are two sources of highly reactive chemicals in the spacecraft. These are the batteries and the lithium hydroxide for the Environmental Control System. Analysis of data and post-fire examination of these objects indicates that they were probably not involved in the start of the fire.

Electrostatic discharge from one of the suits to adjacent material, initiating a fire in Velcro pile or other easily combustible material, has been considered a source. Tests conducted in S C 014 indicate that insufficient energy is generated for ignition to occur. (refer to Panel 8 Report).

The probable cause of ignition follows:

a. <u>DC Wiring for Environmental Control System Instrumentation Burned Through</u>

Three separate harnesses providing DC power for Environmental Control System instrumentation have been found burned through. Two of these harnesses are shown in Enclosure 18-25 as they appeared before the accident. The harness lying over the Waste Management System bare stainless steel line contained both DC bus A and DC bus B power wires. The harness lying on the floor under the plumbing contained DC bus B power wires only. The total complement and identification of all wires in each of these two harnesses is shown in Enclosure 18-26.

The third harness that was burned through provided DC bus A and DC bus B power for an instrumentation sensor power supply. The power supply then provided power to five signal amplifiers. The harness that mates with this harness at an electrical panel near the ECU also is suspect at this time. The total complement and identification of all wires in each of these two harnesses (both similar because connected in series) is described below:

(1) Twenty-three wires total
(2) All wires were 24 gauge
(3) Wires were identified as:

28 volt DC bus A and bus B power leads (2 wires)
28 volt DC return (1 wire)
5.4 volt DC. power supply output (5 wires)
18 volt DC. power supply output (5 wires)
-0.5 volt DC, power supply output (5 wires)
common returns, power supply output (5 wires)

Enclosure 18-27 illustrates the nature of the installation of two of the harnesses on S/C 014. The lower edge of the aluminum access door to the lithium hydroxide holders contacts one of the harness when the door is opened and closed. It is inferred that the installation in S C 012 was similar to that in S/C 014. Enclosure 18-28 shows the remains of these two harnesses after the accident. Sections six to twelve inches in length of each harness are missing. If a short occurred in either of the harnesses, the evidence is gone. In this same enclosure, the third harness that was burned through is shown. This third harness is located within a one inch radius of the center of the photograph, connected to the lower electrical connector on the panel shown at the left.

Splices were made at KSC in the wires of the harness lying over the steel line in the DC bus B power and return wires on September 12, 1966. These splices were made in the wires about four inches away from the point at which the harness ran over the line. The splices are still contained in the harnesses. They have been examined, and all are in a satisfactory condition.

Debris netting lay over the harnesses traversing the complete left side of the Command Module at the floor. If a short did occur in these harnesses, ignition and fire propagation could take place.

The harness lying over the line contained instrumentation power for two measurements, Oxygen Flow Rate and Oxygen Regulator Outlet Pressure. DC bus A and bus B 28 volt power was provided to each instrumentation sensor. Twenty-two gauge wires were used throughout this harness. Two 5 amp circuit breakers were provided for these circuits. Bus B power for both sensors was protected by one breaker, and bus A power by the second breaker. Both circuit breakers were found in an open condition after the accident. Both measurements provided proper output signals until the loss of all data, some 17 seconds after the crew report of fire.

The harness lying under the plumbing contained instrumentation power for the CO_2 Absorber Outlet Temperature. It also carried power to a discontinued measurement. DC bus B 28 volt power was provided for both measurement circuits. Twenty gauge wire was used for all power circuits in this harness. Each circuit was protected by a 1/4 amp fuse. Both fuses were found in a blown condition following the accident. Since the one active measurement circuit provided proper output signals until the loss of all data, some 17 seconds after the crew report of fire, it is concluded that the fuse for this circuit did not blow until after this time. Because no data exists from the discontinued measurement, it cannot be concluded when this fuse blew.

The third and fourth harnesses at the electrical panel contained power for five temperature measurements. Two 5 amp circuit breakers were provided for these circuits; bus B power was protected by one breaker, and bus A power by the second breaker. Both circuit breakers were found in an open condition after the accident. All five measurements provided proper output signals until the loss of all data some 17 seconds after the crew report of fire.

A momentary shorting condition could have occurred in any of the power wires in any of these harnesses without being seen in the telemetered data and without affecting the measurement circuits.

Indications of copper have been found on the bottom of the lithium hydroxide access door. Indications of copper and pit marks have also been found on the stainless steel line over which one of the harnesses lay. The stainless steel line has been examined in the Metallurgical Laboratory at KSC and it has been determined that there are no pit marks indicative of arcing. Two modes of copper deposits were evident. One was apparently caused by molten copper dropping onto a heated line resulting in alloying and diffusion between the copper and stainless steel elements. The other was due to dropping of molten copper onto a relatively cool stainless steel line indicated by molecular diffusion at the bead-tube interface.

It has been determined that the harness containing DC bus B power wires protected by fuses was probably not the fire initiator, as current flow is very limited prior to the fuses blowing. The other three harnesses, each containing both DC bus A and DC bus B power wires, remain as probable causes of ignition.

9. Technical Discussion of Other Suspicious Wiring

A physical examination of wiring and equipment for arcs, shorted and suspicious wiring has disclosed ten specific items, as mentioned in section C-2 of this report. The first was covered in the preceding section as the probable cause of ignition. The remaining nine are not considered probable ignition sources, and each one is discussed in this section.

a. Arc Between a DC Wire and the Cover of J-Box C15-1A52

An arced point was discovered between a wire in a bundle and a metal cover at the lower left corner of the lower equipment bay just to the left inverter 3. The installed cover is illustrated in Enclosure 18-29. The back side of the cover showing the arced point on the cover and the wire is illustrated in Enclosure 18-30.

It was determined that the arc occurred between a wire in the Reaction Control System/Stabilization Control System (RCS/SCS) and the cover protecting the C15-1A52 J-Box. The wiring was traced to a circuit from DC bus A, a 16 gauge wire, protected by a 20 amp circuit breaker. The wire supplied 28 volt DC power to the RCS plus-yaw engine solenoids. The circuit breaker was not opened by the short circuit.

Enclosures 18-31 and 18-32 illustrate the arced point on the cover and the wire magnified many times.

An arc was produced in this bundle when a technician was removing J-Box C15-1A52 on January 17, 1967, and the wire was repaired. The wire which arced against the cover at the time of the accident is a different wire in the same bundle. The wire harness installation had obscured access to two cover plate mounting bracket screws. This was corrected on January 19, 1967, by separating the harness into two bundles for a short distance. With this slight relocation, one of the bundles was adjacent to a portion of the cover not protected by a nylon grommet edging. This is also illustrated by Enclosure 18-30.

An additional interesting point for this cause possibility is that the gas chromatograph wiring harness and the bus B 28 volt DC power harness for the biomed recorder, which might be associated with pre-accident data variations, are attached to the harness that contained the arced wire.

Supporting factors for this ignition cause possibility include the definite evidence of an arc, previous water/glycol spillage in the general area three months before, the flammability of the adhesive for the nylon grommet edging, and the proximity of debris trap netting.

Negative factors include the preventative washing and drying of the wire bundles in the area after the water/glycol spillage and the lack of any telemetry transient indication on that function prior to the crew report of fire. A measurement sampled 200 times per second, which would show a drop below approximately 10 volts, shows no change until shortly after the pressure shell rupture, at which time some evidence of a short is indicated.

Preliminary tests have been conducted on the flammability characteristics of water/glycol and the water/glycol inhibitor at Kennedy Space Center (KSC), Manned Spacecraft Center (MSC), and Raychem Corporation, Redwood City, California. These tests support the possibility of a fire propagation path along wiring that has been exposed to water/glycol spillage or leakage.

A test was conducted at MSC on a simulated cover plate with adjacent flammable materials configured as in S/C 012 with the same oxygen/pressure environment. When the adhesive/nylon grommet edging was ignited with a nichrome wire at the arced point, there was a fire propagation along the adhesive/nylon grommet edging spreading above to the Velcro on the flight qual recorder and to the left to the debris netting in the lower left-hand equipment bay corner.

A test was conducted on a duplicate cover plate at KSC to determine if an electrical arc would ignite the adhesive/nylon grommet edging in the oxygen/pressure environment as existed in S/C 012 at the time of the accident. During this test, ignition from an arc did occur, the fire progressed faster along the adhesive than along the nylon edging, and a section of debris netting on the opposite end of the nylon edging ignited in approximately 9 seconds.

In all tests of flammability of adhesive/nylon grommet edging combinations conducted to date, there was a complete burning of the nylon grommet edging material to the point where it was indistinguishable after the fire. A review of Enclosure 18-30 shows clearly that all of the nylon material in S/C 012 did not burn, but that a decomposition took place. A test applying external flame to the front face of the panel more closely duplicates the melting characteristic of the nylon edging as illustrated in the same photograph. This test indicates that if this arc was the ignition source, then the fire propagation path would not be along the adhesive/nylon grommet edging; the fire propagation path would thus be inferred to be along wiring that had previously been exposed to water/glycol.

A hardness analysis conducted on the aluminum cover disclosed that the left edge was exposed to much higher temperatures than the right edge. The cover was fabricated from 2024-T6 aluminum alloy. The extreme left edge was in a T3 aged condition, while the right edge was in the original T6 condition. The left edge was, therefore, subjected to a temperature in the range of 800 to 885 degrees Fahrenheit. A physical examination also disclosed that the fire progressed from the left side to the right side of the panel cover.

The Velcro on the "flight-qual" recorder panel does not appear to have sufficient fire damage to indicate that the fire was initiated at this point. A hardness and conductivity analysis was performed on this panel. The analysis disclosed that all areas of the panel were exposed to the same level of external heating.

A simulated flight-qual recorder panel used during a special fire propagation test conducted at MSC was sent to KSC for comparison with the S/C 012 panel. It was determined that this panel was of a lighter guage, and that the Velcro was applied with a different adhesive. The MSC results are therefore considered inconclusive.

Special tests were conducted at KSC in an oxygen/pressure environment to determine the current required to produce a similar arc on a wire and cover as that evident from S/C 012 hardware. A test conducted on March 28, 1967, disclosed that the nylon edging/adhesive combination was ignited when an arc was produced approximately 1-1/2 inches away.

It is highly probable that the nylon edging/adhesive combination would be totally burned away if this arc was the initiator of the fire.

b. Shorted Gas Chromatograph AC Wiring

The gas chromatograph was not installed on S/C 012 at the time of the accident. The gas chromatograph connector was placed on the shelf of the gas chromatograph (GC) compartment. The connector was not bagged, and AC bus 1 phase A power was applied to the connector through a closed circuit breaker. Twenty-two gauge wire was used, protected by a 2 amp circuit breaker. The circuit breaker for the GC was found to be open following the accident, with a heavily sooted condition. It cannot be determined when the circuit breaker opened. The harness was not tied down in a flight configuration because the GC was not installed.

Two physical peculiarities were noted concerning the GC wiring and the connector. After the accident, the harness and connector were found on the floor. This is illustrated by Enclosure 18-33. It should be noted that the GC connector lay on a big harness. Enclosure 18-35 shows two spot ties that were unblackened as a result of being protected by the GC connector. Enclosure 18-35 shows the side of the connector that lay against the big harness and protected the two spot ties. This side appears burned and the potting at the back of the connector is melted. The GC connector was stuck to the big harness and had to be pried loose with a tool. It is concluded that the connector was burning in a different location, but fell or otherwise moved to its final location prior to the time the fire swept across that portion of the floor. It can also be concluded that the connector either protruded beyond the GC compartment shelf and was burned in that location, or that it was burned while it lay inside the gas chromatograph compartment before it fell to the floor.

Secondly, the two GC AC wires exhibited peculiar melting characteristics. The output signal leads from the connector were fed through a fiberglass sleeve. One hundred fifteen volt AC power was carried to the connector through a twisted pair of Teflon-insulated conductors. These power conducting wires were run along the signal leads and were occassionally tied together. The power wires show a number of copper balls attached to their surfaces. This condition is illustrated in Enclosures 18-36 and 18-37.

All attempts to simulate this condition by either short circuits or by application of external heat have not resulted in a similar appearance of the AC wires. It is concluded that the beading was caused by localized external heating, with Teflon insulation degradation followed by shorting of the wires, causing molten copper to flow through defects in the wire nickel plating. It has been estimated that the external heat to produce this condition was in the order of 2500°F for less than one second. It is inferred that this condition resulted as the harness fell through the flame to the floor.

X-rays and continuity tests of the connector pins and input wiring showed no evidence of arcs or short circuits. For this reason, this is not a suspect fire initiator.

c. <u>Shorted DC Wires to Scientific Equipment Bay 2</u>

Wires providing DC bus B power to scientific equipment were found to be shorted. These are 22 gauge wires protected by a 20 amp circuit breaker. The circuit breaker was found to be open following the accident and to be in a heavily sooted condition. The scientific equipment was not installed, therefore, no information is available as to when the circuit breaker was opened.

The wires that are shorted are located at the edge of a compartment shelf directly over the entry batteries. The location of the wires is illustrated in Enclosure 18-38.

The pattern of battery swelling and the scorching of the batteries indicates that they were exposed to a source of considerable heat centered at the face of Battery B, and that very high heat flow occurred in front of and in the spaces between the three batteries.

Tape was applied to protect the battery terminals during this test. The spots of scorched residue on the batteries was determined to be similar in all respects to the tape. The burning of this tape could have burned the wiring insulation off, and thereby caused the shorted condition.

Enclosure 18-39 illustrates the shorted wires projecting beyond the shelf. It is concluded that these wires shorted as a result of the fire from the floor (the same heat source that affected the batteries). Tests in the Metallurgical Laboratory at KSC have substantiated that the shorting was the result of external heat.

d. <u>Cabin Air Fan 1 AC Wiring Shorted</u>

The cabin air fan 1 circuit breakers for phases A and C were found to be open after the fire, and electrical tests of the fan circuitry in the spacecraft indicated shorted phases. Cabin air fan 2 was in a satisfactory condition. Cabin air fan 1 is powered by AC bus 1 and fan 2 by AC bus 2. Twenty-two gauge wires are used and each phase is protected by a 2 amp circuit breaker. The circuit breaker for AC bus 1 phase A was found with a very light-sooted condition, and the AC bus 1 phase C circuit breaker was found with a sooted condition.

Enclosure 18-40 shows the location of the cabin fans. They are located on the Command Pilot side of the Command Module. It is not known whether the short circuit occurred before or after initiation of the fire. However, because there is a lack of fire propagation material, it is inferred that the shorting occurred as a result of the fire. A physical inspection of the fan and the fan area for fire damage does not indicate this to be a fire initiation area. Enclosure 18-41 shows the conditions of the fans following the accident.

An inspection of the fans after removal from the S/C shows that both rotors were frozen as a result of melting of epoxy on the stators. No shorted condition has been found in fan 1. The electrical harness was examined and insulation was found burned off in one area. The electrical harness is being checked to verify that the damage was an effect and not a cause of the fire.

e. <u>Crushed DC Instrumentation Harness in Environmental Control Unit</u>

A wire harness for the Compressor Differential Pressure and Glycol Accumulator Quantity instrumentation transducers has been found in a crushed condition. This is an Environmental Control Unit harness that was crushed between a lithium hydroxide canister and the cyclic accumulator control during the assembly process. The harness contained ten 24 gauge wires, and contained both DC bus A and DC bus B power.

The circuit breakers for these circuits were found closed following the accident. The sleeving is intact and does not indicate any ruptures. For these reasons the harness is not considered an initiating source of the fire.

f. Shorted DC Wires Providing Power to the Biomed Recorder

Short circuits have been found on the octopus cable near connector J185. This connector is located directly above the gas chromatograph compartments, and is illustrated in Enclosure 18-42. This wiring has been identified as 28 volts DC bus B power for the biomed Medical Data Acquisition System (MDAS) recorder. Twenty-two gauge wires were used, protected by a 20 amp circuit breaker. The circuit breaker was found to be open following the accident, with a heavily sooted condition. The MDAS recorder provided satisfactory data until after pressure shell rupture, therefore, the circuit breaker opened after this time. The octopus cable was not in a flight configuration as the connectors were not potted.

Enclosures 18-43 shows a closeup of the connector, and Enclosure 18-44 illustrates the shorted condition of the DC wires.

Enclosure 18-45 illustrates the layout of the power wiring to the J185 connector. This wiring runs down a channel alongside the right edge of the chromatograph compartment, then along the edge of the floor of the chromatograph compartment, then down to the floor along the left edge of inverter 3. At the floor, it is tied to the same harness that shows the presence of an arc with the cover of J-Box C15-1A52. This power wiring to the J185 connector is also adjacent to the gas chromatograph harness at all locations from the arced point to the channel entry point. This harness and the gas chromatograph harness were tied together but were not tied down in a flight condition; they were laid up against the gas chromatograph compartment. Both harnesses were found on the floor after the accident.

In addition to the shorted condition on the octopus cable between the J185 connector and MDAS recorder, the DC wires are also shorted at a point near the left end of the gas chromatograph compartment floor. The shorted condition at this location does have a bubbled copper appearance, similar to that noted on the gas chromatograph AC wires.

Preliminary examination of both sets of harnesses have been made in the Metallurgical Laboratory at KSC. The shorting on the octopus cable was found to be superficial and the result of fire damage. The DC power harness to the J185 connector, because of the similar appearance to the gas chromatograph wires, was also the result of fire damage; it is concluded that the harness was subjected to both a short and to external heating from the fire.

g. Shorted AC Wires Providing Power for Suit Compressor 2

Wiring in the four conductor wire harness to suit compressor 2 appeared shorted, with suspected evidence of arcing.

AC power to each of two suit compressors is provided by 24 gauge wires. Each phase for each suit compressor is protected by a 2 amp circuit breaker. The harness for each compressor can provide either AC bus 1 or AC bus 2 power, dependent on the switch position selected by the Pilot.

The switch position following the accident shows that the suit compressor switch was in the compressor 1, AC bus 1 position. The circuit breakers for phases A and B for compressor 1 were found open with heavy soot on the breaker stems. Telemetry data indicates that a compressor was operating until loss of data; therefore the circuit breakers opened after this time.

Enclosure 18-46 illustrates the location of the wiring and suit compressors in the Environmental Control Unit on Spacecraft 012 after the accident.

Suit compressor 2 was not to be operated during the test. A re-examination of the harness disclosed that the connectors for compressors 1 and 2 were reversed from the expected interconnect. With the connectors being reversed, compressor 2 would then have power and the wires could short, and the compressor 1 circuit breakers would open when the shorting would occur. Enclosure 18-47 illustrates the harness for compressors 1 and 2. The connector for compressor 1 was disconnected, and the wires were cut at the connector for compressor 2. Note the metal band with the number "2" for the wires providing power for compressor 1.

A closer examination of the wires disclosed that the shorted appearance was the result of fire damage.

h. <u>Command Pilot Suit Wiring Shorted</u>

Short circuit damage has been found in the Command Pilot's suit wiring. No shorts were noted either in the Senior Pilot or Pilot suit wiring.

Four shorted wires were found in the communications wiring between the suit connector and the helmet communications connector. The wire insulation was discovered to be brittle, discolored and cracked. The wires were identified as microphone signal, microphone signal return, earphone signal and earphone return. Enclosures 18-48 and 18-49 illustrate the shorted condition of the wires.

An intermittent condition was also noted in the 16.8 volt DC biomed power wire in the torso harness between the suit connector and the biomed connector. This condition is considered to be not relevant to the cause of the accident, in that no biomed power was being supplied to the Command Pilot's suit.

The vendors of the torso harness materials have provided the following information:

(1) The nylon sock around the ribbon cable melts at 480 degrees Fahrenheit.

(2) The silicone, of which the ribbon is made, melts at 600 degrees Fahrenheit.

(3) The Milene insulation around the wires cracks at 430 degrees Fahrenheit and melts at 480 degrees Fahrenheit.

From the above information, it is probable that the exterior of the ribbon cable around the area of the damaged wiring was subjected to localized and superficial heat. This would cause damage to the internal wiring insulation without damaging the silicone ribbon.

i. <u>Arc on Structure by Side of Switch S11 in Back of Panel 8</u>

On removal of panel 8 from S/C 012 it was observed that there was an area of damaged conformal coating on wire terminal 2 of switch S11. Continuity checks showed that a potential short existed from the wiring through the damaged conformal coating to the substructure behind the panel. Supplemental examination of the substructure was made to determine the extent of any arcing from panel 8 switch S11 to the substructure. Minute arc pits were found in the substructure which indicate that low power arcing did occur, and could more properly be described as sparking. The lack of silicone dioxide deposits indicates that the temperature generated by the arcing was not high enough to cause significant deterioration of the silicone rubber conformal coating material.

The panel and switch location and substructure appearance is illustrated in Enclosures 18-50 and 18-51. Switch S11 serves as an enable function for Service Module Quads A and C Roll. The wire terminal in the area of damaged conformal coating carried DC bus B power. An analysis of circuit conditions disclosed that this circuit was not powered before or during the fire. It was determined that the switch was in the "OFF" position before and after the fire. Continuity checks have been performed to confirm that the switch was wired properly. Refer to Enclosure 18-41 for a schematic description of switch wiring.

Examination of the wire terminal and pit on the bracket are inconclusive as to existence of an arc and indicate that the observed damage most likely occurred from a mechanical abrasion while the panel was being installed. From the appearance of the area surrounding the pit on the bracket, and the contact area on the wire terminal, it is deduced that any possible sparking generated by the short circuit current was confined under the conformal coating.

From the above it is concluded that, while an arc or short circuit current may have occurred in the contact area of S11 wire terminal and bracket V16-335126-85, this circuit was not energized during this test, and this condition must have resulted from a prior test. Further the evidence indicates that the potential current level through any such fault would have been so low that it would not have caused any significant disturbance on the power bus.

10. Technical Summary

For the last few minutes of the test all recorded test data indicated that all systems were operating satisfactorily with no indication of any malfunctions, with one expection - the communication system. Communications were poor between the ground and the Spacecraft and a live microphone condition was present in the Command Pilot voice loop.

The cause of the live microphone has been atributed to picking up a ground somewhere in the Command Pilot Push-to-Talk circuit in the Spacecraft. The specific source of the ground has not been established. This malfunction, electrical in nature, is not considered to be a fire initiation source.

The overall inputs and outputs of Spacecraft systems were measured and recorded. There is no reason to believe that possible malfunction or abnormality would have been indicated had more detailed measurements been obtained from each system.

For approximately the last thirty seconds prior to the crew report of fire many measurements reflect crew motion in the Spacecraft. There is no way in which crew activity can be derived from these measurements.

An electrical power system abnormality was indicated at approximately ten seconds prior to the crew report of fire. This electrical abnormality occurred in the AC bus 2 power portion of the system. All AC bus 2 voltage measurements were affected. The data from equipment powered by AC bus 2 shows that they were also affected. The composite of these data and special tests conducted after the accident point to the conclusion that the AC bus 2 problem was caused by a momentary loss of inverter 2 output.

The momentary loss of inverter 2 output should not be implied to constitute an inverter failure. The inverter was returned to the supplier for teardown and analysis to positively establish whether it could or could not have malfunctioned in a manner reflected by the data. This has been completed and it has been concluded that the inverter did not cause the AC bus 2 dropout, and that it was not the cause of the fire.

It is believed that the momentary loss of output to inverter 2 was caused by an interruption in the DC power being supplied to inverter 2. This DC power was being supplied from DC main bus B. The most likely cause of an interruption in DC bus B power is a momentary short in a conductor carrying this power or by a malfunction of equipment being supplied from this power source.

The most likely phenomena that would produce such a momentary short is an inadvertant electric arc either within electrical equipment or between a power conductor and the Command Module structure. Such an arc is nominally the result of electrical insulation failure.

No data recorded during the interval of the electrical abnormality shows any variance that could be interpreted as a momentary short in DC bus B power, or DC bus A power. Tests show that a drop in DC voltage to a level below 19 volts for as short a time as two milliseconds is sufficient to affect the inverter and the AC bus. Because all telemetry date is sampled at discrete intervals, a short of two milliseconds duration probably would not appear in the data.

All equipment and wiring has been examined for any and all evidence of arcs, shorts and suspicious appearance, to help explain the electrical abnormality. All items of equipment, except for specific wiring, have been placed into an improbable ignition source category.

Ten cases of arced, shorted and/or suspicious looking wiring have been identified. Tests and analyses are being conducted on a number of these at this time. From this listing, however, only one is considered suspect as being the cause of the electrical abnormality. It can also be the trigger or source of ignition that caused the accident.

The one suspect is wiring providing instrumentation power for some Environmental Control System instrumentation. This wiring contains both DC bus A and DC bus B power, and is located on the Command Pilot side of the Command Module in the vicinity of the Environmental Control Unit and the Lithium Hydroxide Units.

A momentary short could occur in any of four DC bus B or four DC bus A power wires in this wiring. A short would not affect the equipment being powered by these wires, and would not be reflected in any of seven measurement outputs of transducers being provided power because of redundant power with diode isolation for each equipment.

Tests have shown that a short in any of the four DC bus B wires could cause a drop in DC bus B voltage to a level low enough to cause an interruption to inverter 2. A test has been conducted at Launch Complex 34, with an inverter, to simulate this shorting.

Debris netting traversing the floor on the left side of the C/M was within inches of the wire harnesses. If ignited, the netting would burn along the floor toward a vertical flammable material. The vertical material on the left was the polyurethane foam on the Environmental Control Unit evaporator, approximately 7 inches away from the wires. The vertical material on the right, was the debris netting in the corner of the S/C by the water panel, approximately 13 inches away from the wires. The average burning rate of debris netting in a 14.5 psi oxygen environment in a horizontal direction has been determined to be 2 inches per second.

Assuming that this burning rate is valid, it can be postulated that the polyurethane foam on the evaporator would ignite at about 4 seconds and the vertical debris netting in the corner at about 8 seconds after the initial netting ignition. The front cover of the ECU was not installed and the netting on the floor was a couple of inches away from the polyurethane foam on the evaporator. Because of this, it is inferred that the vertical netting in the corner would be the first instance of vertical burning. Vertical burning would occur at about 23:31:03 GMT. Allowing one second for the flames to reach the couch level, the first voice transmission of trouble from the Command Pilot at 23:31:04.7 GMT occurs at the proper time. Unfortunately, there is no physical evidence to support a conclusive determination. This wiring was located in the area where burning was at the highest intensity. Sections of these wires, six to twelve inches long, in the suspect location have been completely burned away.

D. FINDINGS AND DETERMINATIONS

1. Findings:

Several arcing indications were observed in the Command Module -Y +Z sector and a voltage transient was noted in all three phases of AC bus 2. This transient was most closely simulated by a power interruption or short circuit on DC bus B.

Physical evidence and witness statements indicated the progress of the fire to be from the left side of the Spacecraft.

Simulations and tests indicate that combustion initiation due to electrostatic discharge or chemical action is not probable.

No physical evidence of pre-fire overheating of mechanical components or heating devices was found.

Determinations:

No single ignition source could be conclusively identified.

The most probable initiator is considered to be electrical arcing or shorting in the sector between the -Y and +Z Spacecraft axis.

The location best fitting the total available information is that where ECS instrumentation power wiring runs into the area between the ECU and the oxygen panel.

2. Finding:

All Spacecraft records have been reviewed by the various Panels and the results were screened by Panel 18.

Determination:

No evidence has been found to correlate previously known discrepancies, malfunctions, qualification failures or open work items with the source of ignition.

3. Finding:

At the time of the observed fire, data including telemetry and voice communications indicate no malfunctioning Spacecraft systems (other than the live microphone).

Determination:

Existing Spacecraft instrumentation was insufficient by itself to provide data which would identify the source of ignition.

E. SUPPORTING DATA

List of Enclosures

Enclosure	Description
18-1	Sample of Disassembly and Post-Disassembly Requirements Form
18-2	Sample of Test Preparation Sheet
18-3	Sample of Board Action Summary Page
18-4	Listing of Open Circuit Breakers
18-5	VHF/AM and S-Band Voice Recordings
18-6	Transcript of Voice Channel for Last 27 Seconds
18-7	Gas Chromatograph Trace
18-8	AC Bus 2 Data and Associated Changes
18-9	Oxygen Flow Rate and Associated Data
18-10	Oxygen Flow Rate Correlation
18-11	Not used
18-12	ECS Data Correlation
18-13	Surge Tank Pressure Profile
18-14	Motion Indications
18-15	Navigation Base Installation
18-16	Spacecraft and IMU Stable Member Axes
18-17	Navigation Base Installation Detail
18-18	Navigation Base Pitch Angle Change Versus Cabin Pressure

Enclosure	Description
18-19	Selected Temperature, Pressure, and Inertial System Measurements Versus Time
18-20	Suit O_2 Flow Rates
18-21	Gas Chromatograph Trace Comparison
18-22	Electrical Power System
18-23	AC Bus 2 Special Tests
18-24	Audio Key Lines
18-25	Environmental Control System Instrumentation Harnesses Before Accident
18-26	Environmental Control System Instrumentation Harness Wiring Identification
18-27	Spacecraft 014 Environmental Control System Instrumentation Harnesses
18-28	Environmental Control System Instrumentation Harnesses After Accident
18-29	Cover of J-Box C15-1A52
18-30	Arced Point on Wire and Cover of J-Box C15-1A52
18-31	Arc Point on Cover of J-Box C15-1A52
18-32	Arc Point on Wire Related to Cover of J-Box C15-1A52
18-33	Undisturbed Location of Gas Chromatograph Connector
18-34	Area Under Gas Chromatograph Connector
18-35	Side of Gas Chromatograph Connector Which Protected Spot Ties on Harness on Floor

Enclosure	Description
18-36	Copper Droplets on Gas Chromatograph Wires
18-37	Copper Flow and Nickel Pipe Effect on Gas Chromatograph AC Wires
18-38	Shorted DC Wires Above Entry Batteries
18-39	Detail of Shorted Wires Above Batteries
18-40	Location of Cabin Fans
18-41	Main Display Console Panel Number 8 Switch S-11 Wiring
18-42	Location of Octopus Cable J185 Connector
18-43	Detail of J185 Connector
18-44	Shorting on Octopus Cable
18-45	Power Harness to J185 Connector
18-46	Suit Compressor Wiring After Accident
18-47	Not Used
18-48	Command Pilot's Suit Wiring
18-49	Detail of Command Pilot's Communication Harness
18-50	Location of Switch S11 on Panel 8
18-51	Short to Structure by Terminal of Switch S11
18-52	Complete "Status of Investigation Items" dated April 1, 1967
18-53	"Integration Analysis Summary" for each investigation item as available on April 1, 1967
18-54a	"Review of Spacecraft Power Status", dated February 6, 1967, prepared by Panel 18

Enclosure	Description
18-54b	"Supplement to Review of Spacecraft Power Status", dated February 23, 1967, prepared by Panel 1.
18-55	Complete set of "Potential Initiation Theories Evaluation Sheets", dated March 28, 1967.
18-56	Brief Summary of Significant Special Test Results
18-57	List of References

SAMPLE OF DISASSEMBLY AND POST-DISASSEMBLY REQUIREMENTS FORM

No.0060 REMOVE COVER C15-1A52 JUNCTION BOX

DESCRIPTION of TASK 2/9	SUBSYSTEM
REMOVE MECHANICAL COVER ON C15-1A52 JUNCTION BOX INSPECT WIRING WHERE SCREWDRIVER INCIDENT OCCURRED	ELECT. PRIME REASON INSPECTION URGENCY RATIONAL MAY HAVE CONTRIBUTED TO CAUSE
CONSTRAINTS NONE	

ORIGINAL PAGE IS
OF POOR QUALITY

"INVESTIGATION"

B NON-CONFIGURATION & DOWNEY OPERATIONS

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

TPS NO. SC012-SC-002
S/C | CAT. | NO.

MOD. SHEET NO. ________

TEST PREPARATION SHEET

PAGE 1 OF 1

INITIATING ORGANIZATION: SYSTEMS ENGINEERING
V14-3 | DATE 2-10-67 | TIME 1300 | NEED DATE AS SCHEDULED

DRAWING(S), DOCUMENTS, OTP(S) & PART NO.(S): V16-880225

PARTS W/ORKING REQ. N/A | S/N:

SYSTEM: EPS

TPS SHORT TITLE: REMOVE COVER

REASON FOR WORK: TO INSPECT AREA BEHIND CLOSEOUT PANEL OVER C15-1A52

	DESCRIPTION (Print or Type)	TECH	INSP. NAA	INSP. NASA
X	VERIFY EO NO. EO LOG RECORD CLEARED			
	NOT REQ'D TO BE WORKED ON SC014			
	CONSTRAINED BY SC012-SC 049			
1.	PHOTOGRAPH C15-1A52 PNL LOWER EQP. BAY.			
2.	CAREFULLY BACKOUT 4 MTG SCREWS AND WASHERS FROM C15-1A52 HOLDING PANEL V16-441802 (Z51 V16-880225), TO PREVENT IT FROM FALLING.			
3.	PLACE PANEL AND MOUNTING HARDWARE IN PLASTIC BAG. IDENTIFY BAG AS TO CONTENTS.			
4.	SEND BAG TO P/B BOND ROOM FOR STORAGE.			

PART VERIFIED & RECORDED, IF REQUIRED

PREPARED BY: [illegible] | FINAL ACCEPTANCE DATE

Refer to local procedures for specific approvals | Refer to local procedures for specific approvals

[illegible signatures and dates] | [illegible signatures and dates] 2-10-67

ENCLOSURE 18-2: SAMPLE OF TEST PREPARATION SHEET

ENCLOSURE 18-2

BOARD ACTION SUMMARY

ACTION	DESCRIPTION	REASON	BRD APP DATE	TPS #	RESULT SUMMARY
0057 CLOSED B	Remove Pyro Batteries	Only active power source still in C/M	2/8	109	TPS complete 2/15/67. C/M batteries removed. Terminals in good condition. Slight coating of soot.
0058 CLOSED B	Disconnect SM Jettison Controller Batteries.	Remove Active power source on S/M.	2/8	087	TPS complete 2/10/67. Electrical power was removed and battery terminals insulated.
0059 CLOSED A	Inspect ECU Wiring (Non-destructive)	Routine check. Summary required for each S/C entry.	2/8	062	Inspection indicated burned and bare wires. Low level continuity checks and engineering analysis will be performed under Action #0179.
0060 CLOSED	Remove mechanical cover on C15-1A52 Junction Box	Inspect wiring where screwdriver incident occurred.	2/8	082	TPS complete 2/12/67. See Action 0037 for summary and/or analysis. Reference Investigation Item 47.

ENCLOSURE 18-3: SAMPLE OF BOARD ACTION SUMMARY

LIST OF OPEN CIRCUIT BREAKERS

PANEL 22 RIGHT-HAND CIRCUIT BREAKER PANEL

No.	Identification	Rating	Condition
CB18	Master Event Seq. Controller Arm B	5 Amp	HS
CB15	DC Sensor Signal Main A	5 Amp	HS
CB117	Scientific Equipment Bay 1 (J185)	20 Amp	HS
CB118	Scientific Equipment Bay 2 (above batteries)	20 Amp	HS
CB77	Battery Charger Batt B	10 Amp	BS
CB116	Gas Chromatograph AC1	2 Amp	HS
CB45	Telecommunications Group 5	7.5 Amp	HS
CB94	ECS H_2O Accumulator Main A	5 Amp	NS
CB76	Cabin Air Fan 1 AC1 Phase A	2 Amp	VLS
CB74	Cabin Air Fan 1 AC1 Phase C	2 Amp	S
CB33	ECS Suit Compressor AC1 Phase A	2 Amp	HS
CB32	ECS Suit Compressor AC1 Phase B	2 Amp	HS
CB92	ECS Waste and Potable H_2O Main A	5 Amp	HS
CB91	ECS Waste and Potable H_2O Main B	5 Amp	S
CB43	ECS Transducer pressure group 2 Main A	5 Amp	B
CB34	ECS Transducer pressure group 2 Main B	5 Amp	VLS
CB11	ECS Temperature Main A	5 Amp	MS
CB10	ECS Temperature Main B	5 Amp	LS

PANEL 21 RIGHT-HAND SIDE CONSOLE BUS SWITCHING PANEL

CB8	Sensor Unit AC Bus 2	5 Amp	NS

PANEL 25 LEFT-HAND CIRCUIT BREAKER PANEL

CB33	SCS B and D Roll Main B	20 Amp	VLS
CB39	SCS Pitch Main B	20 Amp	NS
CB31	SCS Yaw Main B	20 Amp	MS
CB26	Gimbal Motor Control 1 Pitch Battery A	15 Amp	HS
	Gimbal Motor Control 1 Yaw Battery A	15 Amp	HS
CB16	RCS Propellant Isolate Main A	15 Amp	LS
CB15	RCS Propellant Isolate Main B	15 Amp	MS
CB52	EDS 1 Battery A	5 Amp	MS
CB53	EDS 3 Battery B	5 Amp	MS

PANEL 203

CB3	Inverter Power No. 2 Main B	70 Amp	NS

PANEL 150

CB14	Pyro A Seq. A	20 Amp	NS
CB17	Pyro B Seq. B	20 Amp	S
CB20	Battery Charger Battery C	5 Amp	NS

PANEL 204 INSTRUMENTATION POWER CONTROL

CB3	Essential Instrumentation	7 Amp	

Condition Code:

B - BURNED

S - SOOTY

NS - NO SOOT

MS - MEDIUM SOOT

HS - HEAVY SOOT

LS - LIGHT SOOT

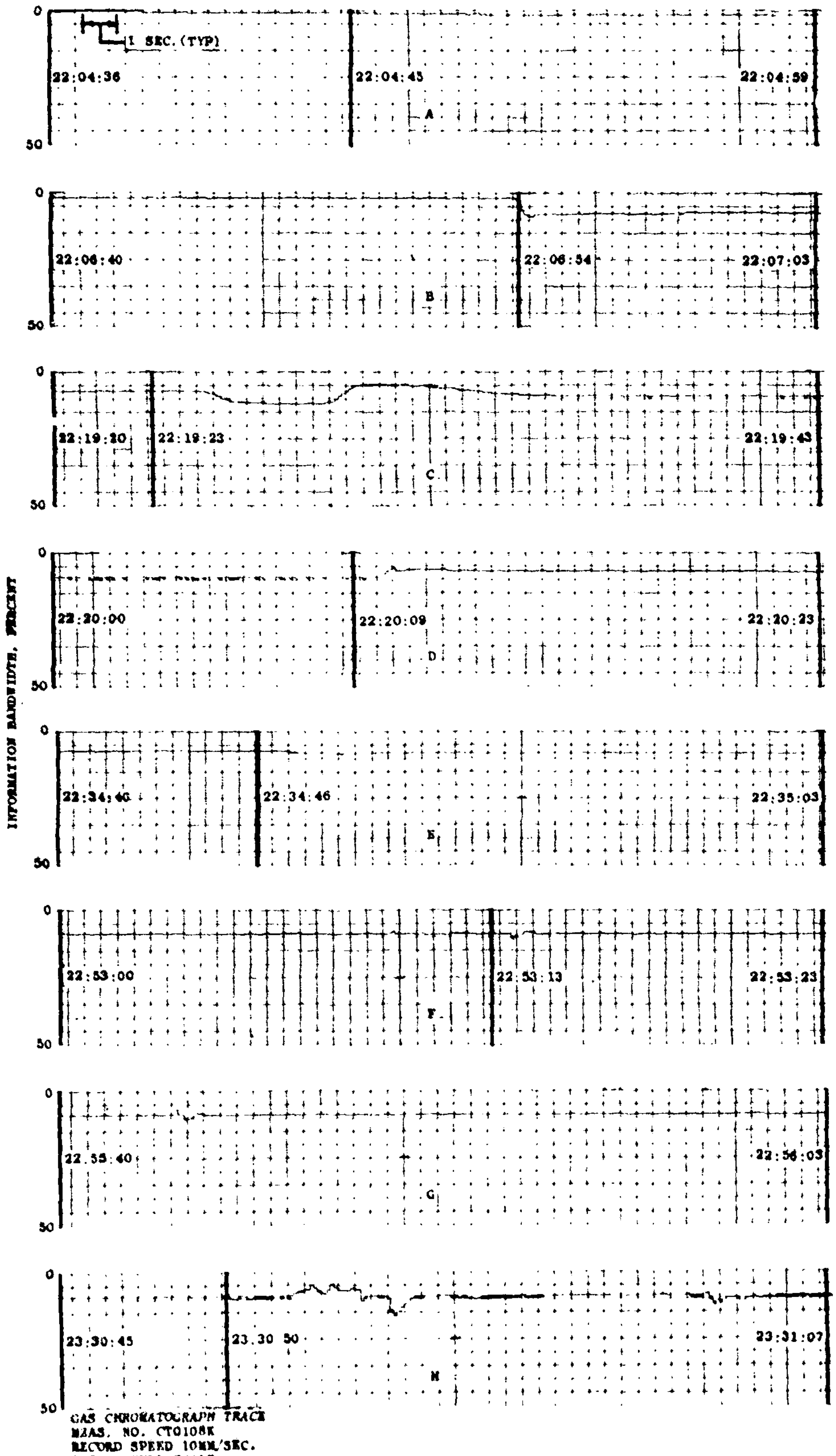
BS - BURNED SOOT

VLS- VERY LIGHT SOOT

TRANSCRIPT OF VOICE CHANNEL FOR LAST 27 SECONDS

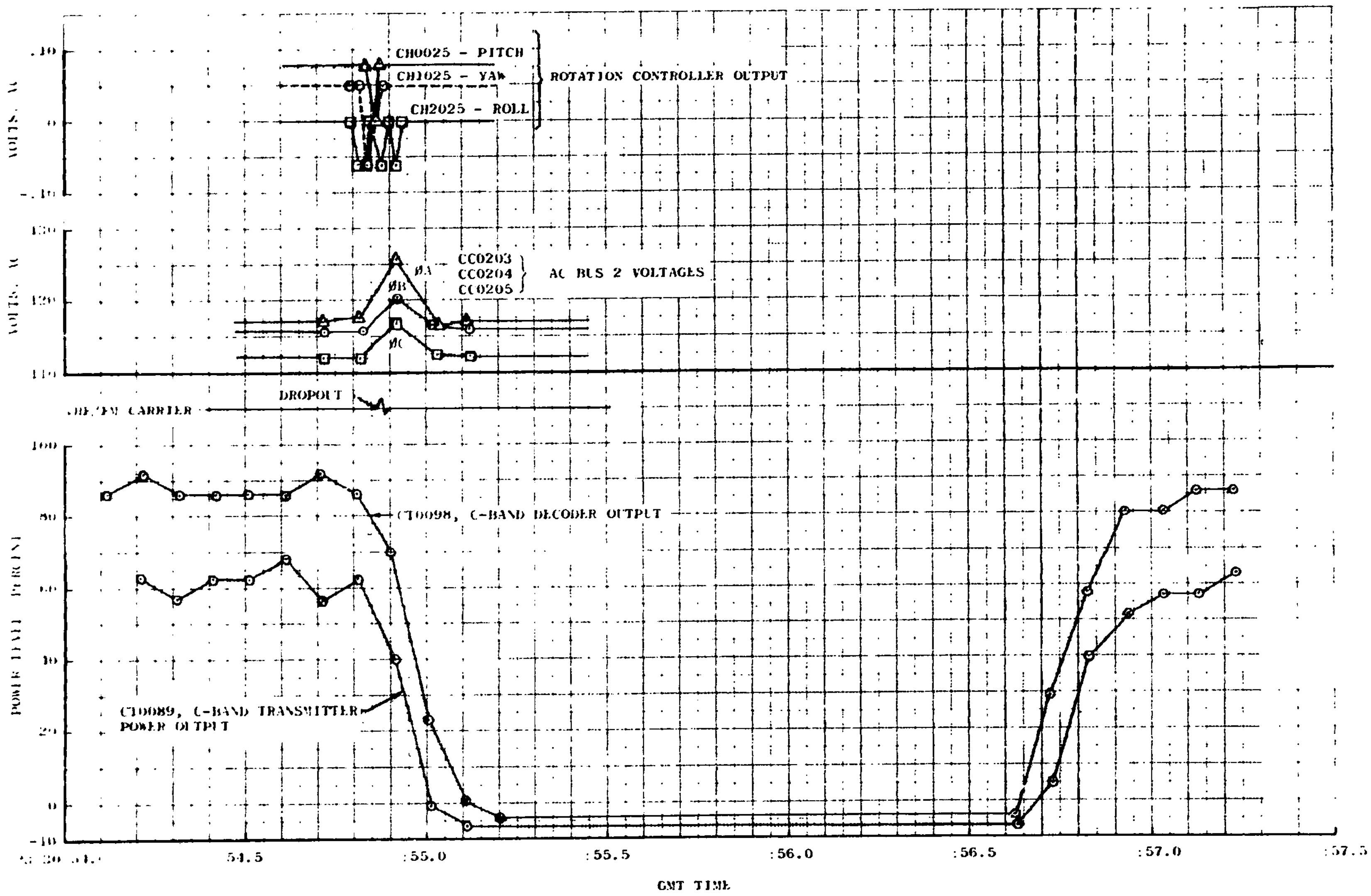
MOLC VHF/AM TRACK TRANSCRIPT		MOLC S-BAND TRANSCRIPT	
		23:30:55.5	(Noise)
		23:30:56	(Breathing sound)
		23:30:56.5	(Noise)
		23:30:58.1	(Noise)
23:30:58.5	(Short noise 0.6 sec.)		
		23:31:04	(Breathing sound)
23:31:10.0	(First voice transmission)	23:31:04.7	(First voice transmission of Spacecraft problem)
23:31:10.0	(End of first transmission)	23:31:10.0	(End of transmission)
		23:31:16.8	(Second voice transmission of Spacecraft problem)
23:31:17.1	(Second voice transmission)		
23:31:21.8	(End of second transmission)	23:31:21.8	(End of second transmission)
|		23:31:22.4	(LOS)

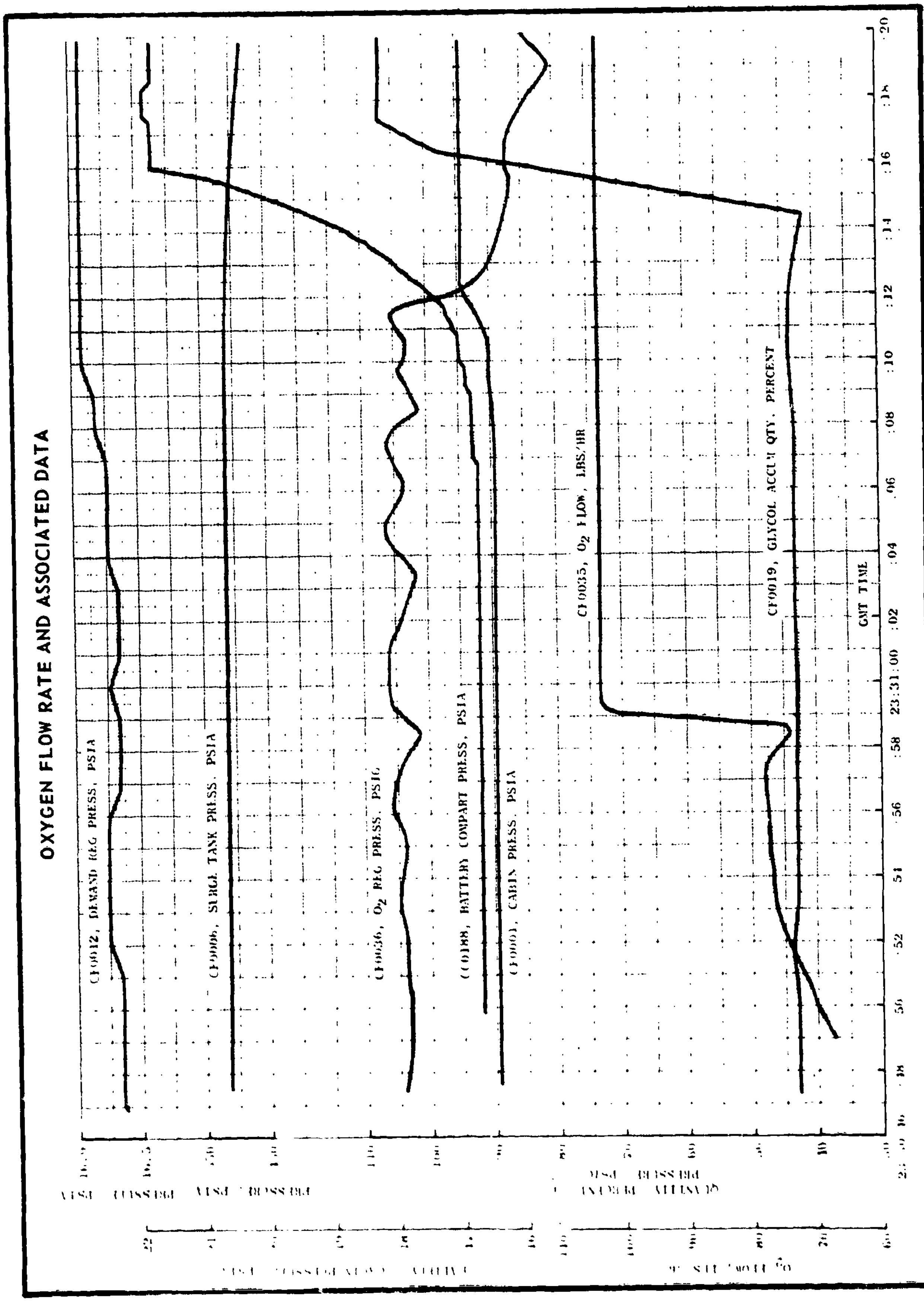
GAS CHROMATOGRAPH TRACE



ENCLOSURE 18-7

AC BUS 2 DATA AND ASSOCIATED CHANGES





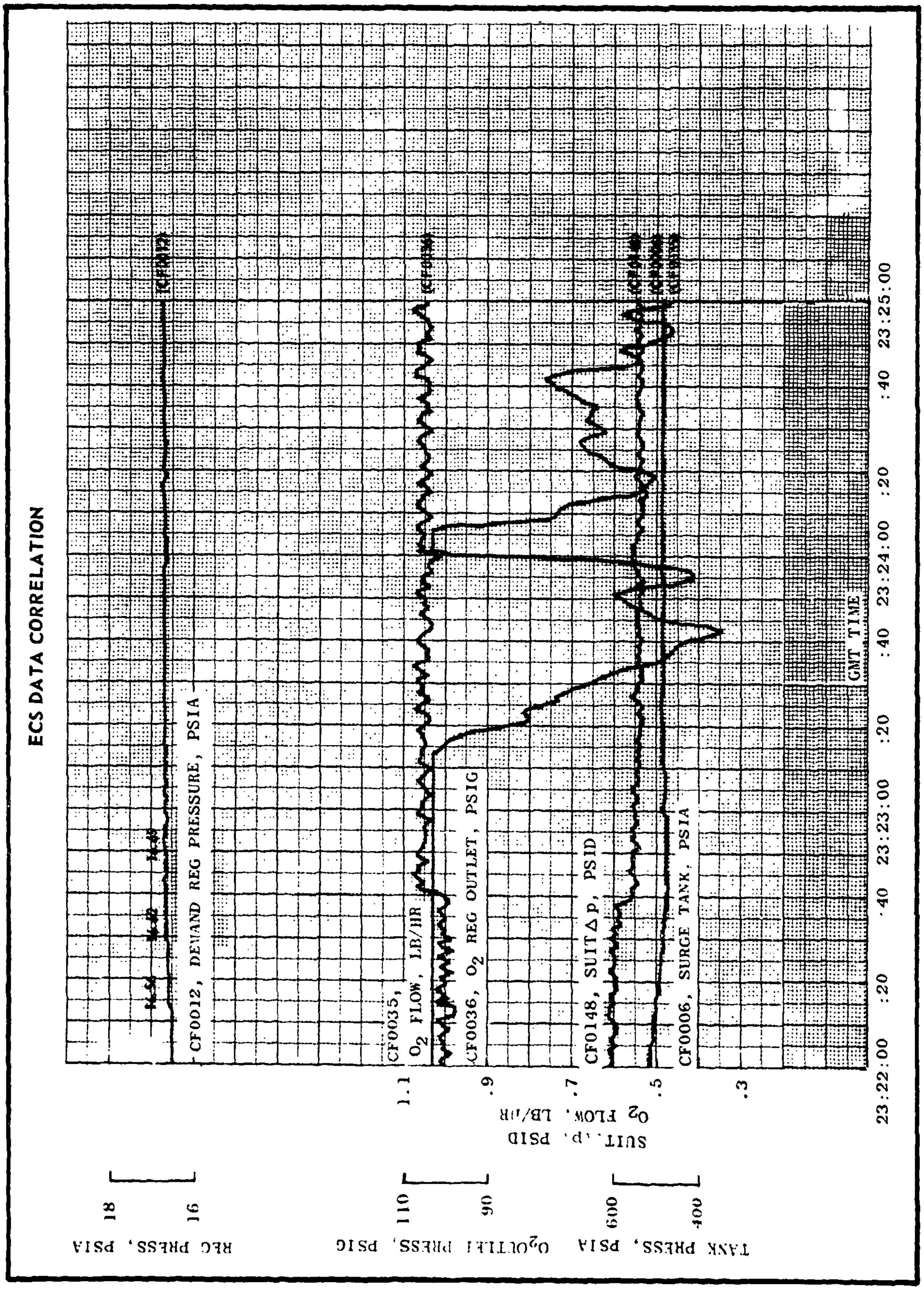
ENCLOSURE 18-9

OXYGEN FLOW RATE CORRELATION

(Correlation of relevant data for unexplained periods when oxygen flow rate (CF0035R) indicates maximum value of 1.033 lb./hr.)

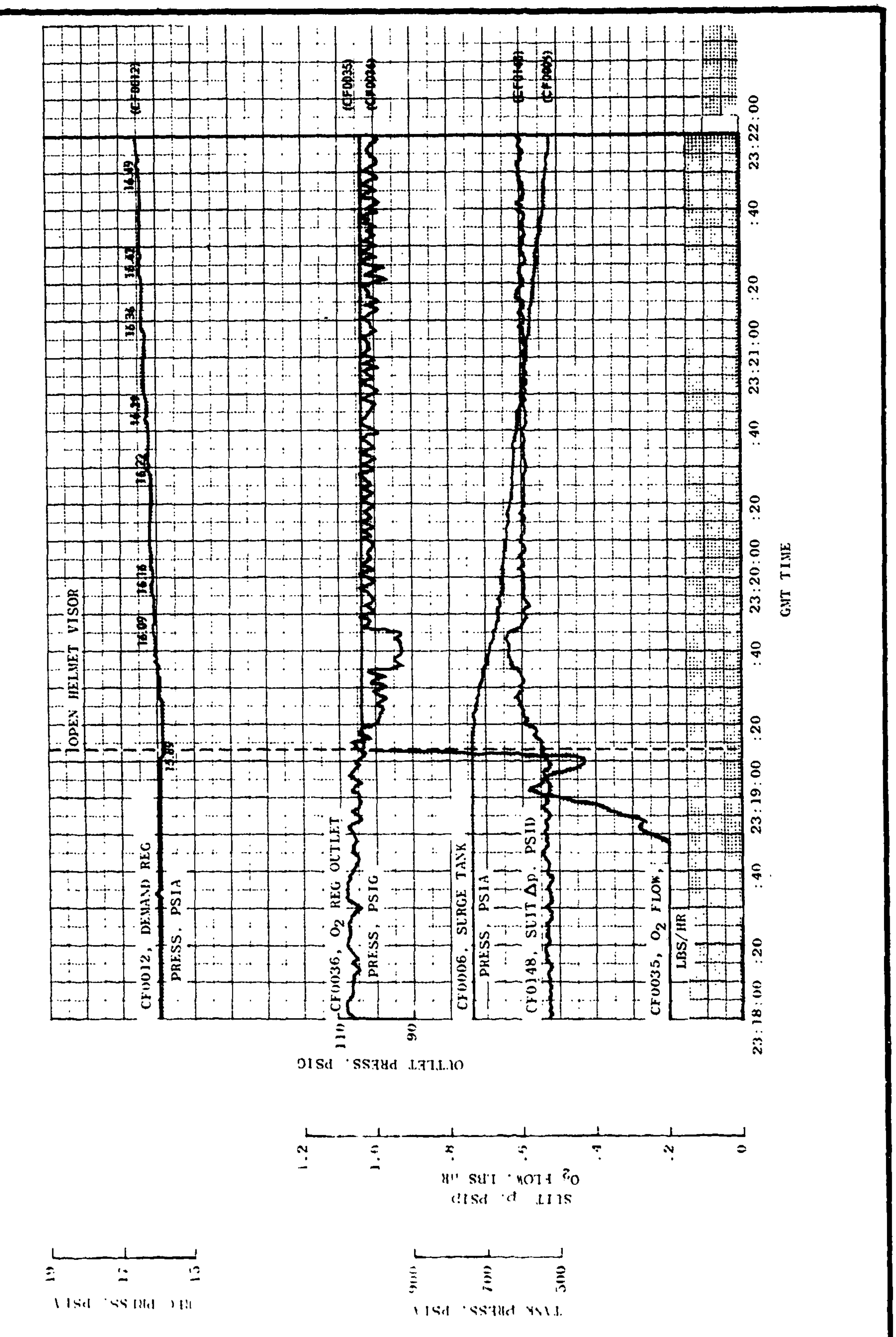
TIME (start/end)	DURATION (min:sec)	C&W INDICATION (on/off)	SURGE TANK PRESSURE CHANGES (psia-start/end)	AVERAGE FLOW (lb./hr.)	MAX RATE OF FLOW INCREASE (lb./hr./sec.)	SUIT PRESSURE CHANGES
1. 20:20:30 20:20:41	00:10	None	None	≥1.033	0.09	Yes
2. 21:27:43 21:27:51	00:08	None	None	≥1.033	0.12	Yes
3. 21:28:34 21:28:40	00:06	None	None	≥1.033	0.14	Yes
4. 21:45:54 21:46:29	00:35	21:46: 21:46:26	None	≥1.033	0.11	No
5. •22:46:07 22:46:24	00:17	22:46:22/ 21:46:24	None	≥1.033	0.24	Yes
6. •22:52:07 22:53:18	01:11	22:52:22/ 22:52:48	734.7/730.5	3.80	0.09	Yes
7. •22:53:47 22:54:16	00:29	22:54:01/ 22:54:05	None	≥1.033	0.06	Yes
8. •22:54:24/	00:16	None	None	≥1.033	0.03	Yes
9. ••23:19:13 23:23:14	04:01	23:19:28/ 23:19:34	739/480.6	≥22.28	0.33	Yes
10. 23:24:03/ 23:24:06	00:03	None	None	≥1.033	0.33	Yes
11. •23:30:59/LOS		23:31:15/LOS	514.5/484.8	64.3	0.29	Yes

NOTE: Average flows computed from surge tank pressure data. •Voice tape indicates crew activity. ••Command Pilot face plate open.



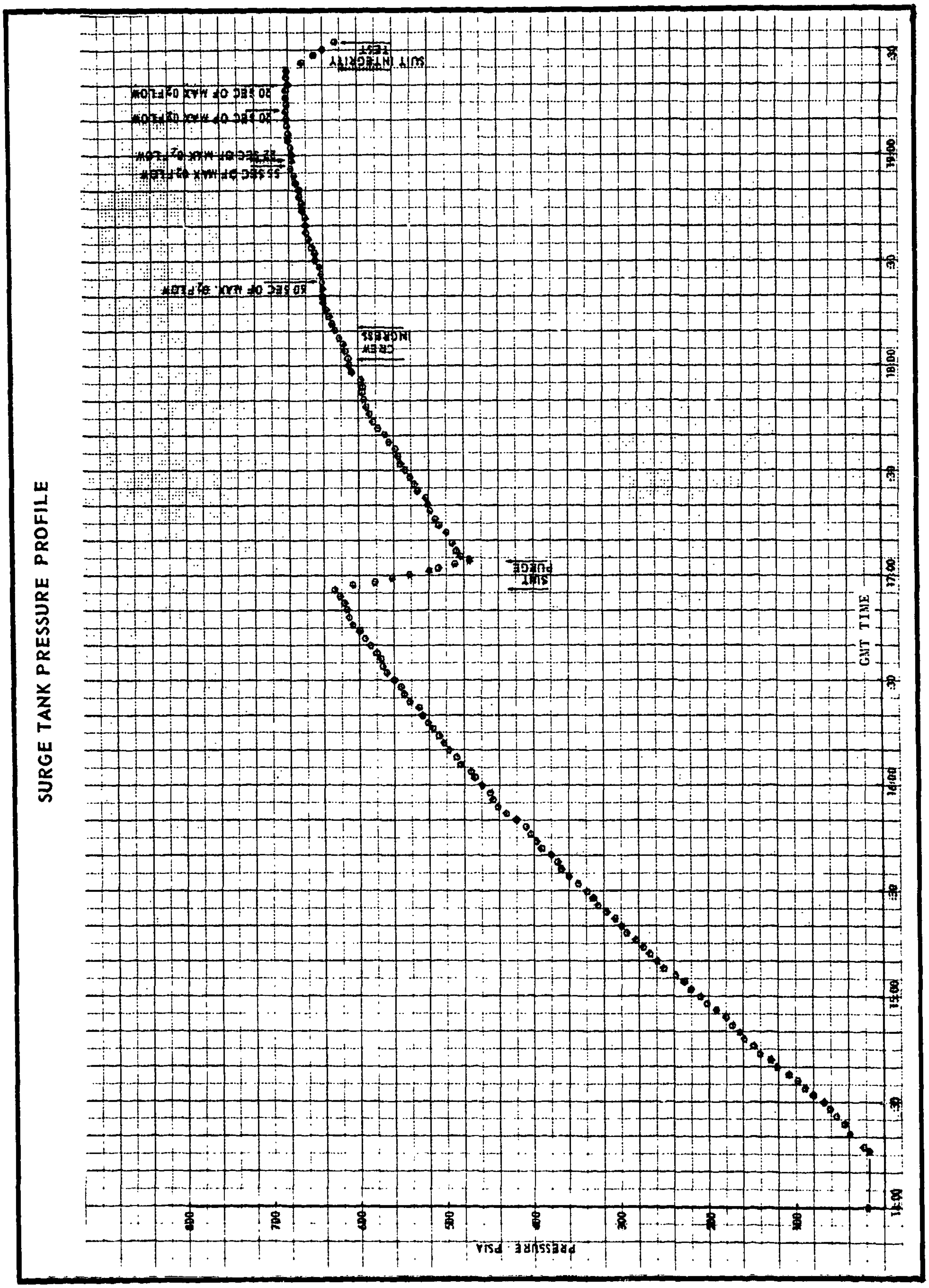
ENCLOSURE 18-12

ECS DATA CORRELATION

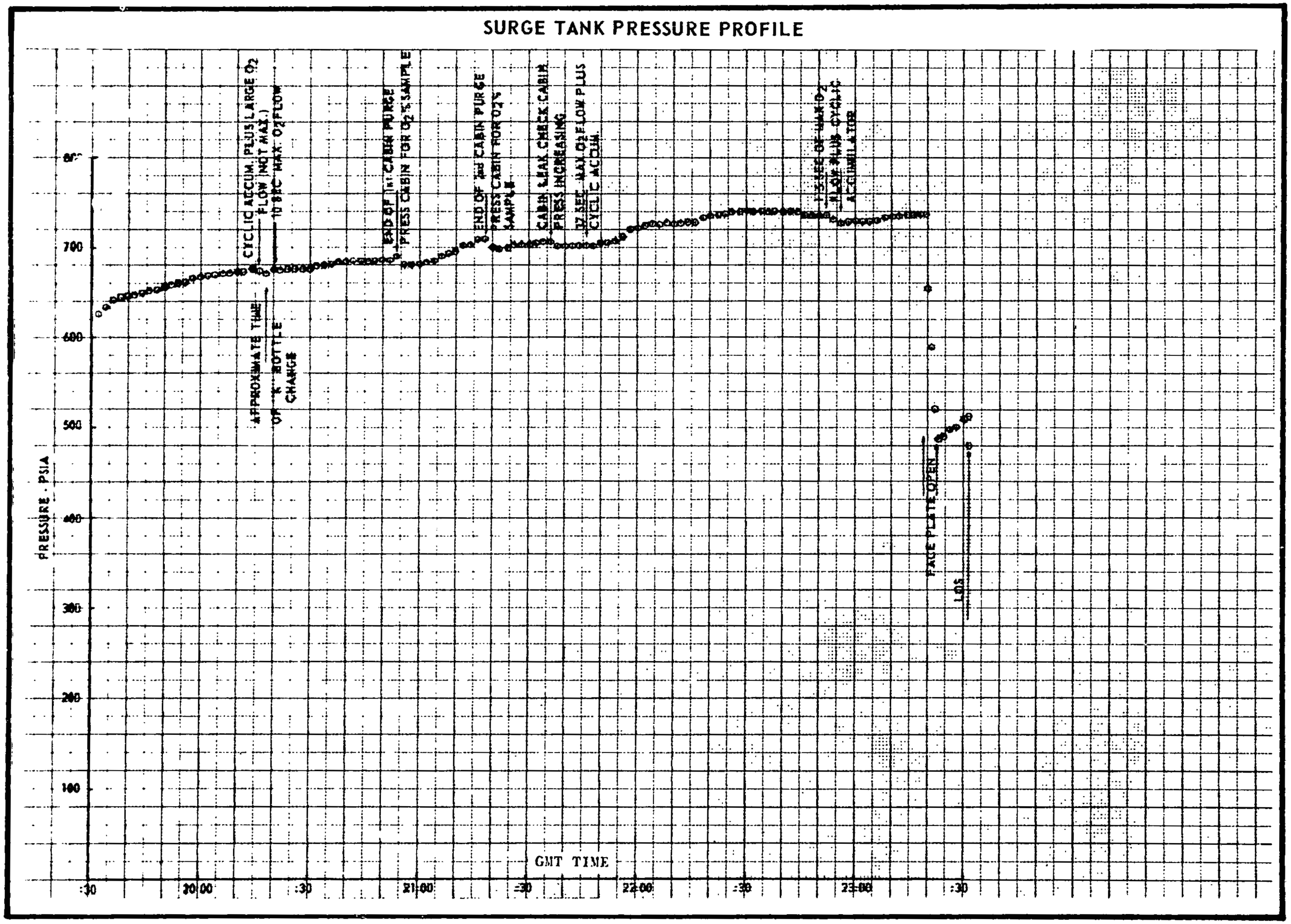


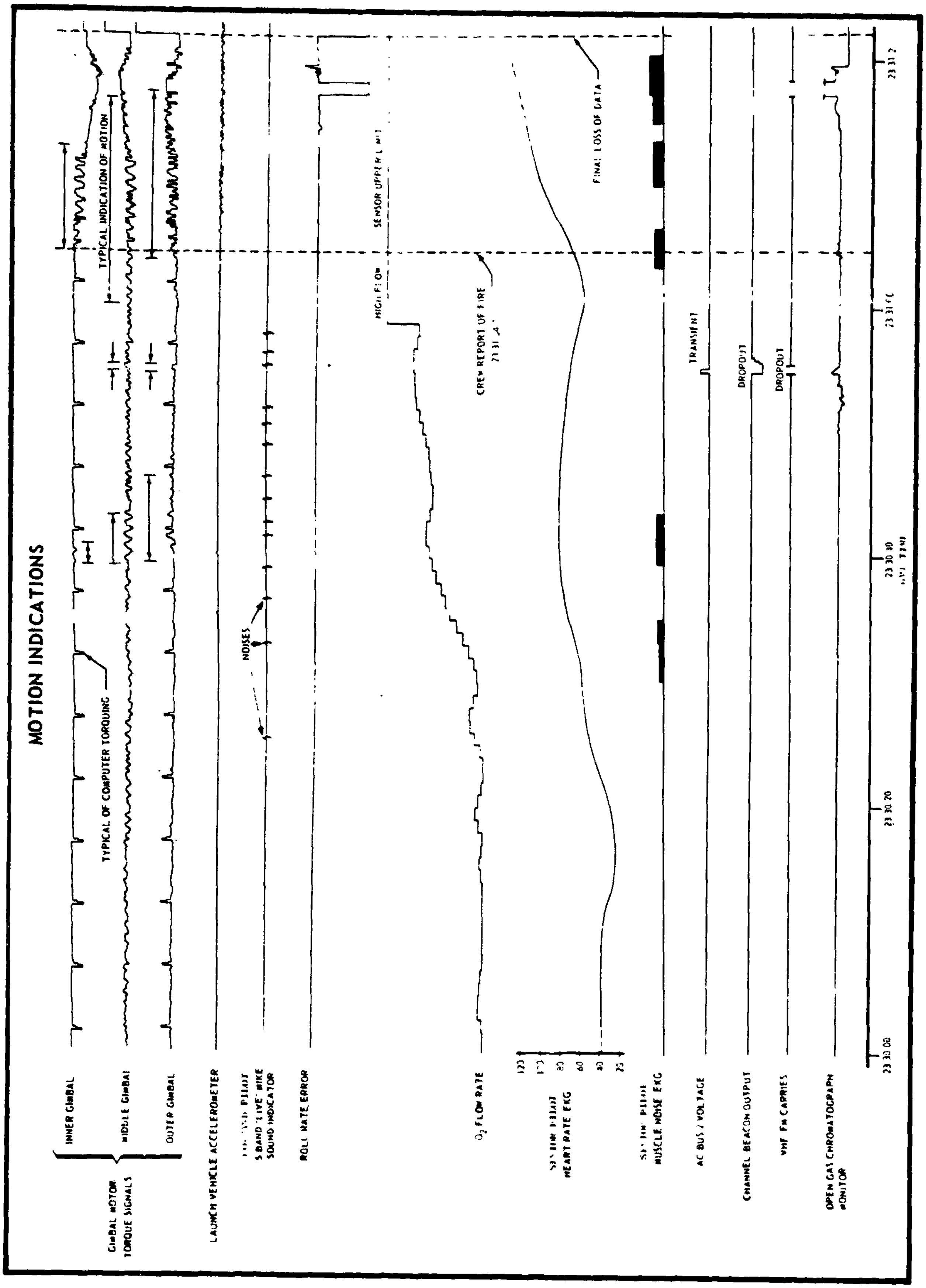
ENCLOSURE 18-12

SURGE TANK PRESSURE PROFILE



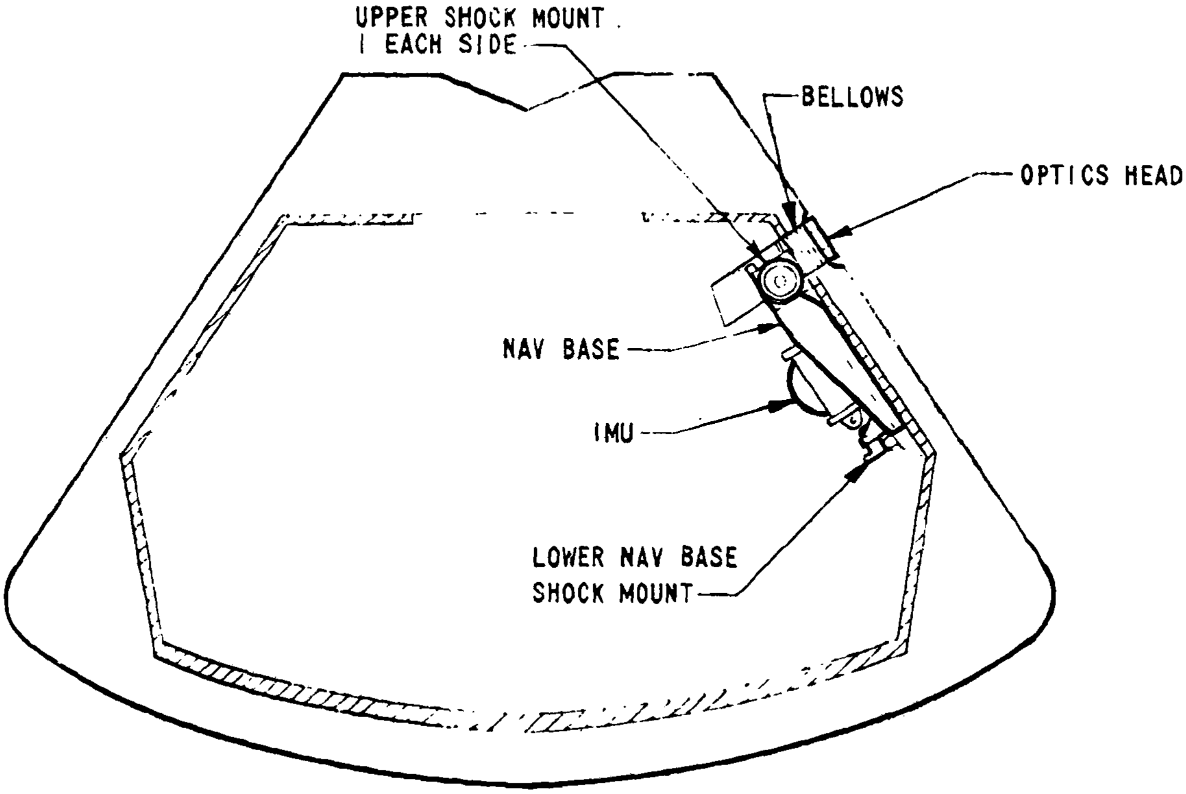
ENCLOSURE 18-13


SURGE TANK PRESSURE PROFILE
CYCLIC ACCUM. PLUS LARGE O_2 FLOW (NOT MAX.)
10 SEC. MAX. O_2 FLOW
APPROXIMATE TIME OF "K" BOTTLE CHANGE
END OF 1st CABIN PURGE
PRESS CABIN FOR O_2% SAMPLE
END OF 2nd CABIN PURGE
PRESS CABIN FOR O_2% SAMPLE
CABIN LEAK CHECK CABIN PRESS INCREASING
17 SEC. MAX O_2 FLOW PLUS CYCLIC ACCUM.
FACE PLATE OPEN
LOS
PRESSURE - PSIA
700
600
500
400
300
200
100
GMT TIME
:30
20:00
:30
21:00
:30
22:00
:30
23:00
:30



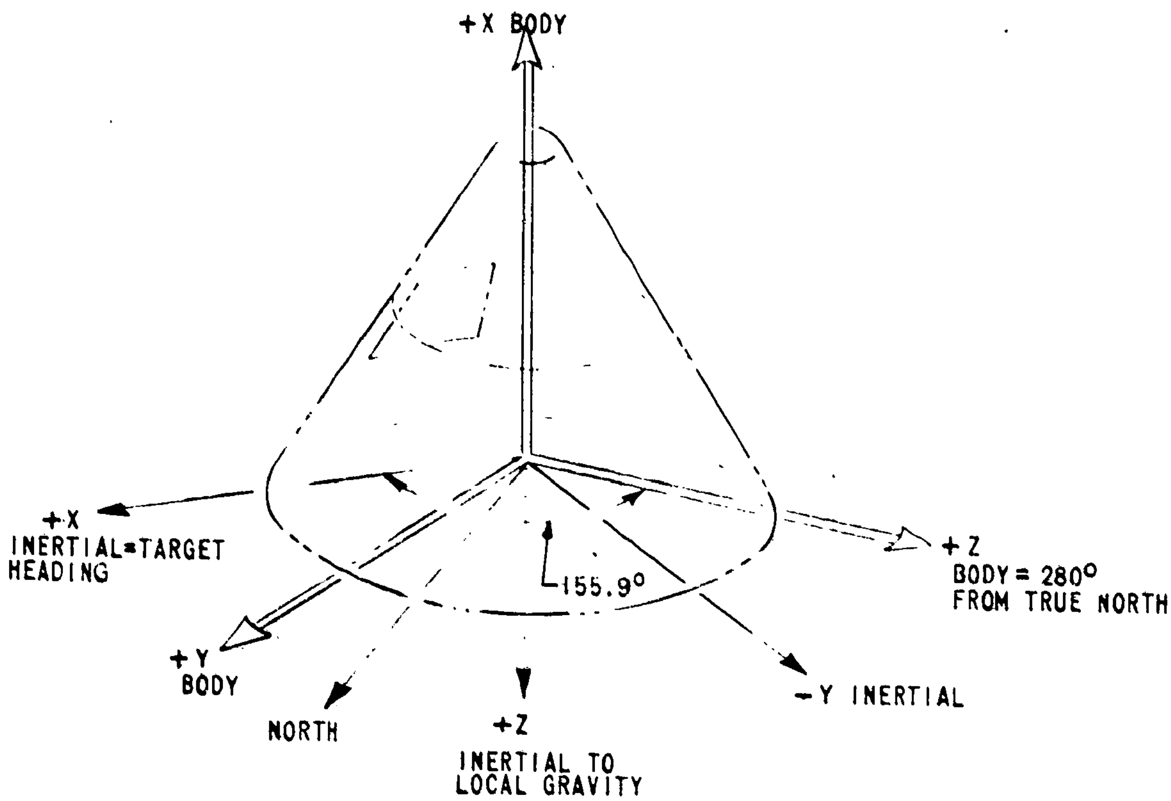
ENCLOSURE 18-14

NAVIGATION BASE INSTALLATION

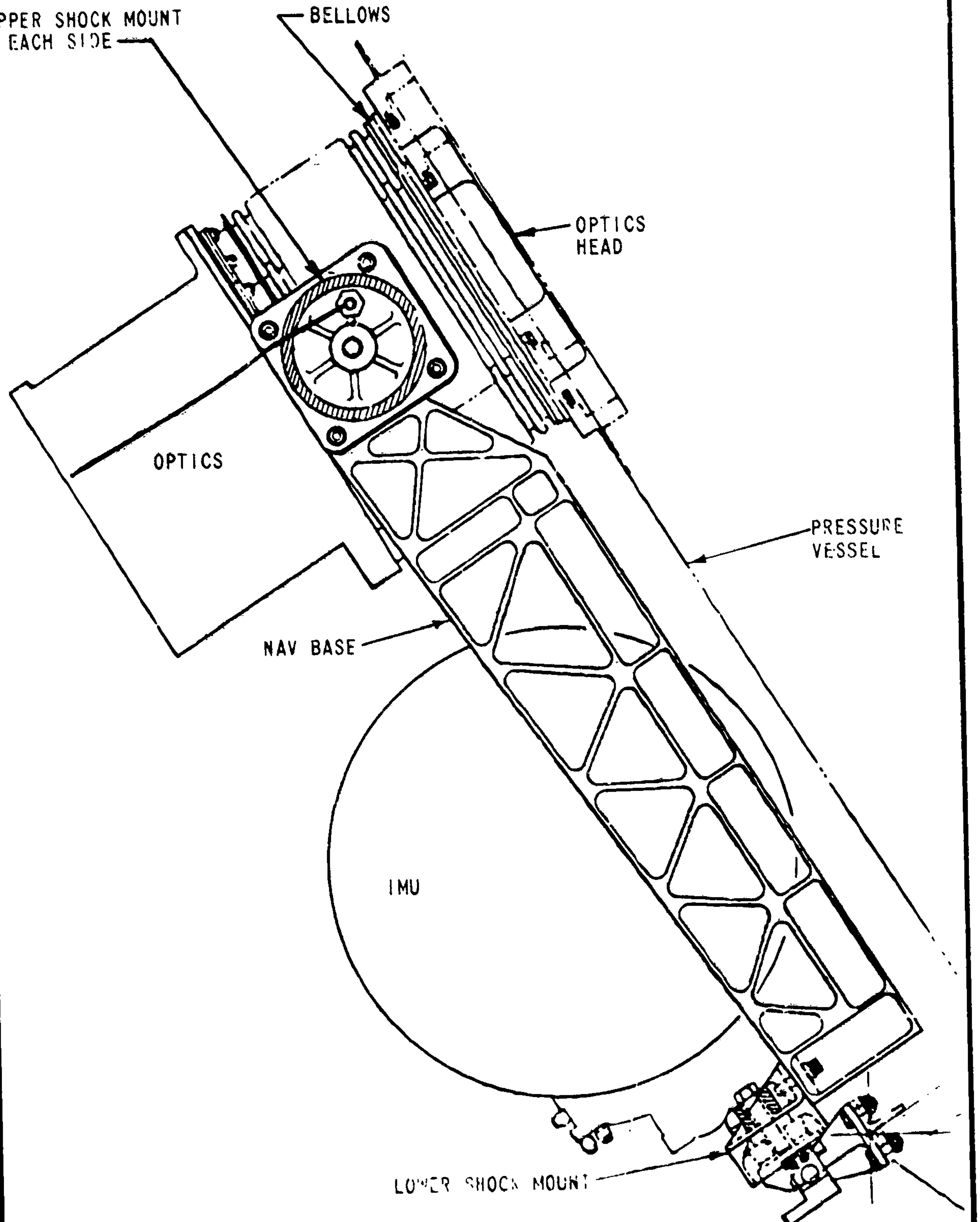


ENCLOSURE 18-15

SPACECRAFT AND IMU STABLE MEMBER AXES

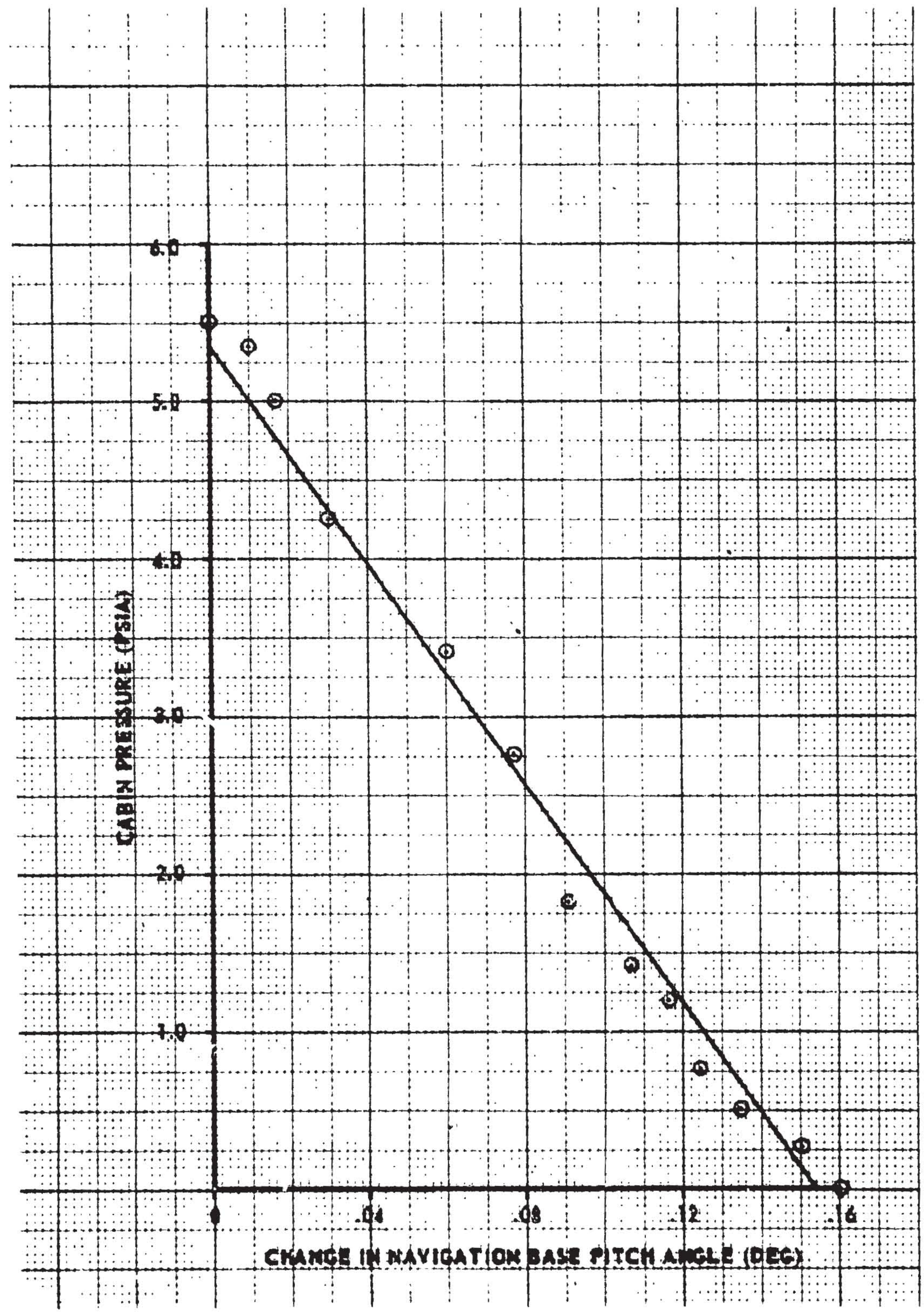


NAVIGATION BASE INSTALLATION DETAIL



ENCLOSURE 18-17

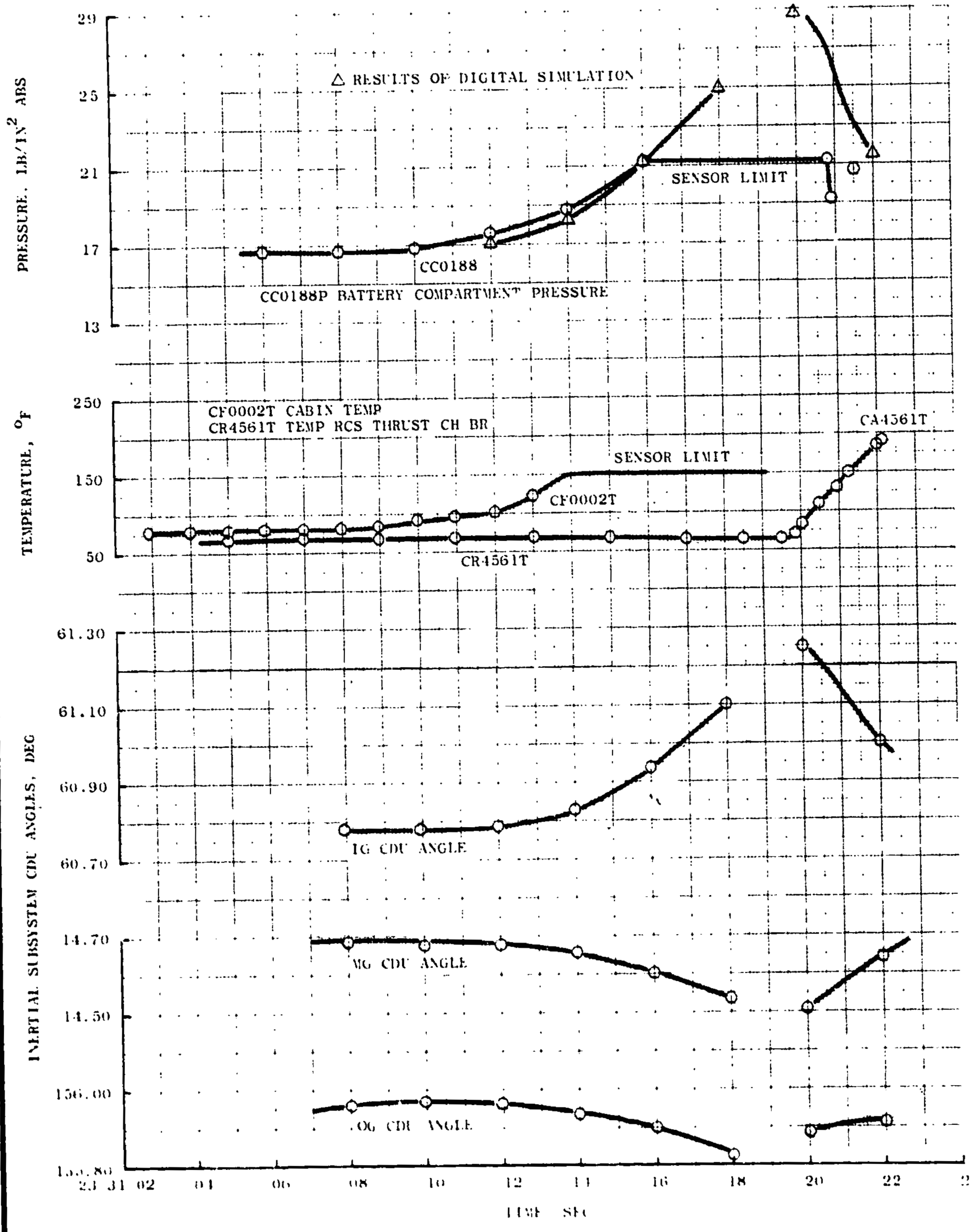
NAVIGATION BASE PITCH ANGLE CHANGE VERSUS CABIN PRESSURE

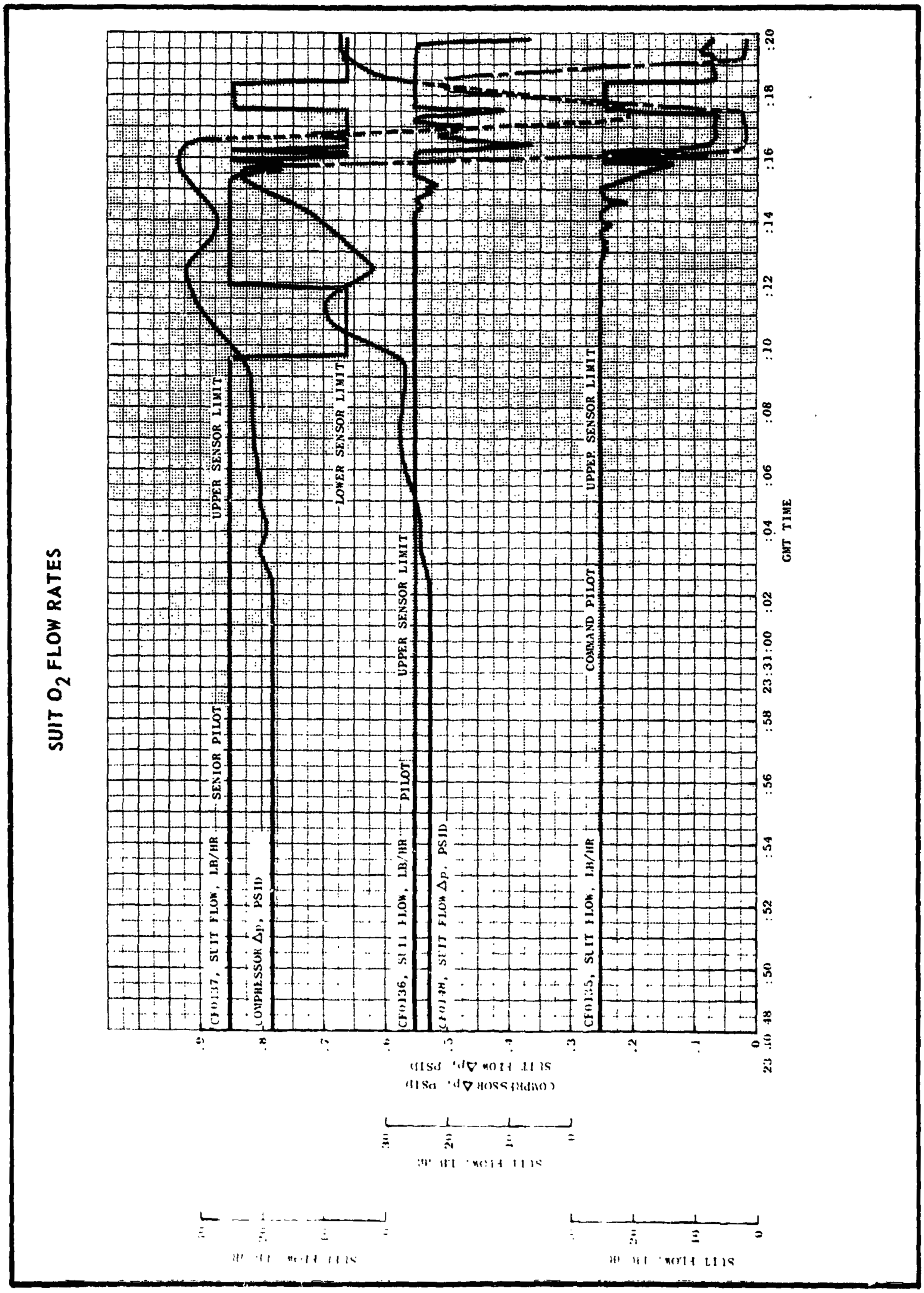


ENCLOSURE 18-18

D. 13.78

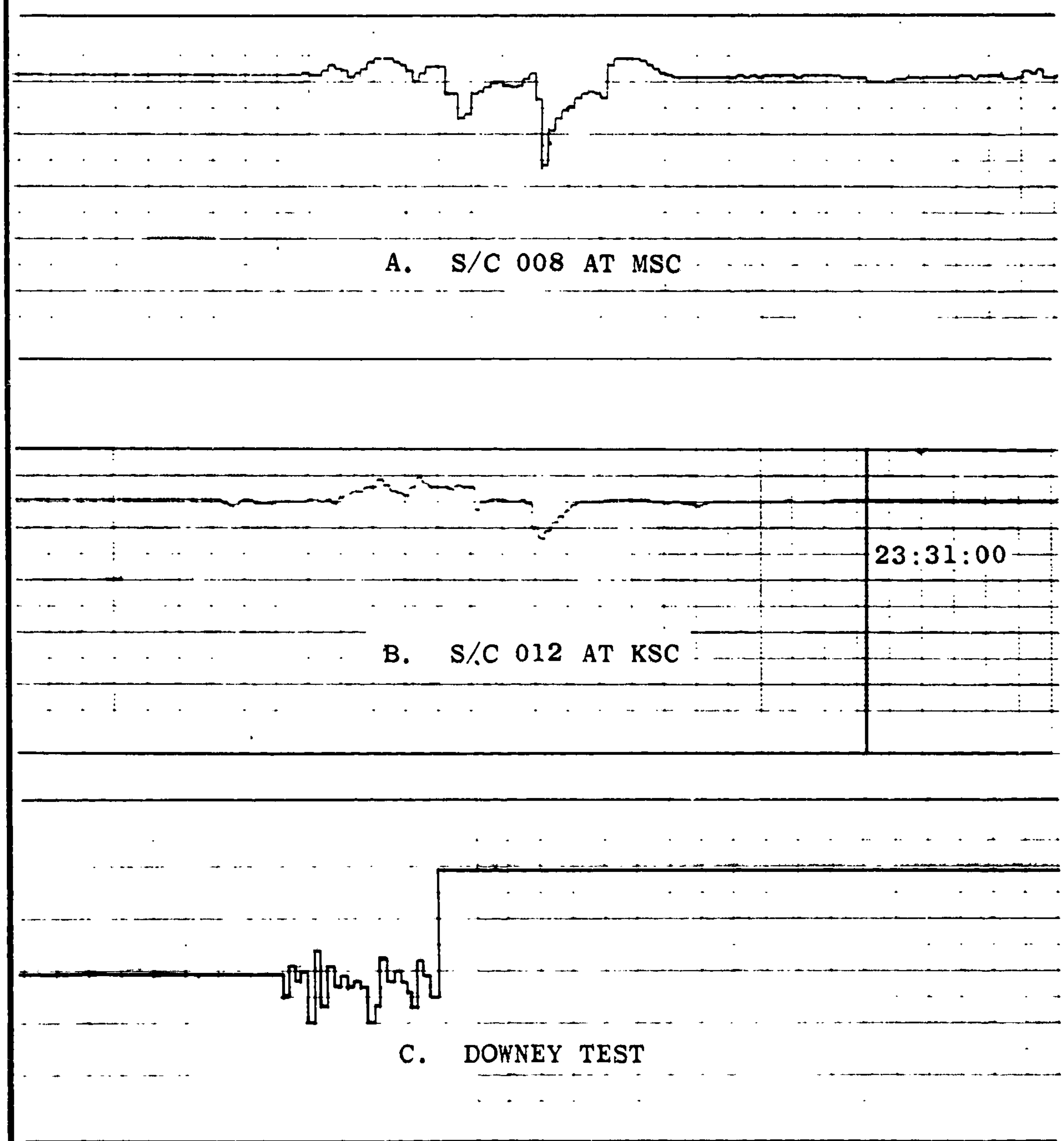
SELECTED TEMPERATURE, PRESSURE, AND INERTIAL SYSTEM MEASUREMENTS VERSUS TIME





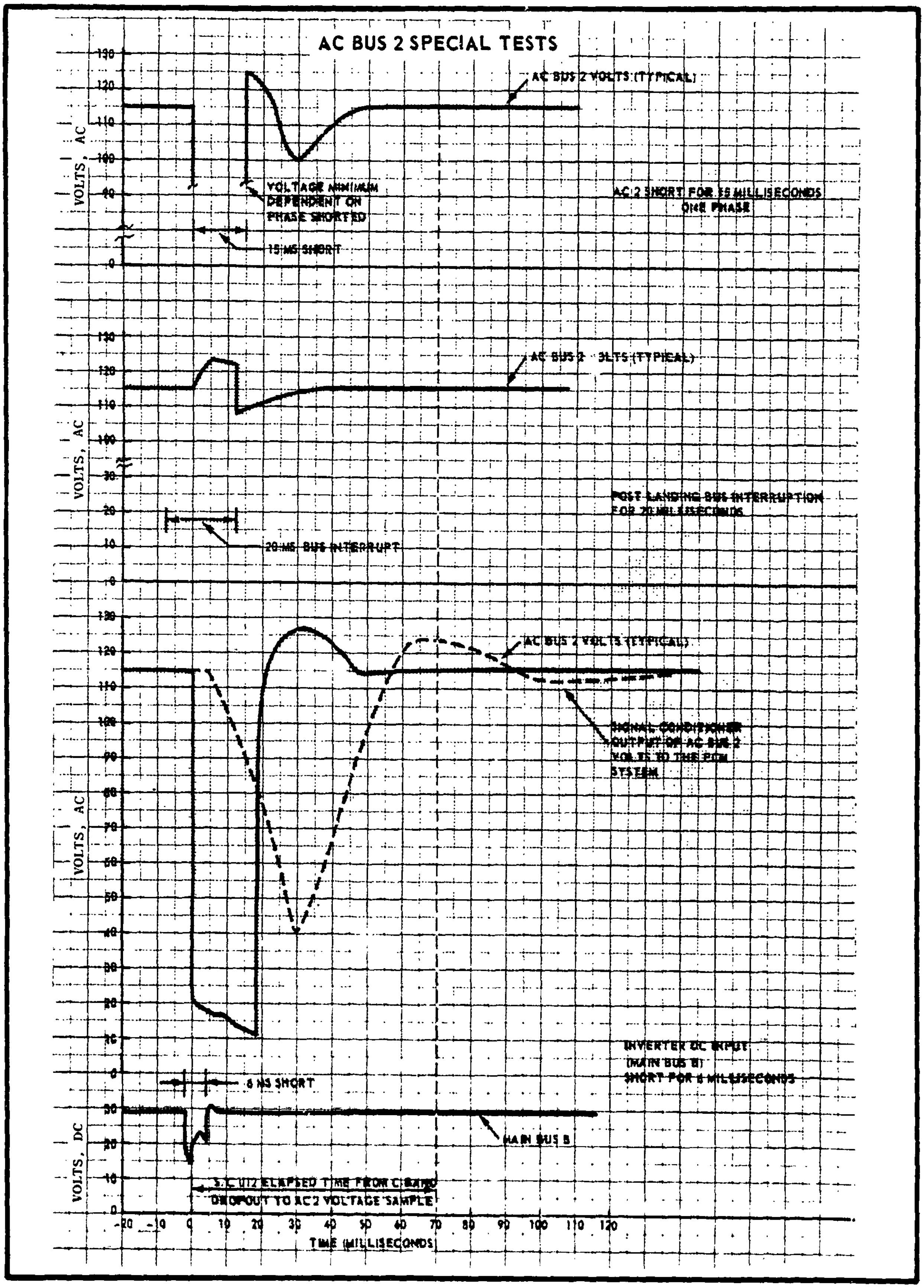
ENCLOSURE 18–20

GAS CHROMATOGRAPH TRACE COMPARISON

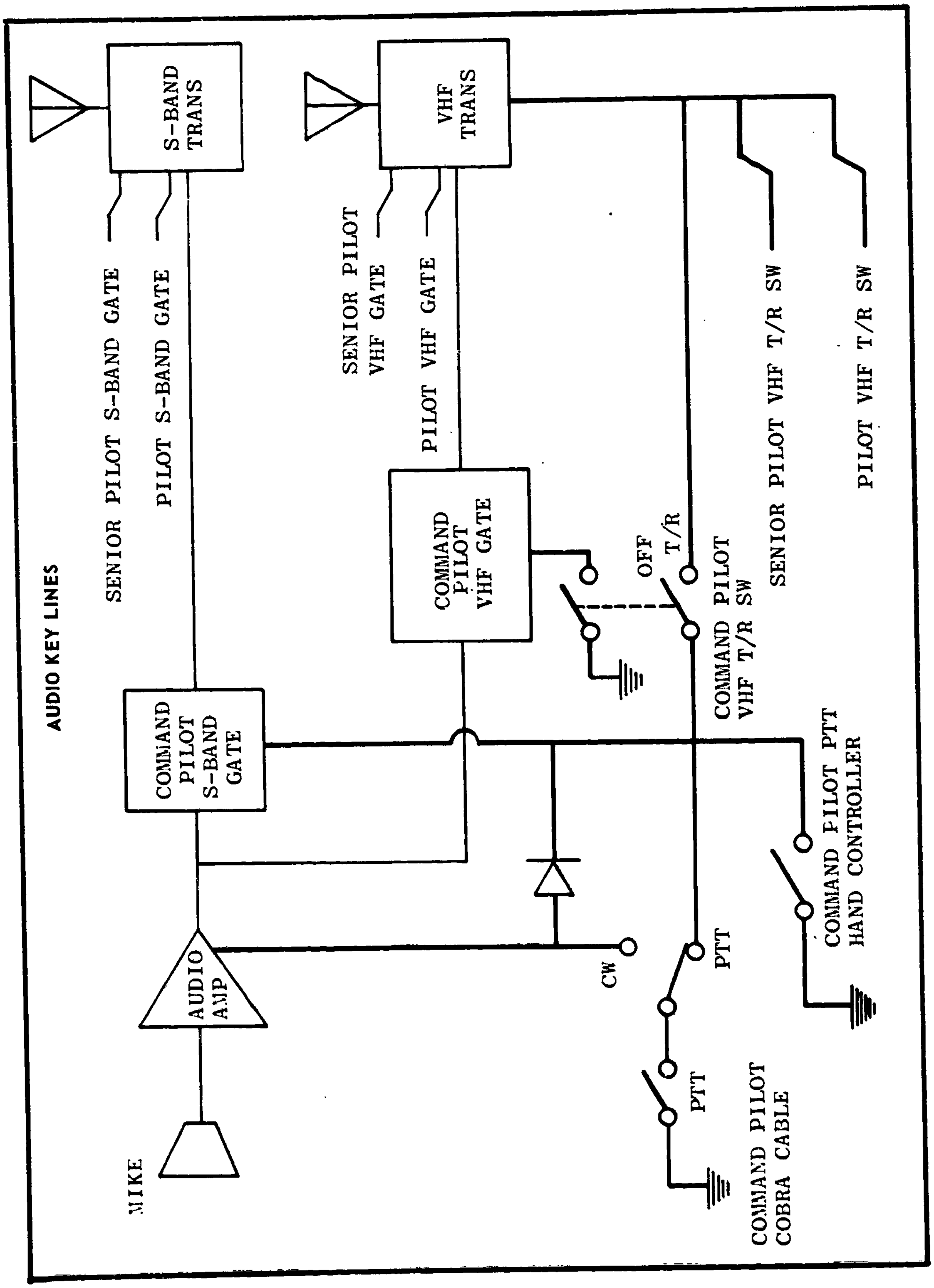


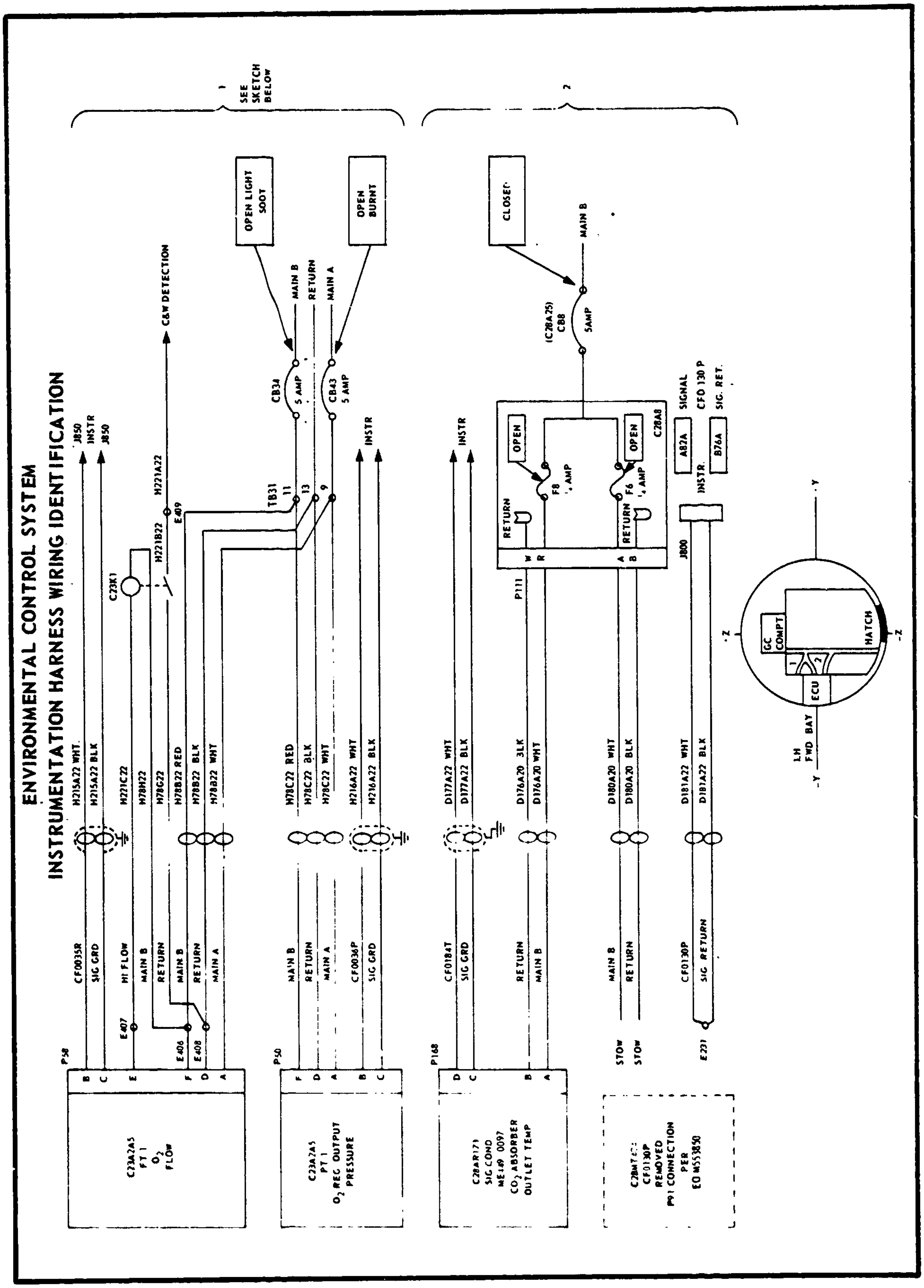
GAS CHROMATOGRAPH TRACE
MEAS. NO. CT0108K
RECORD SPEED 10MM/SEC.
2.5V = FULL SCALE

ENCLOSURE 18-21



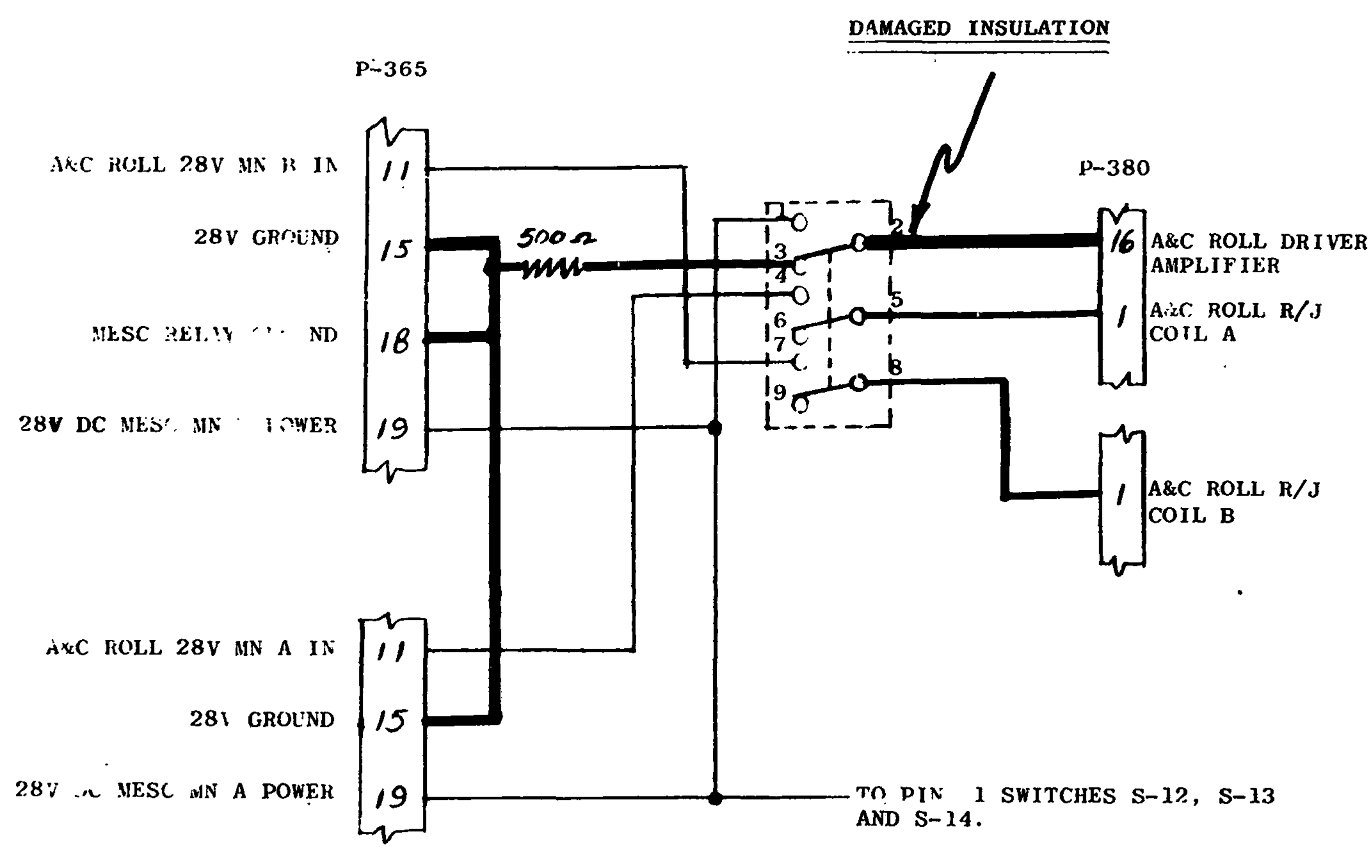
ENCLOSURE 18-23


AUDIO KEY LINES
S-BAND TRANS
VHF TRANS
SENIOR PILOT S-BAND GATE
PILOT S-BAND GATE
SENIOR PILOT VHF GATE
PILOT VHF GATE
SENIOR PILOT VHF T/R SW
PILOT VHF T/R SW
COMMAND PILOT VHF GATE
OFF
T/R
COMMAND PILOT VHF T/R SW
COMMAND PILOT S-BAND GATE
COMMAND PILOT PTT HAND CONTROLLER
CW
PTT
PTT
AUDIO AMP
MIKE
COMMAND PILOT COBRA CABLE


ENVIRONMENTAL CONTROL SYSTEM
INSTRUMENTATION HARNESS WIRING IDENTIFICATION
SEE SKETCH BELOW
OPEN LIGHT SOOT
OPEN BURNT
CLOSED
C&W DETECTION
MAIN B
RETURN
MAIN A
CB34 5 AMP
CB43 5 AMP
(C28A25) CB8 5AMP
TB31
C23K1
C28A8
F8
F6
RETURN
OPEN
INSTR
J850
A82A
B76A
SIGNAL
CFO 130 P
SIG. RET.
J800
P111
H215A22 WHT
H215A22 BLK
H221C22
H78H22
H78G22
H78B22 RED
H78B22 BLK
H78B22 WHT
H78C22 RED
H78C22 BLK
H78C22 WHT
H216A22 WHT
H216A22 BLK
D177A22 WHT
D177A22 BLK
D176A20 BLK
D176A20 WHT
D180A20 WHT
D180A20 BLK
D181A22 WHT
D181A22 BLK
H221B22
H221A22
CF0035R
SIG GRD
HI FLOW
CF0036P
CF0184T
CF0130P
SIG RETURN
STOW
P58
P50
P168
C23A2A5 FT 1 O_2 FLOW
C23A2A5 PT 1 O_2 REG OUTPUT PRESSURE
C28AR171 SIG COND ME149 0097 CO_2 ABSORBER OUTLET TEMP
C28MT CF0130P REMOVED P91 CONNECTION PER EO N55850
GC COMPT
HATCH
ECU
LH FWD BAY

MAIN DISPLAY CONSOLE PANEL NUMBER 8

SWITCH S-11 (SCS A&C ROLL)



Enclosure 18-41: Main Display Console Panel Number 8 Switch S-11 Wiring

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
1	Last voice from crew before fire 2330:03	3-3	3-14	3-14	
	Baseline information only. No Analysis Summary required.	Bell Labs preliminary report received. Information of significance will be covered under appropriate items. ITEM CLOSED			
2	Noise on S-Band voice channel 2330:39.5 to 2330:58.5	3-20	3-31	3-31	
		Bell Labs and MSC preliminary reports received. Their determination on these noises is inconclusive. However, the sounds were similar to those of tapping and brushing a microphone. ITEM CLOSED			
3	IMU gimbal angle data indicates movement: 2330:39 to 2330:44, 2330:54.9 2331:00 to Loss of Data	3-3	3-21	3-21	
		Data have been reviewed to determine if correlation of definitive movement can be established from gimbal torque mortor signals. It was determined that no repeatability or consistancy could be established other than gross indications of motions. ITEM CLOSED			
4	Ground DC power supply number 2 shows a 4 amp increase for a one second sample 2326:30.5	3-3	3-16	3-17	
		An analysis of the data has been completed. It has been concluded that power supplies A and B may have momentarily shifted their shared loads or another load may have been added at this time. Considering the time, it has been concluded that this event could not have contributed to the cause of the accident. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
5	Gas chromatograph output starts movement from this time to loss of data 2330:50	3-5	3-20	3-21	
		The gas chromatograph (GC) was not installed in S/C 012 at the time of the accident. It has been determined, however, that the GC cable acted as an electromagnetic radiation detector. Changes in the GC data trace are an indication of changes of state in the Command Module. ITEM CLOSED			
6	VHF-FM video drops out for 30 milliseconds 2330:54.85	2-10	2-10	2-10	
		Tests conducted showed that the received video signal will drop out if the AC supply drops to less than 50 volts or the DC supply drops to less than 6.5 volts for a period of 15 to 20 milliseconds. This is an effect of an AC bus 2 power interruption. ITEM CLOSED			
7	AC bus 2 voltages transient on all three phases 2330:54.85	3-20	4-1	4-1	
		The AC voltage transient appeared as a rise of 5 to 8 volts for one data sample. Testing has determined that a momentarly interruption of bus B DC power to inverter 2 will cause this type of AC transient. ITEM CLOSED			
8	C-band transponder drops to zero volts for two seconds 2330:54.85 to 2330:56.9	2-10	2-10	2-10	
		AC drop out for very short intervals of time causes the C-Band transponder to go to a protective mode. Normal recovery time is approximately 1.7 seconds. This is an effect of an AC bus 2 power interruption. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
9	O_2 flow rate increases to measurement limit 2330:59.4	2-20	3-20	3-20	
		Telemetered data and engineering analysis of failure modes and circuitry, and an inspection of the flow sensor, leads to the conclusion that the high oxygen flow indication was valid, and that there was no malfunction of the sensor and/or associated wiring prior to the crew report of fire. ITEM CLOSED			
10	Voice data "fire" 2331:04.7	3-21	3-27	3-27	
	Baseline information only. No Analysis Summary required.	Bell Labs and MSC preliminary reports received. Details of their analyses are contained in Section C-7 of the Panel 18 Final Report. ITEM CLOSED			
11	Witnesses report bright glow moving from left to right after fire call	2-13	2-14	3-17	
	Baseline information only. No Analysis Summary required	A TV simulation test was performed utilizing S/C 008 Video tape playbacks were shown to the primary witnesses to verify their observation and time correlations, and no changes in statement resulted. The only positive summary statement is that after the fire call observation of the TV monitor showed flame progressing inside the crew compartment from the left corner of the porthole to the upper right area. ITEM CLOSED			
12	Data indicates the initial cabin temperature increase at 2331:06.4	2-14	4-1	4-1	
		Test conducted by the transducer's vendor (AiResearch) showed that the sensor response time was approximately 300 milliseconds. It is concluded that the time of cabin temperature rise is accuracte to within ±1 second. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
13	Cabin pressure increase began at 2331:06.818 (battery pressure transducer)	2-10	2-14	2-14	
		Response time of the transducer has been determined. Response time plus measurement sampling rate defines the accuracy of this data to be within ± 100 milliseconds. ITEM CLOSED			
14	Cabin pressure increase began at 2331:08.417 (measurement CF0001P)	2-10	2-14	2-14	
		Response time of the transducer has been determined. Because this measurement is sampled only once per second, the battery pressure transducer (Item 13) should be used for cabin pressure data. ITEM CLOSED			
15	IMU gimbal angle data shows ramp starting at approximately 2331:10	2-10	2-10	2-15	
		The IMU gimbal ramp is attributed to an increase in Command Module pressure. This data has been substantiated by data obtained during the second vacuum chamber test on Spacecraft 012 and on special tests performed on Spacecraft 008 at MSC. ITEM CLOSED			
16	Entry battery B transferred to Main Bus B 2331:12.4	2-10	2-10	2-10	
		Two ground and six PCM measurements showed that the entry battery B was transferred to the Main Bus B. Also post test investigation substantiated the position of switch S-10 on panel 22 which is indicative of Pilot action. Refer to Item 17 for corollary information on Battery A. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
17	Entry battery A transferred to Main Bus A 2331:13.6	2-10	2-10	2-10	
		Four PCM measurements showed that the Entry Battery A was transferred to Main Bus A. This was further substantiated by the post test inspection of switch S-9 on panel 22 which is indicative of Pilot action. ITEM CLOSED			
18	Master caution warning light came on 2331:14.7	2-10	2-10	2-10	
		This light was the result of a high oxygen flow rate indication. Whenever the oxygen flow rate increases to its maximum and stays at a miximum transducer saturated level for 15 seconds, the master alarm will come on. ITEM CLOSED			
19	Temperature of oxygen supply began to increase 2331:16.0	2-10	2-14	2-14	
		Post test observations indicate that loss of pressure suit circuit integrity occurred in the Command Pilot's pressure suit and/or return hose. Such an opening would allow warm cabin air to be drawn into the suit compressor. The CO_2 absorber outlet temperature indicates that the CO_2 absorber acted as a heat sink until this time, when it and the suit manifold temperature began to increase. ITEM CLOSED			
20	Momentary interruption in VHF-FM and S-Band data 2331:17.398 to 2331:17.659	2-10	3-10	3-10	
		This loss of data is attributed to soft short circuits occurring in the communications system wiring. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
21	Biomed recorder timing trace inspection for DC dropout.	3-3	3-16	3-16	
		Tests showed that the timing trace amplitude changes were caused by imperfections and dust on the tape. There were no interruptions indicative of a short on DC bus B, on Biomed recorder data from the accident. **ITEM CLOSED**			
22	Additional (seven) gas chromatograph data variations 2204:45 to 2255:43	3-6	3-16	3-16	
		An analysis of the data at these times has been conducted and correlations with other systems changes were seen. It has been concluded that the gas chromatographs cable acted as a electromagnetic radiation detector. **ITEM CLOSED**			
23	Loss of all communications data 2331:21.0 to 2331:22.42	2-14	3-10	3-10	
		This is due to the burning and shorting of wire harnesses during the fire, attributed to a loss of power or loss of a coax cable. **ITEM CLOSED**			
24	MTVC Pitch Rate Command observed at 2330:54.847	2-14	2-23	2-23	
		This happened at the same time as the AC Bus 2 transient. A re-analysis disclosed this was a one bit change in the data which occurred frequently. No significance is therefore attributed to this item. **ITEM CLOSED**			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
25	Senior Pilot suit flow dropped to lower limit then returned to normal flow indication 2331:09.6 to 2331:11.9	3-6	4-1	4-1	
		It is inferred that the Senior Pilot disconnected his suit inlet hose for emergency egress (Reference Item No. 102). **ITEM CLOSED**			
26	O_2 surge tank pressure started to decrease 2331:12.4	3-3	3-20	3-20	
		It is concluded that the oxygen surge tank pressure decay was the result of high O_2 flows into the suit loop. **ITEM CLOSED**			
27	Command Pilot suit flow started fluctuating at 2331:12.9 and Senior Pilot suit flow started fluctuating at 2331:15.4	2-13	2-27	2-27	
		Characteristic of suit flow indications with restricting caused by Command Pilot movements or physical activity. The time period for fluctuations in the Senior Pilot suit flow coincides with increase muscular activity indicated by physiological data. **ITEM CLOSED**			
28	Suit compressor inlet temperature starts increasing 2331:13.2	2-13	2-14	2-14	
		Post-test observations indicate that loss of pressure suit circuit integrity occurred in the Command Pilot's pressure suit and/or return hose. Such an opening would allow warm cabin air to be drawn into the suit compressor. **ITEM CLOSED**			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
29	RCS jet action, data questionable 2329:40	2-14	2-23	2-23	
		A more detailed analysis of the data during this period has been completed. The indicated RCS action was found to be erroneous. ITEM CLOSED			
30	Rotation controller output transient of 1.5% 2330:54.85	3-2	3-31	3-31	
		This happened at the same time as the AC Bus 2 transient. Special tests have shown that the null output transients can be duplicated by a momentary interruption of AC Bus 2 Phase A input power. This is therefore an effect of the AC Bus 2 transient. ITEM CLOSED			
31	Electrical short due to cold flow characteristics of Teflon wire insulation	2-24	4-1	4-1	
		All wire bundles in the spacecraft which showed damage were carefully inspected for signs of arcing. Due to the considerable fire damage and the possibility that shorting could have been a result, evidence of Teflon "cold-flow" is considered inconclusive. ITEM CLOSED			
32	SCS roll rate oscillations starting at 2331:03.85	2-19	2-23	2-23	
		Indicates movement in the command module during this period. Nothing more can be inferred from the data other than movement. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
33	Launch Vehicle pitch and yaw accelerometers start oscillation 2331:04 to loss of data	2-14	2-15	2-15	
		No indications in data during cobra cable change (crew movement). Data shows slight oscillations starting at 2331:04 with maximum activity at 2331:20 ITEM CLOSED			
34	Arcing noted on Junction Box cover plate	3-14	4-1	4-1	
		No positive identification has been made to indicate that this arc occurred prior to the fire. Burning noted in this area does not appear as severe as would be expected had the fire started due to this arc. ITEM CLOSED			
35	Suit differential pressure begins to increase 2331:06.4	2-13	3-20	3-20	
		The oxygen demand regulator senses cabin pressure. An increase in cabin pressure will cause the diaphram of the regulator to be opened allowing oxygen flow into the suit loop. ITEM CLOSED			
36	Saturn I engine 8 anomaly 2052:23.039	2-22	3-31	3-31	
		All launch vehicle data pertaining to this circuit has been reviewed and no anomalies have been found. An intermittent condition could exist somewhere within this system to cause this anomaly. Based on the time of this happening, it has been concluded that this is unrelated to the accident. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
37	Water-glycol accumulator quantity starts decreasing 2331:13.0	2-13	2-13	3-14	
		Attributed to increasing cabin pressure, since accumulator diaphragm is vented to cabin pressure. The water-glycol accumulator transducer sensed the increase in cabin pressure and interpreted this as a decrease in water-glycol quantity. ITEM CLOSED			
38	Pilot suit flow starts to fluctuate 2331:14.3, but violently at 2331:16.2	2-13	2-13	2-27	
		Characteristic of suit flow indications with restrictions caused by Pilot movements or physical activity. ITEM CLOSED			
39	GSE DC power commanded off 2332:46.4	2-10	2-10	2-10	
		ACE data shows that the ground DC power was commanded off at 2332:46.4 and that the power was off at 2332:47.7. This is in accordance with the emergency procedures. ITEM CLOSED			
40	Glycol pump discharge pressure starts increasing 2331:14.4	2-13	3-14	3-14	
		Attributed to boiling of water-glycol within the lines when subjected to intense heat. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
11	Use of loose equipment in chromatograph compartment	3-3	3-10	3-14	
		The storage of loose items has been established prior to crew ingress and all were found still in the compartment after the test. However, some of the equipment may have been moved but there is no evidence to support this belief. No films were contained in any of the cameras. ITEM CLOSED			
12	Elapsed time indicator burned on Spacecraft 014 at Downey (unit associated with caution warning system).	2-10	2-10	2-10	
		The elapsed time indicator was physically examined on Spacecraft 012 and found to be satisfactory with no evidence of burning. (Reference TPS 053). ITEM CLOSED			
13	Internal-external power history during entire test	2-22	2-23	2-23	
	Baseline information only. No Analysis Summary required.	A supplement to the electrical power history has been completed and was presented to the Board on 2-24. ITEM CLOSED			
14	Bottle of MEK found in White Room.	3-3	3-22	3-22	
		Chemical analysis of the bottle has been obtained and it was determined to be MEK. Also a history of cleaning, painting and bonding in Spacecraft 012 has been completed. Use of the bottle on the day of the last test cannot be determined. (Reference Board Action 0147 and TPS MA-003) ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
15	Two broken pressure transducers on ECU	2-22	3-31	3-31	
		The two transducers have been identified (suit supply inlet pressure and water glycol pump outlet pressure). Radiographic examination indicated no evidence of damage within these units. Also there were no visual fire paths from within the transducers. ITEM CLOSED			
16	Couch resistance measurements and status of bonding straps	2-10	2-10	2-14	
		Two bonding straps from the floor to the S/C wall were installed but the two from the Z struts to the center couch were not installed due to parts shortage. Resistance checks were made on the crew couches which indicated an 1 ohm resistance. While this is high (normal 0.03 ohms) it is low enough to prevent any static charge buildup. ITEM CLOSED			
17	Screwdriver caused arc in wire harness (Ref. DR 0917 dtd 1/23/67)	3-4	3-16	3-16	
		Inspection of the arced wire (No. 1C50A16 RCS Quad B + Roll Normal Control) has been completed and nothing suspicious was noted. However, an arc spot was noticed on the cover plate which is located in a different area. Reinspection of the area in which the screwdriver drew an arc has shown that it did not contribute to the fire. (Ref: Item No. 34) ITEM CLOSED			
18	ACE control and computer room configuration	2-18	2-10	2-10	
		The ACE Control Room No. 1 and Computer No. 1 configuration have been defined. All indications are that the system operated properly, that no spurious commands were transmitted and in no way contributed to the accident. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
19	Review of past floodlight failures and floodlight examination and testing.	3-3	3-10	3-14	
		The exact configuration of floodlights during the last test has been reviewed. All six floodlights have been removed and have been examined and tested. and were found to be satisfactory. (Reference TPS 028. 029. 032. 033 and 059). ITEM CLOSED			
50	H_2 tank fan motor variation ? 26:30.4	2-10	3-10	3-10	
		GSE access connector J 22 which normally carries this measurement has been verified as not connected during the accident. Re-analysis of this data variation has been completed. The variation is attributed to random noise in the ACE station. ITEM CLOSED			
51	Hole in translation controller	2-10	2-15	2-15	
		The Fire Analysis Panel has completed their investigation of the translation hand controller. There is no evidence that an explosion occurred inside the controller. It was probably hit by a foreign object. (Reference TPS 022). ITEM CLOSED			
52	Waste management system blower motor failure on Spacecraft 008	2-13	2-15	2-15	
		The WMS blower selector switch has been determined to have been in the OFF position immediately prior to the incident (T-10 min.) per OCP. Post test switch list shows the selector switch in the OFF position. Examination of the blower motor showed no evidence of any electrical difficulty. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
53	Review of heater failures and hardware examination.	3-1	4-1	4-1	
		History data has been received and has been evaluated. There are six different uses for heaters. The review of the failure history of the heaters concluded that no significant problem could be associated with the 204 accident. ITEM CLOSED			
54	Review of ECS water-glycol leakage on 012	3-3	4-1	4-1	
		A detailed survey of all leakage has been completed. After the accident all connectors subject to past water-glycol spills. No evidence of internal arcing was found that could be attributable to prior water-glycol contamination. ITEM CLOSED			
55	RCS thruster temperature sensor indicates cabin rupture. 2331:19.8	2-10	2-10	2-14	
		This time correlates with the time indicated by the G&N and cabin measurements for the pressure shell rupture. (Response time for this measurement system being obtained.) ITEM CLOSED			
56	Lithium hydroxide canisters non-flight type	2-17	3-8	3-10	
		A detailed analysis of the data associated with the oxygen suit loop indicates normal temperatures until approximately 10 seconds after the fire call. It has been concluded that the canister damage was a result and not a cause of the accident. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS		ANALYSIS	
		Investigation/ Validation Action In Work	Validation Completed	Did Not Cause Accident	May have Contributed to Accident
57	Analysis of gas from 2 Beckman oxygen analyzers	2-13	2-15	2-15	
		Neither of the O_2 analyzers contained significant gaseous materials (more than 500 ppm) of anything other than air components. Trichloroethylene was found in the silica gel of the analyzer used for the last sample. This could result from any previous use. (Ref. TPS 007). ITEM CLOSED			
58	On board recording equipment and electrical connector configuration.	3-6	3-14	3-14	
		Post test physical verification indicates that the DSEA (LEM recorder) was not connected electrically; however, the cable was "hot" per the switch configuration. Electrical wiring has been inspected and no indications of arcing or other damage were noted. (Ref. Board Action No. 0153 and TPS CM-IV-081). ITEM CLOSED			
59	S[illegible]ctural assessment report	2-10	2-10	2-19	
	Baseline information only. No Analysis Summary required.	The results of Panel 10 preliminary visual inspection have been prepared and forwarded to the 204 Review Board. ITEM CLOSED			
60	History of all Apollo Progra[illegible] fires	2-13	4-1	4-1	
	Baseline [illegible]ation only. No Analysis S[illegible]ary required.	Data received and has been reviewed for applicability. No correlation with past fires and the AS-204 accident were noticed. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
61	Spark ignition possibility	3-20	4-1	4-1	
		Electrostatic spark ignition testing determined that ignition by electrostatic discharge is not probable explanation of a ignition source. For details see Panel 8 final report. ITEM CLOSED			
62	Water glycol pump failure on Spacecraft 008	2-22	3-16	3-17	
		Pump cap configuration on S/C 008 was plastic. It has been determined that the configuration S/C 012 utilized an inconel cap. This has been validated during teardown of the ECU. Inspection showed that the inconel cap allowed no leakage into the pump motors and that the pumps were in satisfactory condition. ITEM CLOSED			
63	Oxygen flow rate sharp increase to measurement limit 2324:03	2-13	2-23	2-23	
		Tests and data have determined that O_2 flow rates are affected by crew activity. Crew activity has been correlated to the rise in O_2 flow. ITEM CLOSED			
64	Oxygen flow master alarm time excessive, 27 instead of 15 seconds 2145:54	2-13	2-23	2-23	
		It can be inferred that this was not a malfunction because this period of high O_2 flow was interrupted by cyclic accumulator action, and because the time delay worked properly at all other times including during the accident. ITEM CLOSED			

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
65	ECS water glycol system history during test	2-10	2-10	2-19	
		Input provided to Board. Action completed.			
	Baseline information only. No Analysis Summary required.				ITEM CLOSED
66	Oxygen system history during test	2-13	2-15	2-15	
		Input provided to Board. Action completed			
	Baseline information only. No Analysis Summary required.				ITEM CLOSED
67	Communication System history during test.	2-14	2-15	2-15	
		Input provided to Board. Action completed.			
	Baseline information only. No Analysis Summary required.				ITEM CLOSED
68	Review of all elapsed time indicators used on S C 012 of type to be removed before flight.	2-10	2-15	2-15	
		A check was made of all of these indicators on S/C 012 and found to be satisfactory with no evidence of short circuits or burning. (Ref. TPS S/C 012-054).			
					ITEM CLOSED

STATUS OF INVESTIGATION ITEMS

ITEM NO.	ITEM	STATUS: Investigation/ Validation Action In Work	STATUS: Validation Completed	ANALYSIS: Did Not Cause Accident	ANALYSIS: May have Contributed to Accident
69	ECS Fire at AiResearch	2-19	3-7	3-7	
		The fire which occurred on April 28, 1966 during the mission life qualification test of the ECS was attributed to ignition of electrical heater tape which was installed as part of the test equipment. No such commercial grade tape was used on Spacecraft 012. ITEM CLOSED			
70	VHF-AM Receiver failure encountered on Spacecraft 008	2-13	2-15	2-17	
		This was not a transceiver failure but was caused by a cut in a wire. This failure has no applicability to S/C 012. ITEM CLOSED			
71	Suit loop return valve leak encountered on Spacecraft 008	2-13	3-6	3-7	
		Failure data obtained from NAA and applicability of failure reviewed with respect to 204 accident. It has been determined that the leakage problem encountered on S/C 008 cannot be associated with the cause of S/C 012 accident. ITEM CLOSED			
72	MTVC (Manual Thrust Vector Control) engage came on during earlier tests of Spacecraft 012 (Ref. DR 0868 dated 12/28/66).	2-10	3-6	3-6	
		After an inspection of the SCS wiring schematics associated with the MTVC mode and a review of all its associated data, it is concluded that the MTVC signal was a "False" signal. The malfunction was probably in the harness between the SCS and the PCM system. ITEM CLOSED			