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AN EVALUATION OF THE ATM MAN/MACHINE INTERFACE

Phase 3—Analysis of SL-3 and SL-4 Data

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16. ABSTRACT Until Skylab, little effort had been made to objectively assess and document the functional adequacy of "human factored" crew operated systems under operational zero-gravity conditions. Skylab ATM experiment operations generated sufficient telemetry and voice transcript data to support such an assessment effort. This volume documents that effort. In doing so, discussions are presented pertaining to the methodology and procedures used to evaluate the hardware, training and directive aspects of Skylab 3 and Skylab 4 manned ATM experiment operations. Part of the text details specific design and procedural problems uncovered, factors contributing to the problems uncovered and designs or procedural solutions to those problems. Thus, this volume should be of help to mission operations planners and human factors specialists in preparing for future manned operations in either earth based or zero-gravity environments.

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- Man Systems Division:

  Mr. James R. Bathurst, Project Manager - Program Methodology and Procedures

  Mr. Robert C. Harrison - Analysis of Telemetry Data and Voice Transcripts

  Ms. Dana B. Ludewig - Data Reduction Scheme Development and Analysis of Voice Transcripts

  Mr. Kem B. Robertson - Analysis of Telemetry Data and Voice Transcripts

- Systems Research Division:

  Dr. Richard F. Pain - Inferential Statistics

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FOREWORD

This report was prepared by the Man Systems Division of the URS/Matrix Company under Contract No. NAS8-25627, Modification No. 15, "An Evaluation of the ATM Man/Machine Interface - Phase 3, Analysis of SL-3 and 4 Data", for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center. The technical direction was provided by Mr. Lloyd B. Gardner (COR), Man/Systems Integration Branch, EL15. This report is the summary of the technical effort extending from May 24, 1974, to December 15, 1974. These contract results are documented in two volumes: Vol. I, the Executive Summary, and Vol. II, this Technical Report.

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SECTION 1.0

INTRODUCTION

Presented in this report are discussions of the approach, the results and the conclusions of a study designed to assess past operations of a control console for a complex on-orbit manned system, with the expressed goal of applying these findings to the design and development of future on-orbit control and display systems. The report documents the activities and findings of Phase 3 of an overall study program to evaluate the effectiveness of the Skylab/ATM control/display system.

1.1 SKYLAB/ATM BACKGROUND

Launched in 1973, Skylab was the United States' first manned space station. This vehicle was capable of supporting prolonged manned missions with program objectives related to study of the earth, the sun, man and space technology. The station was manned for a total of 171 days in three periods (SL-2, 28 days; SL-3, 59 days; and SL-4, 84 days).

On Skylab, the sun was the subject of intensive investigation by a manned solar observatory -- the Apollo Telescope Mount (ATM). The ATM consisted of an integrated set of eight telescopes to observe, monitor and record the structure and behavior of the sun and its corona. It also included the necessary guidance and navigation systems for attitude control and telescope alignment, thermal conditioning systems and electrical power systems.

Of the total man-hours spent on Skylab (11,918), approximately 8% of the time was spent in solar observations. Instead of the 880 planned man-hours of investigation, the crews actually spent 941, as shown in the table below (this excludes 156 man-hours spent on SL-4 for the Comet Kohoutek).

Table 1-1: Solar Observation Time Per Manned Period

MANNED PERIOD	MAN-HOURS UTILIZED	% OF TOTAL
SL-2	117	6.0
SL-3	305	7.8
SL-4	519	8.5
TOTAL	941	

Of the nearly 12,000 man-hours of orbital time, over 3,000 were spent in scientific investigation, with approximately 940 man-hours (or 30%) devoted to solar observations. Overall scientific investigation time is summarized in the following table.

Table 1-2: Scientific Investigation Per Manned Period

MANNED PERIOD	MEDICAL	SOLAR OBS.	EARTH RESOURCES	CORRELARY, STUDENT & COMET KOHOUTEK	TOTAL PERIOD	SOLAR OBS. % OF TOTAL PERIOD
SL-2	145	117	71	65	398	29
SL-3	312	305	224	244	1085	28
SL-4	337	419	274	503*	1633	32
TOTALS	794	941	569	812	3116	30

*Includes 156 man-hours spent in Comet Kohoutek using ATM equipment.

1.1.1 ATM Configuration

The ATM cluster consisted of the following instruments covering wavelengths ranging from 2 - 6,500 Angstroms (including two targeting telescopes operating in the Hydrogen-Alpha wavelength):

- Hα1 and 2 Telescope
- White Light Coronagraph (S052)
- X-Ray Spectrographic Telescope (S054)
- UV Scanning Polychromator/Spectroheliometer (S055A)
- X-Ray Telescope (S056)
- XUV Coronal Spectroheliograph (S082A)
- UV Spectrograph (S082B)

These instruments sensed various solar phenomena and converted them to solar images, line spectra and photometrics, which were converted to a video presentation, recorded on film, recorded on tape, or telemetered to the ground.

The ATM was mounted on the orbital assembly such that both it and its solar panels were directed toward the sun during solar observations. The control console for this observatory cluster was located in the Multiple Docking Adapter (MDA), a cylinder 10 feet in diameter and 17 feet long, mounted to the Airlock Module (AM) above the Orbital Assembly (OA). In addition to the ATM control crew station, the MDA also housed the Earth Resources Experiment Package (EREP), the Materials Processing Facility, and miscellaneous experiment storage. The console was located just forward of the MDA/AM interface.

1.1.2 ATM Control/Display Console

This integrated control/display console was originally designed for seated operation in the Lunar Module (LM) in an earlier Skylab cluster configuration.

Later in the program, however, it was relocated to the MDA, and the crew elected to operate it from a standing position. This crew station consisted of the ATM Console, the Foot Restraint Platform (Astrogrid), a Skylab Restraint Assembly (a chair, used only by the SL-2 crew) and a Speaker Intercom Assembly (see Figure 1-1). The restraint platform was adjustable to accommodate variations in the total crew (5th - 95th percentile range).

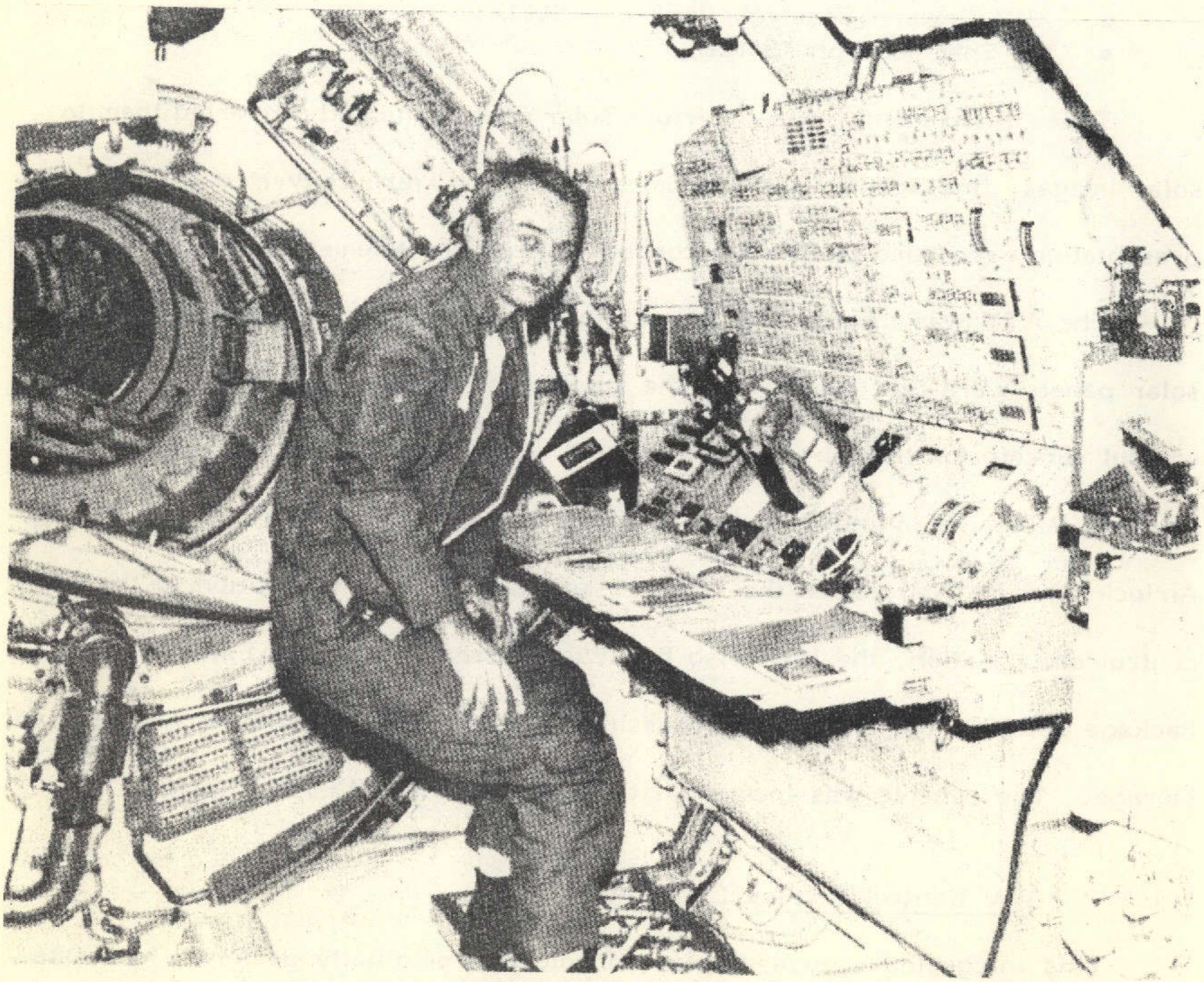

Figure 1-1: Solar Observatory Console (ATM) Crew Station

As illustrated in Figure 1-2, this complex console contained the controls and displays for seven solar experiments, instrument cluster pointing control, electrical power monitoring and control, attitude and stability, two video monitors, etc. The console contained over 1700 square inches of panel space on two planes. The experiment portion of the panel alone housed 96 switches and 37 displays of various types. Each experiment had scientific as well as hardware monitoring status parameters which were measured and telemetered to the ground stations. For example, S082A had 130; S054 had 68. These data were used as inputs to the study.

In order to effectively and efficiently use this complex console in an integrated fashion, various procedure systems were developed called Joint Observing Programs (JOPs). These JOPs (e.g., Program No. 3 - Flares, and No. 14 - Solar Eclipse) enabled instruments to collectively observe solar phenomena. The JOPs consisted of various combinations of intrument configurations, or "Building Blocks" (BBs), thus providing flexibility in selecting the data acquisition method for a particular solar investigation. The JOPs performed on orbit yeilded a voluminous amount of excellent telemetered and film data on solar phenomena.

1.2 PREVIOUS CONTRACT EFFORTS

1.2.1 Phase 1 Activities

In preparation for the assessment of the ATM control/display station interface, the ATM control panel and panel operating procedures were examined to determine what data would be required to reconstruct the panel's operation, post-mission. The projected ATM telemetry measures were then examined to

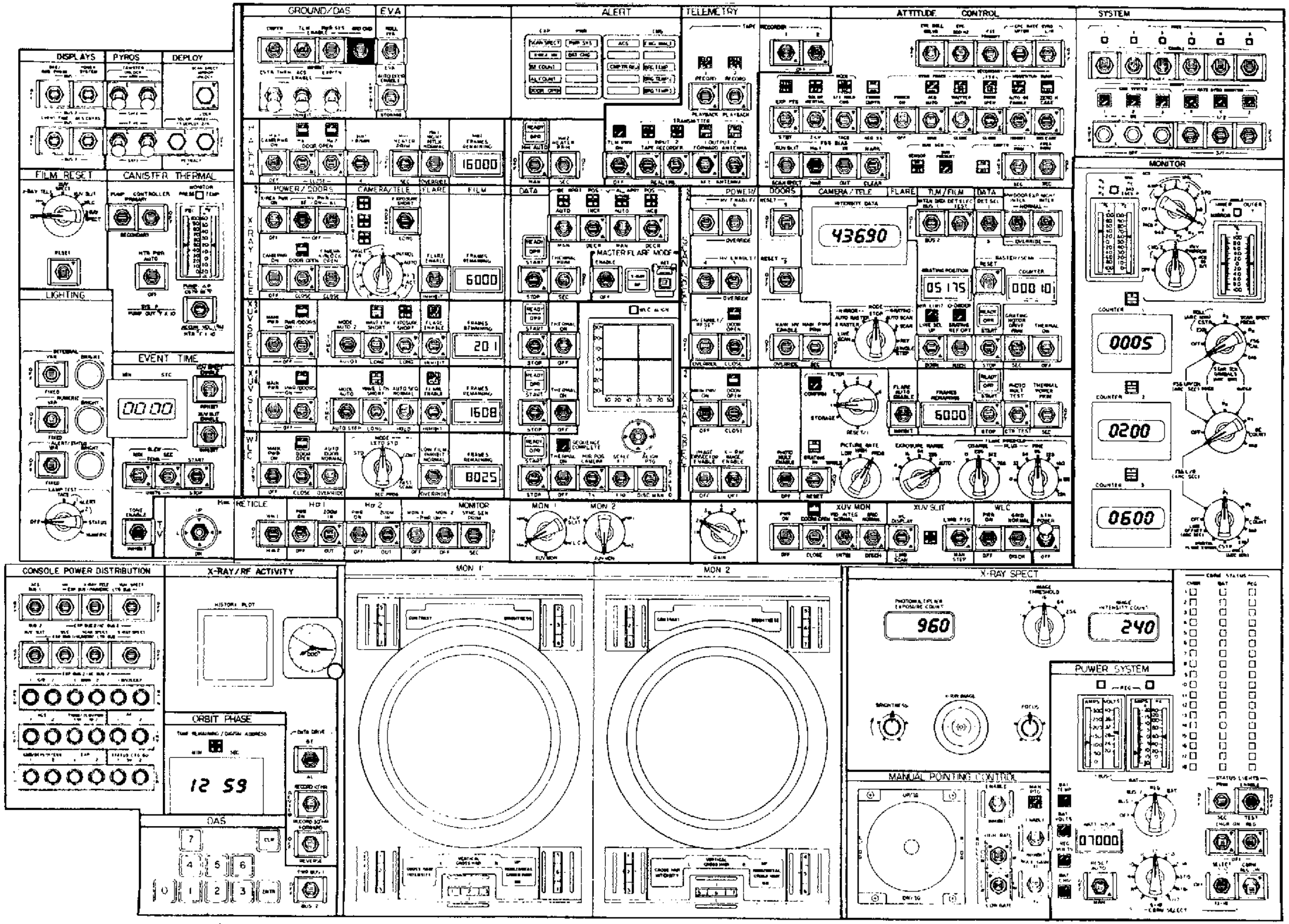

Figure 1-2: ATM Console Control Panels

determine whether the required measures were available, and, upon finding that they were, those that were appropriate to the study were requested.

1.2.2 Phase 2 Activities

In this phase, a compilation of baseline ground data suitable for statistical analysis, a preliminary analysis of SL-2 on-orbit data, and a preliminary statistical comparison of the baseline ground data and the on-orbit data were generated. The results obtained from comparisons of ground based and on-orbit data showed that the same types of errors made during one-g simulations were also made during the on-orbit panel operations.

The findings of the Phase 2 report (Ref. Appendix A), based on an analysis of the SL-2 ATM operations, were:

- The left side of the panel had a higher deviation (error) rate than the right side.
- Three-position toggle switches (F-F-F) used without a display had a high deviation rate.
- Experiment modes that required manual timing by the crewmen were often timed improperly.
- Many of the deviations which occurred during operation of S082B involved confusion with S082A ("B" was set up to "A" specifications).*
- Building Blocks with several subsections separated by pointing commands had high deviation rates for the centermost subsections.

*This was postulated to be due to similarities in controls/displays labeling nomenclature, and BB instructions. For SL-3/4, large red and blue decal letters "A" and "B" and red and blue boundaries (taped strips) were applied to experiments in an attempt to alleviate confusion and, thus, reduce error rates.

- Isolated control actuations had a much higher deviation rate than sequential control actuations.

1.2.3 Applications to Future Missions

Added to the Phase 2 effort was a task to develop a preliminary set of design recommendations, based on the analysis of the deviations in SL-2 panel operation.

Since the operations performed on the ATM console are similar to those projected for the Space Shuttle payloads, the considerations derived from this effort should have direct application for the development of payload control station design criteria and guidelines. These design recommendations are summarized below:

- The number of subsystems (experiments) controlled from the panel's left side should be no greater than the number of subsystems controlled from the right side, assuming similar control/display requirements (control and display density).
- The number of time-phased subsections of Building Blocks should be minimized (preferably four or less).
- Three-position toggle switches (F-F-F) should have a visual display for position indication.
- Experiments that require timing of experiment modes should have dedicated integral timers.
- Isolated control actuations should be minimized. If necessary, they should be accompanied by visual or audible displays, or should be clearly defined in the panel operation procedure.
- If several subsystems (experiments) must be controlled from one panel, similar experiment identification nomenclature (e.g., S082A, S082B) should be avoided. Similar nomenclature for individual controls or displays should also be avoided to prevent confusion, especially when the subsystems are located near each other on the panel.

These data were subsequently incorporated into MSFC-STD-512, Man/System Design Criteria for Manned Orbiting Payloads.

1.3 ANALYSIS OF SL-3 AND SL-4 MISSION DATA (PHASE 3)

Although collection, reduction and analysis of SL-2 ATM panel operations in Phase 2 produced preliminary design criteria applicable to future missions, many of the panel operational problems could not be correlated with panel design features due to an insufficient quantity of data samples (3 crewmen; shortest SL manned mission length). To provide answers to many questions left open by the SL-2 effort, and to increase the confidence level of the resulting design recommendations, an additional effort to collect, reduce and analyze the SL-3 and SL-4 data was undertaken.

1.3.1 Phase 3 Overall Goal and Study Objectives

The overall goal for the Phase 3 effort and, indeed, for the entire ATM Assessment Program, is to update and improve human factors hardware design and procedural guidelines, in order to contribute to improved future manned systems performance. The major objectives outlined and achieved toward that end, during Phase 3, were:

1) Completion of a comparison of Phase 2 results (SL-2 data) with results obtained from the Phase 3 data analyses.

2) Identification of hardware design and procedural parameters contributing to unacceptable ATM experiment system performance.

3) Development and presentation of design guidelines and recommendations for overcoming the unacceptable performance identified in 2) above.

4) Development of a concept and construction of a soft mockup of an optimized, modular control panel envelope capable of accommodating either one or two crew members using ATM component configurations, and being integrated into future Space Shuttle payloads (e.g., Payload Specialist Station).

In the original contract Scope of Work, results of ATM Assessment were to be compared against future mission requirements. The outcome of that comparison was to include identification and documentation of payload missions which would benefit from the criteria and recommendations ensuing from the assessment study and presentation of that information to payload mission designers as an aid to improve the man/system interface. However, in lieu of performing that comparison, the contracting officer directed that a statistical analysis of the data be performed. In accordance with his direction, a statistical analysis was incorporated into the study and the comparison dropped.

1.3.2 Description of SL-3 and SL-4 Crew and Crew Training

As in the previous manned mission (SL-2), the station was manned by three crew members. Each mission included a Commander, a Scientist Pilot, and a Pilot.

Although the scientist pilot (as his name implies) was responsible for the scientific aspect of the mission, all of the crewmen were cross-trained and, therefore, capable of operating the ATM console.

The crews were exposed to various levels and complexity of training for their respective missions, as shown in Tables 1-3 and 1-4. Although the crew for SL-4 had more time in which to prepare, due to their flight date being the latest, they also had less time between the final stages of JOP development and flight date. An attempt was made to keep the workload for SL-4 the same as for SL-3, but, with the added complexity of the mission (e.g., addition of investigation of the comet Kohoutek), the overall time between on-orbit operations was less, thus creating greater ATM activity density for the SL-4 crew.

Table 1-3: Types and Length (in hours) of Astronaut Training - Total ATM

TYPE	SL-2	SL-3	SL-4
SL Simulator	286	419	431
Solar Physics Briefings	290	338	496
Experiment Briefings	82	180	160
MSFC Simulator	26	28.5	65

Table 1-4: Characteristics of JOP

CHARACTERISTICS	SL-2	SL-3	SL-4
Original No. of JOPs	13	15	23
No. of Complex JOPs	8	13	18
No. of Late Modifications	3	2	8
Level of Late Modifications	-	Moderately Heavy	Very Heavy
No. of "Shoppting List"	0	2	2
Time Between JOP Dev. and End of Training (months)	3	$1\frac{1}{2}$ - 2	<1

1.4 PHASE 3 - REPORT OVERVIEW

The Phase 3 study delved into two independent data collections: 1) telemetry data, and 2) voice transcript data. Statistical information about panel usage was derived from telemetry. Due to the voluminous nature of the SL-3 and SL-4 telemetry data, a fixed interval sampling technique was employed in the selection of mission time periods to be analyzed. The voice transcripts were reviewed to document operational problems. In the analyses performed on those data, the following types of factors were addressed in order to assess their effect on ATM panel man/machine integration:

- Control and display component type
- Control and display location
- Operating procedures
- Time of operation in mission
- Panel layout

The methodology used to extract, analyze and test the compiled data is documented in Section 2.0. The data analyses, results and conclusions for the two data collections, as well as the results and conclusions of the hypothesis testing are given in Section 3.0. Section 4.0 contains integrated study results, conclusions and recommendations for future work.

SECTION 2.0

METHODOLOGY

2.1 GENERAL APPROACH

The general approach taken in assessing the man/machine interface on SL-3 and SL-4 incorporated separate analyses of two types of data: 1) telemetry data, and 2) critical incidents noted in the missions' voice transcripts. (See Figure 2-1, Overall Task Flow.) This double approach was used to obtain the most realistic representation possible of the ATM man/machine system.

The telemetry data analysis employed a fixed-interval sampling technique to review routine ATM operations. The critical incidents analysis augmented this routine sampling with information derived from comments made by the flight crews and ground support during and after periods of ATM operation. Subsequent to separate reviews of the two bodies of amassed data, comparisons were made in order to reveal areas of agreement or conflict. Each such area was discussed, and the resulting conclusions were reported.

The overall result of the effort is a set of design recommendations suitable for incorporation into future mission design. The discussion that follows describes each major phase of the study, the assumptions made, the methods employed, and the limitations established.

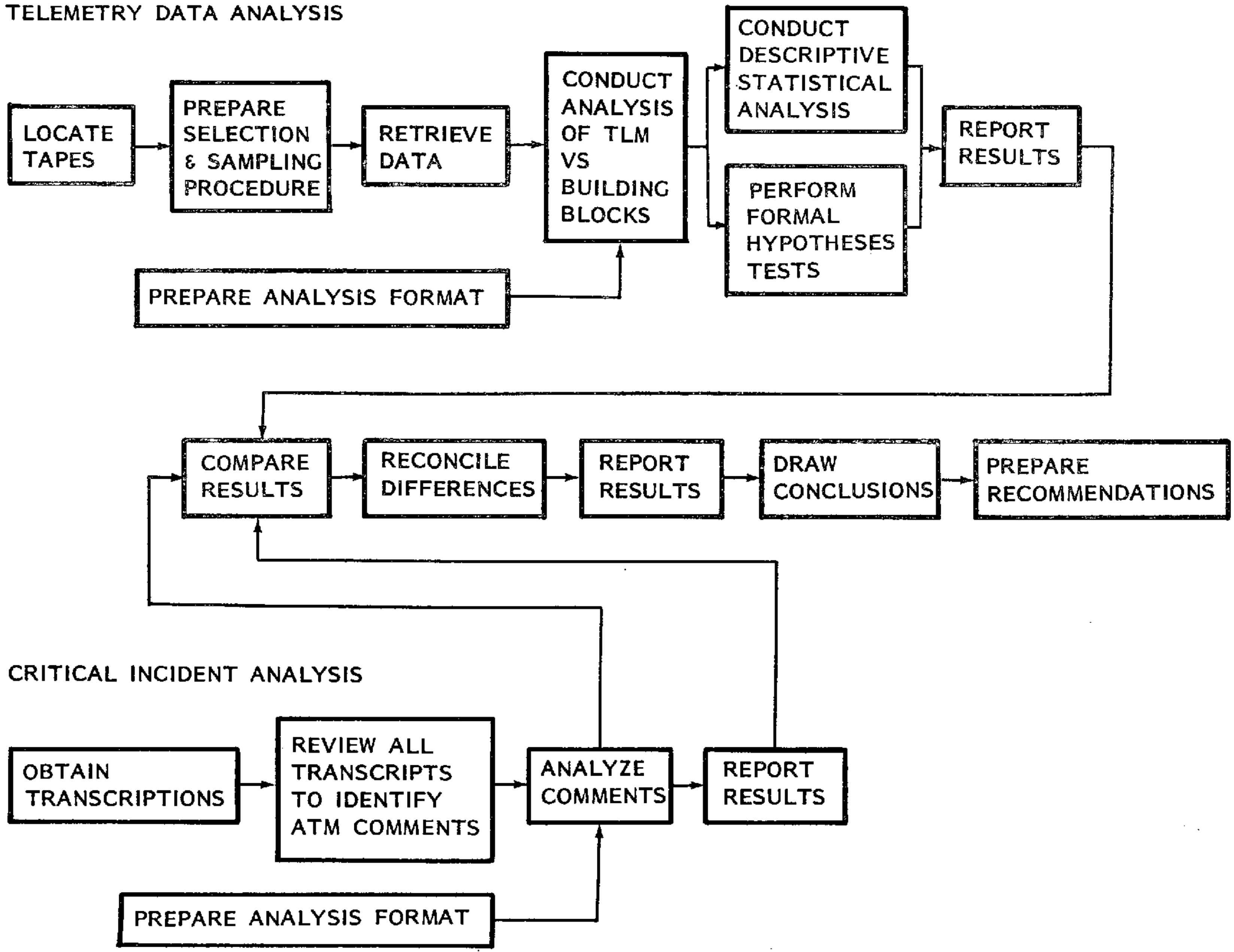

FIGURE 2-1: Study Task Flow Diagram

2.2 TELEMETRY DATA ANALYSIS

2.2.1 Data Point Selection

In order to identify periods of manned ATM experiment operation, the Skylab Mission Events document (Ref. Appendix A) was reviewed. This document describes the activities of each crew member throughout the Skylab 3 and 4 missions. After mission time and duration of each manned ATM operation were identified, the data tapes containing the associated telemetry were located and organized.

A computer program developed by NASA/MSFC during Phase 2 of this contract was used to extract relevant data from the telemetry tapes. Certain information available through telemetry channels appeared to contain useful measures of man/machine performance. A list of the readouts for each ATM experiment is given in Table 2-1. The distribution of components corresponding to each readout and the layout of the ATM control and display panel, as it was flown on SL-3 and SL-4, is illustrated in Figure 2-2.

The ATM panel was selected for analysis for several reasons:

1. The panel represents the most sophisticated, integrated experiment control panel ever used in manned space flight.

2. A considerable amount of data were telemetered to the ground to assist ground-based scientists in planning observations.

3. The panel has undergone some man/machine study during the development and verification process via man-in-the-loop simulation. Results of these ground-based simulations were compared with on-orbit results in an earlier study phase.

4. Some components of the panel represented novel applications of previously used components, and some were entirely new components.

Table 2-1: List of Readouts for Each ATM Experiment

Hα	FR/MIN, 3-POS TOGGLE SW (F-F-F) START-STOP, 3-POS TOGGLE SW (F-F-F)
S056	MODE, ROATRY SW, 11-POS EXPSOURE SW, 3-POS TOGGLE (F-F-F) FLARE ENABLE, 2-POS TOGGLE (F-F) START-STOP, 3-POS TOGGLE (M-F-M)
S082A	MODE, TOGGLE SW, 3-POS (F-F-F) WAVELENGTH TOGGLE SW, 2-POS (M-F-M) EXPOSURE TOGGLE SW, 2-POS (M-F-M) START-STOP TOGGLE SW, 2-POS (M-F-M) FLARE ENABLE TOGGLE SW, 2-POS (M-F-M)
S082B	MODE, TOGGLE SW, 3-POS (F-F-F) WAVELENGTH TOGGLE SW, 2-POS (M-F-M) EXPOSURE TOGGLE SW, 2-POS (M-F-M) START-STOP TOGGLE SW, 2-POS (M-F-M) FLARE ENABLE TOGGLE SW, 2-POS (M-F-M) AUTO SEQ TOGGLE SW, 2-POS (F-F)
S052	MODE, ROTARY SW, 5-POS START-STOP TOGGLE SW, 3-POS (M-F-M) MIRROR POSITION TOGGLE SW, 3-POS (M-F-M)
S055A	MODE, 7 DETECTORS, 3-POS TOGGLE SW (F-F-F) ROTARY SW, 9 POS START-STOP TOGGLE SW, 3-POS (M-F-M) GRATING, 2-POS TOGGLE SW (F-F) GRATING POSITION INDICATOR
S054	GRATING, 3-POS TOGGLE SW (F-F-F) FLARE ENABLE, 2-POS TOGGLE SW (F-F) START-STOP, 3-POS TOGGLE SW (M-F-M) PICTURE RATE ROTARY SW, 4-POS EXPOSURE RANGE ROTARY SW, 6-POS

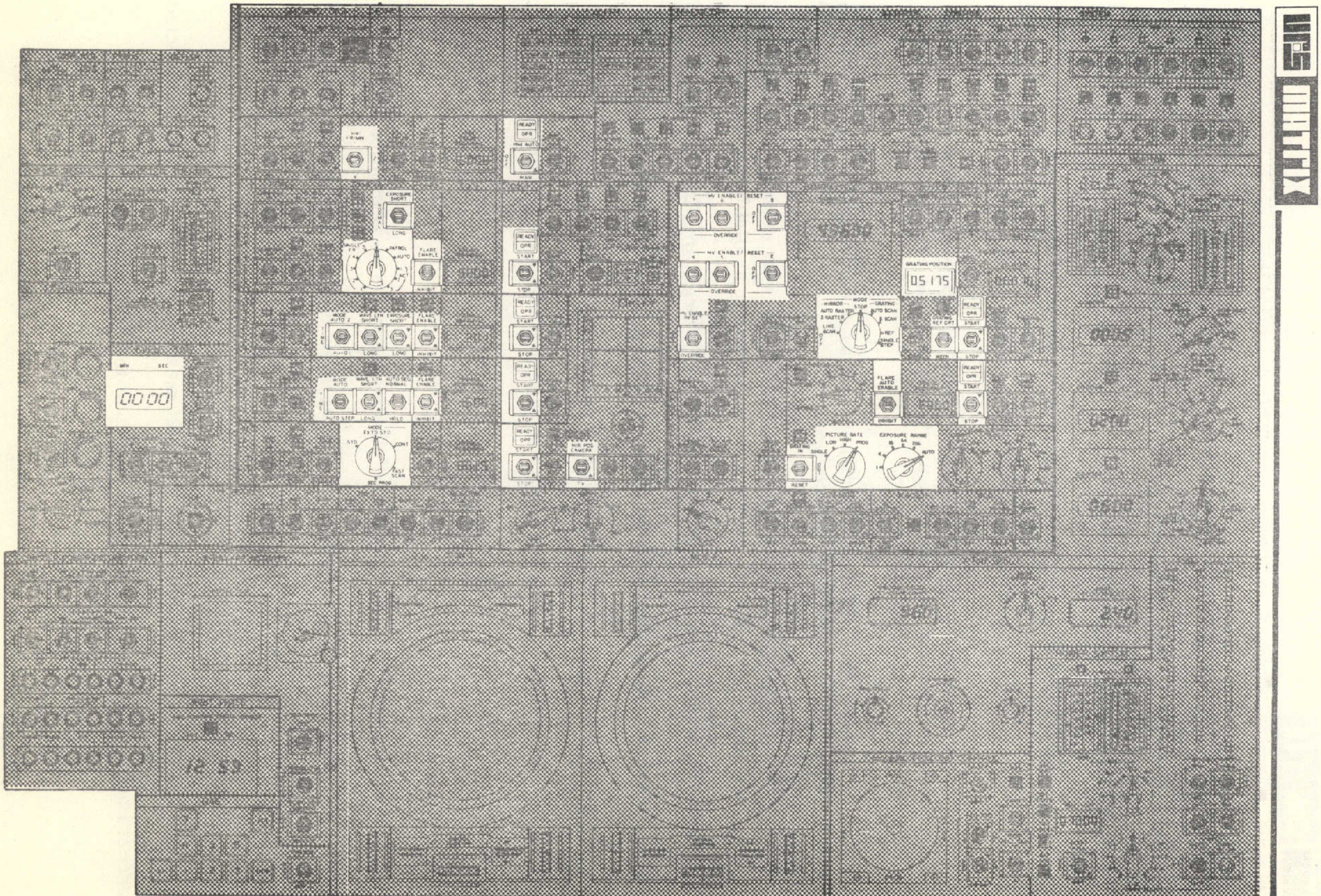

Figure 2-2: Location of Components Monitored in Analysis

The particular components chosen for print-out from the telemetry data tapes were selected to meet certain criteria. Those criteria are listed here in order of priority, with most important first:

1. The component was monitored and telemetered to the ground.
2. The component was involved in key portions of experiment operations.
3. The component complemented other telemetered components in distributing the selected hardware items throughout the experiment portion of the control/display panel.
4. Data from the component could be used as a performance measure when compared to established procedures.
5. The component complemented other components in distributing selected hardware items across types of C/D hardware available on the panel.

From the tapes, data for selected periods of interest in SL-3 and SL-4 were printed out. By sampling every sixth building block from the PAAS (Ref. Appendix A) document, the objective of sampling at fixed intervals throughout the missions was satisfied. This procedure provided 273 total data points to be analyzed. A sample sheet from the PAAS is shown in Figure 2-3 with relevant operations marked.

A sample print-out sheet for one of the experiments is presented in Figure 2-4. Referring to the figure, it can be seen that the print-out provides accurate data on mission time for each operation related to that experiment.

2.2.2 Data Point Scoring

Scoring the telemetry data involved development of a procedure which reflected awareness of several facts regarding the nature of the information.

```
22021  947 55.8195420501954 2050**     43.50.0 0.02017     OBSERVING TIME
22022  948 55.8212822242128222 4 6 32   0.00.0 1.52129SC   55 MAR           &60
22023  948 55.82128222421282224 26 10   0.03.0 5.52130LB1  CMIT82A,82B,54
22024  948 55.82128222421282224 26 10   0.03.0 5.52130LB1  55 MAR DET ALLGRAT 0000
22025  948 55.82128222421282224 26 10   0.02.0 5.52139LB2  OMIT82A,82B,54
22026  948 55.82128222421282224 26 10   0.02.0 5.52139LB2  55 MAR DET ALLGRAT 0000
22027  948 55.82128222421282224 26 10   0.02.0 5.52146LB3  OMIT82A,82B,54
22028  948 55.82128222421282224 26 10   0.02.0 5.52146LB3  55 MAR DET ALLGRAT 0000
22029  948 55.82128222421282224 26 10   0.02.0 5.52154LB3  OMIT82A,82B,54
22030  948 55.82128222421282224 26 10   0.02.0 5.52154LB3  55 MAR DET ALLGRAT 0000
304 22031  948 55.82128222421282224 26 10   0.02.0 5.52201LB4  CMIT82A,82B,54
22032  948 55.82128222421282224 26 10   0.02.0 5.52201LB4  55 MAR DET ALLGRAT 0000
22033  948 55.82128222421282224 26 10   0.02.0 5.52209LB4  CMIT82A,82B,54
22034  948 55.82128222421282224 26 10   0.02.0 5.52209LB4  55 MAR DET ALLGRAT 0000
22035  948 55.8212822242128222 4**      2.00.0 0.02216     OBSERVING TIME
22036  948 55.8212822242128222 4 7  15  0.00.023.52218SC   82B OMIT
22037  948 55.8212822242128222 4 7  15  0.00.023.52218SC   55 STOP DETALLGRAT 0000
22038  949 55.9230123572301235 7 6  32  0.00.0 1.52255SC   55 MAR           &60
22039  949 55.92301235723012357 26 10   0.03.0 5.5225714   OMIT 82A,54
22040  949 55.92301235723012357 26 10   0.03.0 5.5225714   82B EXP N
22041  949 55.92301235723012357 26 10   0.03.0 5.5225714   OMIT 82B       EXP 2
22042  949 55.92301235723012357 26 10   0.03.0 5.5225714   55 MAR DET ALLGRAT 1042
22043  949 55.92301235723012357 26 10   0.02.0 5.5230514   OMIT 82A,54
22044  949 55.92301235723012357 26 10   0.02.0 5.5230514   82B EXP N
22045  949 55.92301235723012357 26 10   0.02.0 5.5230514   OMIT 82B       EXP 2
22046  949 55.92301235723012357 26 10   0.02.0 5.5230514   55 MAR DET ALLGRAT 1659
305 22047  949 55.92301235723012357 26 28   0.03.016.5231314   CMIT82A,52,54
22048  949 55.92301235723012357 26 28   0.03.016.5231314   56 S FR 4      EXP 10:00
22049  949 55.92301235723012357 26 28   0.03.016.5231314   OMIT 56        EXP 2
22050  949 55.92301235723012357 26 28   0.03.016.5231314   82B WV ST      EXP X4
22051  949 55.92301235723012357 26 28   0.03.016.5231314   55 M3RDET12346GRAT 2434
22052  949 55.9230123572301235 7 2A 7A  0.03.0 5.5233221   OMIT 82B,54
22053  949 55.9230123572301235 7 2A 7A  0.03.0 5.5233221   55 MAR DET ALLGRAT 0000
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22055  950 55.8003501300035013 0 6  1A  0.00.0 6.50036SC   82A OMIT
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22059  950 55.8003501300035013 0 6  1B  0.02.019.00042SC   82A OMIT
22060  950 55.8003501300035013 0 6  2   0.02.0 8.00103SC   82A  OMIT
22061  950 55.8003501300035013012E 26   0.02.026.5011321   CMIT82B,52,54
22062  950 55.8003501300035013012E 26   0.02.026.5011321   55 GRAT 00
22063   170
22064  951U55.8020803040208030 4 2AUU1  0.00.017.0024821   52 OMIT
22065  951U55.8020803040208030 4 2AUU1  0.00.017.0024821   54 OMIT
22066  951U55.8020803040208030 4 2AUU1  0.00.017.0024821   55MARDET123467&17
22067  951U55.8020803040208030 4 2AUU1  0.00.017.0024821   55 GRAT 0000
22068  952U56.0034104370341043 7 2AUU1  0.00.041.0034121   52 OMIT
22069  952U56.0034104370341043 7 2AUU1  0.00.041.0034121   54 CMIT
22070  952U56.0034104370341043 7 2AUU1  0.00.041.0034121   55MARDET123467&60
22071  952U56.0034104370341043 7 2AUU1  0.00.041.0034121   55 GRAT 0000
22072  952U56.0034104370341043 7 6 UU1  0.00.019.00422SC   54 OMIT
22073  952U56.0034104370341043 7 6 UU1  0.00.019.00422SC   55MARDET123467GRAT 0000
22074  953U55.8051506110515061 1 2AUU1  0.00.060.0051521   52 CMIT
22075  953U55.8051506110515061 1 2AUU1  0.00.060.0051521   54 OMIT
22076  953U55.8051506110515061 1 2AUU1  0.00.060.0051521   55MARDET 12346&60
22077  953U55.8051506110515061 1 2AUU1  0.00.060.0051521   55 GRAT 2434
22078  954U55.8064807440648074 4 6 UU1  0.00.0 6.00648SC   54 FIL 3
22079  954U55.8064807440648074 4 6 UU1  0.00.0 6.00648SC   55MARDET 12346&60
22080  954U55.8064807440648074 4 6 UU1  0.00.0 6.00648SC   55 GRAT 2434
22081  954U55.8064807440648074 4 2AUU1  0.00.038.00654PT1  52 OMIT
```

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Figure 2-3: Sample Page from PAAS Document

305

MANCE EXPERIMENT/MEASUREMENTS SUMMARY

Orig. req. 16-23-15-0
16-23-35-0

SL-4

START TIME AND INITIAL MATRIX

281*23* 5* * 16

0.00	[illegible]	1.00	0.00	1.0	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	[illegible]	[illegible]	0.00	0.0	1.00	0.00	0.00	1.00	1.00	0.00	1.0	0.00	0.00	0.00	0.00
0.00	[illegible]	[illegible]	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	[illegible]
1.00	1.00	[illegible]	0.00	0.0	0.00	0.00	0.00	0.00	0	1.00	0.00	0.00	0.00	0.00	0.00
1.00	0.00	1.00	0.00	0.0	[illegible]	0.00	0.00	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	[illegible]	[illegible]
1000	1000	1000	1000	100	0	1.00	0	[illegible]	1.00	0.00	1000	0	0.00	0.00	0.00
1.00	0.00	0.00	0	0.00	0.00	0.00	0.00	1.00	0.00	1.00	[illegible]	0.00	0.00	[illegible]	[illegible]

STOP TIME
381 23 35
281*23*36* * 41

LAST MATRIX AND TIME
281*23*35*59*991

1.00	[illegible]	1.0	0.00	[illegible]	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	1.00	0.00	[illegible]	0.00	0.00	0.00	0.00
0.00	0.00	0.00	30	19.64	0.00	0.00	0.00	0.00	0.00	[illegible]	[illegible]	[illegible]	0.00	[illegible]	[illegible]
1.00	[illegible]	3851.28	3907.69	51.26	71.79	15.38	10.26	71.79	2551	1.00	1 .45	14.89	0.00	[illegible]	[illegible]
0.00	[illegible]	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	[illegible]	[illegible]
970	970	972	971	967	0	1.00	974	1009	1.00	0.00	967	42	27.94	0.00	0.00
0.00	0.00	0.00	70	0.00	0.23	0.00	1.00	[illegible]	0.00	1.00	[illegible]	[illegible]	1.00	[illegible]	29.96

PGAS
OMIT 82A, ~~53, 54~~ ok
56 Sfr 4 Exp 10:00 ok
~~OMIT 56 exp 2~~
82B AWV - ST ok time ~~Exp at~~
55 M3R 1234 6 ok
G 2434 ok

BB
56) ~~Sfr~~ omit ok
82A) ~~Time~~ ok
82B) Time
52) ~~Cont (f5)(GH 31D)~~
53) M3R 18-35 ok
54) ~~M3256 x 2~~ ok
H9) 1p/m ERROR 2p/m

Data Point #305
JOP 26
BB 28

381-23-5-0 to 381-23-35-59

2-8

ORIGINAL PAGE IS OF POOR QUALITY

EXPERIMENT H-ALPHA

DAY HR MIN SEC MSEC	H-ALPHA1 CAMERA SHUTTER K409	H-ALPHA1 NIGHT INTLK K042	H-ALPHA1 APR DOOR K295	H-ALPHA1 APR DOOR K296	H-ALPHA2 APR DOOR K289	H-ALPHA2 APR DOOR K290	H-ALPHA1 CAMERA PWR K201	SHUTTER OPEN COUNTER
381*23* 5* 0* 16	CLOSED	NORMAL	OPEN	OPEN	OPEN	OPEN	ON	
381*23* 5* 30*299	OPEN							1
381*23* 5* 32*299	CLOSED							
381*23* 5* 58*299	OPEN							2
381*23* 6* 0*299	CLOSED							
381*23* 6* 30*299	OPEN							3
381*23* 6* 32*299	CLOSED							
381*23* 6* 58*299	OPEN							4
381*23* 7* 0*299	CLOSED							
381*23* 7* 30*299	OPEN							5
381*23* 7* 32*299	CLOSED							
381*23* 7* 58*299	OPEN							6
381*23* 8* 0*299	CLOSED							
381*23* 8* 30*299	OPEN							7
381*23* 8* 32*299	CLOSED							
381*23* 8* 58*299	OPEN							8
381*23* 9* 0*299	CLOSED							
381*23* 9* 30*299	OPEN							9
381*23* 9* 32*299	CLOSED							
381*23* 9* 58*299	OPEN							10
381*23* 10* 0*299	CLOSED							
381*23* 10* 30*299	OPEN							11
381*23* 10* 32*299	CLOSED							
381*23* 10* 58*299	OPEN							12
381*23* 11* 0*299	CLOSED							
381*23* 11* 30*299	OPEN							13
381*23* 11* 32*299	CLOSED							
381*23* 11* 58*299	OPEN							14
381*23* 12* 0*299	CLOSED							
381*23* 12* 30*299	OPEN							15
381*23* 12* 32*299	CLOSED							
381*23* 12* 58*299	OPEN							16
381*23* 13* 0*299	CLOSED							
381*23* 13* 30*299	OPEN							17
381*23* 13* 32*299	CLOSED							
381*23* 13* 58*299	OPEN							18
381*23* 14* 0*299	CLOSED							
381*23* 14* 30*299	OPEN							19
381*23* 14* 32*299	CLOSED							
381*23* 14* 58*299	OPEN							20
381*23* 15* 0*299	CLOSED							
381*23* 15* 30*299	OPEN							21
381*23* 15* 32*299	CLOSED							
381*23* 15* 58*299	OPEN							22
381*23* 16* 0*299	CLOSED							
381*23* 16* 30*299	OPEN							23
381*23* 16* 32*299	CLOSED							
381*23* 16* 58*299	OPEN							24
381*23* 17* 0*299	CLOSED							
381*23* 17* 28*299	OPEN							25
381*23* 17* 29*299	CLOSED							
381*23* 17* 57*299	OPEN							26
381*23* 17* 59*299	CLOSED							
381*23* 18* 30*299	OPEN							27

EXPERIMENT H-ALPHA

DAY HR MIN SEC MSEC	H-ALPHA1 CAMERA SHUTTER K409	H-ALPHA1 NIGHT INTLK K042	H-ALPHA1 APR DOOR K295	H-ALPHA1 AFF DOOR K296	H-ALPHA2 APR DOOR K289	H-ALPHA2 APR DOOR K29[illegible]	H-ALPHA1 CAMERA PWR K2[illegible]1	SHUTTER OPEN COUNTER
381*23* 18* 32*299	CLOSED							
381*23* 18* 58*299	OPEN							
381*23* 19* 0*299	CLOSED							28
381*23* 19* 30*299	OPEN							
381*23* 19* 32*299	CLOSED							29
381*23* 19* 58*299	OPEN							
381*23* 2 * *299	CLOSED							30
381*23* 20* 30*299	OPEN							
381*23* 2 * 32*299	CLOSED							31
381*23* 20* 58*299	OPEN							
381*23* 21* *299	CLOSED							32
381*23* 21* 3 *299	OPEN							
381*23* 21* 32*299	CLOSED							33
381*23* 21* 58*299	OPEN							
381*23* 22* *299	CLOSED							34
381*23* 22* 19*766					CLOSED			
381*23* 22* 3 *299	OPEN							
381*23* 22* 32*299	CLOSED							35
381*23* 22* 58*299	OPEN							
381*23* 23* *299	CLOSED							36
381*23* 23* 30*299	OPEN							
381*23* 23* 32*299	CLOSED							37
381*23* 23* 58*299	OPEN							
381*23* 24* *299	CLOSED							38
381*23* 24* 30*299	OPEN							
381*23* 24* 32*299	CLOSED							39
381*23* 24* 58*299	OPEN							
381*23* 25* *299	CLOSED							40
381*23* 25* 3 *299	OPEN							
381*23* 25* 32*299	CLOSED							41
381*23* 25* 58*299	OPEN							
381*23* 26* 0*299	CLOSED							42
381*23* 26* 3 *299	OPEN							
381*23* 26* 32*299	CLOSED							43
381*23* 26* 58*299	OPEN							
381*23* 27* 0*299	CLOSED							44
381*23* 27* 3 *299	OPEN							
381*23* 27* 32*299	CLOSED							45
381*23* 27* 58*299	OPEN							
381*23* 28* *299	CLOSED							46
381*23* 28* 3 *299	OPEN							
381*23* 28* 32*299	CLOSED							47
381*23* 28* 58*299	OPEN							
381*23* 29* 0*299	CLOSED							48
381*23* 29* 30*299	OPEN							
381*23* 29* 22*299	CLOSED							49
381*23* 29* 58*299	OPEN							
381*23* 3 * *299	CLOSED							50
381*23* 30* 30*299	OPEN							
381*23* 3 * 32*299	CLOSED							51
381*23* 30* 58*299	OPEN							
381*23* 31* *299	CLOSED							52
381*23* 31* 3 *299	OPEN							
381*23* 31* 32*299	CLOSED							53

EXPERIMENT H-ALPHA

PAGE 3

DAY HR MIN SEC MSEC	H-ALPHA1 CAMERA SHUTTER K4?9	H-ALPHA1 NIGHT INTLK K?42	H-ALPHA1 APR DOOR K295	H-ALPHA1 APR DOOR K296	H-ALPHA2 APR DOOR K289	H-ALPHA2 APR DOOR K29?	H-ALPHA1 CAMERA PWR K2?1	SHUTTER OPEN COUNTER
381*23* 31* 58*299	OPEN							54
381*23* 32* 0*299	CLOSED							
381*23* 32* 3?*299	OPEN							55
381*23* 32* 32*299	CLOSED							
381*23* 32* 58*299	OPEN							56
381*23* 33* ?*299	CLOSED							
381*23* 33* 30*299	OPEN							57
381*23* 33* 32*299	CLOSED							
381*23* 33* 59* 49	OPEN							58
381*23* 34* 0* 49	CLOSED							
381*23* 34* 31* 49	OPEN							59
381*23* 34* 32* 49	CLOSED							
381*23* 34* 59* 49	OPEN							60
381*23* 35* ?* 49	CLOSED							
381*23* 35* 31* 49	OPEN							61
381*23* 35* 32* 49	CLOSED							
381*23* 35* 59* 49	OPEN							62

END OF TAPE

EXPERIMENT SC52

PAGE 1

DAY HR MIN SEC MSEC	*** EPCS DYNAMICS *** PES UP-DN G?42	PES L-R G043	IAS UP-DN G?44	IAS L-R G?45 ***	*********** MODE *********** SEC FGM K482	STD X-STD MODE K112	FAST SCAN K112	CONT K112	APR DOOR K112	APR DOOR K298	MIRROR POSITION K433	K434	PWR M35?	DELTA TIME K112
381*23* 5* 0* 16	?.	0.	0.	0.	OFF	ON	OFF	OFF	OPEN	OPEN	FC	FC	0.00	
381*23* 5* 0* 74	0.	0.	0.	0.									0.0?	
381*23* 5* *591						OFF			CLOSED					
381*23* 22* 19*274										CLOSED				0* 0* 0

END OF TAPE

EXPERIMENT SC54

PAGE 1

GMT	START	DELTA TIME HR*MN*SEC	ALTC MODE	FLARE	BIN PK CTR	PWR
DAY HR MIN SEC	KC51A	KC51A	KC51B	KC51C	KC5C	M220
381*23* 5* ?* 16	IDLE	0* 0* 0	MAN	INH	0	0.00
381*23* 5* ?*174					3?	0.00
381*23* 5* 8*816					30	19.64

END OF TAPE

ORIGINAL PAGE IS OF POOR QUALITY

CMT DAY HR MIN SEC MSEC	MIR MODE K252	GRAT MODE K256	DETECTOR 1 M250	DETECTOR 2 M251	DETECTOR 3 M362	DETECTOR 4 M363	DETECTOR 5 M364	DETECTOR 6 M365	DETECTOR 7 M366	GRAT POS K255	LAST GRAT K255	OP/REC REF K254	MIR POS G040	PWR (0-22) M442
281*23* 5* 0* 16	STOP	STOP	OFF	OFF	OFF	OFF	OFF	OFF	OFF	0		OPT	0.00	0.00
281*23* 5* 0*316					ON									
281*23* 5* 0*366										1042			13.32	0.00
281*23* 5* 0*466						ON								
281*23* 5* 0*574	MAR									1042			13.32	0.00
281*23* 5* 0*741			ON					ON						
281*23* 5* 0*991				ON					ON					
281*23* 5* 50*366										1042			23.35	14.93
281*23* 6* 48*366										1042			33.46	14.89
281*23* 7* 46*366										1042			44.43	14.93
281*23* 8* 41*366										1042			54.46	14.93
281*23* 9* 19*366										1042			-1.69	14.87
281*23* 9* 20*741								OFF						
281*23* 9* 20*991									OFF					
281*23* 9* 21*366										1042			10.21	14.87
281*23* 9* 21*466						OFF								
281*23* 9* 22*316					OFF									
281*23* 9* 22*574	STOP									1042			10.13	14.87
281*23* 9* 23*574		GAS								1042			10.21	14.87
281*23* 9* 52*574		SS								1645			10.29	14.87
281*23* 10* 3*574		STOP								1659			10.37	14.87
281*23* 10* 5*574	MAR									1659			10.45	14.87
281*23* 10* 6*466						ON								
281*23* 10* 7*316					ON									
281*23* 10* 7*991									ON					
281*23* 10* 11*741								ON						
281*23* 10* 42*366										1659			0.18	14.87
281*23* 11* 33*366										1659			10.29	14.91
281*23* 12* 28*366										1659			20.40	14.87
281*23* 13* 26*366										1659			30.51	14.87
281*23* 14* 24*366										1659			41.4	14.93
281*23* 15* 24*366										1659			52.44	14.93
281*23* 16* 14*366										1659			-0.29	14.93
281*23* 16* 34*366										1659			10.21	14.87
281*23* 16* 41*991									OFF					
281*23* 16* 42*741								OFF						
281*23* 16* 43*316					OFF									
281*23* 16* 43*466						OFF								
281*23* 16* 43*574	STOP	GAS								1659			10.29	14.89
281*23* 16* 45*574		GAS								1659			10.29	14.89
281*23* 17* 19*574		REF								2425			10.45	14.87
281*23* 17* 20*574		SS								2426			10.21	14.87
281*23* 17* 24*574	MAR	STOP								2434			10.29	14.93
281*23* 17* 28*316					ON									
281*23* 17* 28*466						ON								
281*23* 17* 32*741								ON						
281*23* 17* 56*316					OFF									
281*23* 17* 56*466						OFF								
281*23* 17* 56*574	STOP	GAS								2434			10.29	14.93
281*23* 17* 56*741								OFF						
281*23* 17* 57*574	MAR	STOP								2434			10.29	14.93

EXPERIMENT SC55A

GMT	MIR MODE	GRAT MODE	1	2	3	4	5	6	7	GRAT POS	LAST GRAT	CP/MEC REF	MIR POS	PWR (0-22)
			DETECTOR											
DAY HR MIN SEC MSEC	K252	K256	M250	M251	M362	M363	M364	M365	M366	K255	K255	K254	G040	M442
381*22* 18* 0*316					ON									
381*22* 18* 0*466						ON								
381*23* 18* 2*574	M3R													
381*22* 18* 3*741										2434			10.21	14.93
381*22* 18* 10*366								ON						
381*23* 19* 3*366										2434			0.03	14.87
381*23* 20* 2*366										2434			10.45	14.93
381*23* 20* 53*366										2434			20.48	14.87
381*22* 21* 53*366										2434			30.74	14.93
381*23* 22* 50*366										2434			41.40	14.87
381*23* 23* 43*366										2434			51.43	14.93
381*23* 24* 25*366										2434			-1.84	14.93
381*23* 25* 25*366										2434			8.42	14.87
381*23* 26* 22*366										2434			19.47	14.87
381*23* 27* 15*366										2434			29.50	14.98
381*23* 28* 16*366										2434			39.53	14.93
381*23* 29* 14*366										2434			50.42	14.89
381*23* 29* 16*366										2434			60.52	14.93
381*23* 29* 58*366										2434			-1.84	14.93
381*23* 30* 53*366										2434			8.27	14.87
381*23* 31* 48*366										2434			18.30	14.87
381*23* 32* 44*366										2434			28.33	14.93
381*23* 33* 49*116										2434			38.52	14.87
381*22* 34* 45*116										2434			50.34	14.93
381*23* 34* 49*116										2434			60.60	14.93
381*23* 35* 11*216										2434			8.81	14.93
~~381*23* 35*~~ 11*451						OFF								
381*23* 35* 12* 66								OFF						
381*23* 35* 51*324	STOP	GAS REF			OFF									
381*23* 35* 52*324										2434			10.29	14.91
END OF TAPE										2434			10.45	14.89

EXPERIMENT S056

GMT DAY HR MIN SEC MSEC	FILTER POS K119	DELTA TIME HR MIN SEC K119	SHTR POS K115	CAM AL K117	PWR AMPS K192
381*23* 5* 0* 16	FIL 1	0* 0* 0	CLOSED	OPEN	0.0000
381*23* 5* 19*295			OPEN		
381*23* 5* 35*295			CLOSED		
381*23* 1 * 46*295			OPEN		
381*23* 11* 12*295			CLOSED		
381*23* 11* 13*295	NO FIL				
381*23* 11* 16*295			OPEN		
381*23* 11* 24*295			CLOSED		
381*23* 11* 28*295			OPEN		
381*23* 11* 42*295			CLOSED		
381*23* 11* 45*295			OPEN		
381*23* 12* 2*295			CLOSED		
381*23* 12* 5*295			OPEN		
381*23* 12* 21*295			CLOSED		
381*23* 12* 25*295	FIL 1	0* 7* 25			
381*23* 18* 29*295	NO FIL				
381*23* 18* 53*295			OPEN		
381*23* 18* 56*295			CLOSED	CLOSED	
381*23* 28* 54*295	10 min		OPEN	OPEN	
381*23* 29* 1*295			CLOSED		

SHUTTER OPEN COUNTER 8
END OF TAPE

EXPERIMENT S082A — PAGE 1

GMT	AUTO1	AUTO2	FLARE	FLARE	SHORT WAVE	LONG WAVE	SHORT WAVE	EXP	EXP	SHUTTER	SHUTTER	APR DOOR	APR DOOR	PWR (0-60)
DAY HR MIN SEC	K[illegible]99	K098	K2[illegible]7	K208	K095	K096	K128	K209	K210	K100	K111	K214	K215	M290
381*23* 5* 0* 16	OFF *	OFF *	INH *	OFF *	SHORT*	SHORT*	SHORT*	SHORT*	- *	CLOSED*	CLOSED*	OPEN *	OPEN *	0.0
381*23* 5* 9* 57	*	*	*	*	*	*	*	NOR *	NOR *	*	*	*	*	

SHUTTER OPEN COUNTER 0
END OF TAPE

EXPERIMENT S082B — PAGE 1

DAY HR MIN SEC MSEC	AUTO MODE K179	*AUTO *STEP *K18[illegible]	*FLARE *ENAB *K131	*FLARE *MODE *K22[illegible]	*FOLD * *K133	*LIMB *PTNG *K381	*LIMB *SCNG *K178	*GRAT *SHORT *K103	*GRAT *LONG *K1[illegible]4	*SHTR *OPEN *K1[illegible]8	*SHTR *CLOSE *K130	*APR *DOOR *K215	*TV-M *DOOR *K177	*XUV *DOOR *K244	*PWR *M306
381*23* 5* 0* 16	ON	OFF	INH	OFF	NOR	0.0	OFF	-	LG	CL	CL	OP	CL	0.0	0.0
381*23* 5* 4*807										OP	OP				
381*23* 7* 47*557										CL	CL				
381*23* 1[illegible]* 47*557										OP	OP				
381*23* 1[illegible]* 57*8[illegible]7										CL	CL				
381*23* 11* 1*307										OP					
381*23* 11* 1*557											OP				
381*23* 11* 42* 57											CL				
381*23* 11* 42*3[illegible]7										CL					
381*23* 11* 45*557										OP					
381*23* 11* 45*8[illegible]7											OP				
381*23* 14* 28*557										CL	CL				
381*23* 18* 20*807										OP	OP				
381*23* 19* 1*557										CL	CL				
381*23* 19* 5* 57										OP	OP				
381*23* 21* 47*807											CL				
381*23* 21* 48* 57										CL					
381*23* 21* 51*3[illegible]7										OP	OP				
381*23* 22* 19* 57	OFF														
381*23* 22* 19*299								SH	-				OP		
381*23* 28* 51*557										CL	CL				

END OF TAPE

K1[illegible]8 SHUTTER OPEN 7

2.2.2.1 Data Limitations

The procedure used in scoring the telemetry data (Figure 2-5) included a review of the computer print-outs, the Building Blocks, the voice transcripts, the PAAS document, and the Mission Requirements Document (MRD) for each data point. One of the major shortcomings of a retrospective analysis in an operational environment (as opposed to an experimental environment) is the inability to control variables. This problem manifested itself in the form of unwritten or unrecorded instructions. The analysis reported here is based strictly on performance of the ATM system as compared to updated Building Block instructions. Any "understood" procedures which were not recorded in the mission documentation were not reflected in the analysis. Consequently, if it was understood by the crew that operational times stated for experiments were minimum times, not time limits, overrunning specified times would be appropriate, while underrunning would not be appropriate. In this analysis, however, underrunning and overrunning were evaluated equally because there were no stated instructions to indicate that missing the stated time was acceptable.

Another case in which the problem of unrecorded instructions could have prevailed is that of "understood" procedural deviations. For example, the S055A experiment has a mode switch which allows three mirror raster scans or continuous (auto) raster scans. An understood procedure may have applied in which three rasters at any selected site were adequate. Consequently, by selecting the three-raster mode when formal instructions dictated selection of auto raster, the crewman avoided having to manually terminate the mode. This could have afforded additional

STATISTICAL ANALYSIS DATA POINT SCORING PROCEDURE

1) Secure data point computer print-out.

2) Note mission time on print-out (ref. Step 1).

3) Secure voice transcripts covering data point performance times (± 1 hr.; ref. Step 2).

4) Secure PAAS document.

5) Secure MRD for appropriate mission (SL3 or SL4)

6) Secure ATM experiments description summary document.

7) Secure ATM C&D panel schematic.

8) Secure 1 ea. raw data score sheet.

9) Refer to data point print-out (ref. Step 1) and complete information across top of score sheet (ref. Step 8; e.g., data pt # ___, JOP # ___, etc.).

10) Determine data point BB number (ref. Step 9).

11) Find BB number (ref. Step 10) bar chart in MRD document (ref. Step 5).

12) Note data point performance time (ref. Step 9).

13) Refer to PAAS document (ref. Step 4). Find times that bracket performance period (ref. Step 12) and that pertain to data point BB (ref. Step 10).

14) Record on a note pad special conditions (as presented in PAAS) for modifying BB ordered activity (ref. Step 11).

15) Determine error opportunities:

15a for each ATM experiment in BB (ref. Step 11) note on a pad the control or display activity that must be performed.

15b modify BB steps (ref. Step 15c) as per PAAS instructions (ref. Step 14).

15c refer to voice transcripts (ref. Step 3).

15d update modified BB activity (ref. Step 15b) as per voice transcripts.

15e refer to computer print-out (ref. Step 1) -- modified and updated BB activities (ref. Step 15d) that can be checked via telemetry data for occurrence of errors will be considered error opportunities.

16) Enter error opportunities (ref. Step 15e) on score sheet (ref. Step 8).

16a for each control and display error opportunity (ref. Step 15e), check ATM C&D panel schematic (ref. Step 7) to determine associated hardware type.

16b enter one mark for each error opportunity in appropriate score sheet cell.

16c while performing Step 16b, note whether error opportunity is sequential or single operation and place dot in appropriate score sheet cell.

17) Score Errors

17a From data print-out (ref. Step 1), check data point time of performance.

17b Review the print-out data for the time of performance (ref. Step 17a) and determine which control or display error opportunities (ref. Step 15e) actually resulted in errors.

17c Determine error type and enter first letter of that type in appropriate score sheet cell.

17d While performing Step 17c, note whether error is sequential or single generation and enter dot in appropriate score sheet cell.

Figure 2-5: Procedure for Scoring Telemetry Data time for the crew to conduct other experiments without interruption.

As the data points were selected, it became apparent that the data tapes available included only afternoon and evening operations (GMT 1200-2400 hours). A concerted effort was made to obtain morning tapes, but it was discovered that, in most instances, they were not even existent, due to limitations in ground taping capacity during actual mission flight. After the missions, although the data for most of the morning hours had been telemetered to the ground, MSFC's Skylab Office computer time limitations did not allow transference of the information onto tapes which could be programmed to print out ATM operations. The morning time periods were, therefore, eliminated from the analysis.

2.2.2.2 Distribution of ATM Operations Intervals Analyzed

The fixed-interval sampling technique encompassed data points ranging across most of SL-3 and SL-4 orbital time. Mission times from Day 219 to Day 264 in SL-3 and from Day 331 to Day 398 in SL-4 were sampled. Of the 28 Building Blocks available for use in the SL-3, a total of 14 were exposed to at least one analysis as a data point. Of 39 Building Blocks available for use in SL-4, 19 were subjected to analysis. This distribution of data points across Building Blocks is summarized in Table 2-2.

2.2.2.3 Building Blocks and Other Determinants of Scheduled Operations

The Building Blocks (BBs) were considered the primary procedures instruments for Skylab ATM operations. A sample of these formats, BB #28, is presented in Figure 2-6. As can be seen in the figure, the mode, exposure settings, start

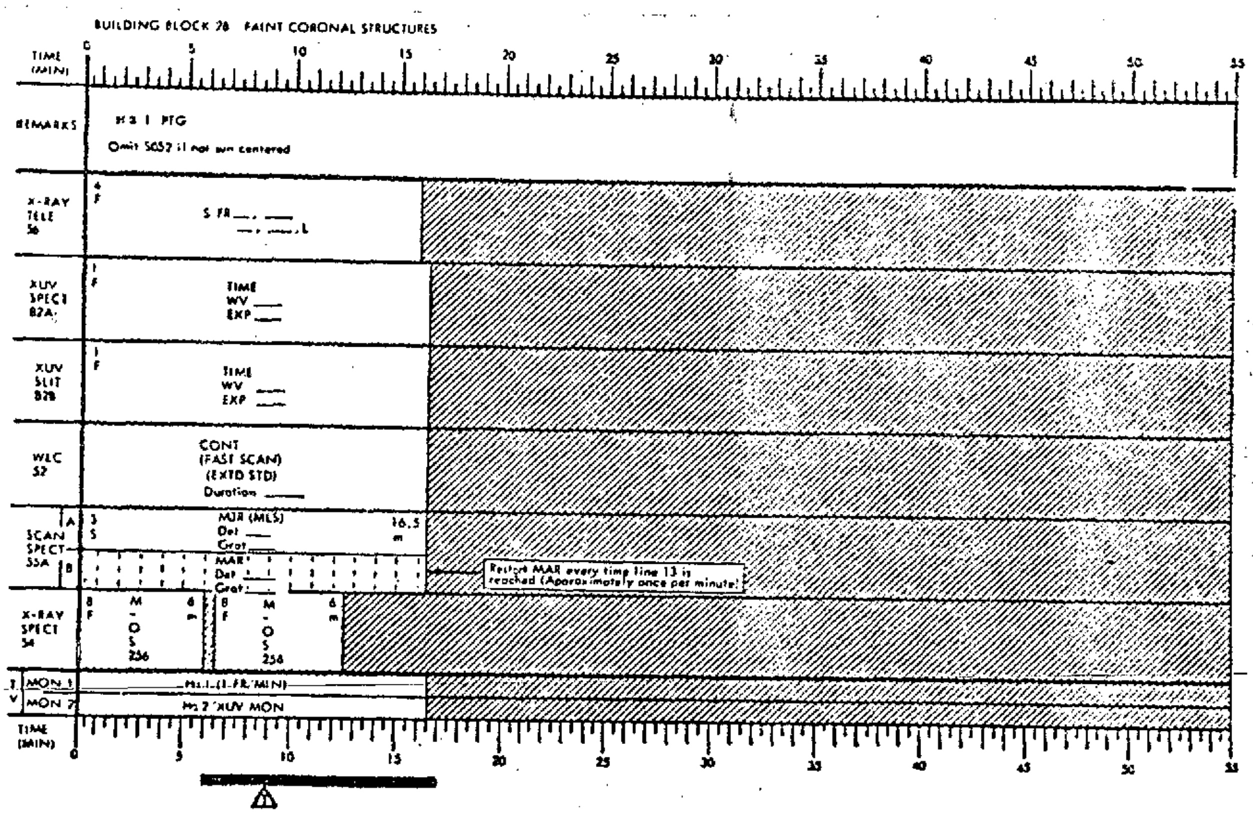
TABLE 2-2: Distribution of Building Blocks Across Telemetry Data Analysis Data Points

SL-3

BUILDING BLOCK NUMBER	NUMBER OF DATA POINTS ANALYZED
10	28
2	20
1	7
11	7
4	5
36	5
5	4
28	4
33	4
13	3
7	2
3	1
17	1
22	1
14	92

SL-4

BUILDING BLOCK NUMBER	NUMBER OF DATA POINTS ANALYZED
10	21
1	19
28	16
32	16
2	9
4	2
11	2
37	2
7	1
8	1
13	1
15	1
17	1
19	1
24	1
26	1
30	1
34	1
39	1
19	98



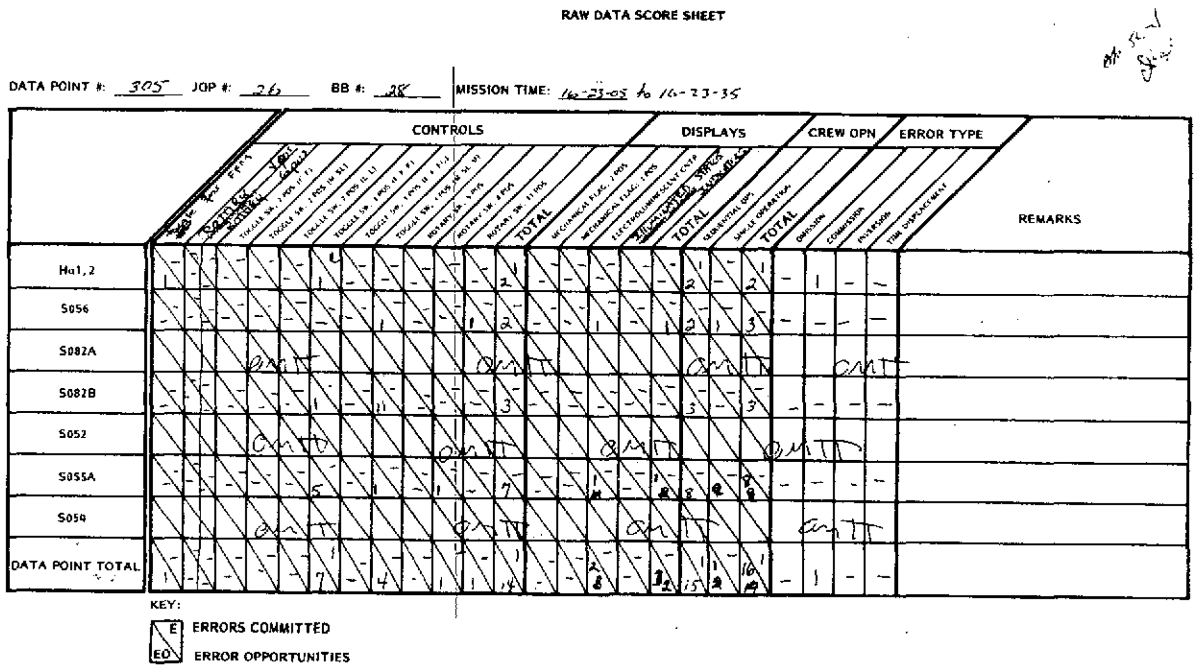
I-MRD-001F
Volume III
Change 6

Figure 2-6: Sample Building Block (BB #28) time, duration, number of frames of data taken, etc., is shown for each experiment operated in a selected Building Block. The clear or unshaded areas represent periods of operation for each designated experiment.

Instructions given via the on-board teleprinter were recorded in the PAAS, and were considered to supersede the Building Block procedures. Similarly, verbal instructions discovered in the voice transcripts were considered to supersede any other instructions. Therefore, procedures indicated in the Building Blocks as modified by the PAAS and/or the voice transcripts, were used as the reference for intended operations. Actual experiment operations (as indicated in the telemetry data print-outs) were compared with the expected operations to identify errors or deviations. Each data point (total of 273) was scored according to the procedure outlined in Figure 2-5, above. A sample Raw Data Score Sheet used for reporting results on each data point is presented in Figure 2.7.

2.2.2.4 Implementation of Data Scoring

One of the difficulties encountered in any analytical process is appropriately defining ground rules, assumptions, terms, etc., relating to the analysis. It is essential to the process to have clearly defined terms and supporting assumptions for use by each member of an analytical team. Therefore, before implementation of data scoring, operational definitions were developed for use by the analysts, in order to assure uniformity of data interpretation. These operational definitions, and several assumptions which were made prior to data analysis, are presented in Figure 2-8.



RAW DATA SCORE SHEET

DATA POINT #: 305 JOP #: 26 BB #: 28 MISSION TIME: 16-23-05 to 16-23-35

CONTROLS | DISPLAYS | CREW OPN | ERROR TYPE | REMARKS

TOGGLE SW. 2 POS; TOGGLE SW. 3 POS; ROTARY SW.; TOTAL; MECHANICAL FLAG; ELECTROLUMINESCENT CKTP; TOTAL; SEQUENTIAL OPS; SINGLE OPERATION; TOTAL; OMISSION; COMMISSION; INVERSION; TIME DISPLACEMENT

Hα1,2

S056

S082A — OMIT

S082B

S052 — OMIT

S055A

S054 — OMIT

DATA POINT TOTAL

KEY:

E — ERRORS COMMITTED

EO — ERROR OPPORTUNITIES

Figure 2-7: Sample Raw Data Score Sheet

Operational Definitions:

1) Control - Hardware item that functions primarily to initiate a change of status.

2) Display - Hardware item that functions primarily to provide operator with information.

3) Control Error - Incorrect control positioning or incorrect control sequencing.

4) Display Error - Inappropriate performance of an operation dependent upon information feedback apart from that provided by a control.

5)* Control Error Opportunity - Control action required by amended Building Block instructions.

6)* Display Error Opportunity - Building Block ordered activity dependent upon information feedback divorced from that provided by controls.

7) Single Operation - An operation separated from its related operations by more than three other events or by more than one minute.

Assumptions:

1) Initiate or terminate actions will be scored as display error opportunities or as display errors when they are keyed to time or unrelated event cues.

2) The ATM Experiments Description Summary document will define equipment operating modes.

3) An error opportunity exists only when sufficient telemetry data are provided for analysts to determine whether or not an error was committed.

---

*Refer to Assumption number three.

Figure 2-8: Statistical Analysis Operational Definitions and Assumptions

In exercising the analytical tools to develop forms, definitions and procedures, it was discovered that, based on telemetry data, it is difficult to distinguish between control errors and display errors. For example, on the S055A experiment, instructions were given to the crewmen to set the grating at a pre-established reading. A digital readout was provided to indicate the grating position. If the operator set the grating at 0112 instead of the instructed 0157, is this the result of misreading the display or neglecting to initiate a stop command to stop the grating scan at the appropriate time? In cases such as this, the error was classified as a display error. By the operational definitions, the "inappropriate performance of an operation dependent upon information feedback apart from that provided by a control" is considered a display error.

In the specific case of the S055A grating position indicator, provisions were made to allow some latitude around the instructed value. A fine point (i.e., $\pm$0005) tolerance around the desired value was established as a reasonable band for positioning the grating. This limit was based on the fact that the units digit of this display changed so rapidly that it was nearly impossible to exactly position the grating without single stepping. Consequently, the tens digit was very likely used for positioning the grating.

Limits or tolerances also had to be established for time sequences. For example, if the Hα1 camera was intended to be operated at 2 frames/min. for 3 minutes. How much time short of and beyond the two minute desired time was considered acceptable? A basic guideline of $\pm$10% of the desired time was considered acceptable. Excursions outside this ±10% band were classified as time displacement errors.

The Raw Data Score Sheet (Figure 2-7) provided space for recording reference information on each data point. Across the top of the sheet are spaces for recording the number of the data point, Joint Observing Program (JOP) Number, Building Block (BB) number, and mission time. This information was available in the PAAS document, with the exception of the data point number which was arbitrarily assigned by URS/Matrix analysts when the time periods for analysis were initially selected from the PAAS.

The remainder of the score sheet was devoted to man/machine performance scores for the various components monitored via telemetry for each ATM experiment. The column at the far left of the score sheet included the designators for the ATM experiments. The scientific name corresponding to each of the designators is presented in Table 2-3.

Table 2-3: ATM Experiments Evaluated

Designator Code	Scientific Name
Hα1 and 2	Hydrogen Alpha #1 and #2
S052	White Light Coronagraph
S054	X-Ray Spectrographic Telescope
S055A	UV Scanning Polychromotor/Spectroheliometer
S056	X-Ray Telescope
S082A	XUV Coronal Spectroheliograph
S082B	UV Spectrograph

The horizontal axis of the data score sheet included columns for control components and display components. The abbreviations after the title of each type of toggle switch refer to the characteristic of each switch position. These abbreviations are: F, fixed; M, momentary; L, latching; SL, spring-loaded; FG, fix-guarded. The display component types are listed in the adjoining columns.

Space was provided at the right side of the data score sheet for classifying the activity as either a sequential or a single operation. The next set of columns afforded space for calssifying the error type. Errors of omission, inversion and time displacement were mutually exclusive categories. The extreme right-hand column provided space for remarks which were felt by the analyst to be relevant to interpreting the score sheet entry.

The cells in the data score sheet provided space for recording number of errors committed (as inferred from comparison of expected activity and telemetered readouts) and error opportunities. The quotient of these two quantities is then used as an error rate in subsequent calculations. In no case is it possible to have an error committed without an error opportunity. That is, even though a haphazard event may have been recorded from telemetry which cannot be reconciled with procedural instructions, it is not recorded as an error without an error opportunity. In this case, an error opportunity was entered in the opportunity space to simplify calculations which were to follow.

2.2.3 Inter-Rater Reliability

The data point scoring was performed by three analysts. Prior to the actual analysis process, these individuals, together with two other senior analysts conducted data scoring exercises with candidate operational definitions and candidate scoring sheets. As several data points were scored, areas of conflict were discussed and the operational definitions and score sheets were modified to alleviate problem areas. This procedure also served as an opportunity to "walk through" the scoring procedure for training purposes. Thus, inter-rater variability was reduced to a minimal level. Prior to the major data point scoring effort, a single data point was scored independently by each of the analysts. A comparison revealed no substantial differences in error rates derived by the three analysts.

2.2.4 Statistical Analysis

2.2.4.1 Descriptive Statistics

To report the results of the telemetry, data descriptive statistics were prepared summarizing the distribution of error rates across the reference variables. Those descriptive statistics included three methods of analysis: 1) a cell to cell comparison of Table 3-1 data, 2) a look at parameter effects, and 3) an in-depth analysis of factors contributing to unacceptable error rates. Tables and discussions supportive to those analyses are provided in subsequent sections of this report to describe and compare error rates by experiment, mission time, Building Block, etc.

2.2.4.2 Hypothesis Testing

As a result of a study of SL-2 telemetry data under an earlier contract phase and the preliminary findings resulting from that study, several hypotheses were developed for testing in the SL-3/SL-4 analysis. These hypotheses are:

1. The use of three-position toggle switches produces a significantly higher error rate than does the use of other types of toggle switches.

2. The use of rotary switches with positions numbering more than four produces a significantly higher error rate than does the use of rotary switches with four positions.

3. The use of rotary switches with positions numbering more than four produces a significantly higher error rate than does the use of other types of switches investigated.

4. Experiments operated on the left side of the C&D panel produce a significantly higher error rate than do experiments operated on the right side.

5. Operating Hα1 produces a significantly higher error rate than does operating any other experiment on the left side of the panel.

6. Performing "isolated actuations" produces a higher error rate than does performing "sequential operations".

7. There is no significant difference in performance between operating S082A and operating S082B.

8. Operating experiments with high C&D layout similarity (e.g., Hα1, S052, S082A, S082B) produces a higher error rate than does operating experiments with dissimilar C&D arrangements (e.g., S056, S055A, S054).

9. Operating the lower half of the ATM panel produces a significantly higher error rate than does operating the upper half of the panel.

10. SL-4 operations produce lower error rates than do SL-3 operations.

11. The first one-third of each mission's operations produce higher error rates than do the remaining two-thirds of each mission's operations.

Two statistical methods were employed to test the hypotheses. These were chi-square and a 2 x 2 analysis of variance for repeated measures. Results of the statistical analysis appear in Section 3.1.2.

2.3 CRITICAL INCIDENTS ANALYSIS

2.3.1 General Approach

Because the telemetry data analysis employed a sampling strategy, it was felt that a review of all the available SL-3 and SL-4 voice transcripts could reveal other periods of problems that might be of interest and could provide a different slant on the operation of the ATM control/display panel. Consequently, these transcripts were obtained and reviewed to identify relevant remarks.

2.3.2 Nature of the Data

In reviewing the voice transcripts for the SL-3 and SL-4 missions, it was recognized that an information body very different from the telemetry data was involved. The most outstanding difference was the subjective nature of the information -- being composed of the actual statements and questions made by the flight and ground crews during and after the ATM passes. Rather than having a record of exactly what happened, the analysts had a partial record of what was perceived. That the voice transcripts contain only flight and ground crew perceptions is obvious -- something must be perceived before a comment about it may be voiced.* The "partial" characteristic of the data may be explained by four limitations:

1) It is not reasonable to assume that everything perceived was voiced aloud.
2) Not everything voiced aloud was recorded.

*The exception to this is mission time, which was coded on the tapes as comments were recorded.

3) Not every recorded verbal comment was translated to tape.

4) Not every taped comment was included in the edited transcriptions of the tapes.

As URS/Matrix analysts worked from the MSFC/HOSC collection of edited voice transcripts in culling for critical incidents, they had to develop a methodology which would allow collection of as much information as possible related to the ATM man/machine interface while, at the same time, accommodating the inherent limitations of the data body.

2.3.3 Types of Information Available

Certain general information was available in the transcripts. Mission day and time were coded as comments were made. Occasionally, the flight crew or ground control referenced their comments to specific JOP, Building Block, Shopping List, and/or experiment numbers. The comments ranged from very broad remarks about whole panel layout and ATM pass scheduling to very specific comments or questions about number of seconds exposure for a certain frame in a certain experiment and problems encountered with a specific control or display. The analysts were able to determine from the comments, with few exceptions, whether the remark was of a positive or negative nature. Adding to these remarks the analysts' own knowledge of panel hardware and experiment procedures, they were able to infer a relative level of severity or benefit to overall ATM, specific experiment, or specific hardware item function intimated by the remark.

2.3.4 Organization and Reduction of Voice Transcript Derived Data

To organize all this information, a Critical Incidents Raw Data Score Sheet (Figure 2-9) was generated. This form enabled the analysts to record as much information as was available from the voice transcripts (not every blank was filled in on every sheet). This information was further reduced by tallying and subsequent across-hardware type, across-procedure, across-experiment, and across-mission comparison, with the experiments rank ordered by frequency of remark occurrence.

The comparison by remark frequency was then complemented by a study of the relative impact of a noted problem, regardless of the number of times it was mentioned. This was done to allow for those instances in which a small number or single remark may have revealed an important problem.

2.3.4.1 Data Breakdown

Before scoring the compiled critical incidents from SL-3 and SL04, the three principal personnel assigned to Critical Incidents Analysis reviewed the total body of data gathered. It was apparent that the incidents reported in the transcripts fell generally into two large categories: 1) reports of errors on the part of the flight crew or the ground, and 2) comments (not associated with an error) criticizing or complementing various procedures, schedules, operations, or hardware.

As the remarks were reviewed, a more detailed picture of the two categories emerged and was refined into the following sets of categories and subcategories:

ERRORS

Errors were divided into four types:

- Commission error - Flight crew performed some operation that was not supposed to be performed, or performed an operation inacurrately.
- Omission error - Flight crew failed to perform a directed operation.
- Inversion error - Flight crew performed two or more operations out of sequence from the way they were scheduled.
- Time displacement error - Flight crew performed some operation early or late, or ran out of time and could not complete an operation.

These were then subclassified, wherever the data indicated, as pertaining to either hardware or procedures, as shown below.

Hardware

- Controls, by type
- Displays, by type

Procedures

- Scheduling or instructions -- as trained, contained on the cue cards, pad, provided by way of special voiced instructions, etc.
- Operations - performing or failing to perform an operation pertaining to the ATM panel.
- Time displacement - not performing an operation at the scheduled time.

COMMENTS

These data were divided into the same hardware and procedural groupings used for subclassifying error categories, e.g.,

Hardware

- Controls
- Displays

Procedures

- Scheduling/Instructions
- Operations
- Time Displacement.

The difference between "comments" and the incidents scored as errors was that the critical remarks scored as "comments" were not immediately and obviously associated with an error. They were mostly remarks about the hardware, schedules, or procedures, i.e., comments about inadequacies in specific hardware parts, suggestions for improving instructions, beneficial discoveries about hardware auxiliary capabilities, questions about proper procedures, and requests for clearer instructions.

2.3.4.2 Basic Scoring Procedure

After review of all the Critical Incidents Raw Data Score Sheets, the three analysts principally involved in reading the transcripts conferred to score each reported incident into the appropriate categories and subcategories described in Paragraph 2.3.4.1. Remarks were scored as,

- *Error* (+ type, *i.e.*, commission (C), omission (O), inversion (I), time displacement (TD))
- "Comment", a remark not associated with an error (recorded as a "positive comment" (C+) or "negative comment" (C-)).

It must be realized that every scored critical incident evolved out of some remark made by either the flight crew or the ground support team, but the term "comment" in the context of critical incidents analysis scoring has a special meaning, as indicated by the discussion of the term in Paragraph 2.3.4.1.

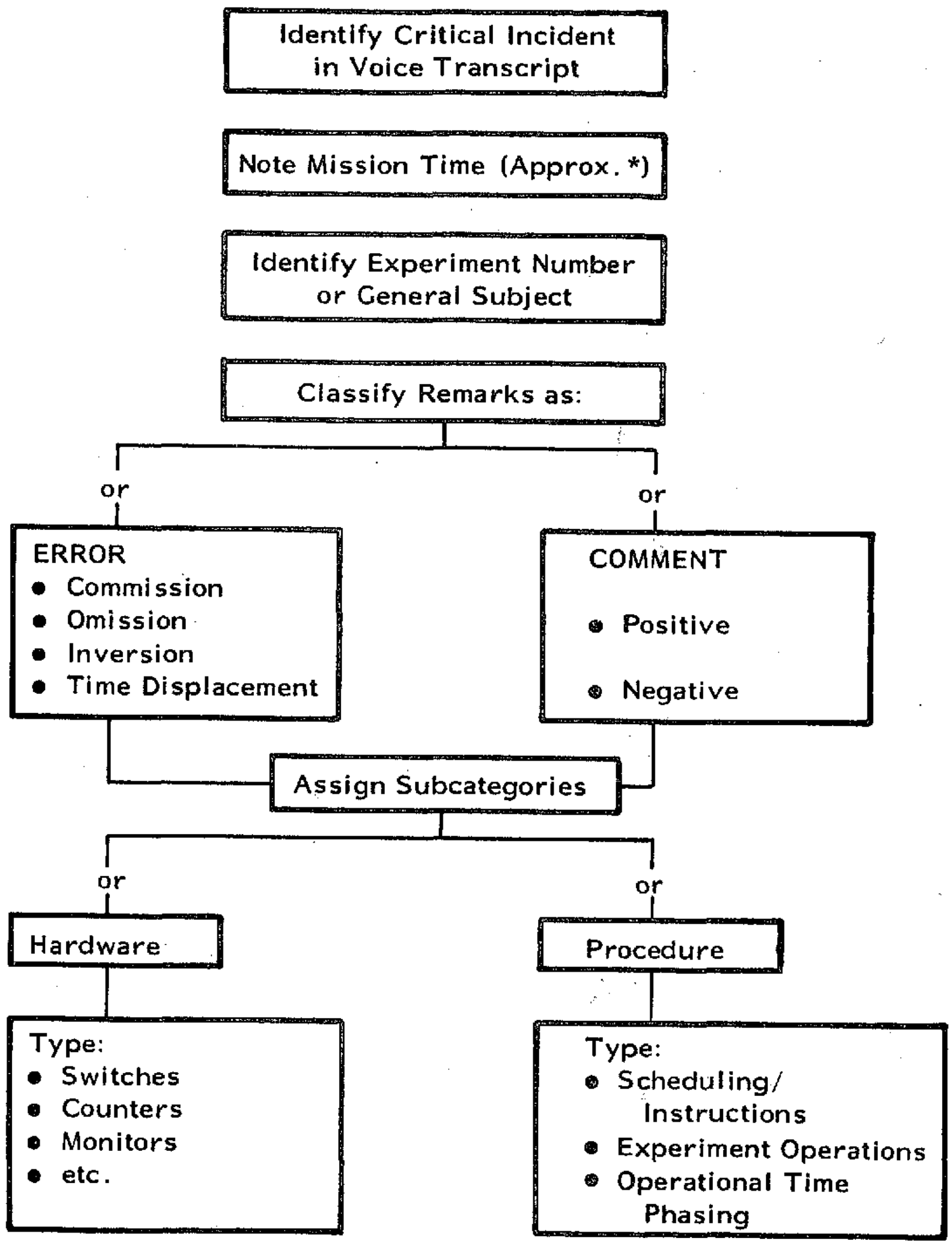
The procedure for identifying, classifying and scoring critical incidents is shown in Figure 2-10.

Some examples of incidents and scores are provided below to show more precisely how scoring criteria were applied.

	Incident	Scored as:
Example #1: Day 231-16-01-02	Crewman began S052 Building Block before ESR by mistake.	Commission Error, Time discrepancy (C, TD).
Example #2: Day 232-10-45-05	Ground informed crew that the Voltage Detector had been left in ENABLE overnight.	Omission Error, Operations (O, O)
Example #3: Day 226-28-06-20	Crew remarked that S055 Detector 5 kept kicking off during MARs, so they turned it off.	Negative Comment, HV Detectors (C-, Detectors)

Basically, these scores were entered into master tables for SL-3 and SL-4 across from the experiment they pertained to and under the hardware or procedure type identified in the remark. Errors and "comments" were tallied separately, so discussion could take place with regard to: 1) noted (or inferred) error frequency, and 2) non-error associated remark frequency. Total incidents (including both noted errors and non-error remarks) were also computed and studied.

In addition to the data scored on the master score sheets for SL-3 and SL-4, a running log was maintained for the purpose of recording single event critical incidents. That is, all voice transcript comments that were, by themselves, considered to be important were noted and saved for future discussion.



*Voice transcripts revealed what time the remark was made and, therefore, the analysts had only an approximate indication of what time the incident actually occurred.

Figure 2-10: Flow Diagram of Critical Incidents Scoring Procedure (Shows major classifications and subclassifications of critical incidents used in data breakdown and scoring.)

The master tables for SL-3 and SL-4 Critical Incidents Analysis and results of the analysis are presented in Section 3.2.

SECTION 3.0

DATA ANALYSES, RESULTS AND CONCLUSIONS

This section addresses the analyses, results and conclusions of separate studies of two bodies of data. Fundamental to many parts of the discussions presented here are detailed descriptions of the analysis procedures and the ways they were used to extract the results and conclusions reported. Therefore, Section 3.1 contains discussions of procedures used, results obtained and conclusions drawn during the descriptive statistical analysis and during the formal testing of hypotheses relating to the telemetry data. Section 3.2 contains discussions of procedures, results and conclusions associated with the analysis of the voice transcript data.

3.1 TELEMETRY DATA

Before the raw telemetry data could be subjected to statistical analysis, it was necessary to tally the rows and columns of all of the individual data point score sheets, an example of which is shown in Figure 3-1. This was done using time as an index, the data were pooled within each one-third of each of the two Skylab missions studied. Thus, three Data Summary Sheets (see Appendix B, Figure B-1a - B-1F) were prepared for each mission. The summary totals for each one-third mission period were, in turn, added with the other two one-third summaries for the same mission to provide a Whole-Mission Data Summary Sheet (Appendix B, Figure B-2a - B-2b). Then, all four data summary sheets for each mission were used

RAW DATA SCORE SHEET

DATA POINT #: 305 JOP #: 26 BB #: 28 MISSION TIME: 16-23-05 to 16-23-35

CONTROLS

	[illegible]	[illegible]	TOGGLE SW. 2 POS (F F)	TOGGLE SW. 2 POS (M SL)	TOGGLE SW. 2 POS (L L)	TOGGLE SW. 3 POS (F F F)	TOGGLE SW. 3 POS (F F FL)	TOGGLE SW. 3 POS (M SL SL)	ROTARY SW. 5 POS	ROTARY SW. 8 POS	ROTARY SW. 11 POS	TOTAL
Ha1,2	-/1	-/-	-/-	-/-	-/-	-/1	-/-	-/-	-/-	-/-	-/-	1/2
S056	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/1	-/-	-/-	-/1	-/2
S082A	OMIT											OMIT
S082B	-/-	-/-	-/-	-/-	-/-	-/1	-/-	-/11	-/-	-/-	-/-	-/3
S052	OMIT											OMIT
S055A	-/-	-/-	-/-	-/-	-/-	-/5	-/-	-/1	-/-	-/1	-/-	-/7
S054	OMIT											OMIT
DATA POINT TOTAL	-/1	-/-	-/-	-/-	-/-	1/7	-/-	-/4	-/-	-/1	-/1	1/14

DISPLAYS

	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTR	ILLUMINATED STATUS INDICATORS	TOTAL
Ha1,2	-/-	-/-	-/-	-/-	-/-
S056	-/-	-/-	-/1	-/-	-/1
S082A					OMIT
S082B	-/-	-/-	-/-	-/-	-/-
S052			OMIT		
S055A	-/-	-/-	1/4	-/-	1/2
S054			OMIT		
DATA POINT TOTAL	-/-	-/-	-/8	-/-	-/32

CREW OPN

	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL
Ha1,2	1/2	-/-	1/2
S056	-/2	-/1	-/3
S082A	OMIT		
S082B	-/3	-/-	-/3
S052		OMIT	
S055A	-/8	-/4	8/4
S054	OMIT		
DATA POINT TOTAL	1/15	1/2	1/16

ERROR TYPE

	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	REMARKS
Ha1,2	-	1	-	-	
S056	-	-	-	-	
S082A		OMIT			
S082B	-	-	-	-	
S052	OMIT				
S055A	-	-	-	-	
S054		OMIT			
DATA POINT TOTAL	-	1	-	-	

KEY:

E — ERRORS COMMITTED

EO — ERROR OPPORTUNITIES

Figure 3-1: Example of Raw Data Score Sheet for Telemetry Data Analysis

Table 3-1: Error Rate Comparison Table

		COLUMN	A	B	C	D	E	F	G	H	I
		X/3 OF MISSION	1/3	2/3	3/3	1/3	2/3	3/3	TOTAL	TOTAL	TOTAL
		MISSION	SL-3	SL-3	SL-3	SL-4	SL-4	SL-4	SL-3	SL-4	SL-3&SL-4
	ROW NUMBER	ROW TITLE									
	1	CONTROLS TOTAL	.041	.050	.026	.007	[.012] .024	[.015] .034	.042	[.012] .021	[.027] .032
CONTROLS	2	Hal	.069	.257	.208	.000	[.000] .125	[.000] .167	.176	[.000] .092	[.058] .129
CONTROLS	3	S056	.033	.032	.027	.009	.045	-	.032	.013	.022
CONTROLS	4	S082A	.000	.030	.000	.000	.000	.024	.011	.011	.011
CONTROLS	5	S082B	.050	.087	.000	.000	.038	.000	.052	.011	.029
CONTROLS	6	S052	.069	.000	.067	.023	.000	.051	.053	.034	.039
CONTROLS	7	S055A	.046	.012	.010	.010	.000	.014	.024	.010	.018
CONTROLS	8	S054	.028	.058	.000	.000	.000	.013	.039	.005	.027
	9	DISPLAYS TOTAL	.271	.092	.070	.125	.068	.023	.141	.067	.100
DISPLAYS	10	Hal	-	-	-	-	-	-	-	-	-
DISPLAYS	11	S056	-	-	-	-	.000	.000	-	.000	.000
DISPLAYS	12	S082A	.250	.000	.000	.000	.000	.000	.062	.000	.023
DISPLAYS	13	S082B	.000	.000	.000	.000	.111	.000	.000	.045	.031
DISPLAYS	14	S052	-	-	.000	.000	.000	.105	.000	.074	.069
DISPLAYS	15	S055A	.279	.117	.088	.195	.091	.000	.164	.090	.130
DISPLAYS	16	S054	-	-	-	-	-	-	-	-	-
	17	CONTROLS & DISPLAYS TOTAL	.055	.054	.030	.018	[.019] .029	[.017] .033	.049	[.018] .026	[.033] .038
CONTROLS & DISPLAYS	18	Hal	.069	.258	.208	.000	[.000] .125	[.000] .167	.176	[.000] .092	[.058] .129
CONTROLS & DISPLAYS	19	S056	.033	.032	.027	.009	.042	.000	.032	.013	.022
CONTROLS & DISPLAYS	20	S082A	.020	.023	.000	.000	.000	.018	.018	.009	.013
CONTROLS & DISPLAYS	21	S082B	.049	.077	.000	.000	.057	.000	.046	.017	.030
CONTROLS & DISPLAYS	22	S052	.069	.000	.063	.021	.000	.060	.052	.039	.042
CONTROLS & DISPLAYS	23	S055A	.073	.026	.021	.033	.014	.012	.042	.021	.033
CONTROLS & DISPLAYS	24	S054	.028	.058	.000	.000	.000	.013	.039	.005	.027
COMPONENT TYPE	25	TOGGLE, 2 POS, F-F	.000	.000	.000	.000	.000	.000	.000	.000	.000
COMPONENT TYPE	26	TOGGLE, 3 POS, F-F-M	.000	.000	.000	.000	.000	.000	.000	.000	.000
COMPONENT TYPE	27	TOGGLE, 3 POS, F-F-F	.063	.070	.026	.003	.040	.062	.058	.032	.046
COMPONENT TYPE	28	TOGGLE, 3 POS, M-SL-M	.026	.029	.011	.000	.017	.018	.024	.012	.018
COMPONENT TYPE	29	ROTARY, 4 POS	.000	.000	.000	.000	.000	.053	.000	.021	.008
COMPONENT TYPE	30	ROTARY, 5 POS	.000	.000	.143	.050	.000	.054	.057	.043	.048
COMPONENT TYPE	31	ROTARY, 6 POS	.080	.195	.000	.000	.000	.000	.127	.000	.080
COMPONENT TYPE	32	ROTARY, 8 POS	.036	.000	.040	.077	.000	.000	.025	.030	.027
COMPONENT TYPE	33	ROTARY, 11 POS	.021	.032	.000	.000	.053	.000	.022	.012	.017
COMPONENT TYPE	34	ELECTROMAGNETIC COUNTERS	.275	.080	.033	.145	.068	.025	.133	.072	.097
COMPONENT TYPE	35	ILLUMINATED STATUS IND.	.250	.133	.154	.000	-	.000	.167	.000	.122
OPN	36	SEQUENTIAL OPERATIONS	.046	.051	.025	.010	.026	.033	.044	.022	.034
OPN	37	SINGLE OPERATIONS	.286	.114	.107	.207	.054	.031	.165	.076	.113
	38	PROCEDURAL DEVIATIONS	.032	.017	.009	.007	.005	.030	.022	.016	.019

[ ] = Revised Rates

◯ = Unacceptable Error Rates

to provide the error and error opportunity data necessary to calculate (by dividing error opportunities into errors, $\frac{E}{EO}$) the error rates that appear in each cell of the Error Rate Comparison Table (Table 3-1). As this table was the point of departure for all of the statistical analyses, and as it is extensively referenced throughout this report, a detailed description of it is presented here.

Upon examination, it is apparent that the comparison table (Table 3-1 above) is made up of nine columns of 38 rows (342 individual cells). Each row has been assigned a number from 1 to 38 and each column has been given a letter from A to I. Arrangement of the rows and columns within the table is intended to facilitate visual as well as mathematical analysis. For example, columns A, B and C contain the error rate data for all the measurement parameters from the first, second and third one-thirds of SL-3, respectively. In the same manner, columns D, E and F contain the error rate data for SL-4. Columns G and H contain the overall error rates for SL-3 and SL-4, respectively. It is, therefore, a relatively easy matter to compare the data from the first mission across time with data from the second mission. It is also easy to compare error rate levels for each parameter from mission to mission by simply referring to columns G and H.

Each row contains the error rate data relevant to the measurement parameter indicated at its extreme right hand side. Of the 38 rows, 37 are used to describe the same population of data in four distinctly different ways:

1) Rows 1 - 16 -- Controls and Displays, separately
2) Rows 17 - 24 -- Controls and Displays, combined

3) Rows 25 - 35 -- Hardware Type
4) Rows 36 - 37 -- Sequential vs Single Operations

Specifically, rows 1 through 8 include error rate data on the controls for each of the ATM experiments. Rows 9 through 16 contain complementary display data for the same experiments. Rows 17 through 24 contain error rates calculated from exactly that same body of data, but grouped into control and display errors combined for each ATM experiment. Rows 25 through 35 contain a third set of error rates calculated for the original data population. These error rates are for each specific kind of ATM panel control or display component investigated. Rows 25 through 33 contain error rates for controls and rows 34 and 35 contain those for displays. One last error rate set describing the data population is grouped in rows 36 and 37. Here, all ATM C&D activity is transposed into error rates according to its membership in one of two classes: single or sequential operations.

Row 38 was added to the table for comparison purposes only. It contains "normalized" procedural deviation data that are unrelated to the ATM control and display hardware. Its method of computation and functional application is fully described later in the text.

3.1.1 Descriptive Statistics

A variety of related descriptive analysis techniques were employed in an effort to describe between -- and within -- Skylab ATM experiment performance relationships. These were: 1) a direct, item by item comparison of Table 3-1 cell data, 2) a search for ordering effects, and 3) an identification of all Table 3-1 cells with error rate values of .05 or greater.

3.1.1.1 Error Rate Cell Comparison

Overall Mission Performance - Comparison of overall mission performance on SL-3 and SL-4 (cells 17G and 17H of Table 3-1), reveals that the SL-4 error rate was approximately half (.53) that of SL-3. Both the controls and the displays contributed to this difference (refer to cells 1G, 1H, 9G and 9H of Table 3-1). While dramatic, this difference is nevertheless, in the direction expected, a fact attributable to the learning that took place on the part of the SL-4 crew and ground support personnel as a result of the previous mission experiences, longer available training time and improved procedures directives. However, when the error rates for both missions are plotted by thirds of mission (Figure 3-1), some unexpected differences appear in the profiles. The SL-3 error rates diminished as the mission progressed. This improvement in performance was expected, and could be explained as being due to the effect of learning and environmental adaptation, but, if learning and adaptation phenomena are used to explain the error rate in SL-3, how can the increases that occurred across SL-4 be explained? For the answer to that question, it is necessary to return to the data. First, referring to Table 3-1, it appears that cells 18E, 18F, 21E and 22F account for the increased error rates for the second and third one-thirds of SL-4. Checking further reveals that the high error rates registered in cells 18E and 18F were due entirely to high Hα1 experiment control error rates (cells 2E and 2F in Table 3-1). Therefore, an in-depth search of the raw data score sheets was made to identify the reasons for the high cell 2E and 2F error rates. (Note: cells 21E and 22F were excluded from investigation at this point because of their relatively lower error rates and their disjointed relationship to each other.) As a result of the

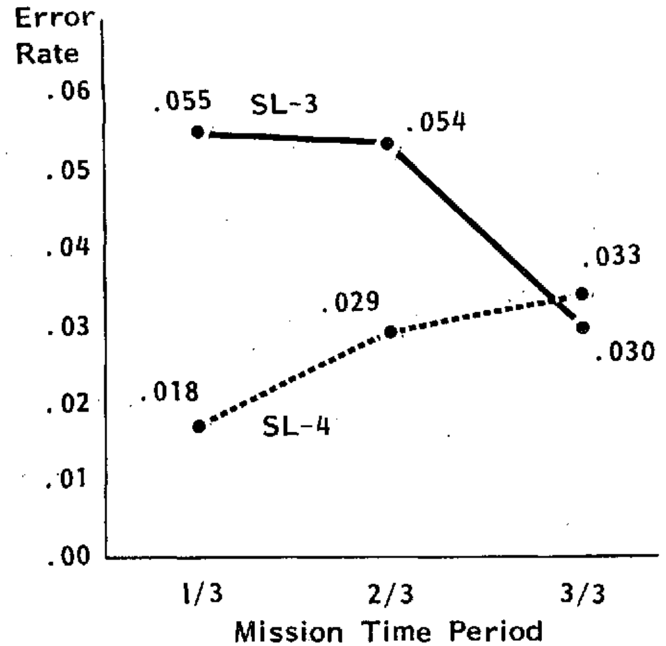


Figure 3-2: SL-3 and SL-4 Mission Error Rate Profiles

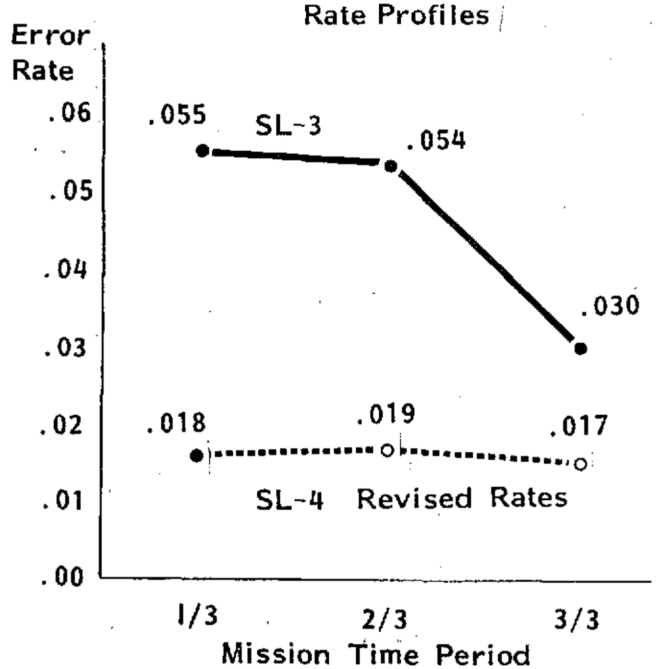


Figure 3-3: SL-3 and SL-4 Mission Error Rate Profiles (Revised)

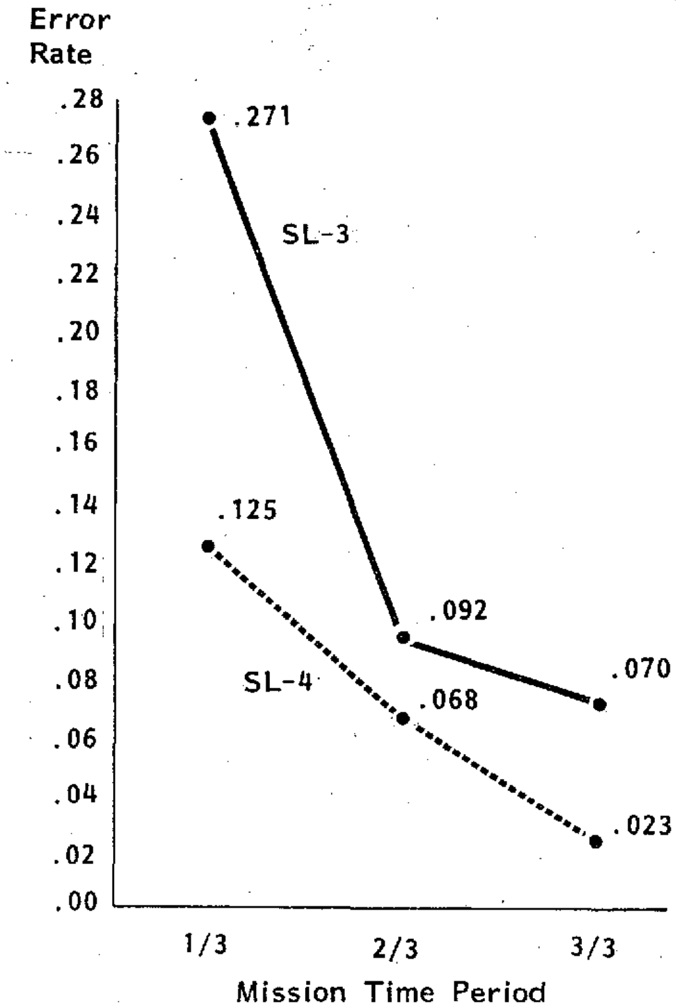


Figure 3-4: SL-3 and SL-4 Display Error Rate Profile

in-depth data search, it was discovered that, during both the second and third one-thirds of SL-4, there were uninterrupted periods of time when the crew's selection of an Hα1 frames per minute rate was always in error. For the second one-third of that mission, the error period spanned data points 253 to 256 and accounted for all four (4) Hα1 errors registered. For the third one-third of the mission, the period covered data points 293 through 309 and accounted for all thirteen (13) Hα1 errors.

If the Hα1 errors registered during the two periods of time investigated had been due to some panel design deficiency, they would be expected to have been scattered more or less randomly through the data. That they were not is indicative of some study data source deficiency -- that is to say, it is likely that the SL-4 crew was either instructed to take Hα1 pictures at a rate other than the one indicated in the Building Blocks or that they decided on their own to take pictures at a different rate. In either case, there is little justification for scoring these events as errors during those two periods. Thus, the error rates for Table 3-1 cells 1E, 1F, 1H, 2E, 2F, 17E, 17F, 17H, 18E and 18F were recalculated. All of the Hα1 error rate cells (Table 3-1 cells 2E, 2F, 18E, 18F) changed to a value of zero. More importantly, cells 17E and 17F (Table 3-1), reflecting overall ATM experiment error rates for the second and third one-thirds of SL-4, were changed to .019 and .017, respectively. This implies that there were no practical differences in error rates between the first, second and third one-thirds of SL-4, so there appeared to be no learning or adaptation effects experienced by the SL-4 crew. This finding, together with the low overall error rates experienced on SL-4 suggests that prelaunch training for SL-4 was more effective and more complete than was that for SL-3 (irrespective of differences in levels of task difficulty and complexity). Before such a statement could be made, however, it was necessary to check the SL-3 data to ensure that no hidden study discrepancies had accounted for the SL-4 error rate profile. When that check was made, it was found that the SL-3 errors were distributed with appropriate homogeneity throughout the mission. Therefore, it appears likely that most of the errors scored for SL-3 were due more to the crew-ATM system interaction effects than to any study artifact. Thus, on the basis of the adjusted overall mission error rate profiles (Figure 3-2, above), some combination of the following may apply:

- SL-4 crew training was more effective and complete than that received by the crew of SL-3.
- SL-3 tasks were more difficult than SL-4 tasks.
- SL-4 crew environmental adaptation occurred prior to their commencement of ATM experiment operations.
- SL-4 ATM experiment work tasks increased in difficulty at a rate which offset any increase in crew proficiency.

Individual Display Performance - While the overall error rate profiles of the two crews differed, both crews were similar in that they greatly reduced their across-time error rates while using displays (Figure 3-3, above). In spite of this, neither crew was able to perform any better than 1/3 to 1/5 as well on displays than they did on controls (Table 3-1, cells 9G, 9H, 1G and 1H). In looking for explanations for those statistics, it was necessary to look directly at the display population characteristics. First, the number of display types contributing data to this study was small -- only three. These included timing devices, experiment ready-operate lights, and the S055A grating position indicator. Second, these displays served only two functions -- timing and positioning.

Timing was accomplished both through the use of timers and by checking the status of ready-operate lights. Many of the operations that involved the use of timers (i.e., displays) were terminated automatically. These were part of a sequential operation, which, judging from the sequential operation error rate data (Table 3-1, cells 3A through F), contributed little to the displays problem. Indeed, when the individual data points are examined, this is borne out. The remaining operations involving the use of timing devices and ready-operate lights were manually initiated single operations. A check of the single operation error rate cells (Table 3-1, cells 37A through F) indicates this is where the problem lies. That manually timed operations were often poorly performed is not surprising, since the displays used on this panel were designed to be of low target value.

Incorrect setting of the S055A grating position involved a totally different problem. That operation was always performed sequentially, and, furthermore, the display was generally closely monitored to ensure its accurate setting. Nevertheless, many grating setting errors occurred. After checking the individual data point score sheets, no doubt remains that some few of the positioning errors resulted from incorrectly interpreting directive information. Most of the errors of this kind, however, were due to the dynamics of the display itself. These occurred in the following way: The directive information specified a grating setting on a particular line. Yet, when the S055A mode switch was set in REFERENCE and the start/stop switch was activated, the last digit on the grating position indicator changed so rapidly that its value was impossible to read. Thus, the operator was forced to use the tens digit together with an anticipatory response in order to approximate the correct setting. Anticipatory response inaccuracies often presented the operator with two distasteful choices. First, if he undershot the mark, he was faced with placing the mode select switch in GRATING, SINGLE and advancing the display number one count at a time with the start/stop switch. Because of this cumbersome procedure, it is likely that the crew tried, instead, to go as close to the mark as possible while in the REFERENCE position. Unfortunately, trying for the close shot often led to an overshoot predicament. In that instance, the operator could decide he was close enough or elect to go back through the whole grating select procedure (incurring a 5 min. delay). Thus, these overshoots, coupled with operator reluctance to repeat a cumbersome and time consuming procedure to arrive at a correct grating setting, led to most of the grating position errors.

Overall Display Performance - Having addressed the finding of overly poor display performance, it is now appropriate to return to the discussion of display error rate profiles. As previously stated, display error rates do decrease across time in both missions. In fact, the decrease in both cases is sufficiently consistent and dramatic to raise some question about the extent to which ground training (i.e., their previous learning as applied to crew ability to use the displays provided) prepared them for inflight display operations. However, the general inability of these displays to serve their intended function is the overriding factor. Since that has already been discussed, the issue will not be pursued further here.

Additional Hardware Problem Areas - In addition to the problem areas already discussed, there are three other points associated with the Error Rate Comparison

Table (Table 3-1) that must be covered. One is the obvious discrepancy between the SL-3 and SL-4 illuminated status indicators error rates (Table 3-1, cells 35G and 35H). Such a discrepancy is sufficient cause to look for some contributing factor. In this case, the factor seems to be the data themselves. Specifically, it is the number of times that an illuminated status indicator was used during the SL-4 Mission, e.g., a use frequency of 13 simply does not justify placing great confidence in the error rate calculated.

The second point to be covered relates to six-position rotary switches. Those switches were also associated with a dramatic shift in error rates from SL-3 to SL-4 (Table 3-1, cells 31G and 31H). Unlike the case of illuminated status indicators, however, these controls were employed a sufficient number of times during both missions to justify some confidence in the error rates calculated. Unfortunately, a close second look at the individual data point score sheets did not uncover any reason for this shift, so it must be written off as an error shift attributable to differences in crew training effectiveness, deliberate operator deviation from directed procedure, unrecorded changes of instructions, or isolated accidental errors.

Procedural Deviations - Procedural deviations is the third point associated with the Error Rate Comparison Table that must be discussed. While included in the table, in truth, these data are more "normalized" than they are error rate quantities. That is, while the error rate data represent the quotient of errors over error opportunities, procedural deviation rates were calculated by dividing the total number of procedural deviations by the total number of control plus display error opportunities ($\frac{\text{Total Proc. Dev.}}{\text{Total C\&D EO}}$). Procedural deviations could not be classified as errors, nor could they enter into determination of the number of error opportunities. Therefore, at first glance, it would not seem appropriate to divide one by the other. Yet error opportunities are the best available measure of ATM experiment work density, so dividing error opportunities into the number of procedural deviations should normalize the data and provide some insight into a procedural deviation "rate".

Now that the procedural deviation number and its method of calculation have been explained, some effort will be made to define the term "procedural deviation". A procedural deviation is any ATM experiment C&D activity involving two or more operations that is performed in place of, or in addition to, the activity required by official directive. In other words, a procedural deviation is activity not called for in the study reference documents, but which was almost certainly done on purpose. Recognizing this, it should be clear that there are at least three reasons for the occurrence of procedural deviations:

1) The operator deliberately added or substituted the activity.
2) Some unidentified source directed the operator.
3) The operator misunderstood his operating instructions.

If the first or second reasons are the predominant causes for procedural deviations, it seems plausable to expect the deviation density value to vary somewhat independently of the overall controls plus displays error rate for the same operating period. Conversely, if the procedural deviations occur primarily as a result of misunderstood instructions (procedural errors) it seems plausable to assume that the deviation density number would correlate positively (at least loosely) with the overall controls plus displays error rates for the same operating period. With this rationale having been explained, it is now appropriate to turn to Table 3-1 to examine the actual procedural deviation density rates. When comparing the rates in cells 38A through C with those in cells 17A through C, a loose similarity of pattern becomes apparent. Thus, to the degree that the assumptions just advanced are sound, the procedural deviations recorded during SL-3 are due to misunderstood or misinterpreted instructions. In other words, they are procedural errors. When comparing the procedural deviation density rates with the controls and displays error rates for SL-4 (see cells 38D through F and cells 17D through F in Table 3-1), a slightly different pattern emerges. At the outset and through the second one-third of SL-4, both rates remain more or less constant. Then, in the third part of the mission, the procedural density rate soars upward while the controls and displays error rate number remains at its former level. Again, to the degree that the assumptions germane to this analysis are correct, the procedural deviations that occurred in the first two thirds of SL-4 are procedural errors. Those deviations occurring in the last third of SL-4, however, are deliberate procedural deviations. Thus, for all SL-3 and SL-4 time periods, save the last one-third of SL-4, there is statistical evidence that procedural errors did occur. Such evidence, in turn, suggests that there were some incidents of procedural directive functional breakdown.

3.1.1.2 Ordering Effects

After addressing the Error Rate Comparison Table (Table 3-1) cell-to-cell relationships, the table data (revised) were given a second look to check for mission-to mission ordering effects.* After rank ordering all the parameter error rates, only

*Revised figures are noted in brackets [ ] in Table 3-1.

one such effect could be found, and that one had to do with toggle switches. Even in that case, only two members (3-position, F-F-F, and 3-position, M-SL-M) were involved. Considering the components and the kinds of errors involved, it is likely that the ordering effect observed was due as much to component function as to any particular physical component attributes.

3.1.1.3 Unacceptable Error Rates

For the analytical purposes of this study, any error rate equal to or greater than .05 was considered unacceptable. Once identified, these error rates (the circled quantities in Table 3-1) were used in a subtractive process to "drive out" their causative factors. Hα1 serves as a straightforward example of the process.

Row 18 of Table 3-1 shows that 8 of the 9 cells contain unacceptable error rates. A quick look at rows 2 and 10 revealed (by the relative absense or presence of unacceptable error rates) that the problem is control related. Therefore, the Hα1 controls row of each Data Point Score Sheet (Figure 3-1, above) was consulted. In so doing, it was determined that all of the Hα1 errors identified occurred in selecting the frames per minute picture rate, an operation that involves the setting of a three-position, F-F-F, toggle switch. This knowledge enabled a factoring out of both the error and the error opportunity numbers from the appropriate half-cells under the Hα1 controls (alone), under the Hα1 controls and displays (combined) and under the three-position toggle switch (F-F-F) headings. Then, the error rate for each cell impacted was recalculated. If the recalculated rate fell below .05, then the factor removed was credited as the one responsible for the unacceptable error rate. During the course of this analysis, if there had been an instance where the removal of no single factor would drive the error rate below .05, then as many contributing factors as possible would have been identified. That done, the fewest number of those factors that, extracted together, would have dropped the error rate to below .05 would have been credited with the unacceptable error rate. Fortunately, in this study, every unacceptable error rate cell could be accounted for by removing just one factor. Those factors together with a compendium of the Table 3-1 cells whose error rates they drove above .05 and presented in Table 3-2.

Table 3-2: Factor Classification for
Error Rates (Cell Values) Exceeding 5%

1. TIME DISPLACEMENT FACTOR

   5B, 5G, 6A, 6C, 6F, 6G, 8B, 9B, 9C, 9E, 12A, 12G, 13E, 14F, 14H, 14I, 15B, 15C, 15E, 21B, 21E, 22A, 22C, 22F, 22G, 24B, 34B, 34E, 35A, 35B, 35C, 35G, 35I, 37A, 37B, 37C, 37D, 37E, 37G, 37H and 37I. N = 41

2. S055A GRATING POSITION FACTOR

   9A, 9D, 9G, 9H, 9I, 15A, 15D, 15G, 15H, 15I, 23A, 34A, 34D, 34G, 34H and 34I. N = 16

3. Hα1 FRAMES PER MIN. FACTOR (Revised Figures)

   1B, 2A, 2B, 2C, 2G, 2I, 17A, 17B, 18A, 18B, 18C, 18G, 18I, 27B, 27F, 27G, and 36B. N = 17

4. MODE SELECT FACTOR

o 5-position rotary sw: 30C, 30D, 30F and 30G	N = 4
o 6-position rotary sw: 31A, 31B, 31G and 31I	N = 4
o 3-position toggle sw (F-F-F): 5A	N = 1
o 4-position rotary sw: 29F	N = 1
o 8-position rotary sw: 32D	N = 1
o 11-position rotary sw: 33E	N = 1
TOTAL	N = 12

Table 3-2: Factor Classification for
Error Rates (Cell Values) Exceeding 5%
(Continued)

5. DATA POINT #6 FACTOR

27A N = 1

The error rates above .05 in 85 of the Table 3-1 cells can be attributed to the presence of the five factors ranked by cell impact in Table 3-2. Indeed, the unacceptable error rates in 84 of those cells can be attributed to the first four factors. The fifth factor accounts for the unacceptable rate in the remaining cell. But, being the performance on an isolated task in the early period of SL-3, that factor is not representative of any recurring problem and will not receive further discussion.

3.1.1.3.1 Time Displacement Errors

Time displacement errors by far accounted for the largest number of error rate cells -- 41 in all, or 47.1% of the 87 total. In addressing this problem, at least four contributors (excluding hardware malfunctions and isolated accidental errors) should be recognized. They are:

1) Deliberate deviations
2) Directive functional breakdown
3) Procedural problems
4) Display functional breakdown

1) Deliberate deviations - In many complex tasks where the operator has decision making authority, deliberate deviations from established procedure are likely to occur. While these deviations are not real errors, when they involved

only one operation, they were scored as errors during this analysis. Therefore, they certainly had some impact on the overall error picture. Unfortunately, the telemetry data do not provide sufficient resolution to allow assessment of problem magnitude.

2) Directive functional breakdown - This category includes such error sources as misread checklists or misunderstood voice communications. And, while no specific examples have been extracted from the telemetry data analysis to support the argument that this category contributes to time displacement errors, for both SL-3 and SL-4 there are telemetry data that establish its role in related kinds of errors (e.g., inversion of order, numerical digit transposition and Hα1 frames/min). Add to this *prima facie* evidence the cluttered Building Block format and some voice transcript comments, and indeed, there is a good face validity argument for information breakdown's contribution to time displacement errors.

One of the likely problems in this area is the way operational directives are presented. In the Building Blocks, for example, manual termination is signified by the use of a dashed line in place of the normal solid one. Because of the physical characteristics of both lines, the distinction can be easily missed by a "pushed" crewman. Another Building Block problem is the method used to identify activity initiation times (i.e., by checking the alignment of noncontinuous lines with hash marks across the top and bottom of a page). Still another source of Building Block information breakdown that contributes to time displacement errors is the lack of prominence given to experiment run time.

The impact of voice communications and other directive sources on time displacement errors could not be investigated using the telemetry data base. Insights pertaining to this area must be derived from the Critical Incidents Analysis, Section 3.2.

3) Procedural problems - Procedural problems that lead to deviations from expected timelines can be caused by factors such as inappropriate mission scheduling, extreme work density, incompatible work task arrangement and equipment malfunctions. In fact, the telemetry data together with the voice transcripts provided evidence that all of those factors played some role in contributing to the time displacement problem. The telemetry data alone, however, are of little utility in determining the exact role of each factor. Therefore, discussion of these factors must also be seated in the Critical Incidents Analysis.

4) Display functional breakdown - This is one area on which the telemetry data provide an abundance of information. For example, the data show repeated instances where S055A was not manually terminated in conjunction with the automatic termination of other experiments as required. Yet when this action is required, the related Building Block directives are among the clearest of all directives presented. Thus, when manual experiment termination is keyed to the automatic termination of another experiment, it appears that the blame for any time displacement errors can be laid at the feet of the displays involved. For an in-depth description of the particular problems associated with the use of those displays, refer to Section 3.1.1.1.

3.1.1.3.2 Setting the S055A Grating Position Incorrectly

The incorrect setting of the S055A grating position placed second in impact behind time displacement errors. At least three factors contributed to the incorrect setting of that grating. They were: deliberate deviations, directive functional breakdown, and display to user functional breakdown. Deliberate deviations pose no problems and will not be discussed further. Directive functional breakdowns, on the other hand, were a problem. In at least one instance where the Building Block operating procedures called for the selection of six different grating positions in order, the order of actual performance was incorrect, and one of the ordered grating positions was omitted.

Display functions breakdowns for the S055A grating position indicator have already been fully treated in Section 3.1.1 and will not be treated further.

3.1.1.3.3 Hα1 Frames Per Minute Errors

Errors in selecting the proper number of frames per minute for Hα1 was the third greatest contributor to the number of cells containing error rate figures above .05. Because the .000 error rate (revised) incurred while operating this frame rate control during SL-4, it is not likely that the control characteristics themselves were responsible for the high SL-3 rates. It is more likely that some combination of deliberate deviations and directive functional breakdown produced the rates above the .05 level. Here again, deliberate deviation are of no concern. Directive to user information transmission breakdowns, on the other hand, are of concern. And, for Hα1, any information transmisssion breakdown most assuredly was the result of the position relegated to frame rate information in the Building Block format.

3.1.1.3.4 Mode Selection Errors

The remaining cells containing error rate above .05 can be accounted for by a mode select control factor. Most probably that factor also contains such contributors as intentional deviations and directive functional breakdown. However, it seems apparent from looking at the hardware variations making up the populations of mode select controls (Table 3-2, above) that control function seemed to play a greater role in error rate than did control type.

3.1.2 Formal Statistical Analysis, Testing Eleven ATM C&D-Related Hypotheses

Up to this point, information about the analysis of SL-3 and SL-4 telemetry data has focused on the signostic or analytic approach taken in studying the various components and characteristics of the control panel. Error data so obtained and the consequent effects of those errors on mission performance served as the criteria for focusing study to specific panel elements on operations. Following that portion of telemetry data analysis, and using data derived from it, a formal analysis which tested eleven hypotheses was conducted. This section (3.1.2) comprises a report of that formal analysis.

3.1.2.1 Hypothesis Development

Based on experience in designing, testing, and using the panel; analysis of SL-2 data; and general human engineering design principles, URS/Matrix developed a list of 25 hypotheses of interest. The data requirements for testing each hypothesis were compared with the data telemetered during SL-3 and SL-4 relevant to the ATM controls and displays. Hypotheses were then categorized in terms of their being directly testable, indirectly testable, or not testable. The directly and indirectly testable hypotheses were discussed with NASA technical representatives.

Table 3-3 contains the hypotheses determined to be of interest and testable, given the data available from SL-3 and SL-4.

Table 3-3: ATM Assessment Hypotheses

HARDWARE RELATED

1. The use of three-position toggle switches produces a significantly higher error rate than does the use of other types of toggle switches.

2. The use of rotary switches with positions numbering more than four produces a significantly higher error rate than does the use of rotary switches with four positions.

3. The use of rotary switches with positions numbering more than four produces a significantly higher error rate than does the use of other types of switches used on the ATM panel.

LAYOUT AND FUNCTIONAL ARRANGEMENT

4. Experiments operated on the left side of the C&D panel produce a significantly higher error rate than do experiments operated on the right side.

5. Operating Hα1 produces a significantly higher error rate than does operating any other experiment on the left side of the panel.

6. Isolated actuations produce a higher error rate than do sequential operations.

7. There is no significant difference in performance between operating S082A and operating S082B.

8. Operating experiments with high C&D layout similarity (e.g., Hα2, S052, S082A, S082B) produces higher error rates than does operating experiments with dissimilar C&D arrangements (e.g., S056, S055A, S054).

Table 3-3: ATM Assessment Hypotheses
(continued)

9. Operating the lower half of the ATM Panel produces a significantly higher operational error rate than does operating the upper half of the panel.

TIMELINE AND OPERATIONAL PROCEDURES HYPOTHESES

10. SL-4 operations produce lower error rates than do SL-3 operations.

11. The first 1/3 of each mission's operations produces higher error rates than do the remaining 2/3 of each mission.

3.1.2.2 Hypothesis Testing and Results

For each hypothesis, appropriate statistical tests were identified and run. To meet the constraints (e.g., repeated measures or correlated samples, non-normal distribution, missing data) imposed by the data, both chi-square and analysis of variance statistical tests were employed (Table 3-4). Table 3-5 presents the number of errors vs error-free operations plus error rate for each hypothesis.

3.1.2.2.1 Hardware Related Hypotheses

None of the hypotheses dealing with controls were accepted. The variation in errors appeared to be less a function of the specific type of control device than of the procedural and functional envelopes surrounding the control. Certain switches, e.g., five-position rotary, three-position toggle (F-F-F) have relatively high error rates (.048 for the former, and .046 for the latter), but these rates were not reflected consistently in other similar switches. This, combined with the observation that high errors for any given control did not occur consistently across time periods for either mission, reinforces two principles of C&D design.

1) The adequacy of a given switch in a complex control panel is only partially dependent on the design of the switch. The relation of the switch to other control elements, layout, sequence, functional procedures, workload, or the general operating envelope around the switch appears to be equally important.

2) Evaluation of control hardware to be used in complex panels or operations must be performed within the full operating envelope, where the interactions noted above can occur.

While not a formal hypothesis, a question of considerable interest is the performance of operations involving the use of controls versus those involving the use of displays. The errors and error opportunities were summed across missions for controls and displays and tested. The resulting chi-square of 38.72 (1 df) is significant well beyond the .001 level. Display operations, with an error rate of .10 relative to the .032 rate for controls operations, clearly contributed heavily to the ATM panel error rate.

3.1.2.2.2 Layout and Procedural Related Hypotheses

Five experiments, Hα, S056, S082A, S082B, and S052, were on the left side of the ATM Panel, two experiments, S055A and S054, were on the right. As expected, the experiments comprising the left side had significantly (.01) higher error rates than the experiments on the right side.

As noted in an earlier section of this report and confirmed in Hypothesis #5, Hα contributes heavily to this result. Fifty-six percent of the error for the five experiments on the left side of the panel occur while operating Hα. When Hα data are removed, the left side error rate is .0279, and the right side is .020. Chi-square shows no significance for this difference.

Thus, left-right location appears to be a relatively minor contributor to error rate. The significant difference is attributable to one deviant experiment rather than left-right location per se.

For Hypothesis #5, the Hα error rate (.1295) was compared with the error rate for all other experiments combined (.0296). The chi-square of 80.51 was highly significant ($p < .001$) and clearly demonstrated the contribution of this experiment to mission error. This finding must be kept in mind when looking at all other testing using data compiled by experiments, since Hα data tends to skew such distributions.

Sequential operations exhibited a significantly ($p < .001$) lower error rate than isolated or single operations. The design implication of this result is that establishing a chain of control activities even if they are only marginally related, should help minimize error. Accomplishing this necessitates extensive attention to the procedural/instructional aspects of the control panel system design.

Hypothesis #7 was accepted; there were no differences in error between S082A and B. These two experiments had the highest degree of similarity, in terms of location, layout, and procedures, and this was expected to contribute to errors of interpolation and location displacement. The errors which did occur did not bear out this expectation considering only S082A and B.

When all experiments were categorized on a similarity/dissimilarity dimension (Hypothesis #8), a significant error difference appeared. This finding must be viewed cautiously because of judgmental assignment to the category and because of the skewing affects of Hα1 already discussed. The experiments included in high similarity were: Hα1, S052, S082A, and S082B, and in low similarity: S056, S055A and S054.

In spite of this, the result provides support based on operational data that conspicuity and discernability must be considered in the design of controls and displays. As other hypotheses have implied, so this one also points to the importance of considering individual C&D and functional sub-units of a panel within their total operating envelope in design.

The final hypothesis in this group tested the exeriments in the upper half of the panel, Hα1, S056, S082A and S055A, and lower half of the panel, S082B, S052 and S054. There was not a significant difference.

3.1.2.2.3 Timeline and Operational Procedures Hypotheses

The differences between SL-3 and SL-4 were tested in several ways. Hypothesis #10 was tested using x^2 which showed the SL-3 error rate significantly ($p < .001$) greater than the SL-4 error rate. Hypothesis #11 was not accepted; the x^2 between the first 1/3 and remaining 2/3 of each mission did not provide an adequate test of the data.

Therefore, a 2x2 analysis of variance for repeated measures (Ref. Appendix A, Weiner, 1962) was used to test missions and time periods. The test was run using both transformed ($x + .5$, Ref. Appendix A, Edwards, 1962) and raw data. Mean error rates were calculated for each control and display category. This was done to alleviate the skewing effect of Hα when the data were summarized by experiment. Table 3-6 gives the results of the test.

Table 3-4: Summary of Results for Hardware, Layout, and Timeline Hypotheses for SL-3 and SL-4

Hypothesis	Statistic	Result	df	P Less Than	
1.------	Chi-square (x^2)	1.573	1	.22	N.S.
2.------	x^2	2.01	1	.15	N.S.
3.------	x^2	.60	1	.80	N.S.
4.------	x^2	8.95	1	.01	*
5.------	x^2	80.51	1	.001	*
6.------	x^2	33.57	1	.001	*
7.------	x^2	.687	1	.45	N.S.
8.------	x^2	20.47	1	.001	*
9.------	x^2	1.22	1	.28	N.S.
10.------	F (Anova)	5.00	1 and 20	.05	*
	x^2	13.67	1	.001	*
11.------					
SL-3	x^2	.66	1	.80	N.S.
	Sandler's A	1.18	6		N.S.
SL-4	x^2	2.81	1	.09	N.S.
	Sandler's A	.488	6		N.S.

Table 3-5: Data for Each Hypothesis

Hypothesis #	Parameters	Errors	Error-Free Operations	Error Rate	Significance of Difference
1.	3-position toggle	90	2208	.0392	Not
	All other toggle	0	62	.000	Significant (N.S.)
2.	4-position rotary	1	126	.007	N.S.
	All other rotary	24	626	.037	
3.	5 or more position rotary	24	602	.0383	N.S.
	All other switch types	89	2752	.0313	N.S.
4.	Left side of panel	77	1474	.049	.01
	Right side	73	2321	.030	
4. (With $H\alpha$ removed)	Left	34	1185	.0279	N.S.
	Right	73	2321	.030	
5.	$H\alpha$	43	289	.1295	.001
	Other experiments	107	3506	.0296	
6.	Single operations	25	197	.113	.001
	Sequential operations	125	3598	.033	
7.	S082A	3	221	.013	N.S.
	S082B	6	196	.029	
8.	High similarity	64	976	.0615	.001
	Low similarity	86	2819	.0296	
9.	Upper half	118	2820	.040	N.S.
	Lower half	32	975	.032	
10.	SL-3	100	1933	.0492	.001
	SL-4	50	1862	.0262	
11. (SL-3)	First 1/3	44	761	.055	N.S.
	Last 2/3	56	1172	.048	
11. (SL-4)	First 1/3	13	721	.018	N.S.
	Last 2/3	37	1141	.031	

Table 3-6: Summary of Analysis of Variance

Source of Variation	SS	df	MS	F
Between	.05	21		
Missions (SL-3/SL-4)	.01	1	.01	5.00*
Within	.04	20	.002	
Within	.06	44		
Time Periods	.01	2	.005	4.54*
Time by Mission	.001	2	.0005	.45
Time within Mission	.0499	42	.0011	

*$p < .05$

The significant difference between errors in SL-3 and SL-4 was confirmed. There was also a significant difference between time periods. This indicated that the differences were not in the periods predicted in Hypothesis #10. Also, there was not a significant interaction between time and missions. When the error rates are plotted as in Figure 3-2, above, the lines converge, but this is not statistically significant.

To determine in greater detail where the significant differences occurred, chi-square was used to compare SL-3 and SL-4 for each time period. The results were:

Time Period 1	$p < .001$
Time Period 2	$p < .06$
Time Period 3	$p < .80$

Within each mission, time periods could only be compared using a statistic for correlated samples. Recently, Sandler's A has been shown mathematically equivalent to the test for correlated samples (Ref. Appendix A, Runyon and Haber, 1970), so this was used. Table 3-7 shows the results.

Table 3-7: Differences Between Time Periods in SL-3 and SL-4

Time Period	SL-3	SL-4
1 vs 2	N.S.	N.S.
2 vs 3	$p < .001$	N.S.
1 vs 3	N.S.	N.S.

The contribution of Hα accounts for the difference in time periods. When Sandler's A was recalculated without Hα data, the significant differences vanished. This was verified by testing time for each mission using analysis of variance. In this case, each experiment was considered a block and the variance attributable to the blocks was not included in the treatment variance. When the unusual variance contributed by Hα was statistically controlled, there was not significant difference between time periods for SL-3 or SL-4. Table 3-8 summarizes the analyses.

Table 3-8: Summary Analysis of Variance for Time Periods

	SL-3				SL-4			
	SS	df	MS	F	SS	df	MS	F
Time Periods	.0313	2	.0156	3.12 N.S.	.00355	2	.001775	1.24 N.S.
Blocks	.0212	6	.0035		.01836	6	.00306	
Residual	.0605	12	.005		.01719	12	.001432	
TOTAL	.113	20			.0391	20		

Turning to consider the experiments, only two showed a consistent pattern of errors over time for both missions. Table 3-9 gives the data for S055A.

Table 3-9: Error Rates for S055A on SL-3 and SL-4 by Time Periods

Time	1	2	3
SL-3	.073	.026	.021
SL-4	.033	.014	.012

Hα varied between time periods, but in the opposite direction from S055A, as shown in Table 3-10.

Table 3-10: Error Rates for Hα on SL-3 and SL-4 Over Time Periods

Time	1	2	3
SL-3	.069	.257	.208
SL-4	.000	.125	.167

These were significant differences for several of the experiments from SL-3 to SL-4. Table 3-11 gives the results. Chi-square with x + .2 used.

Table 3-11: Summary of Differences for Experiments Between SL-3 and SL-4

Exepriment	Difference Between SL-3 and SL-4
Hα	$p < .05$
S056	N.S.
S082A	N.S.
S082B	N.S.
S052	N.S.
S055A	$p < .02$
S054	$p < .05$

In all experiments, the error rate was higher for SL-3 than for SL-4

3.1.2.3 Summary

The formal analysis of the ATM C&D Panel depicts a situation in which there is a significant difference between the two missions. Within these missions, the major changes over time were attributable to one experiment, Hα , which was generally characterized by an increasing error rate over time. Other experiments tended to decrease in error rate over time, but this was not significant.

In terms of hardware design, the major significant finding was a difference between controls and displays. Differences in controls were not consistent enough within type of switch to show significance. This, in combination with the procedural and layout hypotheses (high vs low similarity, and single vs sequential operations) which were significant, highlight the importance of considering designing and evaluating components or functional sub-units (i.e., an experiment) of a control/display panel in terms of the entire operating envelope or circumstances.

A primary use of this formal analysis appears to be as a means to focus or direct the evaluator, designer, engineer, or researcher, to areas, hardware or procedures, where a fine-grained examination can provide additional insight and design related information. Formal analysis, thus, is a useful and relevant but not all encompassing tool in diagnostically assessing man/machine interface in operational settings.

3.2 CRITICAL INCIDENTS

A detailed review of the SL-3 and SL-4 voice transcripts was performed. Mention or errors or other remarks were noted on Critical Incidents Raw Data Score Sheets, an example of which was provided in Figure 3-5. The example shows the type of information that could be noted or inferred from the transcripts (the limits of which have already been discussed in Sections 2.3.2 and 2.3.3).

3.2.1 Determination of Scored vs. Non-Scored Critical Incidents

The Critical Incident Raw Data Score Sheets were being compiled concurrently with the scoring of the telemetry data, and, at the conclusion of voice transcript review, an effort was made to arrange the information so gained in a manner that would permit comparison of the results of the two analyses. The voice transcript data themselves fell rather readily into the two broad categories discussed in Section 2.3 (i.e., "errors", and "comments" not associated with errors), relating to the ATM panel. The exceptions formed a separate group of critical incidents from both missions which related more to hardware deficiencies or malfunctions not directly tied to the ATM controls and displays or the man/machine interface -- the objects of primary scrutiny in this assessment study. This separate group was comprised of remarks relating problems encountered with the environment around the panel (e.g., low light levels making reading of instructions difficult), hardware shortcomings or failures which affected but were not part of the actual ATM panel, and remarks exhibiting concern about resource depletion as it affected ATM operations (e.g., low film supply in the experiments). As assessment of the ATM C&D man/

CRITICAL INCIDENTS RAW DATA SCORE SHEET

1) MISSION TIME 227-15-41-16

2) JOP # ______ Scored: Error (Commission) Schedule/Instructions

3) BB # ______

4) EXPERIMENT S054

5) NATURE OF COMMENT (POS OR NEG) Negative

6) BENEFIT OR SEVERITY (HIGH OR LOW) Low-Severity

7) HARDWARE OR PROCEDURE OF REFERENCE (SPECIFIC) ______

Crewman began running S054 by mistake. Prior instructions had said to omit it. He said he'd finish the one run and omit it from then on.

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 3-5: Critical Incidents Raw Data Score Sheet machine interface was of uppermost importance, these non-directly related remarks were left unscored on the master score sheets. Their repeated occurrence, however, in conversations about ATM operations between the crew and ground support required that they be dealt with in some way. While they were neither part of ATM C&D nor crew-controlled, they appeared to be a logical contributor to some of the difficulties experienced by the crew during ATM operations. For example, if a filter became stuck in one position, due to presence of contamination, as occurred on S056 during SL-3, this had nothing to do with proper operation of the corresponding mode select switch or with the proficiency of the crew in operating the panel. It was, nevertheless, a distraction during operations and also resulted in loss or degradation of experiment data.

3.2.2 Reincorporation of Unscored Remarks

Notations of such remarks were separated from the total collection of critical incidents during scoring, but they were studied to determine to what extent they may have impacted the man/machine interface. Those remarks representing particularly troublesome or persistent problems were reincorporated into discussion of the experiments after the results derived from scored critical incidents (directly ATM-related) had been prepared for comparison with the results of the telemetry data analysis.

3.2.3 Master Score Sheets for SL-3 and SL-4 Critical Incidents

In all, 483 critical incidents were scored and entered into appropriate cells in Figure 3-6 for SL-3 and Figure 3-7 for SL-4.

3.2.3.1 Scoring ATM Hardware-Related Incidents

Examination of the horizontal axis of Figure 3-6 (SL-3) reveals the level of detail to which hardware incidents were classified, i.e.,

HARDWARE

- 2-Position Toggle Switch (F-F)
  - Night Interlock
  - Camera Power
  - Auto Sequence
  - Flare Auto
  - Grating Reference
  - BR-AL Det.
- 3-Position Toggle Switch (M-F-M)
  - Start/Stop
  - Doors
  - Exposure
  - Wavelength
  - Mirror Position Camera

  3-Position (F-F-F)
  - Frames/Minute
  - Mode
  - Exposure
  - Grating
  - Detector

  3-Position (F-F-M)
  - Start/Stop
- Rotary Switch
  - Picture Rate
  - Mode
  - Exposure Range
  - Filter
- Counter
  - Grating
  - Intensity Data
  - Timer
  - Frames Remaining
- Experiment Related Equipment
  - Monitor
  - Pointing

CRITICAL INCIDENTS SCORE SHEET

HARDWARE — 2 POSITION TOGGLE SWITCH (F-F) and 3 POSITION TOGGLE SWITCH (M-F-M)

	NIGHT INTERLOCK (Hα)	CAMERA POWER (56)	AUTO SEQ (82B)	FLARE AUTO (54)	GRATING REF (55)	BR-AL-DET	TOTAL	START/STOP	DOORS (Hα, 82 A&B)	EXPOSURE (82A)	WAVELENGTH (82 A&B)	MIRROR POS CAMERA (52)	TOTAL
H α	3o						3o		1TD 1o				1TD 1o
S056								1c / 1c-	/ 2c-				1c / 3c-
S082 A								2c / 2c-	1c / 2c-				3c / 4c-
S082 B			1o				1o	2c			1c		3c
S052								1o / 1c-				1c 1o	2o 1c
S055	2c 1o				3o		4o 2c		1c				1c
SO54				1o 1c			1o 1c						
EPC													
GENERAL EQUIPMENT													
TOTAL	6		1	2	3		12	6 / 4	4 / 4		1	2	13 / 7

HARDWARE — 3 POSITION TOGGLE SWITCH (F-F-F) and (F-F-M)

	FR/MIN (Hα)	MODE (82 A&B)	EXPOSURE (56)	GRATING (54)	DETECTOR (55)	TOTAL	START/STOP (Hα)	TOTAL
H α	2o					2o		
S056			4o			4o		
S082 A		1o				1o		
S082 B		1o				1o		
S052								
S055					2c 7o / 11c-	7o 2c / 11c-		
SO54				1o		1o		
EPC								
GENERAL EQUIPMENT								
TOTAL	2	2	4	1	9 / 11	18 / 11		

HARDWARE — ROTARY and COUNTER

	PICTURE RATE (4-POS, 54)	MODE (5-POS, 52)	EXPOSURE RANGE (6-POS, 54)	MODE (8-POS, 55)	FILTER (8-POS, 54)	MODE (11-POS, 56)	TOTAL	GRATING (55)	INTENSITY DATA (55)	TIMER	FRAMES REMAINING	TOTAL
H α											/ 1c-	/ 1c-
S056						1c 1o / 1c-	1c 1o / 1c-					
S082 A										1c	/ 1c-	1c / 1c-
S082 B												
S052		2c					2c					
S055				1TD 1c / 1c-			1TD 1c / 1c-	1c / 1c-	/ 2c-			1c / 3c-
SO54			/ 1c-		1c		1c / 1c-			/ 2c-		/ 2c+ 2c-
EPC												
GENERAL EQUIPMENT											1o	1o
TOTAL		2	/ 1	2 / 1	1	2 / 1	7 / 3	1 / 1	/ 2	1 / 2	1 / 2	3 / 7

HARDWARE — EXPERIMENT RELATED EQUIP, ERRORS and HARDWARE TOTAL; PROCEDURES

	MONITOR	POINTING		TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	HARDWARE TOTAL (ERROR / COMMENTS)	SCHEDULE/INSTRUCTION	EXPERIMENT OPERATION	OPERATIONAL TIME PHASING	PROCEDURES TOTAL (ERROR / COMMENTS)
H α	/ 2c+ 5c-	/ 2c-		/ 2c+ 5c-	6			1	7 / 9		/ 1c		/ 1
S056					5	2			7 / 4	1c / 2c-	1c / 2c-	1c 1o	4 / 4
S082 A	2c / 1c+ 2c-			2c / 1c+ 2c-	1	6			7 / 8	1c / 5c-	1o	1o / 1c+ 1c-	3 / 7
S082 B	1c / 1c+ 2c-			1c / 1c+ 2c-	1	5			6 / 3	4o 3c / 11c-	2c / 1c-	1c 5o / 2c-	15 / 14
S052		/ 2c-		/ 2c-	2	3			5 / 3			2c / 1c-	2 / 1
S055		/ 4c-		/ 4c-	11	7		1	19 / 19	1o / 4c-	1c / 1c-	1o / 3c-	3 / 8
SO54	/ 1c-			/ 1c-	2	2			4 / 4	4c 3o 1t / 3c-	/ 2c-	1c 2o / 2c-	11 / 7
EPC		6c / 3c-		6c / 3c-		6			6 / 3	/ 6c-		/ 3c	/ 9
GENERAL EQUIPMENT	1o / 1c-			1o / 1c-	2				2 / 1	1c / 5c+ 10c-	/ 3c-	1c 1o / 7c-	3 / 25
TOTAL	4 / 15	6 / 11		10 / 26	30	31		2	63 / 54	19 / 46	5 / 10	17 / 20	41 / 76

UES MATRIX

Figure 3-6: Master Score Sheet for SL-3 Mission

CRITICAL INCIDENTS SCORE SHEET

HARDWARE

2 POSITION TOGGLE SWITCH (F-F)

	NIGHT INTERLOCK (Hα)	CAMERA POWER (56)	AUTO SEQ (82B)	FLARE AUTO (54)	GRATING REF (55)	BR-AL-DET	TOTAL
H α	1c /						1c /
S056						1c /	1c /
S082A							
S082B							
S052							
S055					2c 2o /		2c 2o /
S054				1o /			1o /
EPC							
GENERAL EQUIPMENT							
TOTAL	1 /			1 /	4 /	1 /	7 /

3 POSITION TOGGLE SWITCH (M-F-M)

	START/STOP	DOORS (Hα 82 A&B)	EXPOSURE (82A)	WAVELENGTH (82 A&B)	MIRROR POS CAMERA (52)	TOTAL
H α		1o /				1o /
S056	3c 1TD 1o /					3c 1TD 1o /
S082A	2c /					2c /
S082B	1TD /	1o /		4c /		4c 1TD 1o /
S052		3o /				3o /
S055	2c /					2c /
S054	2c /					2c /
EPC						
GENERAL EQUIPMENT						
TOTAL	12 /	5 /		4 /		/

3 POSITION TOGGLE SWITCH (F-F-F) and (F-F-M)

	FR/MIN (Hα)	MODE (82 A&B)	EXPOSURE (56)	GRATING (54)	DETECTOR (55)	TOTAL	START/STOP (F-F-M) (Hα)	TOTAL
H α	1o /					1o /		
S056			5c /			5c /		
S082A								
S082B								
S052								
S055					19o 1c / 1c-	19o 1c / 1c-		
S054				4c /		4c /		
EPC								
GENERAL EQUIPMENT								
TOTAL	1 /		5 /	4 /	20 / 1	30 / 1		

ROTARY

	4-POS PICTURE RATE (54)	5-POS MODE (52)	6-POS EXPOSURE RANGE (54)	8-POS MODE (55)	8-POS FILTER (54)	11-POS MODE (56)	TOTAL
H α							
S056						3c 1o /	3c 1o /
S082A							
S082B							
S052		7c 3TD /		1I /			7c 3TD 1I /
S055				1c / 1c-			1c / 1c-
S054	1c /		3c /				4c /
EPC							
GENERAL EQUIPMENT							
TOTAL	1 /	10 /	3 /	2 / 1		4 /	20 / 1

COUNTER and EXPERIMENT RELATED EQUIP

	GRATING (55)	INTENSITY DATA (55)	TIMER	FRAMES REMAINING	TOTAL	MONITOR	POINTING		TOTAL
H α						/ 1c+ 1c-	/ 1c-		/ 1c+ 2c-
S056									/
S082A			1c / 2c+		1c / 2c+		1c / 1c-		1c / 1c-
S082B			2c /		2c /	/ 1c-	1o / 2c-		1o / 3c-
S052						1c 1o / 1c-	1c 1o / 2c-		2c 2o / 3c-
S055	12c 1o / 4c-	/ 1c+ 2c-			12c 1o / 1c+ 6c-		2c / 2c-		2c / 2c-
S054						/ 2c-			/ 2c-
EPC							4c / 12c-		4c / 12c-
GENERAL EQUIPMENT									
TOTAL	13 / 4	/ 3	3 / 2		16 / 9	2 / 6	10 / 20		12 / 26

ERRORS

	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	HARDWARE TOTAL (ERROR / COMMENTS)
H α	2	1			3 / 3
S056	2	12		1	15 /
S082A		4			4 / 3
S082B	2	6		1	9 / 3
S052	5	9	1	3	18 / 3
S055	22	20			42 / 11
S054	1	10			11 / 2
EPC		4			4 / 12
GENERAL EQUIPMENT					
TOTAL	34	66	1	5	106 / 37

PROCEDURES

	SCHEDULE/INSTRUCTION	EXPERIMENT OPERATION	OPERATIONAL TIME PHASING	PROCEDURES TOTAL (ERROR / COMMENTS)
H α	/ 2c-	/ 1c-	/ 1c-	/ 4
S056	2c / 2c-	/ 2c-	/ 1c-	2 / 5
S082A	/ 3c-		1I / 3c-	1 / 6
S082B	1TD / 2c-	1c / 3c-	2c 1TD 1I / 5c-	6 / 10
S052		/ 2c-	1c 1o / 2c-	2 / 4
S055	/ 7c-	4c / 2c-	6c 1o / 9c-	11 / 18
S054	3o 1c / 5c-	2c /	2c 2o / 1c-	10 / 6
EPC	1c / 2c-	/ 1c-	/ 2c-	1 / 5
GENERAL EQUIPMENT	2c / 10c-	/ 1c-	/ 2c-	2 / 13
TOTAL	10 / 33	7 / 12	18 / 26	35 / 71

Figure 3-7: Master Score Sheet for SL-4 Mission

FOLDOUT FRAME

FOLDOUT FRAME

The cells below these hardware types are divided into two parts by a diagonal line. Errors by classification code (C, O, I, TD) were entered into the upper part of the cells, while comments (C+ for favorable; C- for unfavorable) were entered in the lower part. The hardware-type categories are followed by a column separated into four parts, where the totals (by experiment number) for each of the four error classifications (i.e., Omission, Commission, Inversion, and Time Displacement) were entered. These totals refer only to total scored ATM hardware-related errors (by general error type) for a particular experiment.

The "Errors" column is followed, in turn, by a column in which were recorded total hardware-related errors (of all four general classifications) in the upper half of the cell and total hardware-related comments in the lower half.

3.2.3.2 Scoring ATM Procedures-Related Incidents

Following a separating space, a three-part column was used to record errors and comments by experiment number and by procedure category, i.e., Schedule/ Instructions, Experiment Operation, and Operational Time Phasing, for Hα, S056, etc. Again, errors occupy the top of the divided cells, and comments occupy the bottom.

To the right of the totals by procedure type is a final column in which totals for errors across procedure type and comments across procedure type for each experiment are entered into the upper and lower cell halves, respectively.

The vertical axis of the Master Score Sheet lists the ATM experiments followed by a slot for Experiment Pointing Control (EPC) and General Equipment. (The

General Equipment slot applies only to the Procedures column.)

Last, a slot for totals of errors and of comments by hardware type and by procedures type for all vertically listed items is provided.

3.2.3.3 Totalling Incidents in Preparation for Analysis

After the 483 scored critical incidents were entered into appropriate cells on the SL-3 and SL-4 master score sheets, they were totalled and analyzed for significant control/display problems and procedural difficulties. During analysis, the data provided in the master score sheets was assessed by error total, comment total, hardware-related total (both broad and specific), procedures-related total, total errors and/or comments by experiment, and whole mission totals for SL-3 and SL-4. Emerging trends were charted and examined. Any cell with a value of 4 or more (i.e., 4 errors or 4 comments) were closely studied. Other cells, although scoring less than 4, were also studied if they were judged to represent remarks of substantial value to performance evaluation.

The results and conclusions of that analysis are presented below by experiment number, along with mention, where appropriate, of important non-scored incidents.

To simplify organization, the results and conclusions derived from critical incidents analysis are divided by Skylab mission, SL-3 and SL-4. These two broad divisions are each subdivided into Hardware-Related Critical Incidents and Procedures-Related Critical incidents. Discussion under both hardware and procedures is arranged basically by experiment number, with experiments remarked about most often being discussed first, because of the larger data base for those experiments.

3.2.4 Skylab 3 Mission

A total of 117 critical incidents found in the SL-3 voice transcripts were considered to relate directly to the ATM man/machine interface. These were summed by experiment number (and EPC) and were ranked by frequency of remark. Table 3-12 provides a rank-ordered list of scored errors and comments followed by total scored critical incidents by experiment number for SL-3. Percentages and rankings mentioned in the ensuing experiment discussions are taken from those figures.

3.2.4.1 SL-3 Hardware-Related Critical Incidents

S055A

The S055A experiment was discussed via the audio link more frequently than any other SL-3 ATM experiment, and approximately 66% of the remarks scored on S055 occurred during the first nine days of the mission.

With regard to scored errors, most of the errors that were recognized by the crew and ground personnel pertained to the high voltage (HV) detectors. Six out of the seven omission errors scored under the detectors were noted by the ground, and these all occurred on Day 228. A review of the scored comments relating to the detectors was made to try to determine a reason for this relatively large number of errors. It was discovered that 35% of the HV comments referenced Detector #5, which malfunctioned early in the mission. These comments were encountered only in the first 10 mission days.

Though not as frequently remarked on as the detectors, the Night Interlock and Grating Reference switches were also mentioned. All the errors connected with

Table 3-12: Rank-Order of Hardware Errors and Comments by Experiment for SL-3 Mission

TOTAL ERROR			TOTAL COMMENTS			TOTAL CRITICAL INCIDENTS		
1)	S055	19	1)	S055	19	1)	S055	38
2)	Hα1	7	2)	Hα1	9	2)	Hα1	16
3)	S056	7	3)	S082A	8	3)	S082A	15
4)	S082A	7	4)	S056	4	4)	S056	11
5)	EPC	6	5)	S054	4	5)	S082B	9
6)	S082B	6	6)	S082B	3	6)	EPC	9
7)	S052	5	7)	S052	3	7)	S052	8
8)	S054	4	8)	EPC	3	8)	S054	8
9)	Gen	2	9)	Gen	1	9)	Gen	3
	TOTAL	63			54			117

these two components were discovered by ground support. (In fact, 41% of the errors reported on the experiment over the entire mission's length were reported by ground personnel.) The flight crew noted that one of the errors that occurred in connection with the Grating Reference switch was confusion between it and the S055 Start/Stop switch.

Comments offered by the SL-3 crew also noted that the Raster/Scan counter was "acting up" and that the Intensity Counter had required malfunction procedures, but these comments did not include enough detail to conjecture their impact on experiment operation.

H-Alpha

The video monitors were the most frequently discussed hardware on the Hα experiment. Most scored incidents related to the quality of the video display images. During the first 7 days of SL-3 ATM operations, the crew commented on the problems they experienced in efficient Hα operation due to the rapid oscillations and "telescoping effect" they were getting on the video monitors.

Critical incidents scored as commission errors under the Night Interlock switch were all noted by ground support. The voice transcripts contained several instances where ground personnel had to remind the crew to initiate this control. Some of the remarks referred to other times (apparently not recorded on the voice tapes) when the problem had occurred and attributed the errors largely to the crew's Hα instructions. The ground reported that a change would be added to the cue cards to avoid future repetition of this commission error.

S056

Of the hardware-related critical incidents mentioned by the SL-3 crew on S056, 45% were omission errors. The largest number of these errors pertained to the exposure switch. Although a change in position was indicated, this switch was left unchanged from previous procedures on several occasions, and the experiment was set up and initiated with the switch incorrectly positioned. The crew remarked that they later realized the mode was to be changed but that they had forgotten to change the exposure setting.

Although not scored on Figure 3-6, 24 critical incidents were recorded noting a mechanical failure of the filter wheel in the instrument. These failures, when noted, were usually accompanied by crew comments regarding restarting the experiment and missing data. The crew also noted that the problem distracted them from other operations, thus impacting not only S056 data but also data gathered on other experiments which were run simultaneously with it.

S082A

The S082A instrument was remarked upon rather frequently. Experiment operations having to do with timed operations constituted most of the S082A hardware critical incidents, but with no consistent specific problem area. Approximately one-third of the remarks (appearing in the first 7 mission days) tied in with S082A operation were associated not with actual S082A hardware but, instead, with 1) problems encountered with the Hα monitors, and 2) difficulty in using the monitors to identify solar features of interest. These comments, of course, did not represent errors, nor did they conclusively indicate S082A-specific hardware deficiency. Rather, the comments seemed more to imply that the sun was calm and time was lost trying to find some "action".

S082B

Almost half (44%) of the total hardware critical incidents scored on S082B concerned, again, the Hα monitors, as they applied to S082B operations. Difficulties identical to those noted on S082A were described.

In addition, several comments were made by both the flight crew and ground expressing concern about the S082B film supply being very low. To conserve film, many scheduled auto sequences were omitted, with the unfortunate, concommitant loss of experiment data.

S052 and S054

Examination of the remaining ATM experiments, S052 and S054, did not reveal any meaningful trends. The possible exceptions were specific, isolated comments on low film supply, which, again, does not reveal any helpful information about the design of the panel or about the man/machine interface, other than the suggestion that worry about resource depletion may have been a distraction.

3.2.4.2 SL-3 Procedures-Related Critical Incidents

Half (117) the total 234 critical incidents scored on SL-3 involved procedures. By referring to Figure 3-6, above, it can be seen that the scored cells under Schedule/Instructions comprised the largest number of these procedural incidents. Remarks about Operation Time Phasing were of next highest frequency, possibly indicating that some of the errors scored under the Hardware category (e.g., inaccurate display setting) may ultimately be attributable to procedural problems (e.g., crewman being short on time, unsure of instructions and making best guesses).

A summary of procedural critical incidents, rank ordered by experiment (and GEN, EPC), is provided in Table 3-13. Many instances appear in the voice transcripts in which the crewmen attribute incidents (scored in this report as hardware errors) to the quality of some procedures. This raises a question as to whether many difficulties with hardware were not so much an effect of design as of procedural directives.

Scheduling/Instructions

About one-third of the remarks scored as errors under Schedule/Instructions were noticed by the crewmen themselves. Most of their remarks under this category dealt with what were perceived as ambiguous or incomplete instructions and scheduling or instructional conflicts. Also, many of these remarks included more than one experiment or a whole ATM pass, which accounts, in part, for the high ranking of "General" procedural remarks in Table 3-13.

The Experiment Pointing Control (EPC) had a fairly low ranking procedurally, but this ranking may be misleading. Pointing instruction problems, when related to specific experiments (such as S082B) appeared to contribute in a large degree to the rank ordering of those experiments.

Experiment Operation

Fifteen of the total SL-3 scored procedures critical incidents fell under the Experiment Operation category. Several were attributable to errors resulting from revised operational parameters. The largest number of remarks in this group dealt

Table 3-13: Rank Ordering of Procedural Critical Incidents on SL-3

SCHEDULE/INSTRUCTIONAL		EXPERIMENT OPERATION		OPERATION TIME PHASING		TOTAL COMMENTS	
S082B	18	S056	3	GEN	9	S082B	29
GEN	16	S082B	3	S082B	8	GEN	28
S054	11	GEN	3	S054	5	S054	18
S082A	6	S055	2	S055	4	S055	11
EPC	6	S054	2	S082A	3	S082A	10
S055	5	Hα	1	EPC	3	EPC	9
S056	3	S082A	1	S052	3	S056	8
Hα	0	S052	0	S056	2	S052	3
S052	0	EPC	0	Hα	0	Hα	1
	65		15		37		117

specifically with experiment operation, although these remarks were distributed fairly equally across experiments.

Time Phasing

Of the 37 procedural incidents accrued under the Time Phasing category, half were errors noted by the crew due to beginning or terminating an experiment or Building Block out of phase with requested time. These remarks might, therefore, relate to incidents in the Schedule/Instructions category.

3.2.5 Skylab 4 Mission

3.2.5.1 SL-4 Hardware-Related Critical Incidents

The SL-4 voice transcript data was approached in the same manner as the SL-3 data. Analysis of both missions was undertaken simultaneously after the analysts had developed and verified the analysis technique.

Figure 3-7 presents the summarized voice transcript data for the SL-4 mission. The chart is identical in format to the previous figure for SL-3 (Figure 3-6). The SL-4 mission was 42% longer in duration than SL-3, and man-hours of ATM operation on SL-4 exceeded those on SL-3 by 70%. Both of these factors, as would be expected, had an effect on the total number of remarks. In addition, the SL-4 crew appeared to verbalize more on ATM operations. But in spite of the larger number and greater density of remarks made by the SL-4 crew, they did not offer the depth of comment on hardware difficulties offered by the SL-3 crew. This is explainable in light of the fact that the hardware problems were well known and documented by the SL-3 crew prior to involvement of the SL-4 crew.

Table 3-14 presents the ranking of experiments by total number of deduced errors and total comments. As in the SL-3 Mission, the ranking based on comments does not differ substantially from the ranking based on deduced errors.

The discussions which follow describe these errors and comments, and suggest possible causes and relationships between reported phenomena.

S055

The S055 experiment on SL-4, as on SL-3, had the highest number of critical incidents. Also, the SL-4 detector switches, as on SL-3, contributed the highest percentage, 39%, of these incidents. This likeness across missions becomes even more evident when the SL-4 crew's high number of S055 omission errors is compared with SL-3 S055 omission errors. In both cases, the preponderence of these errors occurred early in the flight, e.g., for SL-4, 84% of such errors occurred on three isolated days in the first 15 days of the mission. The major difference between the two missions, with respect to detectors, is the absence in SL-4 of the Detector #5 malfunction mentioned on SL-3.

Unlike SL-3, the SL-4 crew mentioned a higher degree of concern about the Grating Position Indicator. This hardware contributed 32% of total critical incidents on this experiment. Over half of the remarks regarding this piece of hardware indicated that the crewmen would pass by the desired grating position and have to either settle for an approximate setting or completely recycle the instrument. The problem arose out of the mechanical properties of the display; it counted upward, and could not be cycled backward. Consequently, obtaining

Table 3-14: Hardware Critical Incidents
Rank-Ordered by Experiment for Total Mission

75% TOTAL ERRORS		25% TOTAL COMMENTS		100% TOTAL CRITICAL INCIDENTS	
S055	42	EPC	12	S055	53
S052	18	S055	11	S052	21
S056	15	Hα	3	EPC	16
S054	11	S082A	3	S056	15
S082B	9	S082B	3	S054	13
S082A	4	S052	3	S082B	12
EPC	4	S054	2	S082A	7
Hα	3	S056	0	Hα	6
GEN	0	GEN	0	GEN	0
	106		37		143

a correct setting after a miss required approximately five minutes of additional time.

The Intensity Data display received several comments relating the use of the instrument as a pointing aid requiring a relatively long learning period. However, the crew additionally commented that it was a useful tool.

S052

The S052 experiment is notable for its relatively high number of SL-4 critical incidents, as compared to SL-3. These could not be related to any meaningful trends, however, due to their distribution over the entire SL-4 mission. The mode select, 5-position rotary switch received 10 of 21 of the total remarks, all of which were errors. Seven commission errors were attributable to misreading the Pad and three were Time Displacement errors due to the overextension of the Continuous mode. Of the total errors deduced in the voice transcript remarks, 23% were detected by ground support. Some comments reporting a "streak" or "bar" in the S052 display were made; these sometimes interfered with accurately locating certain features, such as the Comet Kohoutek.

The Experiment Pointing Control, when mentioned by the SL-4 crew as a specific piece of hardware or mentioned in relation to the ATM experiments (Figure 3-7 under General Experiment Support Equipment), frequently required more time than expected to achieve required operations, some of these problems may have arisen out of the schedule. Often the crew mentioned that pointing time intefered with scheduled start times of JOPs and building blocks. Another difficulty commented on by the SL-4 crew which was not mentioned in SL-3 was the tendency for the pointing to drift. This condition may have produced poor results on the experiments operating at that time.

S056, S054, S082A, S082B, H-alpha, Hardware-Related Critical Incidents

Hardware-related incidents were rather evenly distributed across the other experiments and over mission duration. Some few stand out from the others, and these are discussed below.

When looking at Figure 3-7, it may be seen that the Wavelength switch on S082B was reported to have had some errors. This component is a 3-position (M-F-M) toggle switch. Interestingly, no errors were reported on the similar component in S082A. S082A and B are the only experiments having timed modes which received scored critical incidents on the timer. S056, which received the highest total number of reported errors on the start/stop switch, had no other hardware comments recorded other than deduced errors. It was the third ranked experiment on SL-4 in total deduced errors recorded. The SL-4 crew mentioned that the frames remaining counters were used as an indication of experiment status.

3.2.5.2 SL-4 Procedures-Related Critical Incidents

The cell scores for procedural problems identified through voice transcript analysis are shown above in Figure 3-7. A ranking of experiments by type of procedure is presented in Table 3-14. As in SL-3, the SL-4 procedures account for a high percentage, 42.5%, of the total SL-4 critical incidents.

Table 3-15: Procedural Critical Incidents
Rank-Order by Experiment for Total Mission

Schedule/Instructional		Experiment Operation		Operation Time Phasing		Total Proc. Comments	
Gen	12	S055	6	S055	16	S055	29
S054	9	S082B	4	S082B	9	S082B	16
S055	7	S056	2	S054	5	S054	16
S056	4	S052	2	S082A	4	Gen	15
S082A	3	S054	2	S052	4	S056	7
S082B	3	Hα	1	EPC	2	S082A	7
EPC	3	EPC	1	Gen	2	S052	6
Hα	2	Gen	1	Hα	1	EPC	6
S052	0	S082A	0	S056	1	Hα	4
	43		19		44		106

In comparing the ranking of experiments by procedural problems with the ranking by hardware remarks, substantial differences are uncovered. Although S055 continued to be the most discussed experiment, S082B, General Comments, EPC and S054 also received a high percentage of procedural remarks, especially in comparison to the low percent of hardware remarks scored for those categories.

There is a similar trend in SL-3. Most of the procedural critical incidents were directed toward scheduling of experiments and their instructions. The crew seeemed to mention most that the instructions were confusing and unclear, in such areas as the Pad formatting, labeling and wording. Changes in procedures, "being engulfed with building blocks", having no observing time due to experiment overruns, and "tight" morning schedules were some of the procedural problems they mentioned.

The SL-4 procedural critical incidents differed highly from SL-3 in the Operation Time Phasing area in the amount of comments made about ESS (Effective Sunset) termination. 54% of these procedural comments were on the termination of experiments at ESS, as compared to 8% in SL-3.

The procedural difficulties on SL-4, in general, appear to be more related to time than the comments on SL-3. Building blocks were updated between the missions, a fact which may have eliminated some difficulties. However, the inclusion of more activities, shopping lists, etc. was reported to have created more timelining and sequencing conflicts on SL-4. Observation periods were used as experiment periods on several occasions in SL-4.

3.3 COMPARISONS

Two comparisons are made in this section: 1) a comparison of the results of the analyses of the two bodies of data considered during this study, and 2) a comparison of the results of the SL-2 ATM assessment study with the results of this study.

3.3.1 Telemetry Data and Critical Incidents Data Comparison

While both bodies of data analyzed contributed to the identification of ATM C&D problem areas, each data source was also able to contribute its own dimension to the study. For example, the statistical analysis of the telemetry data led to the identification and quantification of many factorial relationships. Those factorial relationships, in turn, led to the identification of problem areas for which design or procedural recommendations were formulated.

The critical incidents data analysis led directly to the discovery of problem areas, and, while it did not allow any assessment in terms of absolute frequence of occurrence, it did provide circumstantial insight that aided in the formulation of appropriate design recommendations. Because of the nature of the two analytical techniques, it was unlikely that the results would stand in conflict. In fact, they did not. Rather, the results derived from the two bodies of data tend to be mutually supportive. For example, both techniques:

- uncovered problems in event timing.
- uncovered procedural directives problems.
- uncovered the occurrence of deliberate procedural deviations.
- uncovered many of the same design and use problems.
- uncovered the same kinds of control-related problems.

3.3.2 Comparison of Phase 2 and Phase 3 Results

Of the seven SL-2 study results (Table 3-16), three (Nos. 1, 2, and 4) were in conflict with, two (Nos. 3 and 6) were in support of, and two (Nos. 5 and 7) were not comparable to the SL-3/SL-4 study results.

Table 3-16: SL-2 ATM Assessment Study Results

1) The left side of the panel had a higher deviation rate than the right side.

2) Three-position toggle switches (F-F-F) used without a display had a high deviation rate (9%).

3) Experiment modes that required manual timing by the crewmen were often timed improperly.

4) Many of the deviations which occurred during operation of S082B involved confusion with S082A.

5) Building Blocks with several subsections separated by pointing commands had high deviation rates for the centermost subsections.

6) Isolated control actuations had a much higher deviation rate (21%) than sequential control actuations (2%).

7) One-g control panel operation is a valid predictor of zero-g operation. Although the deviation rates are different, the types and relative frequency of deviations are almost identical.

Specific comparisons between these SL-2 study results and the SL-3/SL-4 study results are described in Section 4.0.

SECTION 4.0

INTEGRATED RESULTS, CONCLUSIONS AND DESIGN RECOMMENDATIONS

This section has three major objectives:

1) to present the study results discussed in Section 3.0 as direct, abbreviated statements.

2) to conclude what factors contributed to the problem areas identified.

3) to advance design and procedural recommendations for overcoming those factors.

In meeting these objectives, the 52 study results obtained from this study are presented in nine tables, together with the number of the Section 3.0 paragraph from which they were extracted. Immediately following each table is a discussion of the factors contributing to the results found and the associated design or procedural remedies.

4.1 INTER-MISSION RESULTS

Table 4-1: Inter-Mission Results

REFERENCE PARAGRAPH	RESULT
3.1.1.1	SL-4 overall error rate was about half that of SL-3.
3.1.2.2.3	SL-3 error rate was significantly higher (< .001) than was that of SL-4.
3.1.1.1	Both controls and displays contributed to the SL-3, SL-4 difference.

Table 4-1: Inter-Mission Results (Continued)

REFERENCE PARAGRAPH	RESULT
3.1.1.1	S054 Exposure Range error rate was dramatically lower for SL-4 than for SL-3.
3.1.2.2.3	Hα 1, S055A, S054 error rates were significantly lower for SL-4 than for SL-3.

All five of these study results can be attributed to the same four factors: 1) differences in procedural directives, 2) differences in task difficulty, 3) differences in training effectiveness, and 4) differences in ground crew experience. While no effort was made to verify the correctness of these assumptions, it is assumed that because SL-4 followed two similar manned flights, it benefitted from previous experience. Therefore, it should be safe to say that, in addition to more experienced ground crews, SL-4 was provided with more understandable procedural directives, less confusing and better arranged tasks, and more effective training. The design and procedural implications of these assumptions are clear: Where possible, prior to a mission,

1) Develop an integrated set of well organized, clearly understandable operating procedures and procedural directives for both the crew and for direct ground support personnel.

2) Train all crews and direct mission support personnel to use those procedures and procedural directives, using the highest possible fidelity integrated mission simulators.

3) Where needed, as a result of the experiences gained in that training simulation, upgrade all procedures and procedural directives and train again.

4) Repeat Steps 1 - 3 until an acceptable level of overall system performance has been attained.

4.2 INTRA-MISSION RESULTS

Table 4-2: Intra-Mission Results

REFERENCE PARAGRAPH	RESULTS
3.1.1.1	SL-3 error rate decreased across time.
3.1.1.1	Display error rate decreased across time for both SL-3 and SL-4.
3.1.2.2.3	There were significant differences in error rates between time periods.
3.1.1.1	SL-4 error rate remained constant over time (revised figures).

With the exception of the third item, Table 4-2 results tend to confirm the recommendations advanced in Section 4.1. Whereas SL-4 mission performance tended to remain at a constant rate (thus tending to confirm suppositions that it received the benefit of more complete, effective training), SL-3 performance did not. Rather, SL-3 mission performance tended to improve over time. In doing so, it exhibited a learning/adaptation effect and, therefore, supports an argument for additional training.

An interesting observation concerning the second result in Table 4-2 (e.g., both missions tended to improve in their display performances over time) is that neither mission crew had been sufficiently trained to use the displays provided for the tasks performed. Thus, recommendations to rectify problems associated with this section's results are the same as the Section 4.1 recommendations.

4.3 COMPONENT FUNCTION RELATED RESULTS

Table 4-3: Component Function Related Results

REFERENCE PARAGRAPH	RESULT
3.1.1.2	Operations involving 3-pos F-F-F toggle switches (mode select function) were performed less accurately than those involving 3-pos M-SL-M toggle switches (predominantly Start/Stop function).
3.1.1.3.4	Mode selection errors accounted for the fourth highest number of Table 3-1 error rate cells.
3.1.2.2.1	Hypothesis #1* - Rejected
3.1.2.2.1	Hypothesis #2** - Rejected
3.1.2.2.1	Hypothesis #3*** - Rejected

In this study, no instance of hardware type superiority over another hardware type was demonstrated. What did emerge from this study is that component function and associated relationships (e.g., panel placement, task sequence order, etc.) seemed to be more important. This stands in direct conflict with the findings of the SL-2 ATM assessment study results, which attributed high error rates to

*Hypothesis #1: Three-position toggle switches have a significantly higher error rate than other types of switches.

**Hypothesis #2: Rotary switches with positions numbering more than four have a significantly higher error rate than rotary switches with four positions.

***Hypothesis #3: Rotary switches with positions numbering more than four have a significantly higher error rate than the other types of switches used on the ATM panel.

the use of three position (F-F-F) toggle switches. Design implications of the Table 4-3 results are not obvious. Therefore, certain physical and procedural similarities along functional lines may help to provide useful insight.

First, the Start/Stop function is always associated with a single control. Each of these is located more or less in the same position with respect to its associated experiments. Moreover, each is accompanied by a ready/operate light which enhances its target value. Together, these physical attributes and the prominence of start/stop instructions in the procedural directives would seem to be sufficient reasons for lower error rates.

The mode select function, on the other hand, is served by a varying number of controls on different experiments. These controls are not located similarly within their respective experiments. The status displays associated with these controls are of relatively low target value. Further, they need to provide more than simple "yes" or "no" information. By themselves, these attributes would seem to be cause enough for degraded mode selection performance. However, in addition to these physical factors, the mode select instructions have been given a position of low prominence in the procedural directives.

While it may seem appropriate to recommend that mode select functions be performed by one control, that the control be located consistently with respect to its function, and, that it be accompanied by a high target value display, these are often not the best design choices. However, one absolute procedural recommendation that can be made as a result of the Table 4-3 findings, is that any procedural instruction to be communicated must be given sufficient prominence in the procedural directives.

4.4 CONTROL RELATED RESULTS

Table 4-4: Control Related Results

REFERENCE PARAGRAPH	RESULT
3.2.1.1	S055A HV detectors were omitted.
3.2.1.1	S055A grating reference (opt./mech) selector was left in wrong position.
3.2.1.1	S055A night interlock was left in override (experiment ran all night).
3.2.1.1	S056 exposure selection switch was associated with commission errors (3-pos., F-F-F toggle switch).
3.2.2.1	S052 mode selection caused errors (5-pos. rotary switch).
3.2.2.1	S054 grating position selection was left in improper position (2-pos., F-F toggle switch).
3.2.2.1	S082B wavelength selection resulted in errors (3-pos., M-SL-M toggle switch).

Rather than having been concluded from error rates calculated from telemetry data as were the results in previous Section 4.0 tables, the results in Table 4-4 were extracted from the voice transcripts. Because of this, no assumptions can be made about their relative contribution to the overall ATM C&D error rates. Nevertheless, since they were of enough concern to have been emphatically voiced by the crew or by first line mission support personnel, they will be addressed here.

Of immediate interest is the diversity of the control population. This tends to support the results of Section 4.3. Also, since all the controls mentioned in

Table 4-4 are "components", they are subject to the same recommendations advanced in Section 4.2. Other recommendations are presented below.

There are seven S055A high voltage detectors (3-pos., F-F-F toggles) located together on the panel. While problems with operating these detectors did not appear in the telemetry analysis, failures to activate those that were required can probably be attributed to the combined effects of three major factors: 1) directive information background, 2) individual control feedback, and 3) control clutter.

Directive information breakdown is the problem addressed at the end of Section 4.3. It has equal applicability to all of the controls listed in Table 4-4. Individual control feedback (visual) is also applicable to all of the controls in this section, but its solutions are well understood. Therefore, except in instances where special comment is deemed advantageous, neither of these two factors will be mentioned again in this section. Control clutter, on the other hand, is a problem unique (among the results in Table 4-4) to the S055A high voltage detectors. It results from the inability to readily distinguish one control from another. The problem can be handled by rearrangement and re-marking, but the design recommendation applicable to control clutter is that similar proximal components should be made individually distinguishable.

S055A grating reference and S054 grating position status information were not always included among the procedural directives. Thus, there was no consistent reminder for the operator to check the related controls. Yet several instances were recorded of valuable data being missed because these controls were left in the wrong positions.

This indicates that there was a need for the operator to check the status of each of these controls on a regular basis. Where this need exists, it must be reflected by inclusion of appropriate instructions as part of the operational directives.

Leaving the S055A night interlock in the override position was another problem which arose. While the problem is similar to the one just discussed, there is an important difference. Whereas the grating reference control can be considered a normal part of the experiment, the night interlock switch cannot. The latter is a control rarely used and, then, under special conditions, so instructions concerning its positional status do not rightfully belong in the normal operational directives. Therefore, if it is inadvertently left "on", it is unlikely that the error will be quickly discovered. To guard against the possibility of controls of this category , being inappropriately left on, a cyclical alert (preferably tonal) should be incorporated. That is, if a control that can adversely affect system performance is left in a dangerous position beyond an acceptable time period, an intermittent tone should be sounded to alert the operator of its status.

The S056 exposure length switch is unusual only in that it is isolated from the rest of its associated components. If possible, isolation of this type should be avoided. If it cannot, particular care must be taken to include necessary instructions prominently in the pertinent operational directives.

The problem cited for the S052 mode select switch specifically mentioned it as being attributable to a misread pad (i.e., procedural directives). Therefore, the procedural directives comment already made should suffice here.

Comments about the S082B wavelength selectors may also have been rooted in problems with procedural directives, but, in this case, there is an additional problem. The control (M-SL-M toggle switch) itself gives no feedback, so a three-position flag is provided for that purpose. If there was a problem with mis-setting this control, it well may have been due to a display legibility problem. Therefore, if the need for display feedback supplementary to a control action has been identified, the designer must ascertain that the required information is faithfully transmitted to the control user under all expected operating conditions (e.g., low light levels).

4.5 Hα 1 FRAMES/MINUTE CONTROL RELATED RESULTS

Table 4-5: Hα 1 Frames/Min Control Related Results

REFERENCE PARAGRAPH	RESULT
3.1.1.3.3	Hα 1 frames/min. rate selection errors accounted for the third highest number of Table 3-1 error rate cells.
3.1.2.2.2	Hypothesis #5* accepted ($<.001$).
3.1.2.2.2	Left side panel operations demonstrated significantly higher ($<.01$) error rates than did right side operations; this effect vanishes if the Hα 1 errors are removed.

(Hypothesis #5: Hα 1 has a significantly higher error rate than any other experiment on the left side of the panel.

Table 4-5: $H\alpha 1$ Frames/Min Control Related Results (Continued)

REFERENCE PARAGRAPH	RESULT
3.1.2.2.2	Highly similar experiments exhibited significantly higher error rates than dissimilar experiments (this result is attributable to $H\alpha$ 1 error rate skewing effect).
3.1.2.2.2	There is no significant difference in error rates between S082A and S082B.
3.2.1.1	Ground control discovered $H\alpha$ 1 frames/min. setting errors.

While it may seem unusual or inappropriate to devote an entire section to the findings surrounding one experiment, the impact of this experiment on overall ATM C&D performance measured, justifies the special treatment. First, $H\alpha$ 1 frames/min. error rates alone accounted for the first four results listed in Table 4-5. Thus, if the reasons for the high $H\alpha$ 1 error rates can be specified, the mechanism behind these results will also have been pinpointed.

Section 3.1.1.1 attributes <u>all</u> of the $H\alpha$ errors for SL-4 to an inadequacy of this study (missing data). This accounts for much of the problem. In fact, it also supports the assertion that the remainder of the problems experienced were not due to hardware inadequacies. Rather, it indicates that the trouble may have had two other sources: training emphasis and procedural directives.

In the first case, it is known that the importance of $H\alpha$ was minimized throughout many of the training sessions (because of its relative operating simplicity and its lack of full experiment stature). Indeed, it is also apparent that this minimization of stature was carried through all the way to the $H\alpha$ 1 operational directives presented in the Building Blocks, e.g., as tiny notations buried in obscure rows at the bottom of the form. Thus, both sources seem to have been contributory to the frames/min. error rate problem.

If a similar problem is to be avoided in future missions, it is imperative that:

1) All mission operations be given appropriate stature during training.

2) All required procedures be presented in the procedural directives with equal prominence.

Having discussed the reasons behind the large $H\alpha$ error rates, it is now appropriate to turn to a discussion of the Table 4-5 results. First, it must be said that, originally, Results #3 and #4 tended to support the SL-2 ATM assessment's left vs. right side and S082A vs S082B results. As amended by the removal of $H\alpha$ 1 errors, however, the results are in disagreement. So, too, is this study's finding comparing S082A and S082B error rates (Result #4) in opposition to the SL-2 assessment finding addressing the same question.

4.6 DISPLAY RELATED RESULTS

Table 4-6: Display Related Results

REFERENCE PARAGRAPH	RESULT
3.1.1.1	Both crews performed 3 to 5 times better on controls than they did on displays.
3.1.2.2.1	Display operations resulted in significantly higher ($<.001$) error rates than did control operations.

Table 4-6: Display Related Results (Continued)

REFERENCE PARAGRAPH	RESULT
3.1.1.3.2	S055A grating position errors were the second highest contributor to the number of Table 3-1 error rate cells.
3.1.2.2.2	Sequential operations exhibited significantly ($<.001$) lower error rates than did single operations.
3.2.2.1	S055A grating position and indicator contributed to operating difficulties.
3.2.1.1	H α video monitor and images were of poor quality (rapid image oscillations and telescoping effect).
3.2.1.1	Hα video image and quality created problems operating S082A.
3.2.1.1	3-position flags for S056 filter position proved difficult to use.
3.2.2.1	Experiment pointing would drift off required position undetected by operator.

Result #4 in the above table is directly supportive of the similar, isolated control actuations finding reported as a result of the SL-2 assessment activity. Further, both of those findings are more or less supportive of Table 4-6 results #1 and #2. That is because display operations are largely equivalent to isolated or single operations. They are not, however, exactly similar. The S055A grating position indicator, usually used as part of a sequential operation, is the exception. Nevertheless, its performance, like that of the other displays, left a great deal to be desired.

The detailed reasons for the disappointing performance of the ATM displays studied was presented earlier in Section 3.1.1.1. For this reason, only a general overview of the problems encountered will be identified.

All of the first five results can be explained in terms of the effects of three factors: directive functional breakdown, display target value, and display dynamics. Results #1, #2 and #4 had directive functional breakdowns and display target value problems related to timing to account for their presence (discussed in Section 4.7 below). Timing, in turn, was dependent upon effective procedural directives and compelling display target values. The S055A grating position indicator results, on the other hand, from display problem relationships (requirements to dyanmics). Specifically, the procedural directives required setting the display units digit to a particular value. That requirement was not compatible with the display's high rate of incrementing. Thus, an overrun situation often arose, which was compounded by the lack of a display decrement provision. At least three design recommendations for eliminating this problem are apparent:

1) Where a digital counter (indicative of a non-continuous control requirement equipment function) must be set, a pre-select feature should be provided. That is, the desired display value should be ordered by the operator and the equipment should effect the setting.

2) If there is a need for precisely setting a digital counter display, and, if no provision can be made for its counting direction reversal, then a single rate of advancement well suited to the task requirements should be provided.

3) If a high counting rate digital display is required, a variable rate control with a reversing feature should be provided.

Both Hα1 video monitoring comments pertain to the same problem -- poor video quality due to rapid image oscillations and a telescoping effect. These problems can be eliminated if the following CRT monitor design criteria are met:

1) Scaling disparity between expected or reference and primary images should be minimized.

2) Sufficient image resolution should be provided to permit operator acquisition of required data.

3) Image pattern and pattern orientation should conform to operator expectations.

4) Sufficient image stability must be provided to assure operator acquisition of the information presented.

The three-position flags that indicate the S056 filter position presented the same problem discussed about the S082B wavelength select display in Section 4.4. That is, it was misread. Thus, the discussion presented in the earlier section also pertains here.

Experiment pointing drift as mentioned in the last comment is another matter. It can lead to a serious impairment of mission objectives across many experiments. Therefore, if encountering such a problem is likely or even probable, a suitable alarm system should be provided to indicate when the monitored function drifts outside tolerance.

4.7 TIME DISPLACEMENT RELATED RESULTS

Table 4-7: Time Displacement Related Results

REFERENCE PARAGRAPH	RESULT
3.1.1.3.1	Time displacement errors accounted for the highest number of Table 3-1 error rate cells.
3.2.1.1	S052 continuous mode was allowed to run past time.
3.2.1.2	Timed operations information in unclear.

Problems associated with time displacement fell into two categories: procedural directives and functioning. Together, these problems caused the late starting and early termination of experiments that required manual timing. This directly supports the SL-2 ATM assessment finding that "experiment modes that require manual timing by the crewmen were often timed improperly."

Specific procedural directive problems related to time displacement errors included: misunderstood voice communications, cluttered checklists, and inadequate Building Block presentation of experiment start, stop and span times. These suggest the following recommendations:

1) Vocally communicated timing directives should be presented in a format, mutually acceptable to both sender and recipient. That format should be capable of transmission (via the intended medium) without significant loss of information intelligibility.

2) Checklists should be laid out to ensure full and accurate transmission of the information they contain.

3) A list of manually performed activities should have the point of initiation for all activities clearly indicated along a single timeline. In addition, all of the operations important to the performance of each activity should be clearly presented and time referenced.

Part of the display functioning problems associated with time displacement were attributable to a lack of target value*. This was true both for clocks (digital and analog) and for ready/operate lights (the two display types used for timing). Because both of these displays are dependent upon the visual channel for their target value, and because the visual channel is often not available, the solution is obvious. If manually timed operations are required, the time reference display should be equipped with an auditory alarm.

The remainder of the display problem was attributable to the lack of a dedicated timing device for each experiment, incorporating manually timed operating modes. Here, too, the design solution is obvious -- all manually timed operations likely to be performed in conjunction with other manually timed operations, should be provided with dedicated timers.

*Target value = the ability to attract attention when competing with other stimuli.

4.8 PROCEDURES/SCHEDULING RELATED RESULTS

Table 4-8: Procedures and Scheduling Related Results

REFERENCE PARAGRAPH	RESULT
3.1.1.1	Both crews erred in following assigned procedures.
3.2.1.2	Pointing instructions were unclear as to coordinate and permissible tolerance.
3.2.1.2	Important information was omitted from procedural directives (pertaining to the S055A Night Interlock, and the Grating Reference (opt./mech).
3.2.1.2	Nearly all S082B and S054 comments cited procedural ambiguity.
3.2.2.2	S082B scheduling difficulties were experienced.
3.2.2.1	Insufficient time was scheduled for experiment pointing.

Each of the first four Table 4-8 results can be attributed to factors that have already been identified and fully addressed. Therefore, neither the results nor the factors to which they are attributed will receive the benefit of further discussion.

Both of the remaining Table 4-8 results address a scheduling problem. From these and other related voice transcript remarks, it would seem that realistic time requirements had not been developed prior to the mission for each of the planned tasks.

If the day to day mission planning is to be scheduled effectively, such time estimates must be provided. It is, therefore, recommended that during the training simulations identified in Section 4.1, an effort be made to accurately record the time required to perform <u>all</u> planned mission tasks.

4.9 UNRELATED FINDINGS AND COMMENTS

Table 4-9: Unrelated Findings and Comments

REFERENCE PARAGRAPH	RESULT
3.1.2.2.2	There is no significant difference between upper and lower control panel associated error rates.
3.2.1.1	S055A Grating Reference select control (2-position, F-F toggle) was confused with the S055A start/stop switch (3-position, M-SL-M toggle switch).
3.2.2.1	Pointing by S055A intensity data display was effective but required practice.
3.2.2.1	Frames remaining counters were used to indicate operating status.
3.2.2.2	Dislike was expressed for the use of two control mode select functions (e.g., S054).

Because these results are more or less unrelated to each other, they will be addressed one at a time.

Finding no significant error rate differences between upper and lower panel operations complements the no right-left differences picture presented in Section 4.5. Taken together, these results more or less indicate that, within the ATM panel area studies, all segments are equally suitable to the control and display operations performed.

Mistaking the S055A grating reference control for the start/stop switch probably resulted because the two components were adjacent and both were under illuminated displays. Thus, each of the components had an equal target value that was higher than that of those surrounding them. Since it is usually the case that only the start/stop switch has the advantage of high target value, both components were perceived as the start/stop switch. Therefore, if a control is intended to have high target value, that target value should not be diminished by placing a similar control, equally able to attract the operator's attention, next to it.

The third comment concerning the need to practice experiment pointing using the S055A intensity data display only underlines the requirement for the high fidelity training simulations identified in Section 4.1.

Use of the frames remaining counters, as described in Comment #4, to indicate an experiment operating status is not a negative finding. It only points out that the operators want to know more than that they have started the experiment or that they have selected the correct mode. They also want to know if the mode they have selected is being performed. Therefore, in situations where such information is not already provided, it is desirable to provide the operator with the feedback necessary to tell him in what mode the system is actually operating.

Finally, the last comment was included to demonstrate that crew subjective comments, while extremely valuable, are not necessarily related to actual system performance. In this case, the comment was made during SL-4 indicating a dislike for the dual control mode select operations required for S054. From that comment, one might expect that an analysis of the telemetry data would reveal relatively high error rates related to S054 control operations. This was not the case. In fact, during the SL-4 Mission, S054 scored the lowest (.005) control-related error rate of all the ATM experiments. Thus, while the voice transcript comments were treated throughout Section 4.0 as though they were indicative of a serious C&D system problem, in many cases, they probably were not. Nevertheless, problems that were only perceived served the same purpose as the "real" ones, i.e., they focused analytical attention on particular areas of the ATM experiment C&D system operation and, in doing so, triggered the development of design guidelines that might be of some future benefit.

4.10 DESIGN RECOMMENDATIONS SUMMARY

Here, in Table 4-10 is a list of all of the design and procedural recommendations advanced in the Section 4.0 subsections. While reviewing this list, there may be a tendency on the part of the reader to consider some of the solutions obvious. That the solutions seem obvious after being stated does not minimize their importance; they do address problem areas identified as a result of a careful scrutiny of SL-3 and SL-4 ATM C&D system performance.

Table 4-10: Design Recommendations Summary

1) Develop an integrated set of well organized, clearly understandable operating procedures and procedural directives, both for the crew and for direct ground support personnel.

2) Train all crews and direct mission support personnel to use the procedures and procedural directives developed, using the highest possible integrated mission simulations.

3) Where needed, as a result of the experiences gained in training simulation, upgrade all procedures and procedural directives and train again.

4) Repeat steps 1 through 3 until an acceptable level of overall system performance has been attained.

5) Any procedural instruction to be communicated must be given sufficient prominence in the procedural directives.

Table 4-10: Design Recommendations Summary
(Continued)

6) Similar proximal components should be made individually distinguishable.

7) Where there is a need for the operator to check control setting status, the need must be reflected by the inclusion of appropriate instructions as part of the operational directives.

8) If a control that can adversely affect system performance is left in a dangerous position beyond acceptable time limits, an intermittent tone should be sounded to alert the operator of its status.

9) If the need for display feedback supplementary to a control action has been identified, the required information must be faithfully transmitted to the control user under all expected operating conditions (e.g., low light levels).

10) All mission operations should be given appropriate stature during training.

11) All required procedures should be presented in the procedural directives with equal prominence.

12) Where a digital counter (indicative of a noncontinuous control requirement equipment function) must be set, a preselect feature should be provided. That is, the desired display value should be ordered by the operator and the equipment should effect the setting.

13) If there is a need for precisely setting a digital counter display, and if no provision can be made for its counting direction reversal, then a single rate of advancement well suited to the task requirement should be provided.

14) If a high counting rate digital display is required, a variable rate control with a reversing feature should be provided.

15) Scaling disparity between expected or reference and primary CRT images should be minimized.

16) Sufficient CRT image resolution should be provided to permit operator acquisition of required data.

17) CRT image pattern and pattern orientation should conform to operator expectations.

Table 4-10: Design Recommendations Summary
(Continued)

18) Sufficient CRT image stability must be provided to assure operator acquisition of the information presented.

19) If important display parameter drift is likely or even probable, a suitable alarm system should be provided to indicate when the monitored function drifts outside tolerance.

20) Vocally communicated timing directives should be presented in a format mutually acceptable to both sender and recipient. That format should be capable of transmission (via the intended medium) without significant loss of information intelligibility.

21) Checklists should be laid out to ensure full and accurate transmission of the information they contain.

22) A list of manually performed operations should have the point of initiation for all activities clearly indicated along a single timeline. In addition, all of the operations important to the performance of each activity should be clearly presented and time referenced.

23) If manually timed operations are required, the time reference display (clock) should be equipped with an auditory alarm.

24) All manually timed operations likely to be performed in conjunction with other manually timed operations should be provided dedicated timers.

25) The time required to perform <u>all</u> planned mission tasks should be accurately measured and recorded during high fidelity training sessions.

26) If a control (or display) is intended to have a high target value, that target value should not be diminished by placing a similar control (or display), equally able to attract the operator's attention, next to it.

27) It is desirable to provide the operator with the feedback necessary to tell him in what mode the system is <u>actually</u> operating.

SECTION 5.0

RECOMMENDATIONS FOR FUTURE WORK

Because of the scope of this effort, much valuable work was left undone. For example, many interactions between the Table 3-1 (above) data cell contributors were not identified. Further, many individual voice transcript incidents were not addressed. Performing these activities would be profitable in terms of triggering additional design recommendations.

More important contributions could be made, however, if the data collected and the results obtained were correlated with other identifiable performance impacting factors. Some of these factors might include work density (as inferred from general mission and ATM schedules), crew physiological status (as indicated by biomedical data), and incidents of hardware failure (from the Skylab mission log).

A final effort that could be of significant benefit is the preparation of a sample set of SL-3 or SL-4 procedural directives that incorporate the Section 4.0 recommendations. The recommendations of this study, together with a set of the present directives and a set of the revised directives for comparison, could contribute to the effectiveness of future mission procedural directives.

APPENDIX A

LIST OF REFERENCES

APPENDIX A

REFERENCES

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UES MATRIX

APPENDIX B

TELEMETRY DATA SUMMARY SHEETS

RAW DATA SCORE SHEET

DATA POINT #: 1/3 ~~JOP~~ #: SL-3 ~~BB~~ DP #: 2-78 MISSION TIME: DAY 219 to DAY 233

	CONTROLS													DISPLAYS					CREW OPN			ERROR TYPE				
	TOGGLE, 3 POS	ROTARY FPM	ROTARY 4 POS 6 POS	TOGGLE SW, 2 POS (F F)	TOGGLE SW, 2 POS (M SL)	TOGGLE SW, 2 POS (L L)	TOGGLE SW, 3 POS (F F F)	TOGGLE SW, 3 POS (F-F FG)	TOGGLE SW, 3 POS (M SL M)	ROTARY SW, 5 POS	ROTARY SW, 8 POS	ROTARY SW, 11 POS	TOTAL	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTP	ILLUMINATED STATUS INDICATORS ~~DIGITAL READOUT~~	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	REMARKS
Ha1, 2													4/58						4/58		4/58	–	3	–	1	
S056													5/152						5/152		5/152	2	3	–	–	Procedural Deviation: |||
S082A													–/47					1/4	1/51		1/51	–	1	–	–	Procedural Deviation: |||
S082B													2/40					–/1	2/41		2/41	–	2	–	–	Procedural ~~Error~~ Dev.: ~~||||~~
S052													2/29						–/26	2/3	2/29	1	–	–	1	Procedural ~~Error~~ Dev.: ||||
S055A													15/325					12/43	21/345	6/23	27/368	1	18	–	8	[illegible] Procedural Deviation: ~~||||~~ |||
S054													3/106						3/104	–/2	3/106	–	1	1	1	Procedural Deviation: |||
DATA POINT TOTAL	–/29	–/24	2/23	–/39			21/331		5/194	–/11	2/56	1/48	31/757			11/40	2/8	13/48	36/777	8/28	44/805	4	28	1	11	TOTAL PROCEDURAL Dev. = 26

KEY:

E/EO: E = ERRORS COMMITTED; EO = ERROR OPPORTUNITIES

Figure B-1a: Data Summary Sheet for First 1/3 of SL-3

ORIGINAL PAGE IS OF POOR QUALITY

RAW DATA SCORE SHEET

DATA POINT #: 2/3 ~~JOP #~~: SL-3 DP ~~DB~~ #: 80 to 157 MISSION TIME: DAY 234 to DAY 249

CONTROLS (each cell: errors committed / error opportunities)

	TOGGLE, 3 POS	ROTARY FPM	ROTARY 4 POS 6 POS	TOGGLE SW, 2 POS (F F)	TOGGLE SW, 2 POS (M SL)	TOGGLE SW, 2 POS (L L)	TOGGLE SW, 3 POS (F F F)	TOGGLE SW, 3 POS (F F FL)	TOGGLE SW, 1 POS (M SL M)	ROTARY SW, 5 POS	ROTARY SW, 8 POS	ROTARY SW, 11 POS	TOTAL
Hα1, 2													17/66
S056													3/93
S082A													1/33
S082B													2/23
S052													–/16
S055A													4/334
S054													10/172
DATA POINT TOTAL	–/32	–/41	8/41	–/41			23/327	–/2	5/172	–/10	–/40	1/31	37/737

DISPLAYS, CREW OPN, ERROR TYPE

	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTR	ILLUMINATED STATUS INDICATOR	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	REMARKS
Hα1, 2						17/66		17/66	7	10	–	–	
S056						3/93		3/93	–	3	–	–	Procedural Deviation: 4
S082A					–/11	1/42	–/2	1/44	–	–	–	1	PROcedural Deviation: 1
S082B					–/3	2/26		2/26	–	1	–	1	Procedural Deviation: 4
S052						–/16		–/16	–	–	–	–	Procedural Deviation: 4
S055A					6/51	6/352	4/33	10/385	3	2	–	5	
S054						10/172		10/172	–	8	–	2	Procedural Deviation: 1
DATA POINT TOTAL			4/50	2/15	6/65	39/767	4/35	43/802	10	24	–	9	TOTAL PROCEDURAL DEVIATIONS = 14

KEY:

E — ERRORS COMMITTED

EO — ERROR OPPORTUNITIES

Figure B-1b: Data Summary Sheet for Second 1/3 of SL-3

RAW DATA SCORE SHEET

DATA POINT #: 3/3 ~~JOP #~~: SL-3 DP# ~~BB #~~: 163 to 196 MISSION TIME: DAY 251 to DAY 264

CONTROLS (each cell: E/EO)

	TOGGLE, 3 POS (FFM)	ROTARY	ROTARY 4 POS to 3 POS	TOGGLE SW. 2 POS (F F)	TOGGLE SW. 2 POS (M SL)	TOGGLE SW. 2 POS (L L)	TOGGLE SW. 3 POS (F F F)	TOGGLE SW. 3 POS (F F FL)	TOGGLE SW. 3 POS (M SL M)	ROTARY SW. 5 POS	ROTARY SW. 8 POS	ROTARY SW. 11 POS	TOTAL
Hα1,2													5/24
S056													1/37
S082A													–/13
S082B													–/14
S052													2/30
S055A													2/209
S054													–/56
DATA POINT TOTAL	–/12	–/13	–/13	–/14			5/189	1/2	1/90	2/14	1/25	–/11	10/383

DISPLAYS, CREW OPN, ERROR TYPE

	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTR	ILLUMINATED STATUS INDICATORS (~~DIGITAL READOUT~~)	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	REMARKS
Hα1,2						5/24		5/24	4	1	–	–	
S056						1/37		1/37	–	–	–	1	PROCEEDURE DEV. 1
S082A					–/1	–/14		–/14	–	–	–	–	
S082B					–/6	–/16	–/4	–/20	–	–	–	–	PROCEEDURE DEV. 1
S052					–/2	2/30	–/2	2/32	–	1	–	1	PROCEEDURE DEV. 11
S055A					3/34	2/221	3/22	5/243	–	2	–	3	
S054						–/56		–/56	–	–	–	–	
DATA POINT TOTAL			1/30	2/13	3/43	10/398	3/28	13/426	4	4	–	5	TOTAL PROCEEDURAL DEVIATIONS = 4

KEY:

E — ERRORS COMMITTED

EO — ERROR OPPORTUNITIES

Figure B-1c: Data Summary Sheet for Third 1/3 of SL-3

RAW DATA SCORE SHEET

DATA POINT #: 1/3 ~~JOP~~ #: SL-4 ~~BB~~ DP #: 197 to 239 MISSION TIME: DAY 331 to DAY 350

CONTROLS

	~~4PS~~		~~SIDE ALIGNMENT~~		TOGGLE SW, 2 POS (F F)	TOGGLE SW, 2 POS (M SL)	TOGGLE SW, 2 POS (L L)	TOGGLE SW, 3 POS (F F F)	TOGGLE SW, 3 POS (F F FG)	TOGGLE SW, 3 POS (M SL M)	ROTARY SW, 5 POS	ROTARY SW, 8 POS	ROTARY SW, 11 POS	TOTAL
Hα1,2														–/74
S056														1/107
S082A														–/28
S082B														–/47
S052														1/44
S055A														3/294
S054														–/76
DATA POINT TOTAL	–/37	–/19	–/19	–/27			1/306		–/171	1/20	3/39	–/32		5/670

DISPLAYS / CREW OPN / ERROR TYPE

	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTR	DIGITAL READOUT	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	REMARKS
Hα1,2						–/74		–/74	-	-	-	-	
S056						1/107		1/107	-	-	-	1	Procedure Deviation: I
S082A					–/9	–/37		–/37	-	-	-	-	
S082B					–/10	–/57		–/57	-	-	-	-	Procedure Deviation: III
S052					–/4	1/46	–/2	1/48	-	1	-	-	Procedure Deviation: I
S055A					8/41	5/308	6/27	11/335	1	5	-	5	
S054						–/76		–/76	-	-	-	-	
DATA POINT TOTAL			8/55	–/9	8/64	7/705	6/29	13/734	1	6	-	6	TOTAL PROCEEDURE DEVIATIONS = 5

KEY:

E — ERRORS COMMITTED

EO — ERROR OPPORTUNITIES

Figure B-1d: Data Summary Sheet for First 1/3 of SL-4

B-5

RAW DATA SCORE SHEET

DATA POINT #: 2/3 ~~LOP #~~: SL-4 DP# ~~DB #~~: 242 to 285 MISSION TIME: ~~DAY 352~~ to DAY 374

	CONTROLS													DISPLAYS					CREW OPN			ERROR TYPE				REMARKS
	Toggle, 3 pos (FFM)	ROTARY	ROTARY 4 pos 6 pos	TOGGLE SW. 2 POS (F-F)	TOGGLE SW. 2 POS (M-SL)	TOGGLE SW. 2 POS (L-L)	TOGGLE SW. 3 POS (F-F-F)	TOGGLE SW. 3 POS (F-F-FG)	TOGGLE SW. 3 POS (M-SL-M)	ROTARY SW. 5 POS	ROTARY SW. 8 POS	ROTARY SW. 11 POS	TOTAL	MECHANICAL FLAG. 2 POS	MECHANICAL FLAG. 3 POS	ELECTROLUMINESCENT CNTR	ILLUMINATED STATUS INDICATOR	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	
Hu1,2													4/32						4/32		4/32	1	3	-	–	
S056													3/69					–/4	3/67	–/4	3/71	-	–	-	3	
S082A													–/17					–/5	–/17	–/5	–/22	-	-	-	–	
S082B													1/26					1/9	1/25	1/10	2/35	–	-	-	2	
S052													–/37					–/4	–/37	–/4	–/41	-	–	-	-	
S055A													–/121					2/22	1/129	1/14	2/143	1	-	-	1	PROCEEDURE DEVIATION: 1
S054													–/36						–/36		–/36	-	-	-	–	PROCEEDURE DEVIATION: 1
DATA POINT TOTAL	–/16	–/9	–/9	–/13			5/25		2/14	–/13	–/18	1/19	8/336			3/44	–/–	3/44	9/343	2/37	11/380	2	3	–	6	TOTAL PROCEEDURE DEVIATIONS = 2

KEY:

E — ERRORS COMMITTED

EO — ERROR OPPORTUNITIES

Figure B-1e: Data Summary Sheet for Second 1/3 of SL-4

RAW DATA SCORE SHEET

DATA POINT #: 3/3 ~~JOP #~~: SL-4 ~~BB #~~ DP#: 286 to 333 MISSION TIME: DAY 375 to DAY 398

CONTROLS (each cell: E/EO)

	Toggle SW, 3 pos (F-F-M)	Rotary 4 pos	Rotary 6 pos	TOGGLE SW, 2 POS (F F)	TOGGLE SW, 2 POS (M SL)	TOGGLE SW, 2 POS (L L)	TOGGLE SW, 3 POS (F F F)	TOGGLE SW, 3 POS (F F FG)	TOGGLE SW, 3 POS (M SL M)	ROTARY SW, 5 POS	ROTARY SW, 8 POS	ROTARY SW, 11 POS	TOTAL
Ha1, 2													13/78
S056													–/122
S082A													1/42
S082B													–/20
S052													5/97
S055A													4/277
S054													1/77
DATA POINT TOTAL	–/39	1/19	–/18	–/22			17/276		4/225	2/37	–/43	–/34	24/713

DISPLAYS, CREW OPN, ERROR TYPE

	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTR	~~ILLUMINATED~~ DIGITAL READOUT STATUS INDICATORS	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	REMARKS
Ha1, 2						13/78		13/78	3	10	–	–	All Errors were clustered together & were incorrect Exposure rates ∴ Likelyhood of deliberate activity: Procedural Deviation: 1
S056					–/2	–/121	–/3	–/124	–	–	–	–	Procedural Deviations: 6
S082A					–/14	1/51	–/5	1/56	–	–	–	1	Procedural Deviations: 3
S082B					–/3	–/22	–/1	–/23	–	–	–	–	Procedural Deviations: 4
S052					2/19	5/93	2/23	7/116	–	2	–	5	Procedural Deviations: 4
S055A					–/47	4/291	–/33	4/324	4	–	–	–	(all 4 errors occured on DP# 306 - 3 pos toggles, Photomult.) Procedural Deviations: 2
S054						1/77		1/77	–	1	–	–	Procedural Deviations: 4
DATA POINT TOTAL			2/81	–/4	2/85	24/733	2/65	26/798	7	13	–	6	TOTAL PROCEEDURAL DEVIATIONS = 24

KEY:

E ERRORS COMMITTED

EO ERROR OPPORTUNITIES

Figure B-1f: Data Summary Sheet for Third 1/3 of SL-4

RAW DATA SCORE SHEET

SL-3 TOTALS

DATA POINT #: ________ JOP #: ________ BB #: ________ MISSION TIME: ________

	CONTROLS												DISPLAYS					CREW OPN			ERROR TYPE				REMARKS
	TOGGLE, 3 POS FPM	ROTARY 4 POS / 6 POS	TOGGLE SW, 2 POS (F-F)	TOGGLE SW, 2 POS (M-SL)	TOGGLE SW, 2 POS (L-L)	TOGGLE SW, 3 POS (F-F-F)	TOGGLE SW, 3 POS (F-F-FG)	TOGGLE SW, 3 POS (M-SL-Al)	ROTARY SW, 5 POS	ROTARY SW, 8 POS	ROTARY SW, 11 POS	TOTAL	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTR	ILLUMINATED STATUS INDICATOR	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	
Hα1, 2												26/148						26/148		26/148	11	14	–	1	
S056												9/282						9/282		9/282	2	6	–	1	8
S082A												1/93					1/16	2/107	–/2	2/109	–	1	–	1	4
S082B												4/77					–/10	4/83	–/4	4/87	–	3	–	1	10
S052												4/75					–/2	2/72	2/5	4/77	1	1	–	2	10
S055A												21/868					21/128	29/918	13/78	42/996	4	22	–	16	8
S054												13/334						13/332	–/2	13/334	–	9	1	3	4
DATA POINT TOTAL	–/73	–/78; 10/71	–/94			49/847	1/4	11/456	2/35	3/121	2/90	78/1877			16/120	8/36	22/156	85/1942	15/91	100/2033	18	56	1	25	TOTAL PROCEDURE DEV. = 44

KEY:

E ERRORS COMMITTED

EO ERROR OPPORTUNITIES

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Figure B-2a: Whole Mission Data Summary Sheet for SL-3

RAW DATA SCORE SHEET

SL-4 TOTAL

DATA POINT #: ________ JOP #: ________ BB #: ________ MISSION TIME: ________

	CONTROLS												DISPLAYS					CREW OPN			ERROR TYPE				REMARKS
	2 POS FFM TOGGLE SW 4 POS	DISC ALIGNMENT / ROTARY SW 6 POS	TOGGLE SW, 2 POS (F-F)	TOGGLE SW, 2 POS (M-SL)	TOGGLE SW, 2 POS (L-L)	TOGGLE SW, 3 POS (F-F-F)	TOGGLE SW, 3 POS (F-F-FG)	TOGGLE SW, 3 POS (M-SL-M)	ROTARY SW, 5 POS	ROTARY SW, 8 POS	ROTARY SW, 11 POS	TOTAL	MECHANICAL FLAG, 2 POS	MECHANICAL FLAG, 3 POS	ELECTROLUMINESCENT CNTR	DIGITAL READOUT	TOTAL	SEQUENTIAL OPS	SINGLE OPERATION	TOTAL	OMISSION	COMMISSION	INVERSION	TIME DISPLACEMENT	
Hα1,2												17 / 184						17 / 184		17 / 184	4	13	–	–	1
S056												4 / 296					– / 6	4 / 295	– / 7	4 / 302	–	–	–	4	7
S082A												1 / 87					– / 28	1 / 105	– / 10	1 / 115	–	–	–	1	3
S082B												1 / 93					1 / 22	1 / 104	1 / 11	2 / 115	–	–	–	2	~~4~~ 7
S052												6 / 178					2 / 27	6 / 176	2 / 29	8 / 205	-	3	-	5	~~3~~ 5
S055A												7 / 692					10 / 110	10 / 728	7 / 74	17 / 802	6	5	–	6	3
S054												1 / 189						1 / 189		1 / 189	–	1	–	-	5
DATA POINT TOTAL	– / 92	' / 4 ; – / 46	– / 62			23 / 707	[illegible] / 38	6 / 510	3 / 70	3 / 100	1 / 85	37 / 1719			13 / 180	[illegible] / 13 58	13 / 193	40 / 781	10 / 131	50 / 912	10	22	–	18	Procedural Errors = 31

KEY:

E — ERRORS COMMITTED

EO — ERROR OPPORTUNITIES

Figure B-2b: Whole Mission Data Summary Sheet for SL-4