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APOLLO EXPERIENCE REPORT - APOLLO LUNAR SURFACE EXPERIMENTS PACKAGE DATA PROCESSING SYSTEM

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16. Abstract

Apollo Program experience in the processing of scientific data from the Apollo lunar surface experiments package, in which computers and associated hardware and software were used, is summarized. The facility developed for the preprocessing of the lunar science data is described, as are several computer facilities and programs used by the Principal Investigators. The handling, processing, and analyzing of lunar science data and the interface with the Principal Investigators are discussed. Pertinent problems that arose in the development of the data processing schemes are discussed so that future programs may benefit from the solutions to the problems. The evolution of the data processing techniques for lunar science data is related to recommendations for future programs of this type.

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APOLLO LUNAR SURFACE EXPERIMENTS PACKAGE

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SUMMARY

A system was established for the processing of scientific data transmitted from several Apollo lunar surface experiments packages deployed on the lunar surface by Apollo crewmen. The data processing system that has evolved is based on the Principal Investigator requirements for their scientific experiments that have been placed on the Moon.

The system resulted from the consolidation of the requirements of Principal Investigators and from the need to use existing equipment. The requests of Principal Investigators were based on experience with previous short-lived tests, such as seismic detonations, rocket firings, and laboratory tests. Even the checkout tests of the instruments were of short duration, compared to the duration of the Apollo lunar surface experiments package project. The lunar data sampling is still producing data 24 hours per day per package. Most original data processing estimates were based on 1 year's operation. The bulk of data generated as a result of the indefinite extension of the project greatly increased the workload of the Principal Investigators and the personnel of the NASA Lyndon B. Johnson Space Center (formerly the Manned Spacecraft Center).

Data processing equipment was being improved continually. Faster computers, tape decks, and display units were added by the Manned Spacecraft Center to support manned space flight, testing, and systems evaluation. The equipment and personnel were available to process experiment data between manned flights at little or no extra cost to the Government. Scientists recognized this potential and requested more postflight data support. Additional overall processing is being performed because large workloads can be handled efficiently and supplementary or complementary information is readily available.

The discussion section of this report presents four case histories that highlight the problems encountered in developing an efficient Apollo lunar surface experiments package data processing system, the solutions to the problems, and the resultant evolution of the data processing procedures. The discussion of Case I explains the

change from a tape loop analog system and a digital computer scheme to an all-computer processing system, which is more reliable, more economical, and faster. The change from using many different computers and different software to a consolidated scheme using primarily one computer, one tape packing density, and fewer software programs is discussed in Case II. The discussion of Case III explains the use of general purpose (non-real-time) computers usually available at the larger centers such as the Manned Spacecraft Center to produce quick-look and supplemental data processing even though the machines are not part of a real-time management scheme. The interchange between three different centers or agencies that are geographically dispersed is discussed in Case IV. The work of each group was completed according to standard guidelines. In this example, an insight by each group into the details of each other group saves duplication of effort over long periods of time.

INTRODUCTION

In the fall of 1965, plans for scientific investigation of the Moon as part of the Apollo Program were completed with the identification of the experiments to be included in the initial Apollo lunar surface experiments package (ALSEP). The development of scientific experiments, a central power supply, and data transmission equipment to withstand the lunar environment was the primary goal during the early hardware design and construction phases. The Principal Investigator (PI) requirements for data acquisition, processing, and distribution were an integral part of the ALSEP program planning; however, these requirements were unique when compared to terrestrial experiences in the physical sciences. The requirements included a method of transmitting continuous data from several experiments over a single telemetry system to several Manned Space Flight Network (MSFN) receiving stations on Earth for no more than 2 years. The values and duration of data to be obtained from the experiments were unknown. The data transmission was significantly extended beyond the original estimate of 1 year, and Earth processing systems overlap each time a new ALSEP system is initiated.

Two basic problems in preparing the ALSEP data management plans were incomplete analysis of the PI data requirements, including format, amount, real-time needs compared to postmission needs, work schedule, and processing equipment, capability of the NASA Lyndon B. Johnson Space Center (JSC) (formerly the Manned Spacecraft Center (MSC)) to process data to meet the PI requirements. Long-term projects such as these require continuous updating of plans and methods. The resolution of these problems resulted in a workable data processing system initiated for the Apollo 11 mission and subsequently modified to meet the requirements of the Apollo 12 to 17 missions. The initial plan included upgrading the capability of the PI to process data at his laboratory and increasing the ability of MSC personnel to further preprocess data before release to the PI.

DISCUSSION

The ALSEP scientific experiments flown on the Apollo 11 to 14 missions are listed in table I. The ALSEP was transported to the lunar surface aboard the lunar

TABLE I. - TAPE LOADING PLAN FOR ALSEP DATA

Experiment	No. of words per frame	Maximum data per reel, hr	Average data per reel, hr	Approximate no. of tapes required per year
EASEP[a] (Apollo 11)				
Passive seismic	48	33	24	1095
Housekeeping and engineering	5	135	96	92
ALSEP A (Apollo 12)				
Passive seismic	48	33	24	1095
Magnetometer	7	100	72	122
Cold-cathode gage	5	960	720	13
Solar wind	9	100	72	122
Housekeeping and engineering	5	135	96	92
Suprathermal ion detector	10	87	48	183
ALSEP B (Apollo 13)				
Passive seismic	48	33	24	1095
Heat flow	3	448	336	26
Charged particle	11	87	48	183
Cold-cathode gage	.5	960	720	13
Housekeeping and engineering	5	135	96	92

[a]Early Apollo scientific experiments package.

TABLE I. - TAPE LOADING PLAN FOR ALSEP DATA - Concluded

Experiment	No. of words per frame	Maximum data per reel, hr	Average data per reel, hr	Approximate no. of tapes required per year
ALSEP C (Apollo 14)				
Passive seismic	48	33	24	[a]1095
Suprathermal ion detector	10	87	48	183
Charged particle	11	87	48	183
Cold-cathode gage	.5	960	720	13
Housekeeping and engineering	5	135	96	92
ALSEP D (Apollo 15)				
Passive seismic	48	33	24	[a]1095
Magnetometer	7	100	72	122
Solar wind	9	100	72	122
Suprathermal ion detector	10	87	48	183
Heat flow	3	448	336	26

[a]In addition to the 365 tapes required by the Principal Investigator, two co-Principal Investigators each received 365 tapes.

module (LM) and was deployed by two crewmen. Each package remained on the lunar surface after the crewmen had departed and, with the exception of the Apollo 11 package, was designated to transmit data back to Earth by way of the MSFN for a minimum of 2 years. Internally generated and Earth-based commands control the ALSEP operations, which include the data acquisition and Earth transmission rates. As shown in table I, the volume of data returned from each ALSEP package is reflected in the approximate number of tapes required each year for each PI. For example, for ALSEP A, the number of tapes ranges from approximately 13 to 1095 and represents a continuous reading of data from the selected lunar surface experiment. The magnitude and complexity of the returned ALSEP data and the overall data processing problem were not uniformly anticipated by all personnel concerned.

In 1968, several months before the Apollo 11 lift-off (July 11, 1969), an in-house MSC review of the data management system for ALSEP investigators indicated that in the early evaluation, PI data processing needs (as agreed on) represented a heavy workload that involved producing tape copies to be cut into tape loops for spectral analysis. A workable system was required to meet the Apollo flight schedule. The resultant data processing system was evolved by consolidating the PI requirements and by defining the role and scope of the MSC computer facility in data preprocessing, together with the PI laboratory data processing capability.

The PI data requirements were presented originally in the contract with the investigators' institutions. The contracts required that each PI process all his own Apollo experiment data. However, after review and cost evaluation of the individual PI data plans, it was found that it was neither practical nor economically feasible to provide the Principal Investigators with the funds to obtain the equipment necessary to process telemetry tapes recorded at the MSFN sites. To minimize expenditures and time delay in making the data available to the PI, the MSC data processing facility was modified to include the capability for stripping out and reformatting the scientific data, as they were received and recorded from the Moon/Earth radiotelemetry. The format of each of the different PI strip-out tapes was designed to be compatible with the unique hardware and software that each PI used in his processing and analysis programs.

A diagram of the data processing flow after receipt of the MSFN telemetry tape is shown in figure 1. Because each of the raw telemetry tapes contained 6 to 8 hours of ALSEP data, whereas the computer-compatible tapes held many more data, a merging process was accomplished. The data words in the ALSEP instrumentation data matrix determined the amount of data that could be merged onto a computer tape (table I).

Each PI further processes the experiment data in his own facility. Computer programs are prepared to edit the data, to calibrate the data counts into scientific units of measure, and to "time correlate" the data with other information, such as ephemerides, discrete events, and command responses. The following case histories are typical examples of the problems that arose in the development of a workable data processing system for ALSEP investigators.

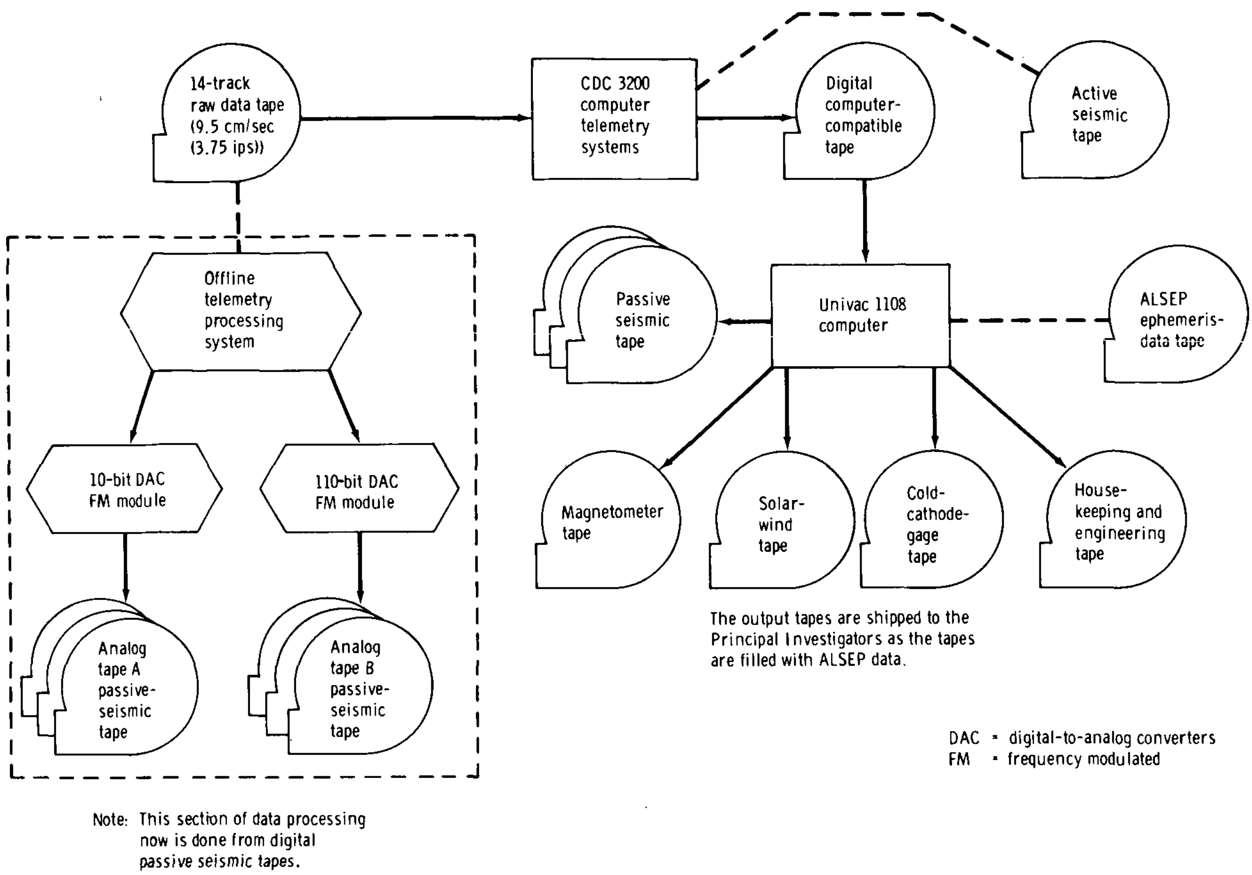

Figure 1.- The data processing flow of ALSEP A at MSC.

Case I: Inadequate Computer Facility Available at the Principal Investigators' Institutions

When realistic appraisals of the data requirements for lunar scientific study were made, inadequate computers, computer programs, and ground station capability at the Principal Investigators' data processing facilities became evident. The problem of data processing was compounded when, as in the example of the passive seismic experiment (PSE), the lives of the experiments overlapped and when data were obtained from two or more seismometers for longer periods of time than had been originally planned. To solve this investigator problem, an additional small computer was provided by MSC under the support contract. Purchase of the computer was justified because the original PSE requirement stipulated that analog tapes were to be prepared from selected PSE seismic data channels (fig. 1). The analog tapes were to be used to produce strip-chart recordings and other visual displays of the raw seismic data. Based on an analysis of the strip charts, pertinent areas were to be cut into tape loops and processed as spectral data. In addition to the analog tapes, the PSE requirements included a request for computer-compatible tapes containing all the recorded PSE scientific data. With this new system, strip charts could be produced from computer-compatible digital tapes rather than from the more expensive analog tapes; therefore, analog tapes no longer were required at the PI facility. A computer program developed at MSC to produce spectral analysis data was used by the PI until his own program could be written. By purchasing this small computer system for the PSE PI, an estimated savings of $2 to $3 million in data processing was realized.

With the PSE data processing system used from 1968 to 1972, MSC was required to produce strip charts and some selected spectral analysis data. This type of data processing support was required for the first 45 days following ALSEP PSE deployment and was necessary during such events as Saturn IVB impact, LM ascent stage impact, meteoroid impact, and so forth, because the data were available sooner at MSC than at the PSE PI's facility. Because the real-time data facility at MSC was adjacent to the postflight data processing facility, mission event times were instantly available.

The ALSEP data were recorded at the remote MSFN sites on magnetic tapes in blocks of 6 to 8 hours of ALSEP data; therefore, any required segment of data was retrieved easily. This screening of data while still in 6- to 8-hour blocks proved to be such an efficient method that the PI requested more quick-look data from MSC.

Case II: Use of Obsolete Computers and Equipment

The trend in the use of tapes for collation and recovery of data is toward higher packing densities of information on magnetic tape, such as 315 bits/cm (800 bpi) on seven-track tape and as much as 630 bits/cm (1600 bpi) on nine-track tape. The result is a decrease in computer time costs because of less tape to pass.

This trend, however, was incompatible for data processing from the suprathermal ion detector experiment (SIDE) and the charged-particle lunar environment experiment (CPLEE). The Principal Investigators used Rice University data processing facilities and specified that their stripped-out data tapes be recorded at a packing density of only 219 bits/cm (556 bpi) during the preprocessing at MSC. This request resulted in increased computer time because it took longer to record a tape, required more footage of magnetic tape to be run through the tape recorder, and required that more reels of tape be handled and shipped.

When the 219-bits/cm (556-bpi) tapes were received by the SIDE investigator, the tapes were copied at 79 bits/cm (200 bpi) before being processed on the small computer that again increased (by approximately three times) the number of tapes to pass. Although this procedure of using many different computers to copy tapes at different packing densities was slow, the task was still accomplished. This is a specific example in which an increased tape packing density and computer capability were not required to fulfill the PI needs but would have decreased the overall cost. The MSC now has consolidated computer programs and has done most of the data processing on one computer to support the SIDE PI; thus, the cost has been reduced significantly.

Case III: Real-Time/Postmission Data Requirements

Preparation for processing ALSEP returned data required a clear definition of the role and capability of the MSC Mission Control Center (MCC) and the needs of the PI for real-time data to assess operations of experiments and postmission scientific evaluations.

The Principal Investigators were advised that ALSEP data would be returned to MSC and displayed in the MCC at their request. However, definite limits were imposed by the MSFN data formatting and transmitting system, by the landlines or microwave links available to the remote ground stations, and by the number of ALSEP systems transmitting data simultaneously. Consequently, during mission operations, the MCC real-time data facilities were adequate for processing and displaying only enough ALSEP data to reassure the controllers that the scientific instruments were operating satisfactorily. Based on this limited mission real-time display capability, real-time decisions had to be made and uplink commands had to be transmitted to the individual experiments.

Few of the Principal Investigators were advised of (or fully understood) the capability and the capacity of the MSC postflight data processing system to perform customized data processing. The MSC postflight data facility can process data at extremely high data rates (bit rates), and several data bit streams can be accommodated simultaneously. High-speed processing of large amounts of data can usually be done between other tasks. In addition, the data display options at MSC or any larger center are superior to those at most of the PI facilities.

Some investigators requested and received preliminary postflight data processing at MSC as soon as the remote-site tape recordings of ALSEP data were received. The PI requests to MSC included data from strip-chart records to spectral analysis data processing. These data were used by the PI as quick-look data and served as the basis for the first science reports required of each PI. In addition, these quick-look data at MSC, when correlated with the data produced at the investigator's facility, increased the confidence in the science data itself, as well as in the data processing techniques.

Case IV: Data Deposited in the National Space Science Data Center

The National Space Science Data Center (NSSDC) is concerned with the scientific data obtained from space probes, satellites, sounding rockets, high-altitude balloons, and aircraft. It has become apparent in the last few years that satellite measurements produce a tremendous amount of data to be processed and analyzed. A great need exists for wider dissemination of these data to groups other than the scientists involved in the specific experiments.

Each PI, after being approved by NASA, was required to submit science reports of his experiment to the NSSDC at the Goddard Space Flight Center. Few PI contracts included any detailed reference to the NSSDC, and, therefore, most investigators did not include a line item for the cost of preparing data to be presented to NSSDC. The MSC Science and Applications Directorate (S&AD) added a statement in each PI contract to make the investigator aware of the need to cooperate with the NSSDC in planning data processing routines. The NASA Headquarters direction stated that the science data format being sent to NSSDC would be based on an agreement between NSSDC and the PI. Some reprocessing was necessary if the NSSDC and the PI did not coordinate the format beforehand. If reprocessing was necessary, it would be done at S&AD expense. The data flow for ALSEP data processing and the manner in which the NSSDC normally would fit into this process is illustrated in figure 2.

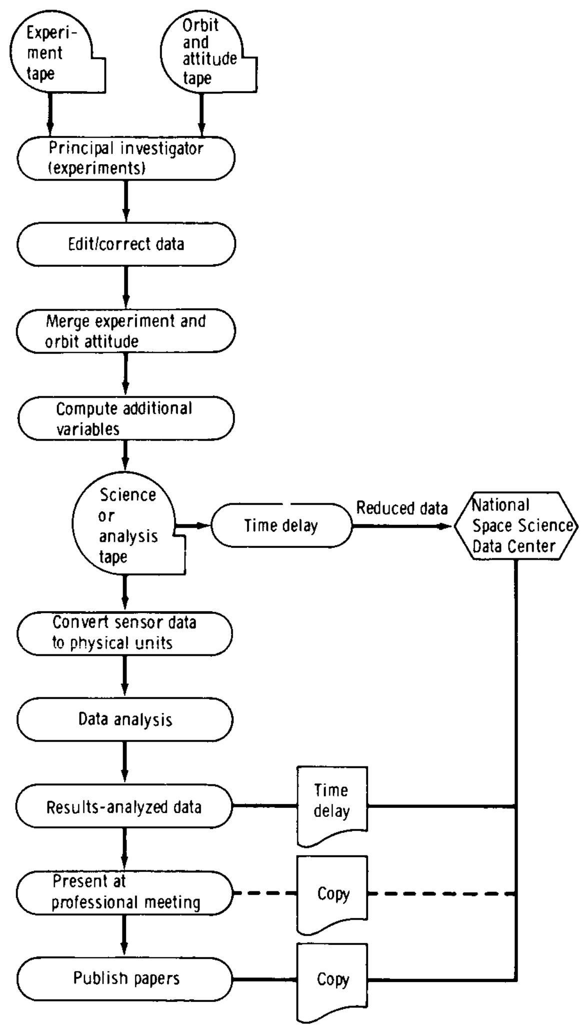

Figure 2. - Diagram of satellite data flow from experimenter through analysis to final publication.

CONCLUDING REMARKS AND RECOMMENDATIONS

The steps necessary to establish a system to process the scientific data from the Apollo lunar surface experiments were as follows: processing the Manned Space Flight Network telemetry data at the NASA Lyndon B. Johnson Space Center (formerly the Manned Spacecraft Center) by means of the computer facility, reformatting the data to be compatible with the Principal Investigator facility, upgrading the Principal Investigator computer (data processing) capability to be compatible with the higher standards of more modern equipment, and devising a more efficient method for further analysis of the data.

The following recommendations should be helpful for future programs in which the problems encountered are similar to those that arose in establishing the data processing system for the Apollo lunar surface experiments package project. Management, systems engineers, and computer programers should consider the following recommendations.

1. More emphasis should be placed on the communications toward data effort before and after experiments are deployed. The data processing effort should be continually reviewed when it involves expensive computers. (See Case I.)

2. More data processing work should be performed by data experts at any large facility to allow scientists to evaluate scientific data. This work could be fill-in work between peak workloads such as manned space flights. (See Cases II and III.)

3. When planning data processing systems involving a variety of outside groups, the majority of data processing should be consolidated at a large facility (such as the Manned Spacecraft Center) to maintain one computer system at the large facility instead of maintaining one or more at each outside facility (such as the Principal Investigator facilities). Any additional programs, expertise, and equipment could be used on subsequent projects. (See Case III.)

4. The systems planners should be well acquainted with all the work and all the facilities available at a larger facility, with more emphasis being placed on postmission science as well as on real-time efforts, in controlling the mission. (See Case III.)

5. The program managers should take a more active role in ensuring proper arrangements for the submittal of Principal Investigator scientific data to the National Space Science Data Center or any other federal data center. (See Case IV.)

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