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TITLE- Summary of a Detailed Study of the Apollo Up-Data System

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DATE- September 29, 1968

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AUTHOR(S)- R. L. Selden

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ABSTRACT

A summary of the results of a study of the Apollo up-data system is provided. The study included the elements and operation of the ground and spacecraft systems as well as an analysis of the expected system performance. A review of the performance of the system during Apollo missions 4, 5 and 6 is also included. The study results indicate that no changes in system hardware appear to be in order at this time, and that the predicted performance is adequate to support an Apollo lunar mission. Flight experience to date correlates with the predicted performance.

(NASA-CR-73520) SUMMARY OF A DETAILED STUDY OF THE APOLLO UP-DATA SYSTEM (Bellcomm, Inc.) 12 p

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SUBJECT: Summary of a Detailed Study of the Apollo Up-Data System - Case 900, 320

DATE: September 29, 1968

FROM: R. L. Selden

TM: 68-2034-16

TECHNICAL MEMORANDUM

This memorandum provides a summary of the results of a study of the Apollo Up-Data System. The detailed study results are included in a series of memoranda which include a description of the ground system,[1] the spacecraft system,[2] a performance analysis of the ground data transmission system,[3] a performance analysis of the ground to spacecraft to ground radio frequency system,[4] and flight performance to date of the total system.[5]

The Apollo Up-Data System is a closed loop system which provides a data service from the Mission Control Center (MCC) at Houston to one of the Apollo space vehicles. Vehicles having a capability to receive these digital data include the Command and Service Module (CSM), the Lunar Module (LM), and the Instrument Unit (IU) of either the Saturn IB or Saturn V launch vehicle. The system provides flight controllers with the capability of controlling vehicle functions by the use of Real-Time Commands (RTC), to provide data to the space vehicle computers for subsequent use of processing (CMC, LGC and LVDC loads to the CSM, LM and IU), to provide Central Timing Equipment up-dates to the CSM, and to test the vehicle's up-data equipment.

The Apollo Up-Data System is comprised of the following major elements:

1) the Real Time Computer Complex (RTCC) located at MSC,

2) the Flight Control team (the human element in the system),

3) the Communications Command and Telemetry System (CCATS) located at MSC,

4) the NASA Communications Network (NASCOM),

5) the remote sites of the MSFN including their Remote Site Data Processors (RSDP), their RF equipment and their up-data buffer which interfaces the two, and

6) the spacecraft receiving and decoding equipment.

As mentioned before, the system is a closed loop system when in normal operation. That is, every time a message transmission to a spacecraft is requested by a flight controller, a verification is supplied to the same flight controller indicating that the requested data has been successfully received by the spacecraft.

The method of operation of the system can be varied as required to satisfy mission requirements. The discussion that follows relates to the normal mode of operation. In general, all data to be transmitted to a space vehicle is available at the appropriate remote site of the MSFN prior to the passage of the vehicles over that site. RTC's and test messages are stored on magnetic tape prior to the start of the mission; spacecraft computer input data is normally transmitted to a particular remote site from the Mission Control Center prior to the pass. During a pass, when it is desired to transmit ("up link") a command or computer load, a flight controller in the MCC-H causes the CCATS to transmit an "execute command request" (ECR) to the appropriate remote site. This ECR tells the remote site to uplink a particular message to the specified vehicle. Proper receipt of this request by the remote site command computer (RSCC) is acknowledged by the transmission back to MCC-H of a Computer Analysis Pattern - Validation (CAP-VAL) via the remote site telemetry computer (RSTC) and the NASCOM. After proper receipt of the ECR, the RSCC encodes the command for transmission and presents it to the up-data buffer. The up-data buffer serves to interface the RSCC and the stations transmitting equipment. The up-data message is then transmitted to the appropriate vehicle via a UHF command transmitter (for the S-IB) or the Unified S-Band Equipment (CSM, LM, S-V). The spacecraft receives and decodes the message and, if valid, proceeds to act upon it. Upon correct receipt by the vehicle, a message acceptance pattern (MAP) is telemetered to the MSFN in the case of RTC's, test messages and CTE up dates or retransmits via telemetry the received computer data.

The RSCC, at the remote site of the MSFN, than checks the MAP or computer data to insure proper receipt by the vehicle. If the up data message appears to have been properly received by the space vehicle, a verification is transmitted back to MCC-H by the RSTC via the NASCOM. If no verification is received from the space vehicle, a NONVER (no verification) message is transmitted back to the flight controller. Actually, if no MAP is received, the RSCC attempts a retransmission automatically for a specified number of transmissions. In the case of computer data, the flight controller must reinitiate his request. Also in the case of computer data, several intermediate verifications are transmitted to MCC-H and flight controller response is required to continue the up link transmissions and final entry of data into the vehicle's computer. A more detailed description of system operation is contained in Reference 1.

To minimize the chance of the space vehicle receiving and operating on invalid commands of computer data, a large amount of redundancy is added to all transmissions, both on the ground transmissions and the rf link to the space vehicle. The ground network, including CCATS at MSC and the remote site data processors, use Bose-Chaudhuri-Hocquenghem (BCH) codes to provide protection against errors (error detection). The ground to space vehicle link uses simple redundancy. Briefly, the data transmitted from CCATS to a remote site, whether it be a command request (ECR) or a data load to be uplinked, is transmitted in 60 bit blocks, 30 of which are data, 27 error protection and 3 filler bits. These data are transmitted to Goddard Space Flight Center (GSFC) via a 50 kbps wide band data circuit. On the CCATS to GSFC circuit eight 60 bit blocks are formatted into a 600 bit block; the 120 additional bits include, in addition to normal overhead, 33 bits of error protection. At GSFC, the 600 bit blocks are checked for errors; if none are detected, the 60 bit blocks are separated and formatted back into 60 bit blocks and transmitted to the appropriate remote site via a 2.4 kbps high speed data circuit. If an error is detected at GSFC. the data is simply deleted. When the 60 bit blocks of data are received at the remote site by the RSCC, each block is checked for error. If no error is detected, the data is appropriately processed and a"CAP VAL" is transmitted to MCC-H. The CAP VAL is transmitted in a 26 bit block which is protected by the addition of 14 redundant bits. This transmission again passes through GSFC and is formatted as before, into 600 bit blocks for transmission to CCATS. Generally, CCATS continues to transmit data until a CAP VAL is received, which serves to terminate the transmission.

For transmission of data to a space vehicle from a station of the MSFN specific formats are used for each type of up data message. Each message uses the first three bits as a vehicle address, the second three bits for system address (or message type) and the subsequent field of bits for the data. For RTC's, six more bits are used to provide a command capability of 64 different functions; for timing up dates, 24 bits are used to provide timing down to the seconds level; and, for computer input data, 15 bits plus a check bit follow the vehicle and system addresses. The 15 bits in the computer message are further coded by transmitting 5 bits of data, then its complement, then the original 5 bits. This "data, data complement, data" format is checked in the vehicle's computer system and serves primarily to protect the transfer between the vehicle's up data equipment and the computer. (This is analogous to the simple parity check used in most ground computer systems). Each of the information bits discussed above is sub-bit encoded. That is for each information "one" or "zero", a specific five bit pattern is used for encoding. The spacecraft must detect all five bits correctly and compare this received pattern with the "one" pattern that was stored, premission, on the spacecraft. One error then, in detection of a single sub-bit, will cause rejection of the message.

The MAPS and computer data transmitted by the space vehicle to Earth to provide verification are essentially uncoded (the computer words do have one parity bit for each 15 bit word).

The foregoing is meant to be a very general description and again the reader is referred to Reference (1) and (2) for specific detail and optional modes. The question which naturally arises after a description of this type is "How well does the complex system perform?" The balance of this memorandum provides an answer to this question.

The redundancy in the Apollo Up-Data System was arrived at by trading off message rejection rate with error protection (probability of accepting an uncorrect message). Because of the redundancy in the system, the probability of an undetected error either on the ground or in the spacecraft is extremely remote. However, if the message rejection rate becomes high, the time to transmit valid messages increases. Put another way, degradation in system performance manifests itself in increased operations time rather than operation with increased error. It should be pointed out here that the overall design goals for system operation are that no more than one correct message in 1000 will be rejected and that no more than one false message in 10^9 will be accepted.

The BCH codes used for all ground transmissions have properties which make them extremely attractive when used for error protection. For example, the 57/30 code (57 total bits, 30 of which are data) used to transmit blocks of data from CCATS at MCC-H to the remote sites can detect all bursts of errors up to length 27. The length of an error burst is defined as the number of bits between and including the first and last erroneously received bits in a particular code word. Additionally, these codes can detect most errors if they occur at random. The 57/30 code can, for example, detect up to 10 random errors in a 57 bit block. As mentioned before, some type of BCH coding is used for all ground/ground transmissions involving command data. Table I summarizes the codes used and presents some error detection properties of each.

TABLE I

BOSE-CHAUDHURI-HOCQUENGHEM (BCH) CODES USED

TO PROTECT COMMAND DATA TRANSMISSION

Circuit	Block Length/ Information Bits	Error Performance (Per Block) Burst Detection	Total Errors
CCATS-Remote Site	57/30	27	10
CCATS-GSFC	600/567	33	∿14
Remote Site - CCATS	40/26	14	∿4

To determine the performance of the ground network requires only that the above properties (in addition to other parameters relating the codes performance on all other error patterns) and the statistics of error distribution of the circuits used in the NASCOM be related. Unfortunately, error pattern statistics are not available for these circuits so another approach must be taken. (See Reference 3). Using an approach or model developed by Mr. E. O. Elliott at Bell Telephone Laboratories and data taken from typical Bell System circuits at various data rates, an analysis was completed that, it is felt, is accurate to within an order of magnitude. The results of this analysis taken from Reference 3 are tabulated in Table II.

TABLE II

Performance of the NASCOM - In Transmission of Apollo Command Data

Probability of an Undetected Error	
- MCC-H to Remote Site (Per 60 Bit Block)	10^{-13}
- Remote Site to MCC-H (Per 40 Bit Block)	10^{-9}
Probability of Detected Error (Block Rejection) (Upper Bound)	
- MCC-H to Remote Site	10^{-3}
- Remote Site to MCC-H	10^{-3}

It should be noted that the performance of the link from MCC-H to the GSFC is factored into the performance data presented above. This link does not materially affect the overall performance (except in a time sense) because errors detected here simply result in no retransmission to the remote site. The block error detection rate (one 600 bit block containing 60 sub-blocks) has been measured on this channel and found to be 5×10^{-4}. The circuit bit error is, in general, approximately 10^{-5} and time varying.

The performance of the link from the ground to the spacecraft and spacecraft to ground is analyzed in Reference 4. For the link between the ground station and the spacecraft, the same measures of performance are of interest. The channel performance, that is sub-bit error rate, was taken as 10^{-6}. This error rate is poorer than expected when an Apollo spacecraft is at lunar range operating with an omnidirectional antenna. Reference 4 provides an evaluation for all types of up-data messages using probabilities of message rejection, undetected error with a signal input and undetected error with a noise input. The latter two measures relate to the probability of the spacecraft accepting as valid a message received in error. The results of Reference 4 are tabulated below.

TABLE III

Performance of the Ground to Spacecraft Up-Data Channel

Parameter	Type of Message	Performance
. Message Rejection	RTC (CSM)	10^{-4}
	CTE (CSM)	10^{-4}
	Computer (LM&CSM)	10^{-4}
. Undetected Error	RTC	10^{-29}
(Signal Input)	CTE	10^{-29}
	Computer	10^{-90}
. Noise Input	RTC	10^{-16}
	CTE	10^{-38}
	Computer	10^{-32}

Alternative configurations were also evaluated, which included performance without the sub-bit coding on the up link as well as elimination of the code-code complement-code format used on computer input data. The results of this analysis showed that the sub-bit coding could be reduced from five bits to three and the complement format removed and still meet the specified performance criteria. The overall time required to command however, is not significantly reduced because most of the time is used for verification and validation.

The telemetry link from the spacecraft to Earth is also evaluated in Reference 4 so that a measure of performance can be obtained for the verification process. To verify the correct receipt of an up-data message requires that a specific 4 bit pattern (MAP or message Acceptance Pulse) be received via telemetry for RTC's and CTE up dates (an 8 bit MAP from the LM) and that a comparison be made for all computer data. This comparison must show two good comparisons out of eight tries between the telemetered computer words and the load that was transmitted to the spacecraft. A summary of the telemetry channel performance relative to verification is presented in Table IV.

TABLE IV

Summary of Down Link Telemetry Performance

Probability of No Verification

Vehicle	TLM Bit Error Rate	Message	Performance
CSM	10^{-3}	RTC	10^{-5} (two attempts)
	10^{-6}	RTC	10^{-11} (two attempts)
LM	10^{-6}	RTC	10^{-10} (two attempts)
CSM or LM	10^{-6}	Computer	10^{-4} (two out of two comparisons)
			10^{-25} (two out of eight comparisons)

It should be noted that the expected performance of the telemetry channel at lunar range is better than a 10^{-6} bit error rate (when using the vehicle high gain antenna). When the vehicle omnidirectional antenna is used only the low bit rate telemetry mode is available and the bit error is on the order of 10^{-3}. At present, there is no requirement to verify anything but RTC's and CTE up dates in this low bit rate mode (no requirement at all for the LM).

Three recent Apollo 4, 5, and 6 missions have used the up data system described here. The launch vehicle for the Apollo 4 and 6 missions was a Saturn V and used an S-Band link to provide the up data function. The Saturn IB used for the Apollo 5 mission carries UHF up link equipment. The spacecraft involved in these missions were CSM's on Apollo 4 and 6 and LM-1 on Apollo 5. The performance of the up-data system, during these missions substantiates the analysis and conclusions of the study.

The Apollo 4 mission demonstrated essentially nominal operation of the system. The major causes of system failure on this mission were due to ground station or operator problems. In total, on the AS 501 mission, 6044 valid commands were transmitted; 20 of these were rejected by the spacecraft due to anomolies in the transmitted signal (e.g. over deviation of rf carrier, false lock in the ground receiver and miscellaneous modulation discrepencies). Of the remaining 6024 commands only two were rejected by the space vehicle (one by the CSM and one by the SIVB/IU). The rejection by the CSM was caused by the spacecraft computer failing to get a valid code, code complement, code check after the message had been properly received and decoded by the spacecraft up data equipment. This performance corresponds to a 1.6×10^{-4} rejection rate by the space vehicles. No commands received in error were determined to be valid by either vehicle.

On the other two missions, namely Apollo 5 and Apollo 6 the up-data system did not perform as well. The spacecraft for the Apollo 5 mission was LM-1. During this mission, a total of 686 commands were transmitted to LM-1 and only 649 accepted. The failure of the system on this mission has been attributed to a spacecraft RF system failure which caused signal levels at the UHF command receiver input to be below the threshold for much of the mission. The Apollo 6 mission appeared to fare better; however, a specific command summary was not completed as part of the study. Again on this mission, hardware problems were experienced which caused an impact on the up-data system performance. Namely, an apparent interference problem on the input to the computer which caused the computer to reject input data from the command system. One message rejection by the CSM has been identified. In summary, the performance of the Apollo Command System as demonstrated on these three missions has performed as expected except for the spacecraft equipment anomalies and some ground station failures. Both of these areas can be expected to improve.

Summary and Conclusions

The Apollo Command System has been provided a high degree of redundance to protect all transmissions against undetected errors. From the performance analysis, it would appear that this quantity of redundancy is about right to meet the specified performance levels of 10^{-3} rejection rate and 10^{-9} probability of undetected error. It is possible to eliminate a small amount of this redundancy and still meet design goals; the benefit, however, in increased information rates does not justify this potentially costly modification. It would appear also that removing all of the redundancy without procedural changes in the method of operation would decrease the time to command by no more than half. For these reasons and the fact that any redundancy elimination is bound to lower the system's immunity to error, it is recommended that no changes be considered in data formats. (It appears also that present system operation times are adequate for mission operation).

The past flight experience indicates performance of the system itself correlates well with the analysis. However, several anomalies in performance have been noted in the areas of spacecraft equipment malfunction ground station checkout and operations. These areas will be improved by procedures, training, and experience.

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J. J. Hibbert for
R. L. Selden

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