NASA TECHNICAL MEMORANDUM

NASA TM X- 53737

May 3, 1968

X1.19
XIV.7

NASA TM X-53737

FLIGHT EVALUATION OF THE COMMAND AND COMMUNICATION SYSTEM ABOARD AS-501

By Olen P. Ely and Joseph H. Kerr
Astrionics Laboratory

NASA

George C. Marshall Space Flight Center Huntsville, Alabama

TECHNICAL MEMORANDUM X-53737

FLIGHT EVALUATION OF THE COMMAND AND COMMUNICATION SYSTEM ABOARD AS-501

By

Olen P. Ely and Joseph H. Kerr

George C. Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT

The first test of the command and communications system, a unified frequency S-band system, aboard AS-501 was successful. Compatibility of this system with the MSFN/USB sites was established. The onboard transponder and antenna system including antenna switching performed as predicted. The command performance was excellent with 5747 valid commands received onboard out of 5748 commands transmitted. Data reduction problems prevented a complete analysis of the tracking data. Telemetry system performance was satisfactory with a measured bit-error-rate of 4×10^{-5} while over the Ascension Island station.

This flight provided valuable data which can be used to define vehicle-to-ground-station interfaces, to establish attitude constraints during translunar injection, and to improve operational procedures. One more test as successful as the AS-501 test would qualify the system as operational.

NASA — GEORGE C. MARSHALL SPACE FLIGHT CENTER

NASA — GEORGE C. MARSHALL SPACE FLIGHT CENTER

TECHNICAL MEMORANDUM X-53737

FLIGHT EVALUATION OF THE COMMAND AND COMMUNICATION SYSTEM ABOARD AS-501

By

Olen P. Ely and Joseph H. Kerr

ASTRIONICS LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

TECHNICAL MEMORANDUM X-53737

FLIGHT EVALUATION OF THE COMMAND AND COMMUNICATION SYSTEM ABOARD AS-501

SUMMARY

The first test of the command and communications system, a unified frequency S-band system, aboard AS-501 was successful. Compatibility of this system with the MSFN/USB sites was established. The onboard transponder and antenna system including antenna switching performed as predicted. The command performance was excellent with 5747 valid commands received onboard out of 5748 commands transmitted. Data reduction problems prevented a complete analysis of the tracking data. Telemetry system performance was satisfactory with a measured bit-error-rate of 4×10^{-5} while over the Ascension Island station.

This flight provided valuable data which can be used to define vehicle-to-ground-station interfaces, to establish attitude constraints during translunar injection, and to improve operational procedures. One more test as successful as the AS-501 test would qualify the system as operational.

INTRODUCTION

The results of the analysis of the command and communications system (CCS) performance on vehicle AS-501 are presented herein.

The analysis effort has been concentrated in seven main areas:

1. Updata performance.
2. Downlink telemetry performance.
3. Tracking performance.
4. Signal strength evaluation.
5. Operational problems as they affect areas one through four.

6. Transponder evaluation.
7. Antenna switching evaluation.

The intent of the analysis was to:

1. Establish vehicle to ground system compatibility.
2. Determine effects on system performance of different modes of operation found in Table I.
3. Determine capability of switching antennas in flight.
4. Determine attitude constraints for the different modes of operation.
5. Establish a confidence factor in the ability to predict system performance.

TABLE I. TRANSMISSION MODES

UPLINK

Mode	Modulation Scheme	Information
I - A	PM	Carrier, PRN*
I - C	PM/FM/PM	Carrier, Updata
I - E	PM & PM/FM/PM	Carrier, Updata, PRN
I - J		Carrier

DOWNLINK

Mode	Modulation Scheme	Information
I - D	PM & PM/PM	Carrier, PRN, TLM
I - G	PM/PM	Carrier & TLM
I - H	PM/PM	AUX OSC & TLM

*Pseudo random noise

Vehicle and ground system compatibility, antenna switching capability, and the ability to predict system performance were definitely proven feasible. Valuable information has been gathered on command, telemetry, and tracking system performance, and this will improve the methods of computing attitude constraints for each mode of operation.

The analysis falls short in some areas because insufficient data were available. The lack of sufficient data was caused in some instances by procedural errors at ground stations. In other instances, data reduction problems were greater than anticipated and delayed the analysis. Additional constraints, imposed by the mission profile, caused varying signal levels during all mission phases except the waiting orbit phase. During the latter phase the signal-to-noise ratio was outside the range of interest much of the time.

The test of AS-502 should produce more useful data as a result of the experience gained with AS-501. Also, the mission profile is better suited to giving data necessary for a CCS evaluation.

SYSTEM DESCRIPTION

The CCS is composed of a transponder, power amplifier, and antenna system. The system was designed to be electronically compatible with the Manned Space Flight Network (MSFN) ground stations.

The CCS is designed with one uplink and one downlink carrier frequency to provide two prime functions and one auxiliary function. The prime functions are to update the launch vehicle digital computer (LVDC) remotely and to provide telemetry data from the launch vehicle. Tracking is the auxiliary function.

To accomplish the communications requirements, the system was designed to operate at S-band frequencies and to utilize the multimodulation schemes and mode combinations. A more detailed treatment of system parameters is given in Tables II and III.

The transponder receiver is a superheterodyne type with a second order phase-lock tracking filter that preserves the uplink carrier phase information and generates a downlink carrier that is phase coherent with the uplink carrier whenever the system is in lock. When the CCS is not locked to the uplink carrier, the downlink carrier is generated by a crystal-controlled oscillator designated as the auxiliary oscillator. This assures that a phase stable downlink frequency of 2282.5 MHz is always available for modulation by the telemetry subcarrier.

TABLE II. DOWNLINK PARAMETERS

Functions & Parameters	CCS Values (Theoretical)
1. Transmitting characteristics	
a. Frequency	
(1) Auxiliary oscillator mode	2282.5 MHz ±40 kHz
(2) Phase lock mode	2282.5 nominal
b. Power output	15 W
c. Circuit losses	7 dB max
d. Antenna gain	
(1) Omni	-3 dB over 90% of sphere
(2) Lo gain	6 dB
(3) Hi gain	12 dB
e. Antenna beamwidth	
(1) Lo gain	70°
(2) Hi gain	40°
f. Antenna polarization	
Directional antennas	Right circular polarization
Omni antennas	Linear
g. Beam ellipticity (boresight axis)	1.5 dB max
2. Ranging channel	
a. Type	PRN code
b. Modulation	
(1) Type	PM
(2) Index	0.3 radian
c. Clock rate	498 kHz
d. Premodulation bandwidth	1.25 MHz min
3. Telemetry	
a. Subcarrier frequency	1.024 MHz
b. Modulation	
(1) Type	PSK ±90°, PM
(2) Index	1.22 radians
c. Data rate	72 KBPS nominal
d. Word length	10 bits per word straight binary (MSB, 2, 3, . . . , LSB)
e. Premodulation bandpass filter bandwidth	150 kHz

TABLE III. UPLINK PARAMETERS

Functions & Parameters	CCS Values (Theoretical)
1. Receiving characteristics	
a. Frequency	2101.8 MHz
b. IF bandwidth	4.0 MHz
c. Circuit losses	3.0 dB max
d. Antenna	
(1) Type	Omni
(2) Gain	-3 dB over 90° sphere
e. Noise figure	13 dB maximum
f. Dynamic range	-15 dBm to -115 dBm
2. Ranging and tracking	
a. Carrier tracking	
(1) Threshold (0 dB S/N)	-132 dBm
(2) Threshold loop noise bandwidth	400 Hz
(3) Threshold S/N in 2 BLO (usable level)	6 dB
(4) Strong signal loop noise bandwidth	1.238 kHz
b. Ranging channel	
(1) Type	PRN code
(2) Modulation	PM@ 0.6 radian
3. Updata	
a. FM detection bandwidth	20 kHz
b. Required subcarrier detection S/N in 20 kHz bandwidth	10 dB
c. Post FM detection bandwidth (-3 dB points)	3 kHz, flat within 1 dB
d. Required post detection S/N	24 dB
e. Modulation index	PRN 0.3 radian Updata 1.22 radians

The transponder also has a provision for turning around the PRN ranging information. There is no provision for removing the 70 kHz subcarrier from the uplink PRN channel prior to remodulating the code on the downlink. Theoretically, it is possible for the telemetry signal-to-noise ratio to be fixed in the transponder modulator by the cross modulation products that modify the telemetry bit stream and make the demodulation scheme less effective. This is especially noticeable if the 70 kHz subcarrier is being modulated with updata in addition to PRN. The data degradation is insignificant as far as the average data user is concerned.

Figure 1 depicts the block structure of the CCS transponder. Figure 2 illustrates the updata word format.

POWER AMPLIFIER

The power amplifier utilizes a traveling wave tube (TWT) to produce a 15 W output and is driven by a 250 mW RF level. The time delay on the power amplifier on AS-501 was 22 Ns (22×10^{-9} sec). Provisions for shutting down the CCS transmitter are available in the power amplifier and were satisfactorily tested over the Carnarvon station on pass 3.

ANTENNA SYSTEM

The CCS utilizes three different antenna configurations; omni, directional low gain, and directional high gain. The omni is used for a receiving antenna at all times. For most launch and orbital operations, the same type omni is also used for transmitting. In the omni transmitting position, the CCS and S-band PCM/FM telemetry share the same antenna.

The CCS antenna fail-safe position is low gain. In this position, the system has a 3 dB beamwidth of 70 degrees and a gain of 6 dB with respect to an isotropic radiator. When switching from omni to high gain, the antenna goes through the fail-safe position. This takes 0.25 second to accomplish and a small "glitch" is noted in the signal strength recording. This causes no major problem and is considered standard operating procedure.

In the high gain position, the CCS has 12 dB gain with respect to an isotropic radiator and a 3 db beamwidth of 40 degrees. This allows the launch vehicle to reach a slant range greater than 72 000 km and still meet all requirements for telemetry and tracking if the correct attitude is maintained.

Tables II and III list the antenna system characteristics.

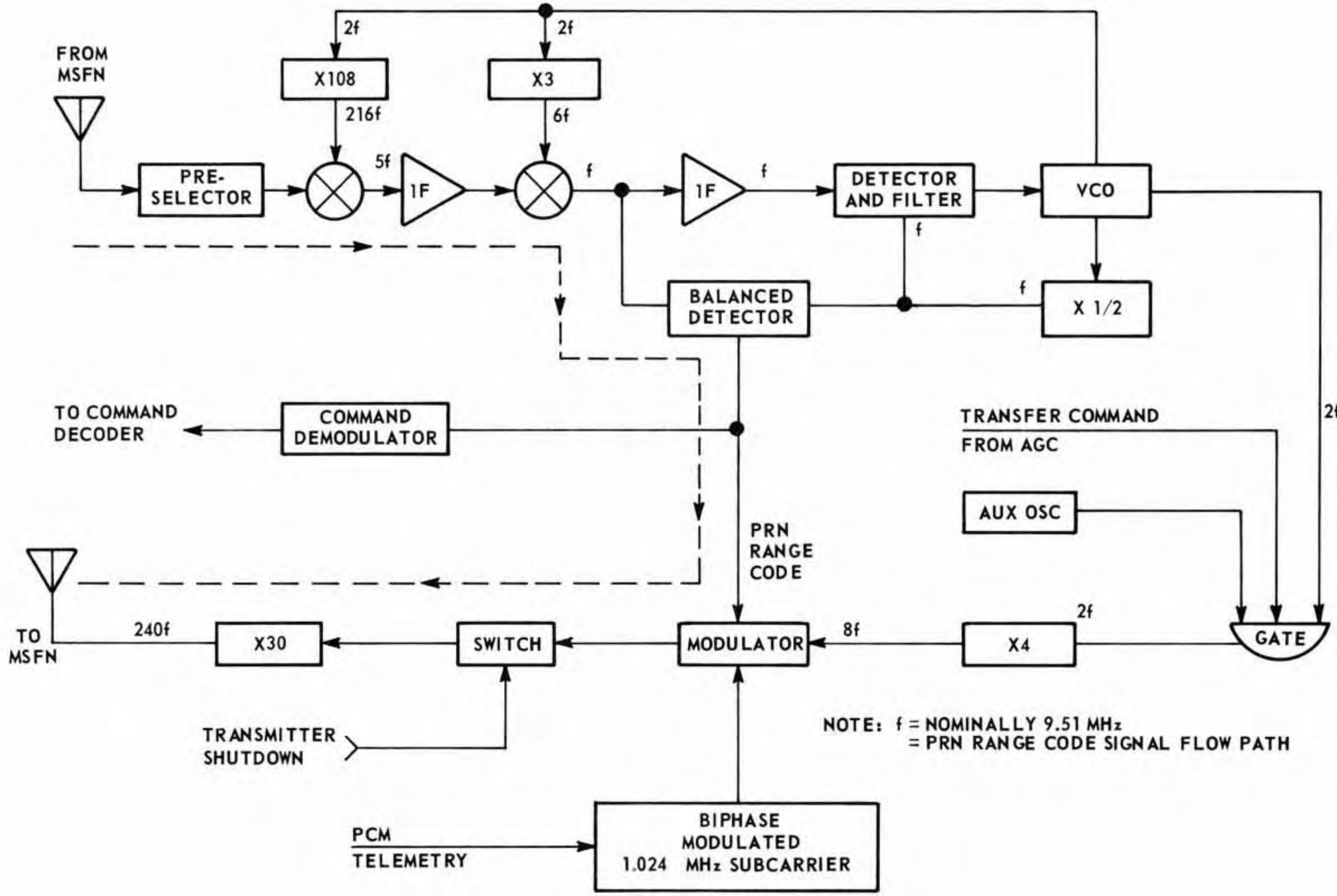


FIGURE 1. CCS TRANSPONDER BLOCK DIAGRAM (SATURN V)

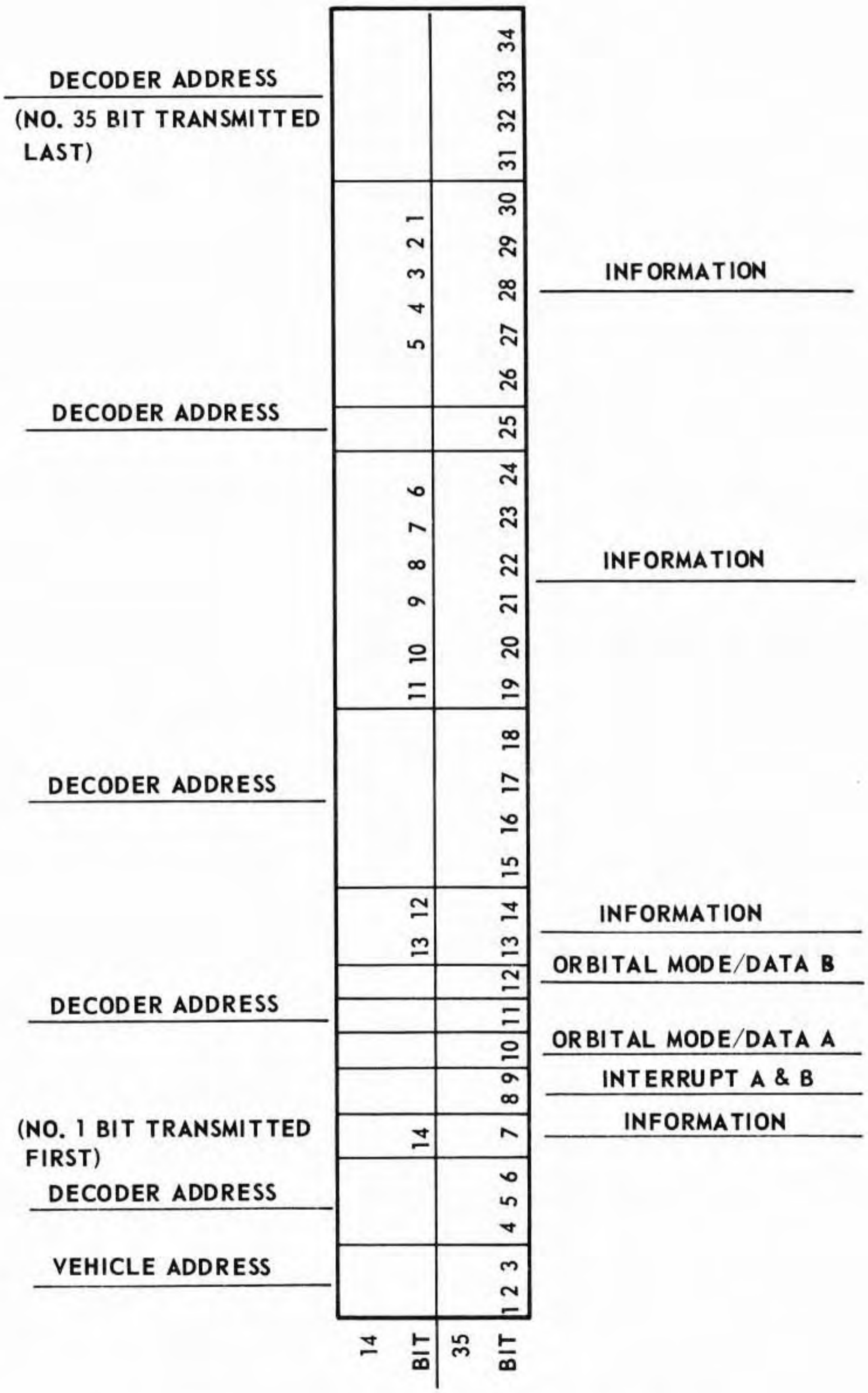


FIGURE 2. COMMAND WORD FORMAT

UPDATA PERFORMANCE

A major objective of this analysis was to determine how well the updata system performed. The evaluation shows that the performance was excellent. On an operational mission the command system is intended for use only in a contingency situation, or for updating a system where it is impossible to predict the mode of operation the system will use because of some variable, such as launch azimuth. However, since one of the objectives of AS-501 was to test the CCS system, several commands were planned into the mission.

The commands on this vehicle fell into two categories. Category number one was flight commands, which included possible contingency commands, preplanned switching of antennas and communication equipment, and updating information. Each of these commands was decoded by the command system and fed into the LVDC. Acceptance of a valid command was verified by an address verification pulse (AVP) from the command system and a computer reset pulse (CRP) from the computer, both of which were transmitted back to the ground stations and Mission Control Center (MCC-H) via onboard telemetry. Category number two, which represents the majority of commands transmitted on AS-501, was a test word consisting of all zeroes. The LVDC was programed not to accept this message; therefore, no CRP was received when this command was transmitted. Correct receipt was verified by an AVP.

Analysis of the command performance was rather extensive because the initial ground station printouts indicated that a large number of test word commands were missed. The analysis proved that the commands were received and that the error was caused by a malfunction in the ground system.

Figure 3 describes the approach used in the command system analysis. The two inputs are taken from magnetic tape recordings which are made at the ground stations sending the commands. Each station sending commands uses a ground verification receiver to receive and record the output of the ground transmitter. The 70 kHz command subcarrier detects and records on magnetic tape at the site. The analyst plays these data back through a decoder exactly like the one flown on AS-501. The output of this decoder is represented by point A in Figure 3. The stations sending commands and a block diagram of the system used for evaluating these records are shown in Figure 4. The AVP's and CRP's transmitted over the telemetry system were stripped out and are represented as input B in Figure 3. The remainder of the diagram is self-explanatory except for items C and D. On several occasions, commands were

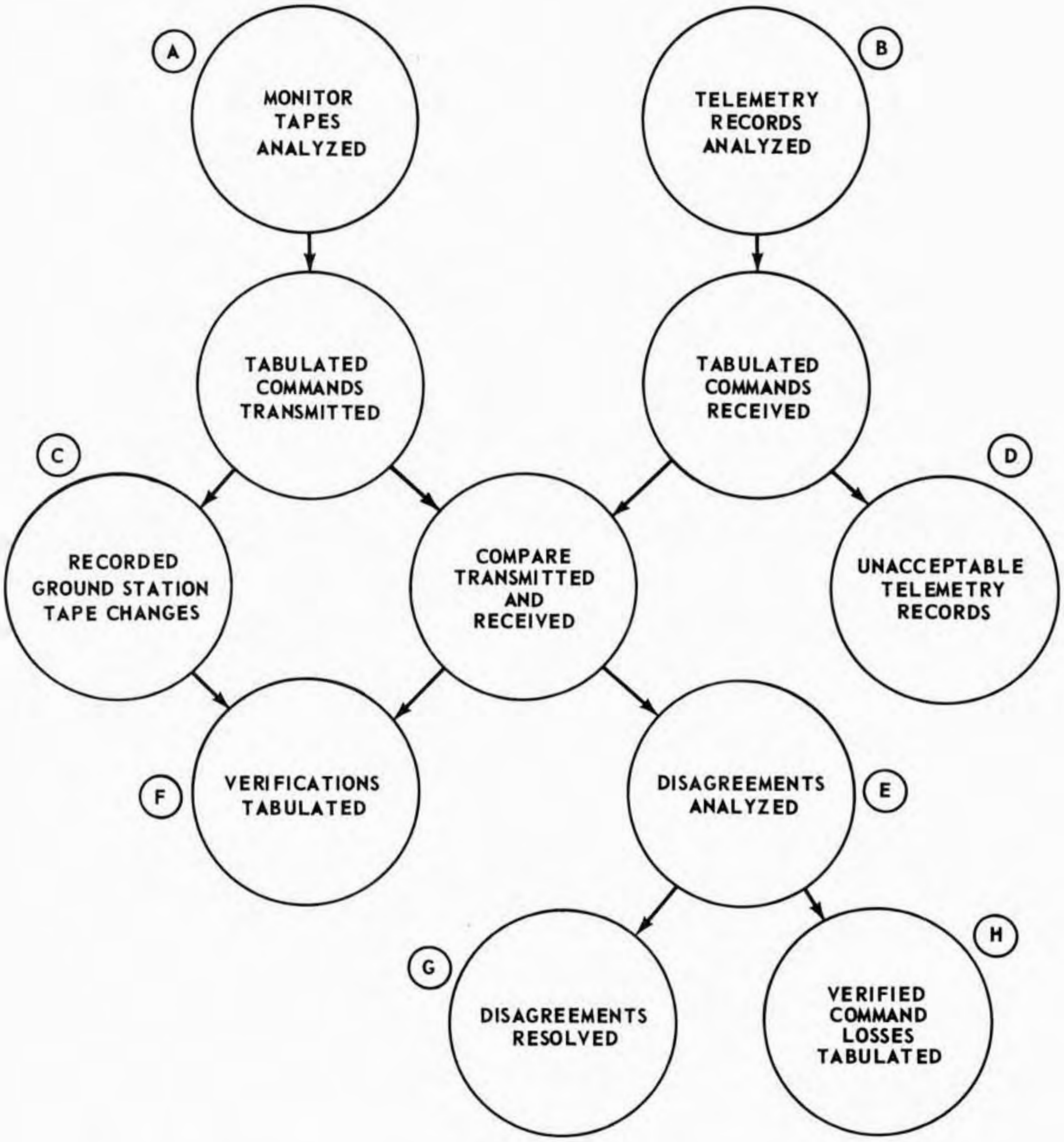


FIGURE 3. METHOD OF ANALYSIS, AS-501 COMMAND HISTORY

(A) MONITOR TAPES ANALYZED

GROUND MONITOR TAPES

STATION	START (Z)	STOP (Z)
CARNARVON	12:52:47	12:58:50
	17:32:59	18:09:44
TEXAS	13:35:13	13:36:31
	15:07:22	15:08:49
GODDARD-MILA	13:38:08	13:39:28
	15:09:23	15:10:45
ASCENSION	15:36:32	17:11:46
HAWAII	14:52:32	14:53:33

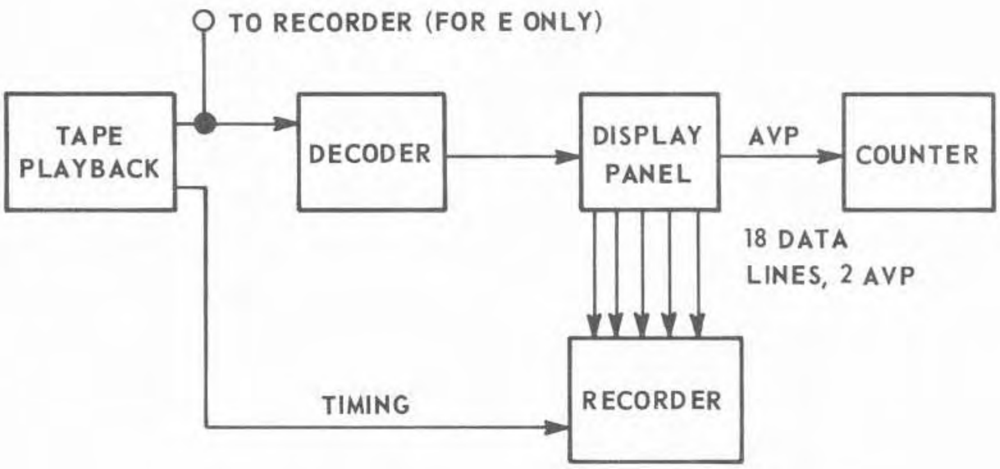


FIGURE 4. MONITOR TAPE PLAYBACK DIAGRAM

being transmitted while the ground station operators were changing tapes. These areas required special analysis. Another problem area was created by an operational error at Carnarvon when they continued to transmit commands after the vehicle had passed over the horizon. The Hawaii station also created a problem when it acquired a false lock and transmitted commands before it had a solid two-way lock. Modulator errors at the ground station accounted for eight missed commands. With the exception of these problems, it was possible to verify the acceptance or rejection of all commands.

Table IV is a composite tabulation of all flight commands. This table shows that 373 commands were transmitted and all were received onboard. The computer did not accept all of these commands because some of them had ground formating errors. However, as far as the onboard command system was concerned, 100 percent of the flight commands transmitted were received.

TABLE IV. COMPOSITE TABULATION (FLIGHT COMMANDS ONLY)

Station	Pass	Ground Station Transmissions	Telemetry Verified Received	Telemetry Verified Missed
Texas	2	36	36	0
Goddard-Mila	2	5	5	0
Ascension	3	119	119	0
Carnarvon	3	213	213	0
Total		373	373	0

Table V lists the history of the test word commands. Forty-four test word commands could not be verified because of the telemetry problems identified earlier. It is highly probable that all of these commands were not received by the onboard system because the vehicle was over the horizon. This is not considered a problem because it is not recommended that commands be sent when the vehicle is less than 3 to 5 degrees above the horizon. If these commands and the modulator errors discussed below are ignored, it can be seen from Table V that only one test command was missed out of 5376 valid commands transmitted. Considering both flight and test commands, only one command was missed out of 5748 valid commands transmitted. No reason could be established for this missed word. However, one missed word should not be alarming when so many words were transmitted. The command would have been rejected if any of the 175 sub-bits in a command word were incorrectly received. A total of 985 960 valid sub-bits were transmitted. Records from Ascension and Carnarvon were analyzed to make sure the loss was not caused by a telemetry dropout.

TABLE V. COMPOSITE TABULATION (TEST COMMAND SEQUENCE)

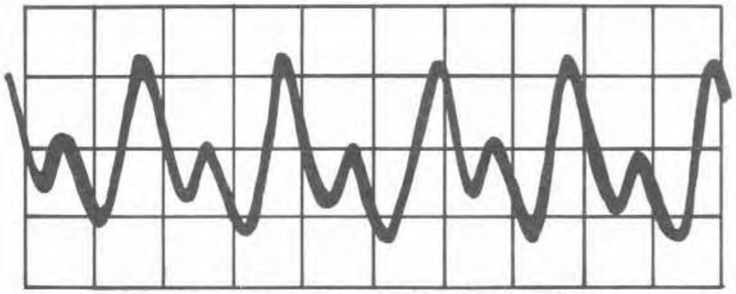
Station	Pass	Transmissions Attempted	Telemetry Noisy D	Verify Rec'd. F	Disagreements Resolved G	Verify Missed H
Carnarvon	1	616	38	576	2	0
Texas	1	172	--	172	--	0
Goddard-Mila	1	177	--	177	--	0
Hawaii	2	137	6	129	2	0
Ascension	3	2352	--	2351	--	1
Carnarvon	3	1975	--	1971	4	0
Total		5429	44	5376	8	1

As previously stated, eight commands were missed because of modulator errors. Table VI lists the times and types of modulator errors experienced at two stations, Hawaii and Carnarvon. If the missed command at Ascension had been caused by any of these types of errors, with the possible exception of the amplitude fluctuation, the test setup used for verification would have also rejected the command.

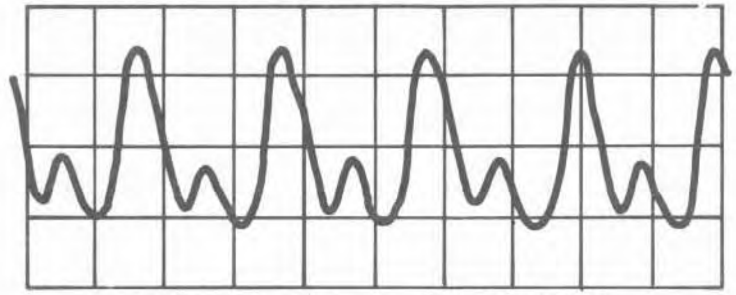
In some cases, the composite 1 and 2 kHz waveform was analyzed. Some of the waveforms that were evaluated are shown in Figures 5 and 6. Analysis of these waveshapes shows that the distortion was excessive. It could not be determined immediately if the distorted wave was transmitted or if the distortion was caused by the receiving and/or recording system. In any event, efforts should be made to improve the ground system, especially if this is the waveshape being transmitted.

TABLE VI. MODULATOR ERRORS

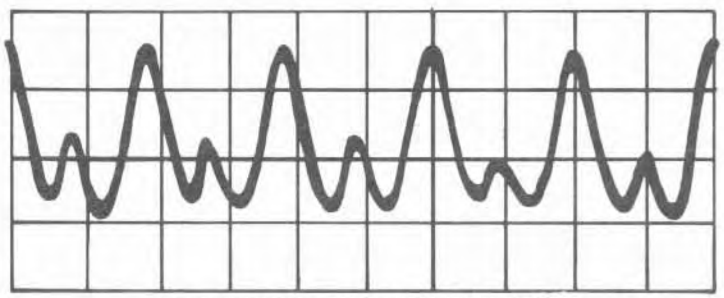
	Hawaii		Carnarvon					
Modulator Errors	14:52:33	14:52:35	12:54:38	12:55:43	17:42:56	17:44:57	18:06:58	18:09:01
Subcarrier interrupted	X	X	X	X	X	X	X	
No subcarrier modulation	X	X						
Transmission shortened			X	X	X	X	X	
No vehicle address			X	X	X	X	X	
Incorrect sub-bit pattern			X	X			X	
Large amplitude fluctuation								X



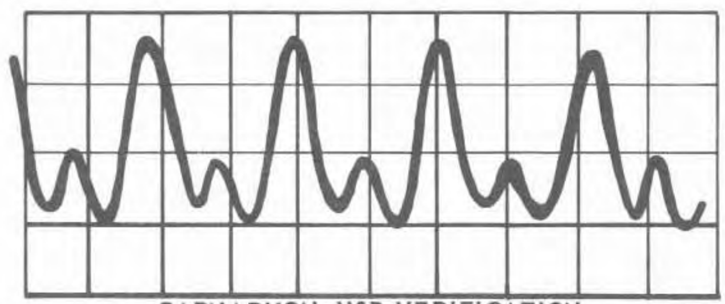
GODDARD-MILA, USB VERIFICATION
RECEIVER NO.1 INVERTED; $\phi_s \approx$ 22 DEG.
(W.R.T. 1 kHz)



GODDARD-MILA, USB VERIFICATION
RECEIVER NO. 2 INVERTED; $\phi_s \approx$ 34 DEG.
(W.R.T. 1 kHz)

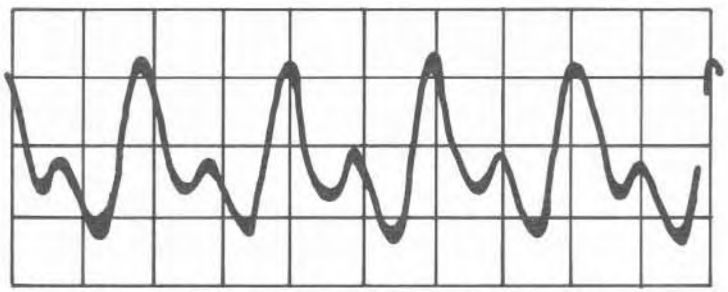


CARNARVON, USB VERIFICATION
RECEIVER NO. 1 INVERTED; $\phi_s \approx$ 41 DEG.
(W.R.T. 1 kHz)

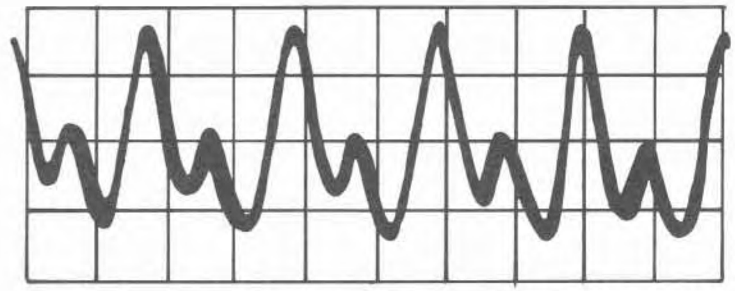


CARNARVON, USB VERIFICATION
RECEIVER NO. 2 INVERTED; $\phi_s \approx$ 34 DEG.
(W.R.T. 1 kHz)

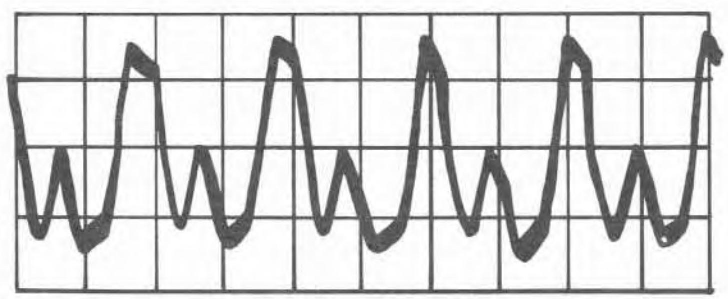
FIGURE 5. COMMAND WAVEFORMS



TEXAS, USB VERIFICATION
RECEIVER NO. 1 INVERTED; $\phi_s \approx 22$ DEG.
(W.R.T. 1 kHz)



HAWAII, USB VERIFICATION
RECEIVER NO. 1 NOT INVERTED; $\phi_s \approx 14$ DEG.
(W.R.T. 1 kHz)



ASCENSION, USB VERIFICATION
RECEIVER NO. 1 NOT INVERTED; $\phi_s \approx 34$ DEG.
(W.R.T. 1kHz)

FIGURE 6. ADDITIONAL COMMAND WAVEFORMS

The results of this analysis have proven conclusively that the onboard command system is compatible with the ground network when the correct commands are transmitted. Some testing of the system is still desirable, should it ever become necessary to transmit commands during the powered flight phase of the mission. Evaluation of the 70 kHz subcarrier measurement shows that three times during the launch phase commands could not have been received by the onboard system. The first dropout occurred at S-IC/S-II separation and lasted for 1 second. The second dropout occurred at interstage jettison and lasted for 0.6 second. The third dropout occurred at 189.3 seconds and lasted for 0.5 second. The uplink signal strength record (Fig. 7) shows that the ability to send a command was marginal in two other areas. The first period was in the vicinity of 200 seconds when all signal strengths in the Cape area experienced a decrease, and the second period was at 401 seconds when the signal decreased sharply for 0.4 second. In both cases, the problem was one of very low aspect angle with respect to the tail of the vehicle. The look angles changed sharply at all stations near the launch area between 190 and 200 seconds. The look angle was less than 0.7 degree off the tail of the vehicle in the period between 398 and 416 seconds. The onboard antenna pattern is very noisy and undefined in this area. The command problem can be reduced by handover to Bermuda as soon as feasible after this station acquires a steady signal. Usually, this problem requires a trade-off between low elevation angle to the ground site and low look angle to the vehicle. If the ground station going to accept handover has been locked to the downlink solidly for 30 seconds, this station is probably a better risk, even at elevation angles between 3 and 5 degrees, than a station with a tail aspect angle which falls between these same two limits.

TELEMETRY SYSTEMS PERFORMANCE

The performance of the CCS telemetry link has taken an added significance since the S-band PCM/FM telemetry transmitter has been removed from the IU beginning with vehicle AS-504. This means that the CCS telemetry system is the only link with the vehicle once the slant range to the ground station exceeds 5000 to 6000 km.

In particular, the requirement for telemetry places constraints on the attitude of the vehicle during the translunar injection phase of the mission because it represents the broadest bandwidth data on the downlink, thus requiring the highest signal level to achieve a given accuracy. The attitude constraints are imposed by the necessity for correctly pointing the vehicle antenna to maintain the minimum acceptable signal strength.

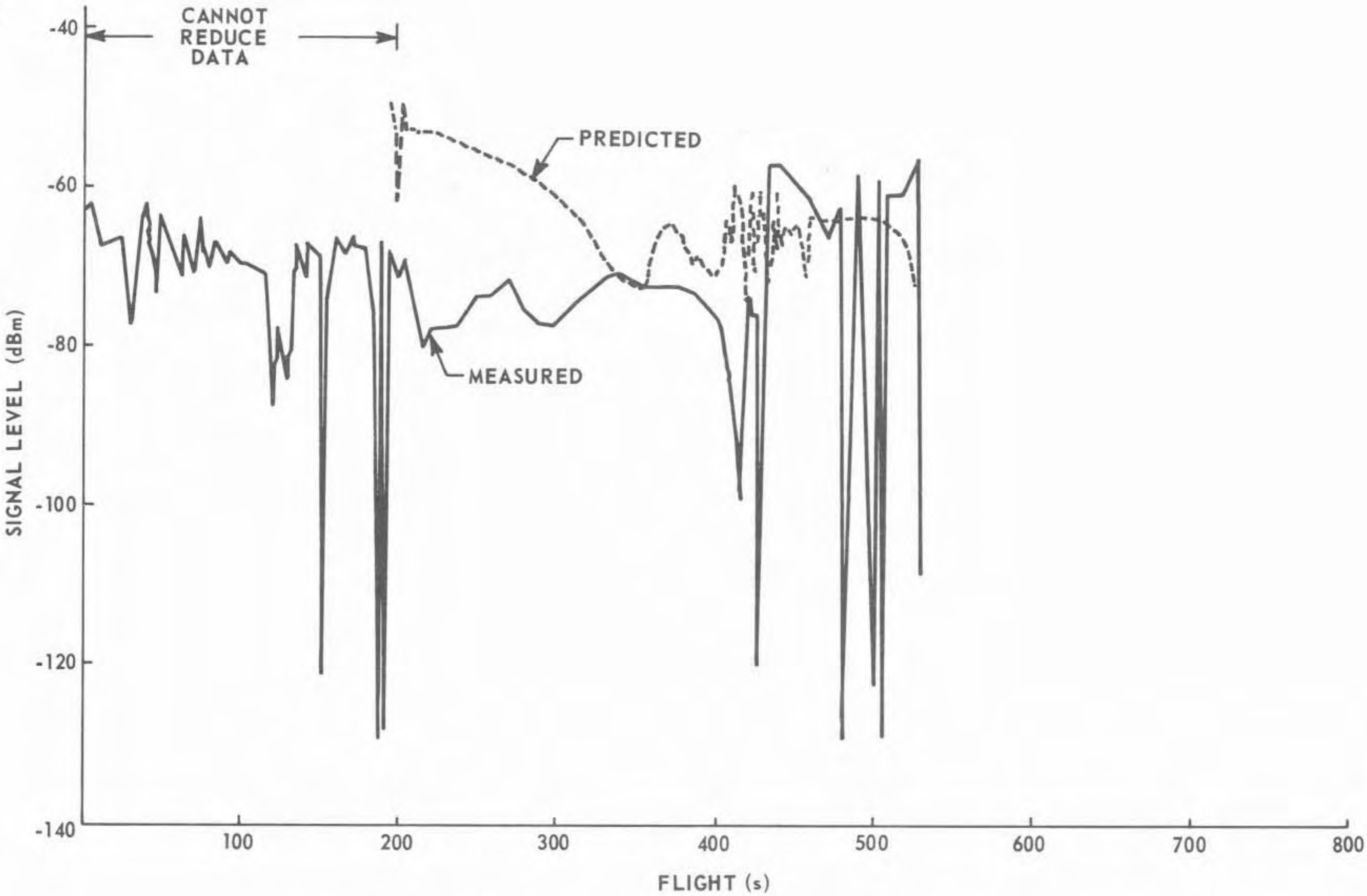


FIGURE 7. ONBOARD SIGNAL STRENGTH

One of the objectives of the analysis was to determine the signal levels required for given bit-error-rates. The data evaluated were helpful, but insufficient data were available to reach final conclusions. One reason was that not enough data at relatively constant signal-to-noise ratios were available to measure bit-error-rates of 10^{-5} to 10^{-6}. Bit-error-rates better than 10^{-3} or 10^{-4} could never be measured using sync bits because the system uses only 3600 sync bits per second and it would take too long to gather sufficient data.

A period of time was chosen over Ascension Island when the signal level remained relatively constant for 2000 seconds. An attempt was made to measure the errors in the system by comparing the bit stream (all 72 000 bits per second) of the CCS telemetry with that of the PCM/FM S-band telemetry. It was assumed that the error rate was small enough that correlation of the two bit streams at any instant of time implied no errors. During the entire 2000 seconds, the only time that perfect correlation was not achieved was when the ground station lost synchronization on one of the links. The reasons for losing sync have not been determined. In some cases, it could easily be seen that the bit stream was shifted one bit and the dropouts were related to that shift. As a result, a computer program was written following the logic outlined in Figure 8. This program shifts the two bit streams to align them for maximum correlation and then counts the missed bits as errors. Using this technique, the number of bits missed at Ascension Island between 17 000 and 17 900 seconds on AS-501 was 2592. Approximately 64 800 000 bits were transmitted during this time so this would represent a bit-error-rate of approximately 4×10^{-5} if confidence limits are not too strict.

When attempts are made to evaluate a system such as this, it must be remembered that more factors affect the evaluation than what is normally considered when perfect theoretical bit-error-rate curves for white gaussian noise are derived. Even under the best conditions in a laboratory, it is not possible to approach theory closer than 1 or 2 dB. In the real world, other factors such as intermodulation, impulse noise, tape dropouts, and sync problems occur and in many cases are uncontrollable.

The intent of this analysis and future analyses is to determine and to eliminate as many of these problems as possible. One parameter which may be causing some of the dropouts experienced on this flight is tape quality. The data on this flight were not recorded with the best quality tape available. The oxide on the tape flaked badly, and it is doubtful that bit-error-rates of 10^{-5} to 10^{-6} could consistently be recorded. A better quality tape would pay for itself in computer and analysis time involved in looking for lost data.

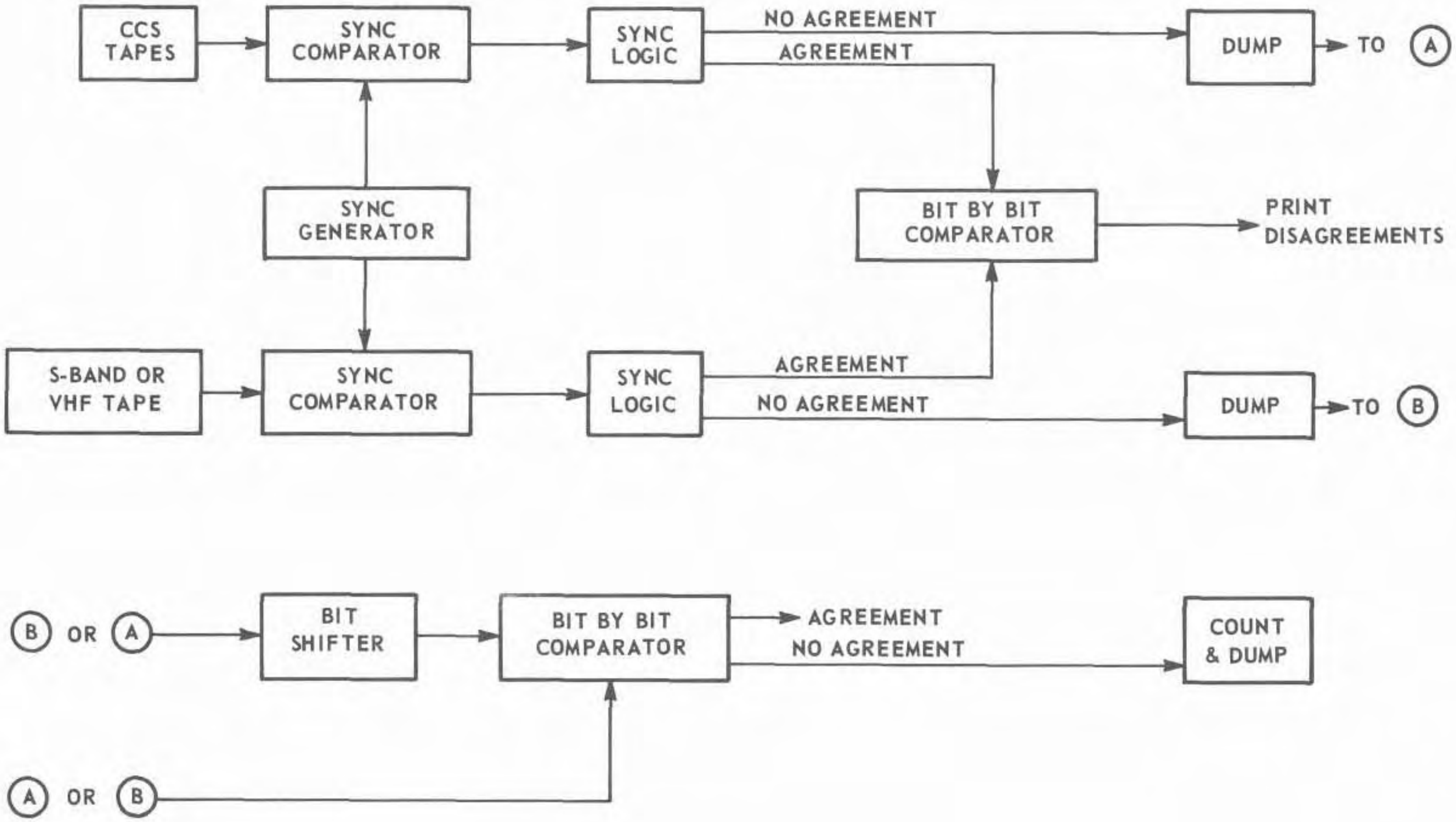


FIGURE 8. TLM PROCESSING SEQUENCE

One intent of the analysis was to determine if intermodulation products created by updata, clock, or PRN set the bit-error-rate onboard the vehicle. The data from Ascension Island are not of sufficient detail to measure the effects of uplink modulation on the downlink telemetry subcarrier. The limited analysis that could be performed showed no correlation between lost data bits and the different operational modes. Additional analysis in this area will be required on future missions.

One problem experienced with CCS telemetry data was phase reversal following dropout. The MSFN ground stations are programed to check for this problem and theoretically no more than one-fourth of a second (one master frame) of data will be lost following a dropout. MSFC's data reduction facilities depend on an operator to turn a switch when he sees a light come on and this corrects the phase. However, the operator occasionally was occupied with something else and failed to operate the switch for several seconds. It is recommended that the MSFC scheme be automated similar to the MSFN scheme.

Insufficient data were received to permit an update of the attitude constraints by the requirement for telemetry. The constraints shown in Figures 9 and 10 and in Table VII are limits on the look angles phi (ϕ) and theta (θ) as a function of slant range from the ground station. Phi and theta are defined in Figure 11. The constraints are derived by calculating the required onboard antenna gain to give a signal level of -106 dBm at any MSFC ground station using a 9.2 m (30 ft) dish. Based on the AS-501 results, it is believed that some ground stations can deliver excellent quality data at signal levels considerably less than -106 dBm. However, it is too early to begin opening the constraints because of some of the problems outlined previously and in the sections on signal strength and operational problems.

The AS-502 vehicle will provide some very useful information in this area. In particular, this mission is designed to simulate a lunar mission following spacecraft separation and to sweep through the main beam of the antenna pattern. Trying to stay inside the limits imposed by Figures 9 and 10 causes tight constraints on the translunar injection attitude for a lunar mission. In many cases, these constraints conflict with spacecraft lighting constraints, and every effort will be made to broaden them following AS-502 or AS-503, if sufficient data can be gathered to do this and still assure a successful lunar mission.

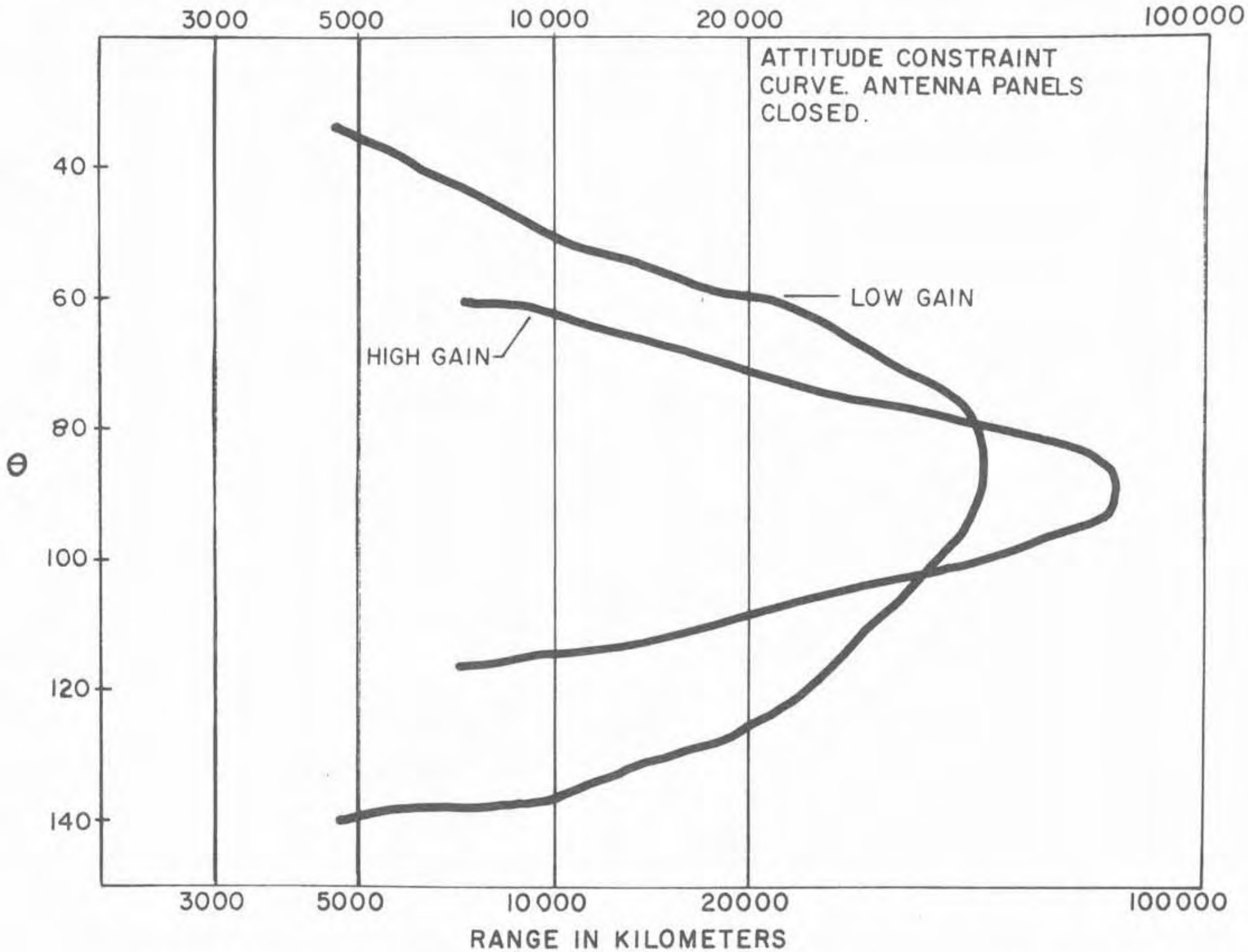


FIGURE 9. LOOK ANGLE CONSTRAINT CURVE (θ) — PANELS OPEN

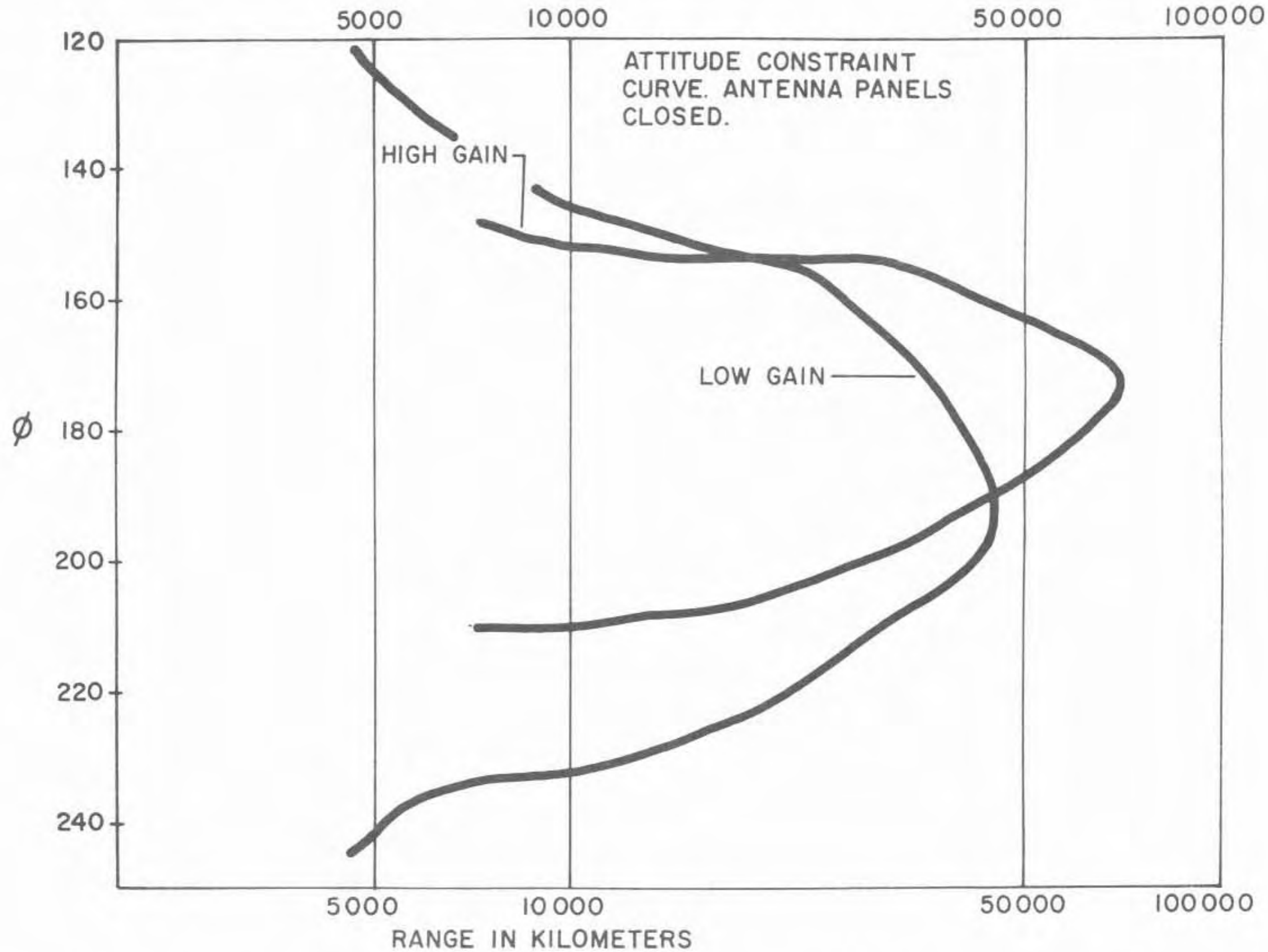


FIGURE 10. LOOK ANGLE CONSTRAINT CURVE (ϕ) — PANELS OPEN

TABLE VII. LOOK ANGLE CONSTRAINTS

	Slant Range (km)	Phi (ϕ) (deg)		Theta (θ) (deg)	
		min	max	min	max
High Gain Antenna	7 200	148	210	60	116
	8 000	150	210	60	116
	9 300	152	210	60	114
	10 300	152	210	62	114
	11 400	152	210	64	114
	12 900	154	208	66	112
	14 500	154	208	66	112
	16 100	154	208	68	110
	18 500	154	206	70	110
	20 900	154	206	72	108
	23 300	154	204	72	106
	25 700	154	202	74	106
	29 000	154	198	74	104
	32 100	156	198	76	104
	37 000	158	196	78	102
	41 000	160	192	78	102
	45 000	160	190	80	100
	51 500	164	188	80	98
	57 900	164	184	82	96
	64 400	166	176	82	94
	72 400	172	174	86	94
Low Gain Antenna	4 650	112	234	34	140
	5 150	114	232	36	138
	5 800	120	226	36	138
	6 400	126	224	38	138
	7 200	126	224	38	138
	8 000	128	222	38	138
	9 300	132	222	48	138
	10 300	138	222	52	136
	11 400	138	222	52	134
	12 900	138	220	54	132
	14 500	140	218	56	130
	16 100	142	214	58	130
	18 500	142	214	60	128
	20 900	144	212	60	126
	23 300	146	208	62	124
	25 700	148	206	64	122
	29 000	152	202	66	120
	32 100	154	198	70	118
	37 000	162	194	72	104
	41 000	166	192	74	100
	45 000	174	188	78	94

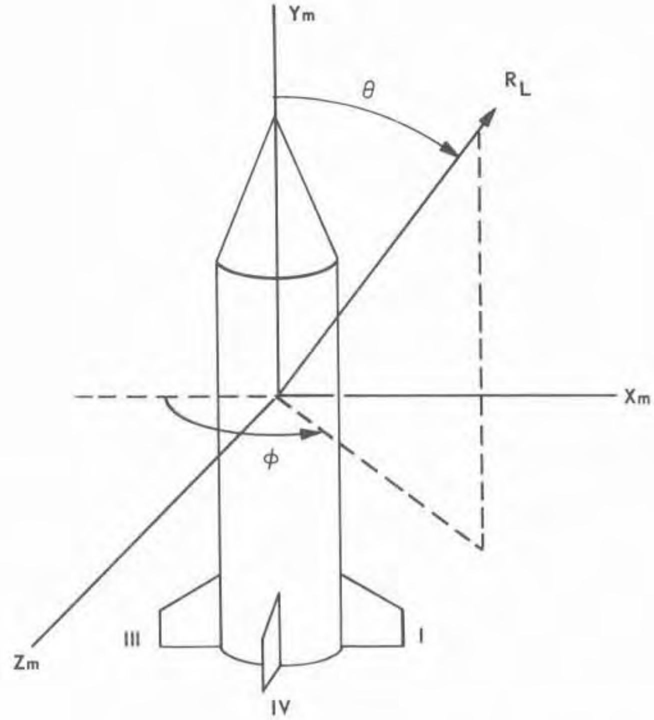


FIGURE 11. VEHICLE COORDINATE DEFINITION

TRACKING PERFORMANCE

Attempts to evaluate the tracking system performance have been unsuccessful. Range and range rate errors exceeded 1000 meters and 100 meters/second, respectively, at most of the sites evaluated when compared to the best estimate trajectory (BET). At this writing, it has not been determined if these errors were caused by the onboard system, the ground station, or the data reduction technique used for performing the comparison. All indications point to the reduction program as causing the problem. Goddard Space Flight Center stated in Reference 1 that the tracking data were not as good as expected, but they did not experience errors as large as those above.

One reason it is believed that the transponder and ground station were compatible and did not cause the large errors is that GSFC reports that the only times it was necessary to reacquire ranging on the CCS transponders were:

1. At S-IC/S-II staging.

2. When the ground station locked onto an antenna side lobe or a transponder sideband.

3. When it was planned as a part of the mission.

The one minor problem experienced appears to have been an incorrect range delay for the onboard system. The high-speed tracking data transmitted at launch showed a range decrease of about 300 meters during the first 6 seconds after launch. During this time the range rate was only 0.2 meter/second. The GSFC report [1] states that this difference in range may be caused by the errors in transponder delays measured on the launch pad. These delays included multipath which would make the range appear greater. The report suggests that more reliance be placed in factory or acceptance test procedure measured delays for future missions. MSFC is working to improve these measurements. Another test on the pad which might prove useful would be to switch the vehicle antennas to the different positions of omni, high gain, and low gain and to measure the delays. This should change the delay time if the error is the result of multipath. The three antennas will have different delays because of the differences in cable lengths, but this can easily be measured.

The intent of the analysis was to correlate angle, range, and range rate errors to variations in signal strength but it was not possible to do this because of the problems previously outlined. The few comparisons that were possible showed correlations only for gross changes in signal level. This could be expected in most cases because the signal-to-noise ratio was very high.

The tracking data should be improved on AS-502 because of improved operational procedures at the ground sites and because there will be fewer data reduction problems. In addition, the mission profile following spacecraft separation is better suited to obtaining data which will aid in this evaluation. The evaluation would have been more thorough on this mission if better data had been received from the Ascension Island site which tracked the CCS system.

The AS-501 CCS test plan was written to evaluate the performance of the 498 kHz clock and the PRN code. Because of the aforementioned problems, this was not feasible. The AS-502 test plan was also written to accomplish this test, and it is anticipated that the necessary information will be obtained.

SIGNAL STRENGTH EVALUATION

A thorough signal strength evaluation is considered to be a very important part of this analysis since most preflight analysis is based on predicted signal strengths. The launch and orbital phases of the mission used the omni directional antenna system. The antenna patterns for this system are made on a 1/20 scale model of the vehicle. The translunar injection phase of the mission used the low and high gain antenna system. The patterns for this system were made on a flat ground plane with a full scale antenna. Since other stages of the vehicle were not included, the accuracy of the patterns is limited to angles within the main beam of the antenna as shown in Figure 12. This figure also shows the signal strength at Carnarvon during the high apogee ellipse over that station. Note that Carnarvon is outside the main beam of the high gain antenna prior to 19 400 seconds, and the differences in predicted and measured signal levels are significant. When the low gain antenna is switched in, this places Carnarvon in the main beam of the antenna, and good agreement between predicted and measured signal strength is immediately apparent.

Predicted and measured signal strengths for other stations used during this mission are shown in Figures 13 through 25. The agreement between predicted and measured signal strengths was excellent except for the following times:

1. When the aspect angle was less than 5 degrees off the tail of the vehicle.
2. When ground stations were locked on an antenna side lobe.
3. When ground stations were locked on a transponder sideband.
4. During launch when the ground station operator failed to recognize that the system had dropped lock.
5. When the elevation angle was less than 3 degrees.
6. At handover.
7. When the ground station antenna passed through the "key hole" (a mechanical limit of the system).
8. At Bermuda during launch when the ground antenna experienced a large pointing error.

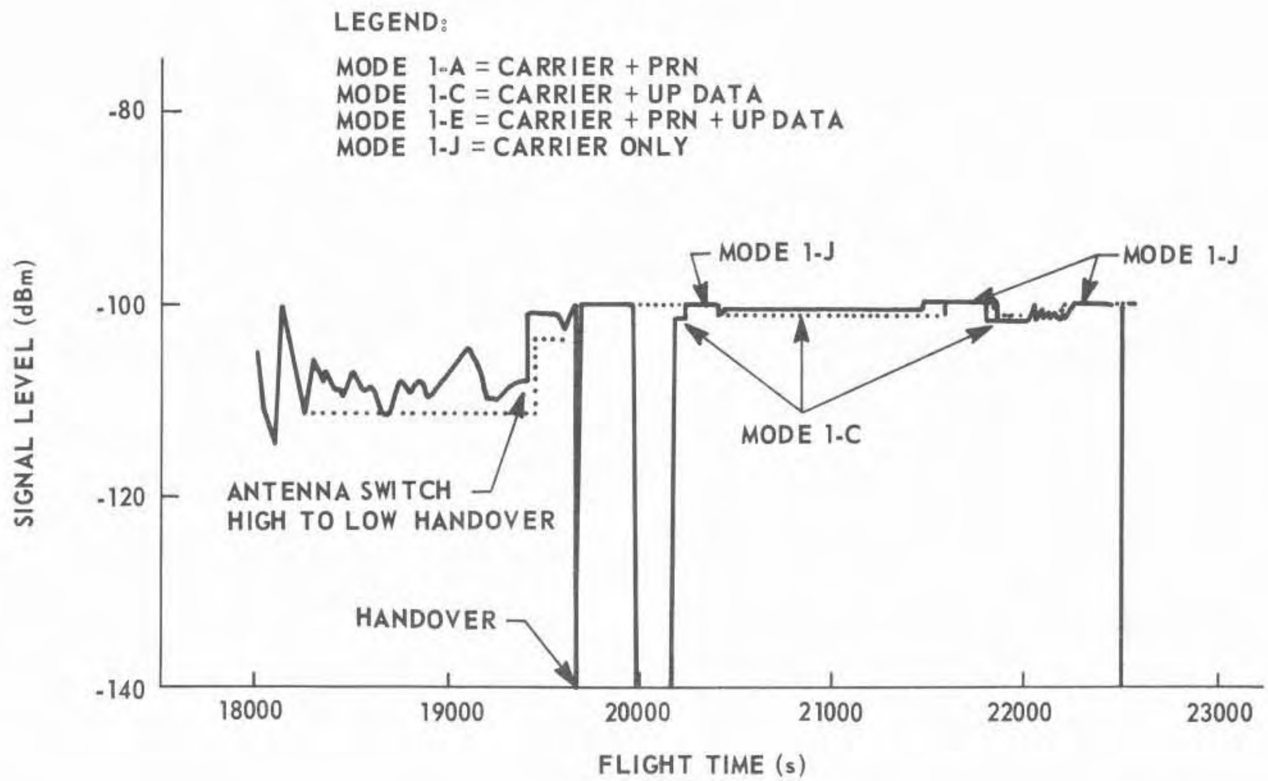


FIGURE 12. CARNARVON CCS DOWNLINK CARRIER SIGNAL STRENGTH (AS-501)

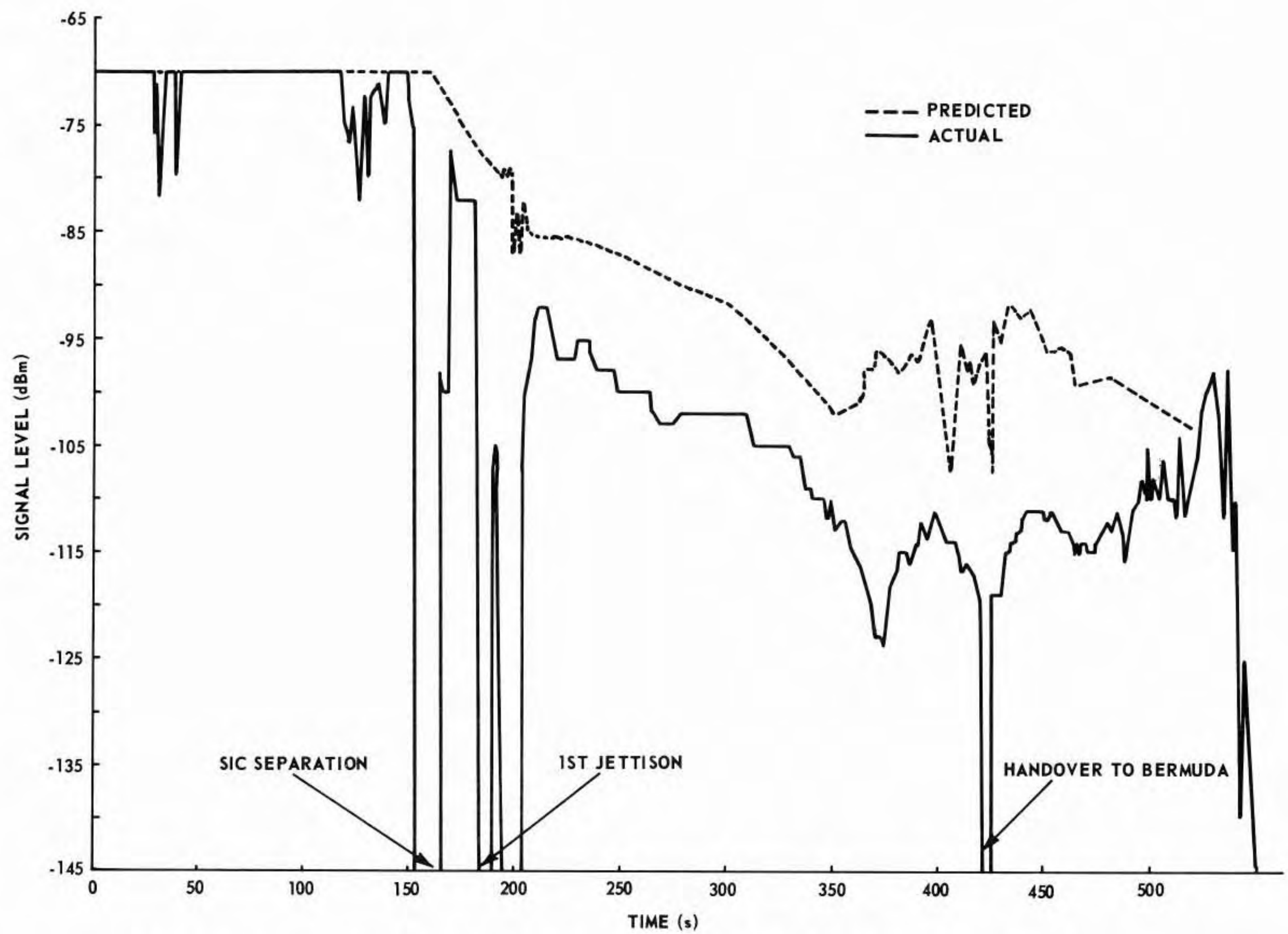


FIGURE 13. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — MILA

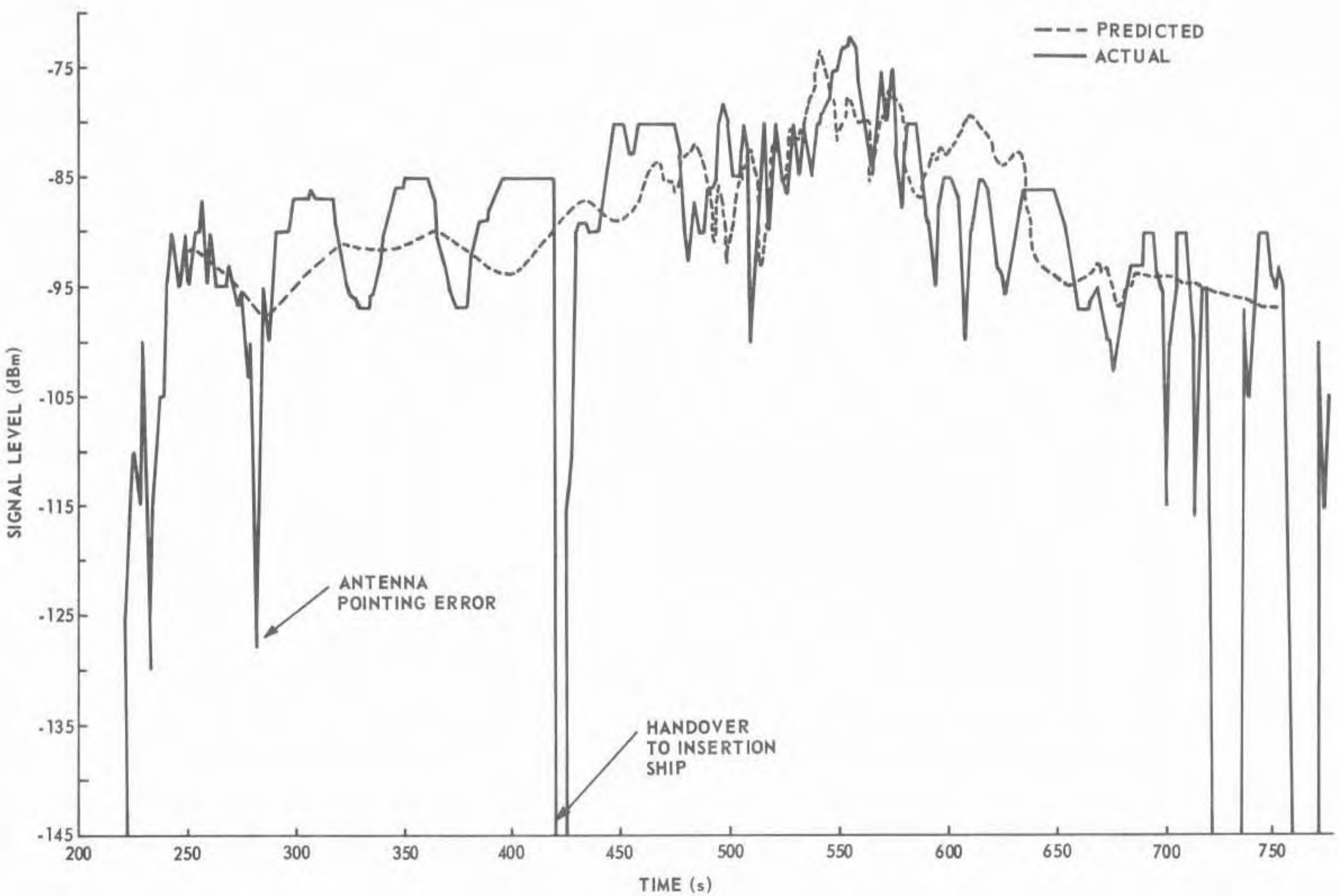


FIGURE 14. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — BERMUDA

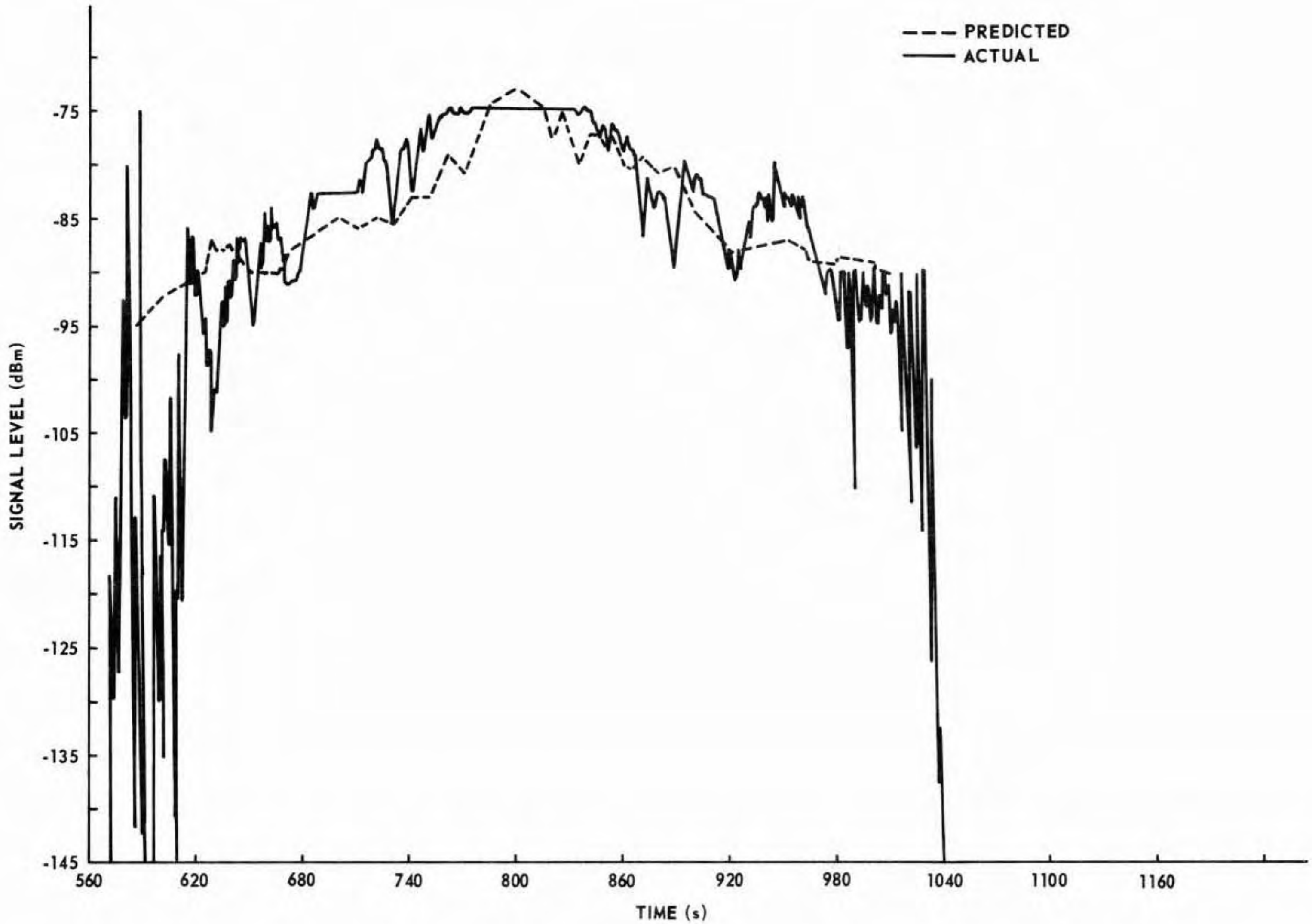


FIGURE 15. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — VANGUARD

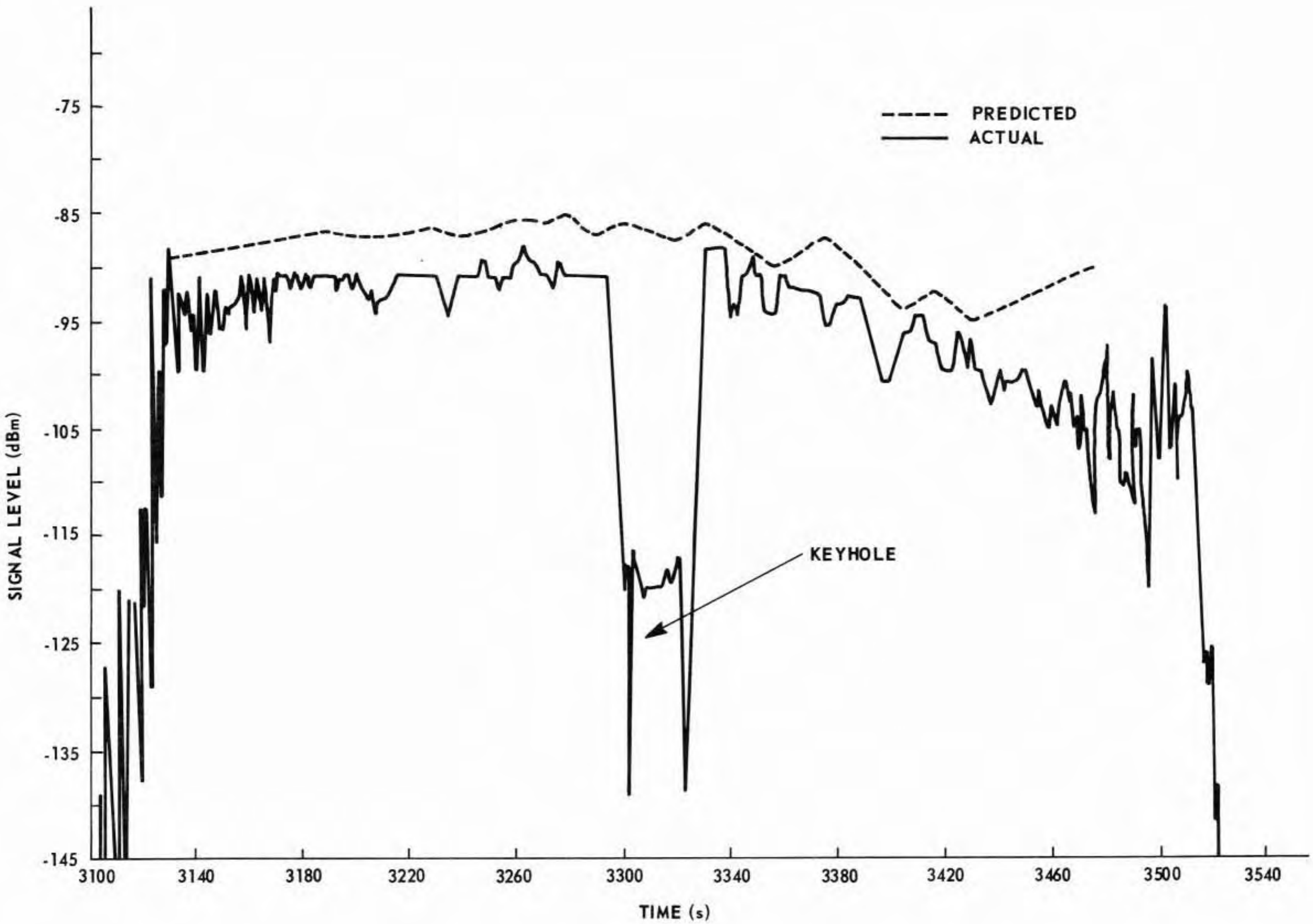


FIGURE 16. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — CARNARVON

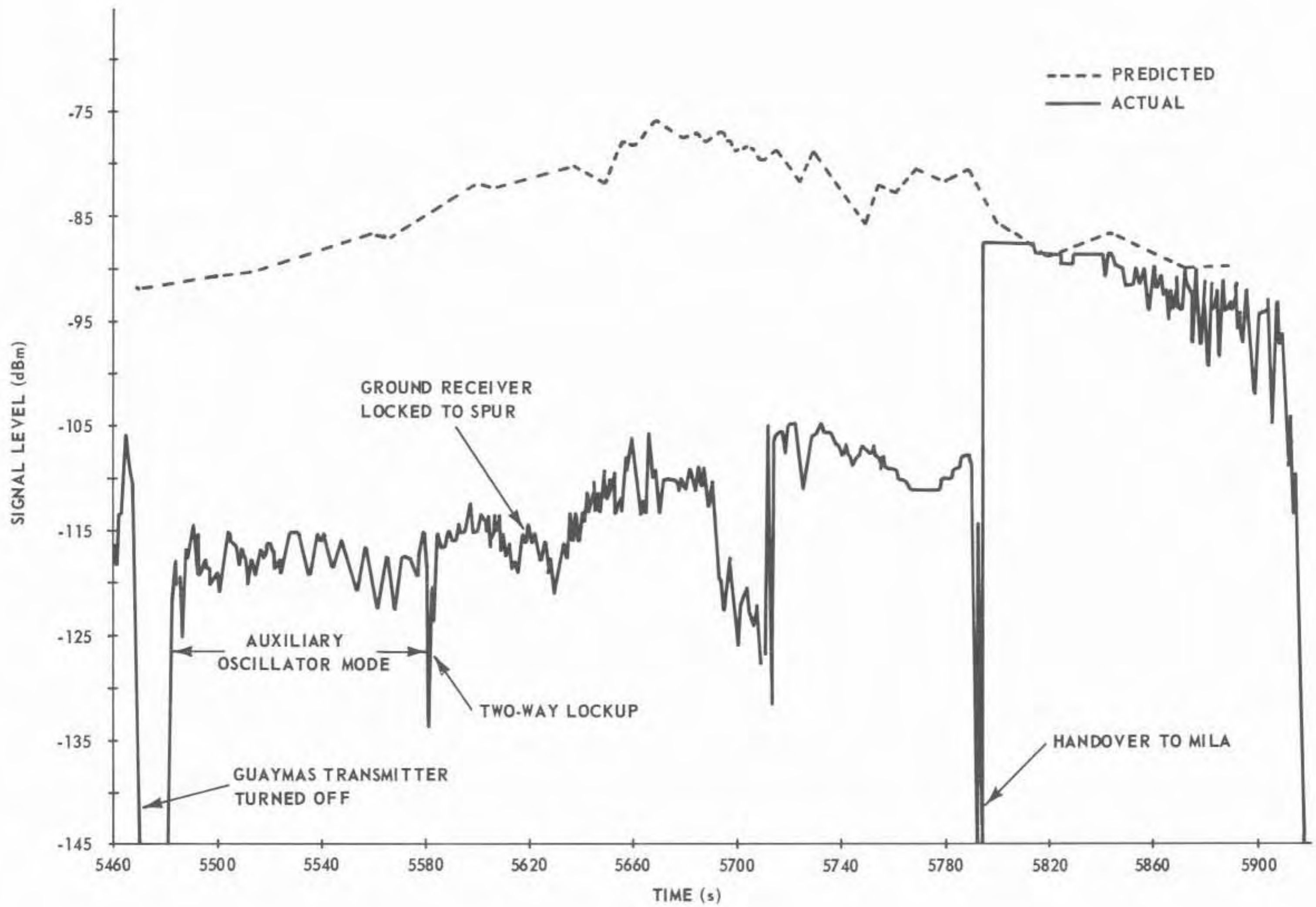


FIGURE 17. CCS DOWNLINK CARRIER SIGNAL STRENGTH — TEXAS

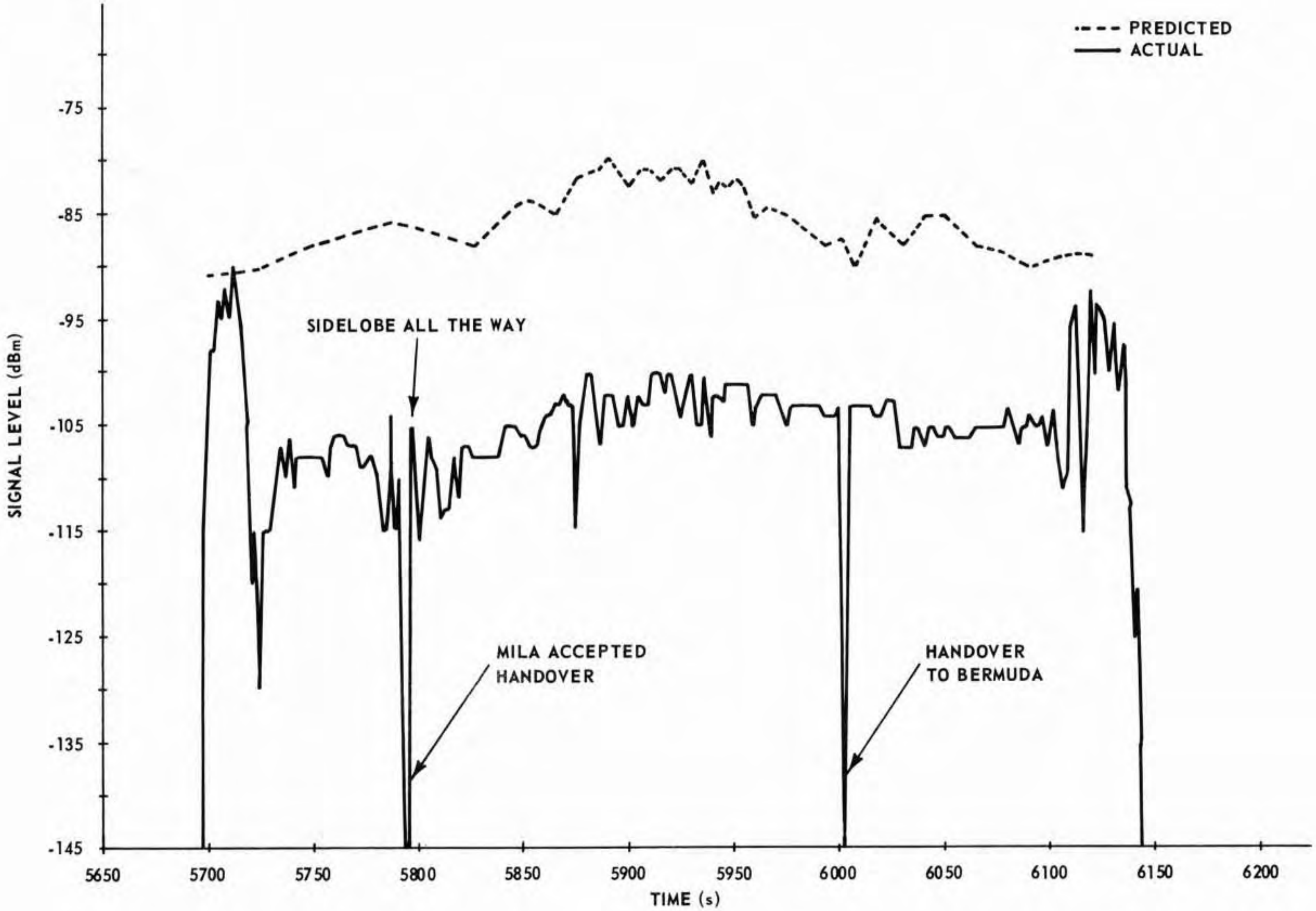


FIGURE 18. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — MILA

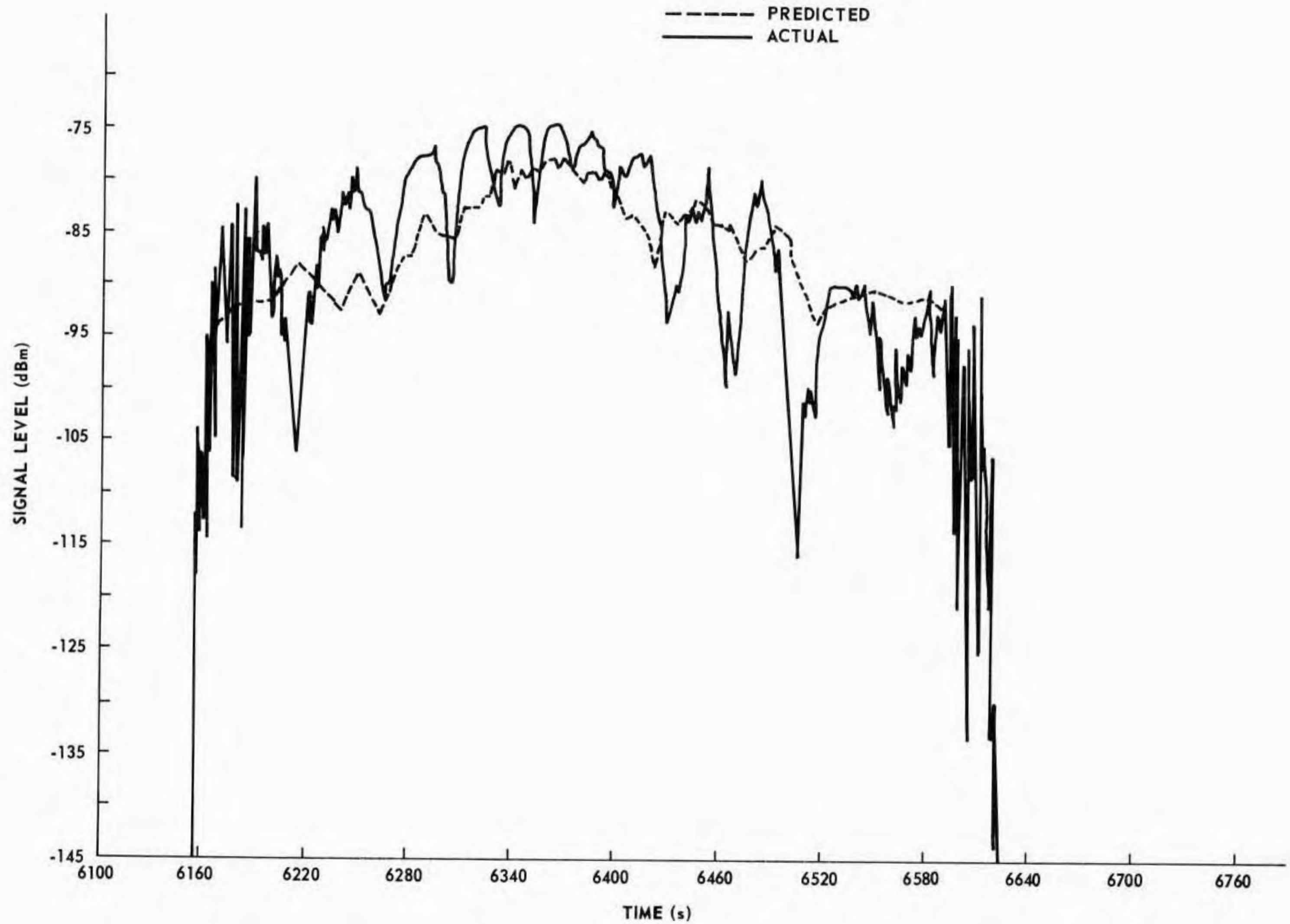


FIGURE 19. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — VANGUARD

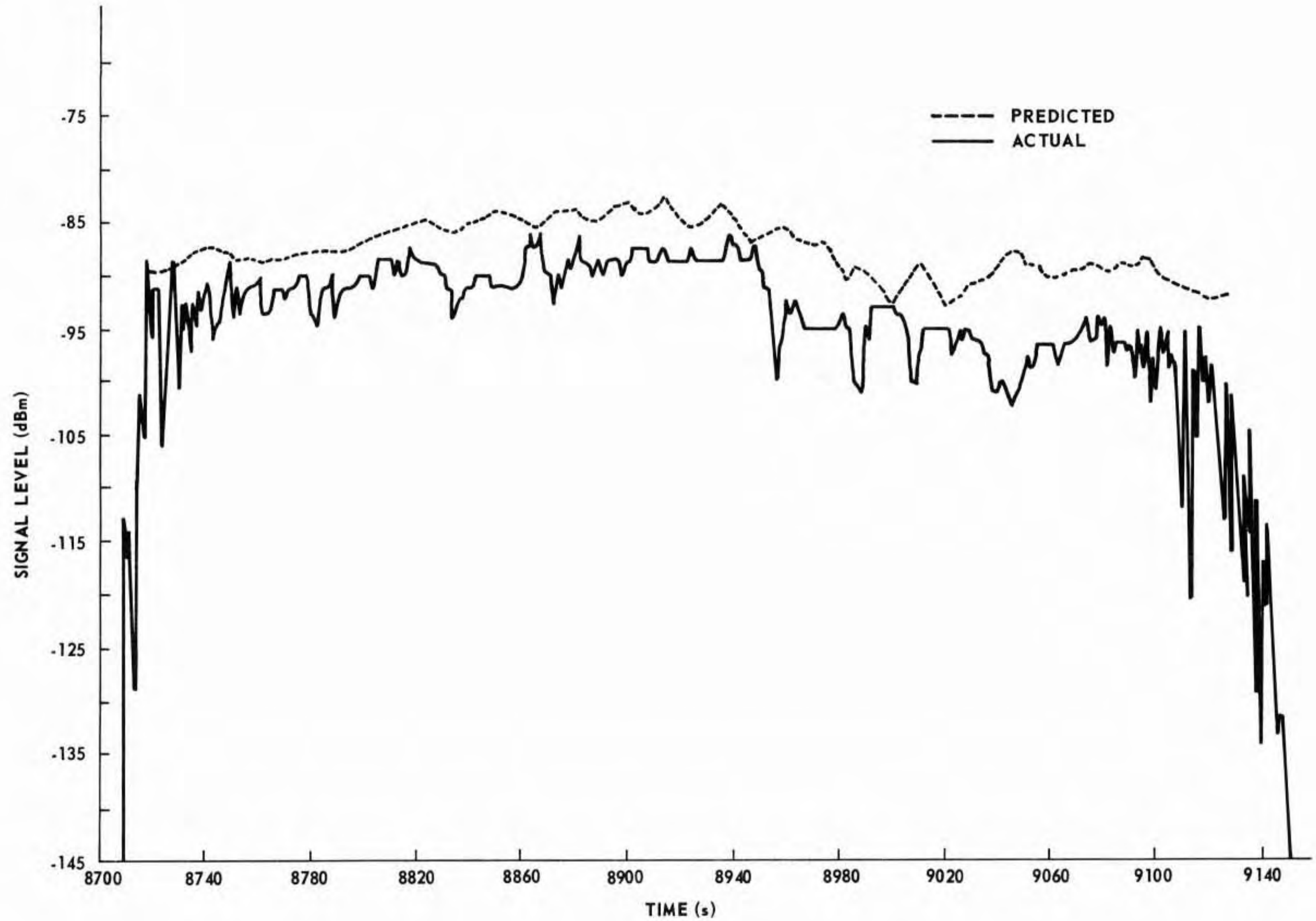


FIGURE 20. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — CARNARVON

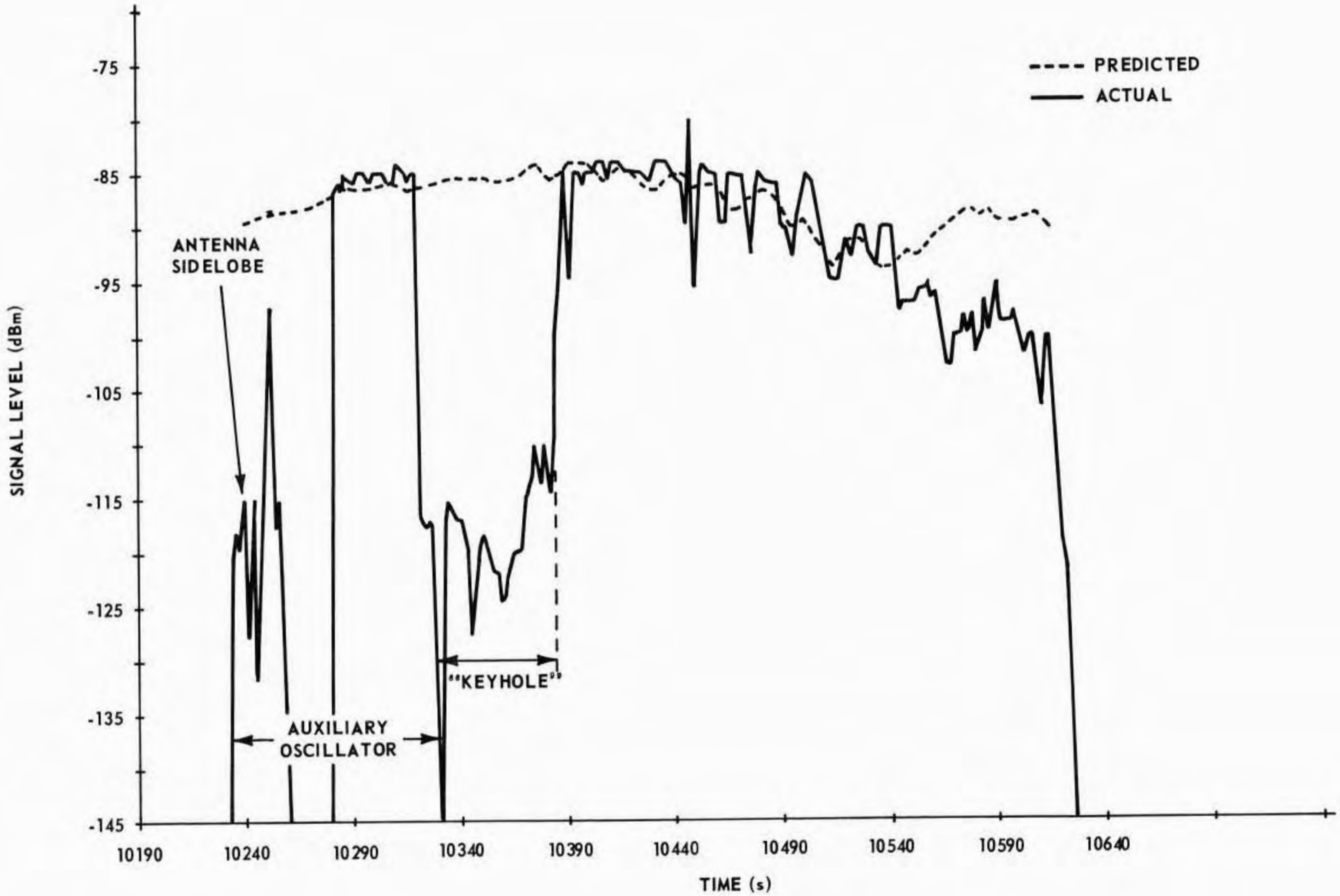


FIGURE 21. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — HAWAII

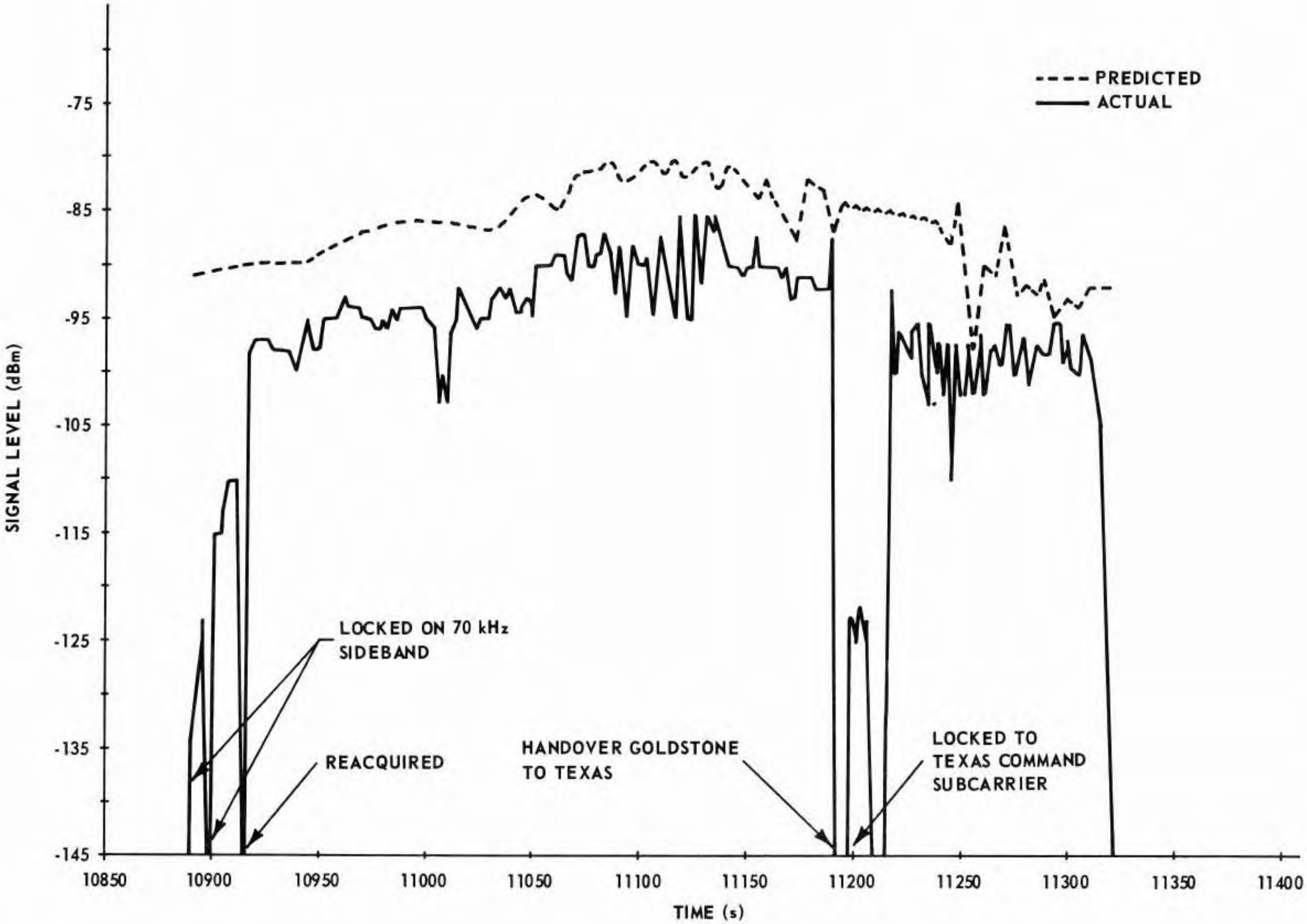


FIGURE 22. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — GUAYMAS

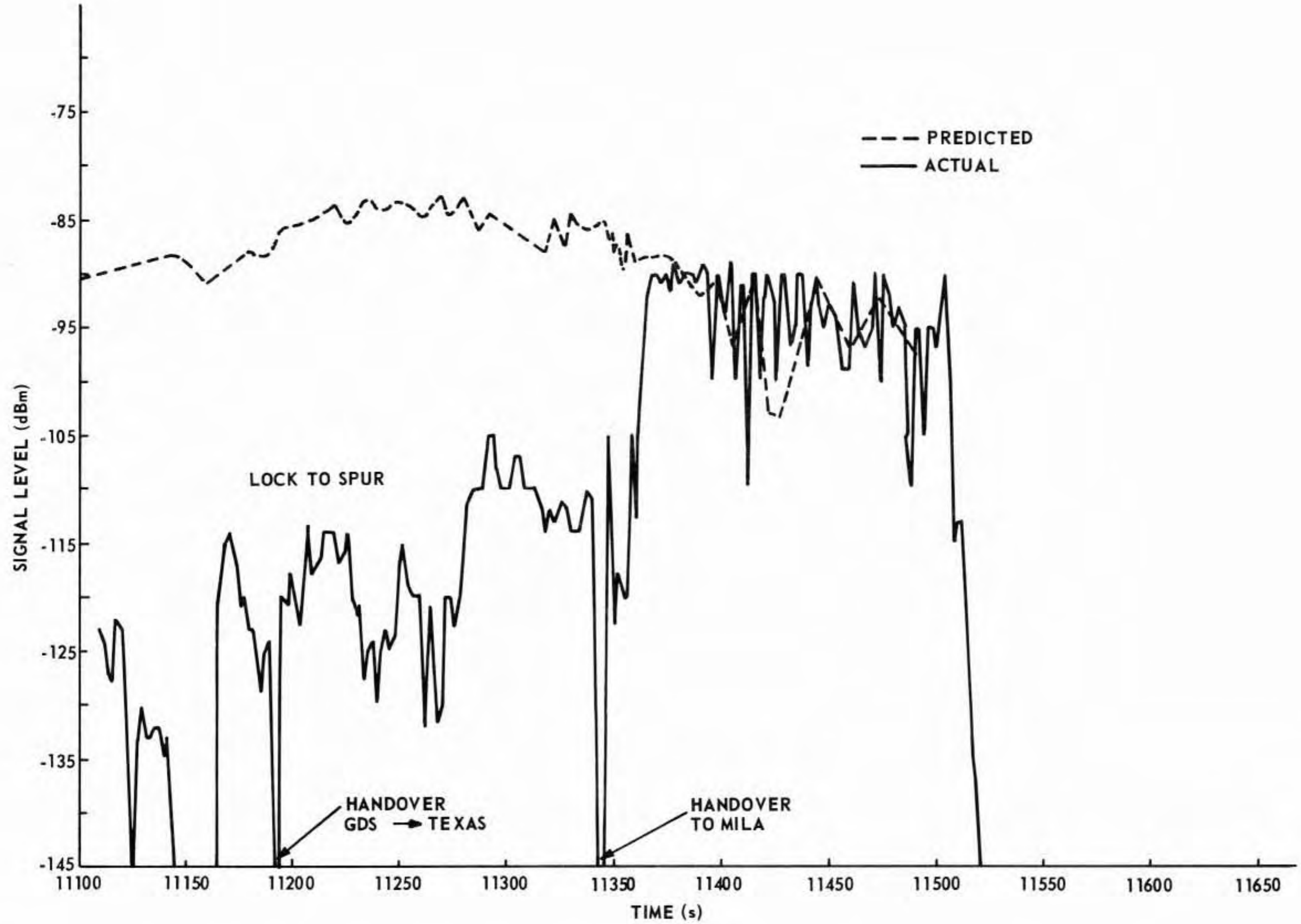


FIGURE 23. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — TEXAS

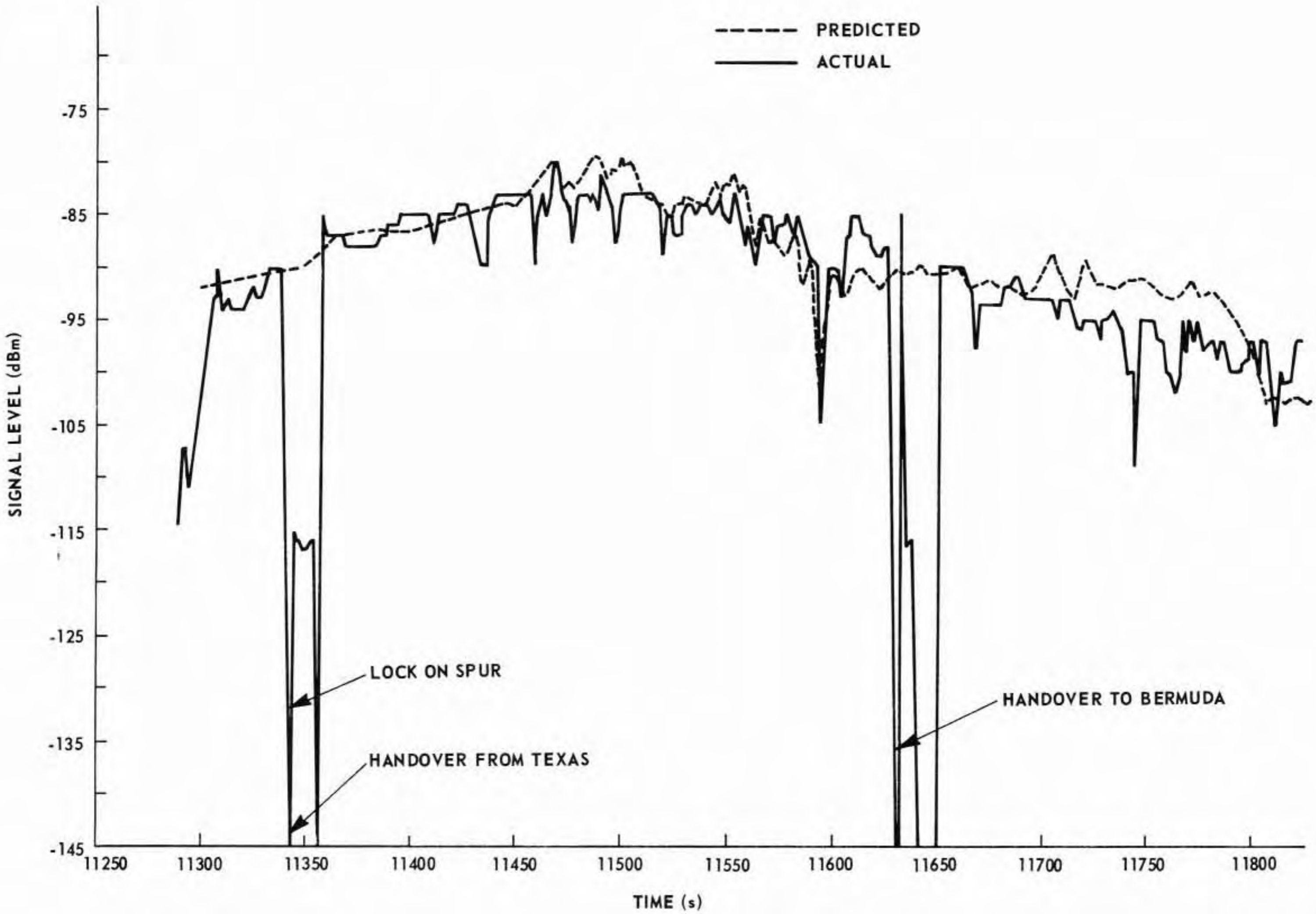


FIGURE 24. AS-501 CCS DOWNLINK CARRIER SIGNAL STRENGTH — MILA

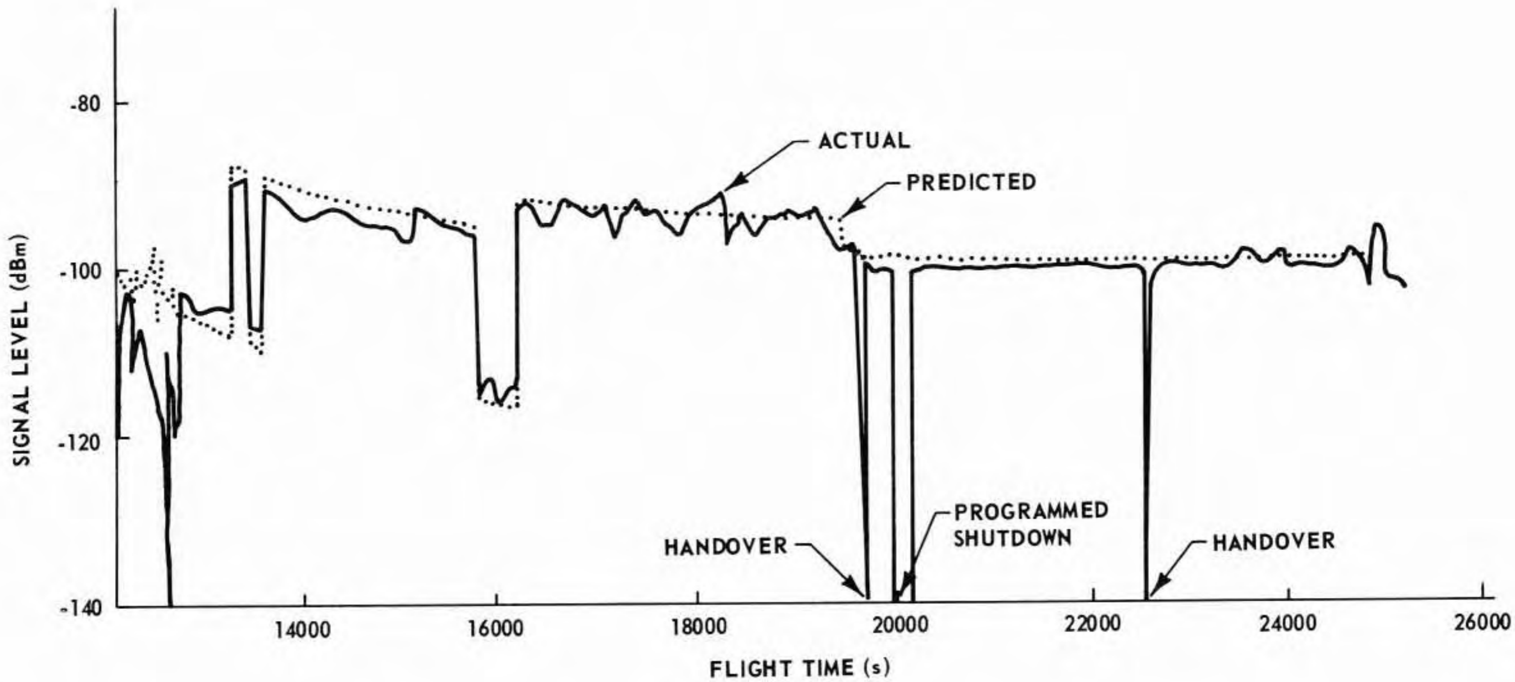


FIGURE 25. ASCENSION CCS DOWNLINK CARRIER SIGNAL STRENGTH (AS-501)

Items 2, 3, 4, and 7 will be discussed in the next section. The other items are discussed in this section. The events causing these differences are identified as accurately as possible in Figures 12 through 25.

The predicted and measured signal strengths were not adjusted in any way. Both data were plotted just as they came off the computer. Note that on many of the curves close agreement exists between the peaks and the valleys of the predicted and measured signal strengths. In still other areas, the peaks and the valleys appear to be out of phase. Analysis indicates that closer agreement exists between predicted and measured signal strength variations when the look angle is looking into the side of the vehicle, away from the vehicle nose or tail.

The pattern inaccuracies and fluctuations near the tail are indeed unfortunate because the attitude of most Saturn V vehicles during launch is such that the look angles for more than 50 percent of the mission are within 5 to 10 degrees of the tail of the vehicle. This accounts for much of the difference between predicted and measured signal strength at Mila during launch (Fig. 13). Most orbital passes do not come closer than 15 degrees to the nose or the tail of the vehicle. The patterns are accurate enough for predicting within a few decibels at these angles. The largest differences in orbit occurred when the elevation angles were less than 3 degrees. In many cases, the fluctuations had ceased, and predicted signal strength agreed closely with measured signal strength at elevation angles close to one degree. However, it is not recommended that any dependence be placed on predictions below an elevation angle of 3 degrees for signals at S-band.

Hawaii acquired the signal prior to the vehicle crossing the horizon. The antenna began tracking on a side lobe and tracked for approximately 25 seconds. Meanwhile, the acquisition receiver acquired the signal, and the operator apparently noticed he was on a side lobe by comparing the main receiver signal level to that of the acquisition receiver. He then dropped lock on the main receiver purposely to get onto the main lobe. The acquisition receiver was receiving a strong signal during the time the main receiver was out of lock. Figure 21 shows that the signal came back in slightly above the predicted signal level when the main receiver reacquired phase lock.

During all this time, the receiver had been tracking in the auxiliary oscillator mode. The antenna entered the "key hole" at approximately 10 318 seconds, and the ground station operator began sweeping the onboard transponder at approximately 10 326 seconds. Two-way lock was acquired within approximately 4 seconds just as the ground antenna was entering the key hole. Figure

21 shows that the downlink signal was 25 to 35 dB below predictions while in the key hole. However, neither the uplink nor the downlink lost lock once two-way lock was acquired.

Figure 16 shows the effect on the downlink at Carnarvon during the "key hole." Significant differences are apparent between predicted and measured signal levels during this time, but two-way lock was maintained.

The fact that both of these stations maintained two-way lock during the key hole should not lead anyone to believe that this will be the case for future missions. Mission planning should never include requirements for uplink nor downlink data during this time period.

The various modes of operation listed in Table I were tested during the translunar injection and coast phase of the mission. The results of these tests were not in sufficient detail to make an accurate comparison between the theoretical and measured differences of the carrier signal strength caused by changing modulation modes. The best resolution of the measured data was approximately 0.25 dB. However, it was detailed enough to show that, in general, the calculations were very good approximations of the measured data, as shown in Figure 12.

It is anticipated that the measured data from future flights will be calibrated such that a more detailed study of the system can be made to determine the behavior because of mode changes and modulation schemes.

Additional discussions of signal strength variations may be found in the following section.

OPERATIONAL PROBLEMS

This section concerns the effect of ground station operational problems on the operation of the onboard system.

This was the first time many of the ground stations had an opportunity to track a unified frequency system such as the CCS transponder. Many operational problems were expected and several problems occurred. Some of the problems such as handover caused fewer problems than anticipated. Even though these problems were greater than expected, the operational performance of the mission was a success when it is considered that the system is very complex and is still in its early stages. The AS-502 performance is expected to be better, based on the experience gained on AS-501 and the Tracking and Training Satellite (TTS) which was placed in orbit after AS-501.

As expected, the launch phase caused the most operational problems. Figures 26 and 27 show the events taking place in the time period between separation at 152 seconds and the time when satisfactory two-way lock was achieved again at approximately 205 seconds. The curves in these figures were traced directly off the strip charts received from the Goddard-Mila station. The top two lines on these figures represent the onboard receiver signal strength and static phase error as telemetered back to the ground station. It can be seen from these two measurements that the uplink did not lose phase lock at retro-rocket ignition. However, both downlinks dropped lock, and the ground station operator failed to notice for approximately 11 seconds. When he began sweeping the exciter, downlink lock was reacquired almost immediately, but the signal strength was down by approximately 20 dB. Subsequent tests at Mila and in the laboratory at MSFC have shown that the downlink was probably locked onto a 72 kHz sideband which is created by the 72 kilo-bit PCM telemetry. It was believed at first that the system was locked onto a power supply spur. However, this has been ruled out because this spur was down 58 dB and the signal strength was down only 20 to 25 dB. The operator apparently noticed that the system was locked onto a sideband and shorted the loop. The system then acquired properly within three-fourths of a second.

Essentially, the same series of events occurred again following loss of downlink lock at second plane separation which occurred at 182 seconds. The operator failed to recognize loss of phase lock for approximately seven seconds this time. About the same time the operator began sweeping the exciter, the uplink lost lock. Reference to the exciter sweep #1 indication just prior to 190 seconds in Figure 27 shows that the rate of change of sweep was much sharper than that used at any other time. It is thought that this rapid rate of change may have over-stressed the loop, thus causing loss of uplink lock. In any event, reacquisition of the uplink took approximately one-half second. When the downlink reacquired, it was locked onto a sideband again. The differences between the acquisition receiver and the main receiver are unexplained in the time interval between 193 and 203 seconds.

There were several other instances where ground stations locked onto a sideband, which was 20 to 25 dB below the carrier. Since this 72 kHz sideband is the closest sideband at this power level, it is believed that all stations were locked onto it. In still other instances, some ground stations acquired the signal on their first sidelobe which is 1.7 degrees off the main beam and approximately

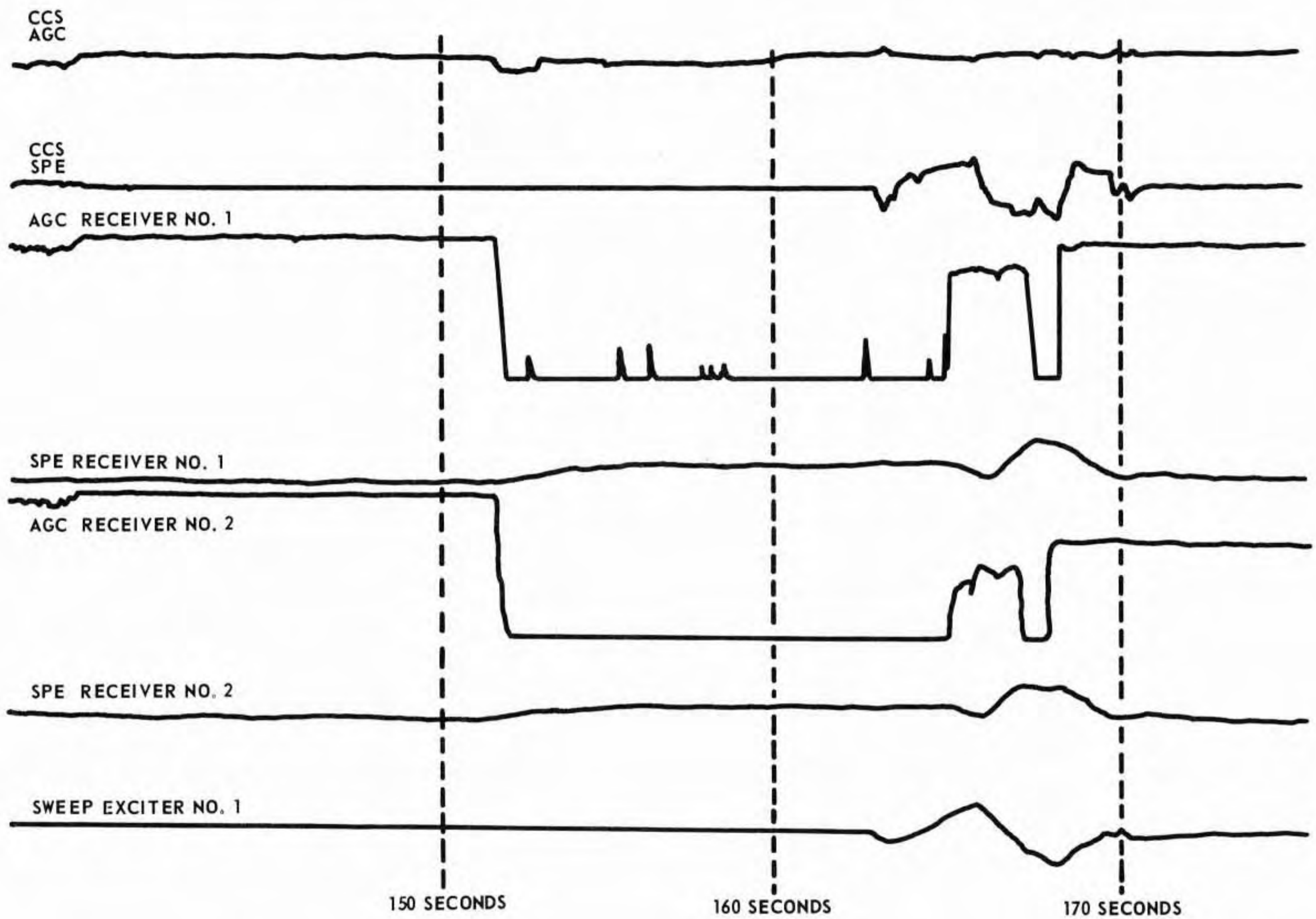


FIGURE 26. TRACE OF STRIP CHART FROM GODDARD-MILA (150, 160, 170 SECONDS)

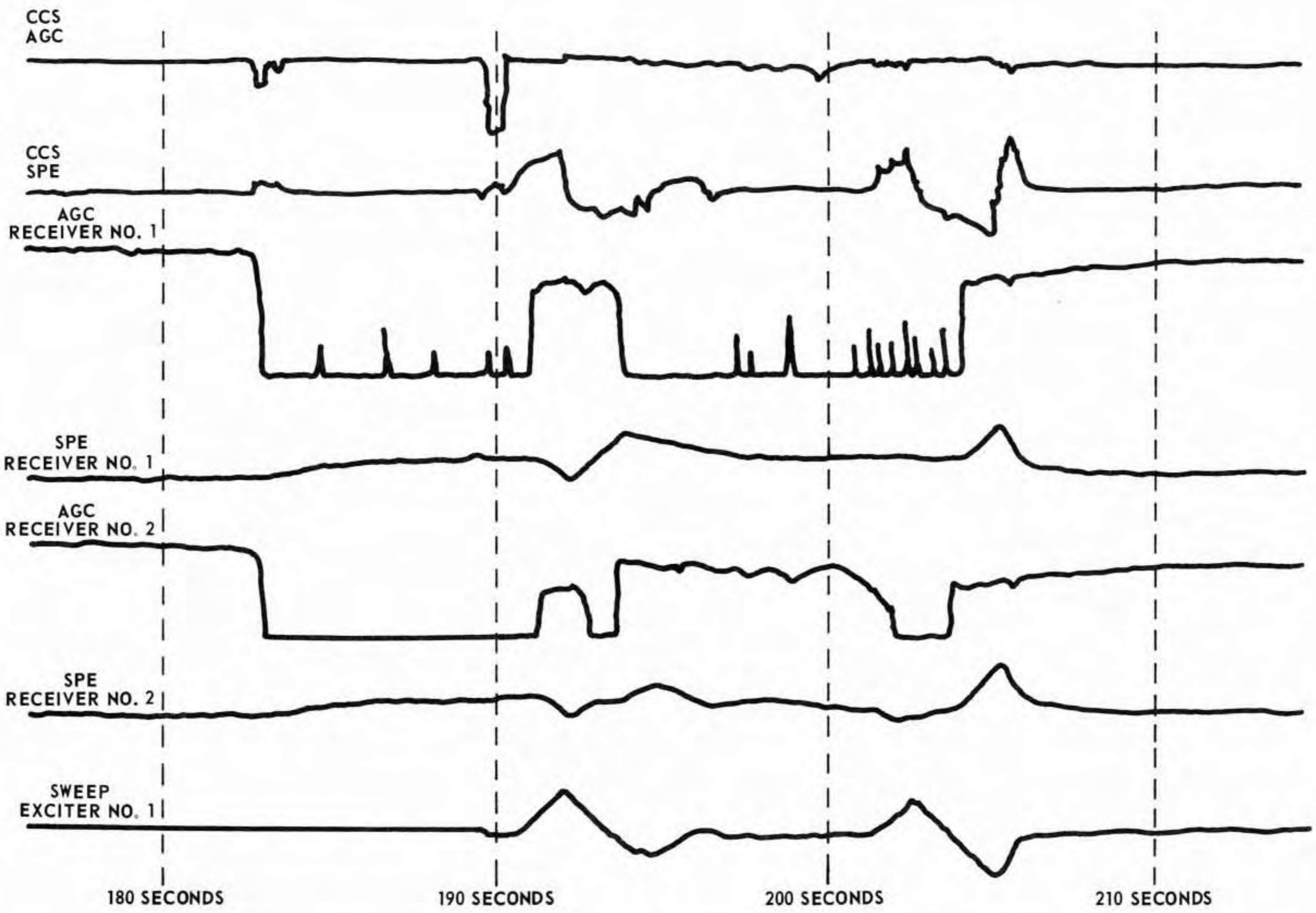


FIGURE 27. TRACE OF STRIP CHART FROM GODDARD-MILA (180, 190, 200, 210 SECONDS)

18 dB down. The large differences in predicted and measured signal strength in Figures 17, 18, and 23 are caused by these two problems. Several of the ground station operators identified these problems immediately and corrected them during the first few seconds. Still others, such as Texas on pass one and two and Mila on pass two, failed to recognize the problems.

It is believed that the ground station operators are now aware of both of these problems, and in the future they will correct them immediately. One way to eliminate the problem of locking onto a sideband is to have the exciter sweep the downlink frequency and reacquire automatically when the system loses phase lock. The problem of sidelobe and sideband lock can be reduced by giving the ground station operator a set of signal strength predictions for each pass, and he can certainly tell that something is wrong if his signal strength is down by 20 dB. MSFC publishes predictions prior to each mission and will make them available to ground station operators.

Many problems were expected with handover from one ground station to another. This was one of the most efficiently executed maneuvers of the mission and shows what the ground station operators can do when they are aware of a problem. The average out-of-lock time during handover on this mission was 3.5 seconds for the uplink and 5 seconds for the downlink. Any improvements in this area would probably require a change in procedure. The mission should be able to accept this loss of data.

EXHAUST PLUME

As expected, the S-IC stage exhaust caused attenuation, amplitude, and phase modulation of the CCS signal. The ability to accurately measure these effects at the Goddard-Mila site was hampered by a saturated signal level and the extremely low frequency response of the AGC circuit. Evidence of the effects was discernible on both the uplink and the downlink frequencies. The modulating effect was particularly noticeable on the range correlation channel from 118 seconds until 138.5 seconds. The effect on the range correlation channel began to diminish at approximately 133 seconds and would have ceased earlier had it not been for some unexplained anomaly which occurred at 136.5 seconds, causing effects to 138.5 seconds. This same burst completely wiped out the VHF telemetry on the S-IC stage and affected RF signals on other stages also. The signal strength was not affected by the exhaust plume from 138.5 seconds to separation at 152 seconds. The range correlation channel experienced only minor noise in this time period.

Other exhaust plume effects causing problems with receiving the CCS signal were S-IC/S-II separation and interstage jettison. Both of these events caused phase unlock.

No attempts were made to transmit PRN during the early launch phase, but the 498 kHz clock was on. It had been expected that the tracking errors would increase rapidly in this time interval because large errors were experienced on the USB system flown on AS-202. Because of the problems outlined previously, the analysis is incomplete. An attempt will be made to analyze the effects on the exhaust on tracking for future missions.

It is too early to reach conclusions about the effects of flame on the CCS; however, the effects on the performance of AS-501 were less than expected prior to the flight. The modulating effects always affect phase sensitive systems in an adverse manner, and it had been questioned whether the system could maintain phase lock throughout the various periods of exhaust interference. The system survived the effects of S-IC exhaust, but lost lock at S-IC/S-II and second plane separation. There were no significant effects at S-II/S-IVB staging. Although some variance can be expected on future missions, there is no reason to believe the effects will be significantly different.

TRANSPONDER EVALUATION

The fact that almost all the data were received speaks for the operation of the transponder. In addition to the data transmitted and received by the system, eight onboard measurements were telemetered back to the ground station which monitored the transponder performance. They are shown in Table VIII.

The table also shows the nominal range of values expected for measurements J79 through J82, and the average value measured from samples taken at several of the ground stations. The other measurements have been discussed in other sections of the report. None of the measurements exceeded the nominal limits at any time during the mission.

TABLE VIII. ONBOARD CCS MEASUREMENTS

Onboard Measurement	Assignment Number	Nominal Range	Average Value
Static Phase Error	J75-603	-150 to 150 kHz	--
AGC	J76-603	-70 to -126 dBm	--
Carrier in Lock Indication	J77-603	ON or OFF	ON
70 kHz Subcarrier in Lock Indication	J78-603	ON or OFF	ON
Amplifier Regulator Output	J79-603	19 to 21 V	19.8 V
Amplifier Anode-Helix Voltage	J80-603	ON or OFF	ON
Amplifier Cathode Current	J81-603	40 to 60 mA	51.9 mA
Amplifier Helix Current	J82-603	0 to 10 mA	5.62 mA

DATA PROBLEMS

To assure a more meaningful analysis on future Apollo/Saturn mission communications systems, it is recommended that the quality of data be improved, especially the strip charts and magnetic tapes. The AS-501 strip charts were of such poor quality that it was almost impossible to evaluate the data. The magnetic tapes were noisy in many instances and were not calibrated. This was especially true of the DSS-72 magnetic tapes that contained the CCS data.

The more detailed testing plan has been submitted to MSFC mission operations for the AS-502 testing of the CCS. The plan submitted should add valuable data to the stockpile accumulated on the AS-501 flight. If the strip chart and magnetic tapes are improved, then a more detailed analysis of the CCS should be forthcoming from the AS-502 mission.

CONCLUSIONS AND RECOMMENDATIONS

The AS-501 CCS system performance, including both onboard and ground stations, was satisfactory. The compatibility of the vehicle to ground interface was demonstrated. In addition, the ability to predict the system performance with a reasonable degree of confidence has been successfully demonstrated.

Some operational problems have been identified, but it is believed that these problems will be reduced now that the ground station operators are aware of them. Several data problems were encountered, including data reduction problems. These problems should not recur because everyone is now aware of their existence and their cause.

One way to reduce data loss at any time following a dropout is to cause the exciter sweep to track the downlink frequency and to automatically reacquire any time there is a loss of phase lock. This is particularly important at the Goddard-Mila site where dropouts are most likely to occur.

All MSFN stations should check their 1 and 2 kHz command waveforms to eliminate distortion. In addition, it is recommended that the verification receivers and the recording equipment be checked to see if they are introducing distortion.

A study should be performed to determine a better operational method for sending commands. It appears at present that the operator issuing commands from the Mission Control Center (MCC-H) does not have sufficient information to know if the system is ready to accept commands. At a minimum, he should have a display before him listing the following information:

1. The station presently locked to the uplink.

2. Status of uplink subcarrier indication.

3. Station and system (VHF, S-band, or CCS) decommutation of AVP's and CRP's.

4. Average signal level on the uplink and downlink.

5. Predicted signal level on the uplink and downlink.

6. Elevation angle to station sending command and decomming AVP's and CRP's.

7. Times of anticipated handover and other operational mode changes.

If the operator does not have this information, many errors can be expected on future missions. Perhaps a better method for updating the system would be to place the commands in a buffer at the ground station and let the ground station operator determine the optimum time to transmit them.

A survey of data users should be made to determine if they find the tape quality acceptable. If not, a better quality tape should be purchased for future missions.

The MSFC data reduction facility should implement an automatic system for correcting phase reversals following dropouts.

Handover time is critical during the launch phase because of low aspect angles to the vehicle. Analysis shows that handover should not be attempted at elevation angles less than 5 degrees unless the vehicle to ground station look angle is less than 5 degrees. In this case, handover at elevation angles of 3 degrees would be recommended if the station accepting handover has been receiving a steady signal for at least 20 to 30 seconds.

Additional effort must be placed on establishing confidence levels for preflight predictions and for establishing command and telemetry bit-error-rates and tracking accuracies as a function of signal level. Additional studies are being implemented which will add to the knowledge in this area. This information can be used to improve the attitude constraints curves and could result in fewer constraints on the lunar missions.

REFERENCES

Performance Evaluation of the Unified S-Band Ground System for AS-501, Goddard Space Flight Center, X-834684, January 1968.

TMX-53737

APPROVAL

FLIGHT EVALUATION OF THE COMMAND AND COMMUNICATION SYSTEM ONBOARD AS-501

By Olen P. Ely and Joseph H. Kerr

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

THOMAS A. BARR
Chief, RF Systems Branch

For J. T. POWELL
Chief, Instrumentation and
Communication Division

W. HAEUSSERMANN
Director, Astrionics Laboratory

DISTRIBUTION

INTERNAL

I-MO
Dr. Speer

I-MO-R
Mr. Golden

R-AERO-R
Mr. Lindberg

R-COMP-R
Mr. Houston

R-ASTR-DIR
Dr. Haeussermann/Ref. File
Miss Flowers

R-ASTR-I
Mr. Powell

R-ASTR-IE
Mr. Cox
Mr. Escue

R-ASTR-IT
Mr. Threlkeld

R-ASTR-IR
Mr. Barr (50)

CC-P

I-RM-M

MS-T (6)

MS-H

MS-IL (8)

MS-IP (2)

EXTERNAL

NASA Headquarters
National Aeronautics and Space Administration
Washington, D. C. 20546
Mr. McClannahan, MOR
Mr. Hibbert, MSF/MLS
Mr. Raleigh, MSF/MLS

NASA
Goddard Space Flight Center
Greenbelt, Maryland 20071
Mr. Varson, MFSO
Mr. Owen, MFOD
Mr. Slaughnessy, 834
Mr. Newman, 834
Mr. Shelton, 834
Mr. Dalton, 553
Mr. Dowling, MILA-USB

NASA
John F. Kennedy Space Center
Kennedy Space Center, Florida 32899
Mr. Hershey, IN-TEL
Mr. Byrne, IN-TEL-3
Mr. Edwards, LV-INS
Mr. McMath, LV-INS-1
Mr. Collins, IN-QAL

DISTRIBUTION (Concluded)

EXTERNAL (Continued)

NASA
Manned Spacecraft Center
Houston, Texas 77058
Mr. Kyle, ED
Mr. Travis, EB-3
Mr. Moorehead, EB-2
Mr. Dauphin, EB-3
Mr. Lenett, EE-3

Scientific and Technical
Information Facility (2)
P. O. Box 33
College Park, Maryland, 20740
Attn: NASA Representative (S-AK/RKT)

Mr. E. A. Hoffman-Heyden
RCA, Pulse Radar Group
Tech Lab
Patrick AFC, Florida 32925

Dr. H. A. Peohler
PAA Tech Staff
Tech Lab
Patrick AFB, Florida 32925

Mr. John Stovall
Bldg. 1, Dept. 215
IBM
150 Sparkman Drive
Huntsville, Alabama 35805