RESULTS OF THE UHF TELEMETRY SYSTEM R&D FLIGHT TESTS AT WHITE SANDS MISSILE RANGE

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Summary This paper describes results of UHF telemetry R&D tests conducted at White Sands Missile Range (WSMR), New Mexico. UHF telemetry problems, such as multipath and target scintillation, are discussed. Several recommendations which may improve the reliability of telemetry data transmission at UHF frequencies are made based on experience and data gained from many UHF telemetry tracking operations.

Introduction WSMR developed four tracking and receiving systems for use in investigating UHF telemetry operational problems. Performance and physical characteristics of the four systems, designated SCR-584, T9A, T9B, and TELTRAC, are shown in Table I. These systems were used to gather UHF telemetry data during twenty-nine aircraft and missile flight tests conducted under the WSMR program. In addition, the tracking systems were used to gather UHF data on six ATHENA reentry flights. Two of the ATHENA payloads were-tracked through reentry velocities of about 20,000 feet per second. Plasma effects caused 35 dB signal attenuation. The other four payloads did not reach reentry velocities.

UHF Telemetry Aircraft Flight Tests The primary purpose of the F-100 and L-20 aircraft tests was to investigate near-horizon UHF tracking phenomena. The F-100 was used for high altitude long range tests, whereas the L-20 was used for low altitude short range tests. The L-20 aircraft was also used to determine the dynamic tracking capabilities of the telemetry tracking systems.

A typical F-100 telemetry package contained a VHF, an L-band and two Sband telemetry transmitters. The same signal modulated each transmitter. The power output of each transmitter was about two watts. Slot antennas manufactured by Dorne & Margolin, Inc.[1], were used on the F-100. The VHF antenna gain was minus 3 dB and the L- and S-band antennas had a gain of O dB in the aft direction.

During a test conducted on 17 April 1968, an F-100 aircraft was flown at an altitude of 37,000 feet MSL out to a distance of 250 miles from the UHF telemetry trackers. The SCR-584 received the L-band signal; the T9A received the two S-band signals, and an helix antenna with 13 dB gain received the VHF signal. All telemetry receivers used a 500 kHz second IF bandwidth.

During the aircraft outbound run, the SCR-584 was operated in the auto track mode and the T9A was operated in the slave mode (radar chain). Useable telemetry data was received at distances of 175, 190, and 195 miles from the VHF, S-band, and L-band links, respectively. Selected video and AGC outputs are shown in Figures 1A and 1B. The T9A momentarily lost track at 188 miles when the radar chain input was transferred from down-range radars to up-range radars. The SCR-584 lost track at 195 miles when the antenna went into its lower limit stop due to multipath. The system was switched to the slave mode to reacquire the aircraft and continued to track to 208 miles although the signal was below FM data threshold. Similar tests at lower altitudes with L-20 aircraft have yielded comparable results. Telemetry data has been received out to the distance of radio line of sight for both L-20 and F-100 aircraft tests.

Missile Tests Five POGO and one AEROBEE missile flights have carried UHF telemetry at WSMR. Three of the POGO tests will not be covered since they were reported upon previously[2].

The POGO has a maximum acceleration of 21 g, maximum velocity of 3,400 feet per second, a spin rate of 2 rps, and reaches an altitude of 100,000 feet.

The fourth and fifth POGO tests were conducted on 23 August 1967. All available systems tracked the missile and received FM data from lift off to impact. Both POGO trajectories were abnormal. The recovery parachute failed to deploy on the fourth missile and it followed a ballistic trajectory to impact. The fifth missile broke up in flight; however, the UHF receiving systems tracked the telemetry section to impact. The data received via the VHF and UHF links were comparable except for a number of UHF dropouts which are attributed to the missile antenna pattern.

The AEROBEE experiment was conducted in cooperation with the Air Force Cambridge Research Laboratory on 13 December 1967. The AEROBEE has a maximum acceleration of 12 g, maximum velocity of 5,200 feet per second, a spin rate of 2 rps, and reaches an altitude of 102 miles. The missile was instrumented with an FM/FM telemetry package with identical data transmitted over both VHF and UHF links. The UHF transmitter was a Conic UHF CTM-3 with a nominal power output of 3.5 watts. The UHF antenna system was a two element quadraloop array designed by New Mexico State University.

The SCR-584, T9A, and TELTRAC UHF tracking systems were located 7.3 miles from the AEROBEE launcher with optical line of sight between trackers and launcher. The TELTRAC and SCR-584 lost track at lift off. Both antennas descended into their lower limit stops as the missile ascended. They were immediately switched to the slave mode (radar chain) and reacquired the target. The T9A auto tracked from lift off to impact without difficulty. The TELTRAC also lost track midway through the flight when the servo bandwidth was being switched in an attempt to obtain smoother tracking. A comparison of the VHF and UHF signal level and a sample of FM data from each system is shown in Figure 2.

Similar operational problems have been encountered at missile lift off during the POGO and AEROBEE tests. However, the VHF and UHF telemetry data from these flight tests were comparable.

ATHENA Flight Tests The ATHENA project has conducted six S-band telemetry experiments at WSMR since February 1967. The ATHENA is a four-stage reentry vehicle launched from Green River, Utah, to impact at WSMR--a distance of about 430 miles. The vehicles can attain an altitude of 700,000 feet and reach a reentry velocity of 20,000 feet per second with axial acceleration of 23 g. The maximum vehicle spin rate was 5 revolutions per second. The payload carried FM/FM telemetry which consisted of 18 IRIG proportional bandwidth subcarriers, with channel H the highest subcarrier. Data was transmitted through two separate Conic UHF CTM-3 transmitters operating at 2281.5 MHz and 2288.5 MHz with the latter link delayed seven seconds to insure complete telemetry coverage during reentry blackout. The missile antennas were two diametrically opposed recessed stub antennas. The average radiation pattern was zero dB to minus 6 dB relative to an isotropic antenna. The maximum antenna gain was 6 dB and the nulls exceeded minus 18 dB.

The four WSMR telemetry tracking systems were located about 30 miles southwest of the ATHENA payload impact area. Radar chain data was available for target acquisition but was not required. Initial acquisition was attained by pointing the antennas at the horizon to the predicted missile azimuth position. No problem was encountered in frequency acquisition when the receiver second IF bandwidth was set at 1.5 MHz. The VFO was used at the first local oscillator (LO) and crystal reference was used at the second LO. The AGC time constant of the T9B receiver operating at 2281.5 MHz was 4 milliseconds and all other receiver AGC time constants were 260 milliseconds.

A successful ATHENA reentry mission was conducted on 16 November 1967[3]. All systems acquired signal at T+90 seconds, (Figure 3) about 400 NM from the receiving site to the missile, and automatically tracked the payload through reentry to impact. The telemetry signal gradually increased and useable telemetry data was received at T+120 seconds when the missile was at a slant range of 370 NM. During reentry, the telemetry signal strength decreased gradually at the average rate of about 4.5 dB per second for 8 seconds and remained at the maximum attenuation level of about 35 dB for an additional 2 seconds. Nominal RF transmission resumed 8 seconds after the most severe plasma attenuation. Erratic tracking occurred during reentry; however, all four tracking systems tracked the payload in the automatic mode through reentry to impact.

Significant Problems in the UHF Telemetry System Although the UHF telemetry system flight tests at WSMR have not been completed, the aircraft, missile and reentry vehicle tests have demonstrated typical operational problems one expects to encounter under similar environments. Efficient UHF transmitters and airborne antennas must be designed and mass produced to meet the design constraints and data requirements. Ground tracking systems must be reliable under various target dynamics. The complete UHF telemetry system must be integrated to meet unique missile project requirements under the most severe propagation phenomena.

Missileborne UHF Transmitters WSMR received 14 UHF transmitters from 1959 to 1967 under six development or fixed price contracts. During the past year, WSMR has received 10 additional UHF transmitters from four different manufacturers. Only four of these 10 transmitters have been accepted, and one of these had to be reworked by the manufacturer before acceptance. Several other units have been rejected two or more times. The most common problems were failure to meet vibration, altitude, and temperature requirements. It should be emphasized that these transmitters have been rigorously tested at WSMR to insure satisfactory operation during flight tests. Consequently, these transmitters,have been used on three missile and numerous aircraft tests at WSMR within the past year without a single failure. Also, WSMR has participated on five ATHENA reentry tests without a single UHF transmitter failure. One L-band transmitter has been certified in accordance with the stringent requirements of IRIG 106-66. These results indicate that reliable UHF transmitters can be developed to meet existing requirements. However, mass production of UHF transmitters remains a rather critical problem.

Missileborne UHF Antennas Perhaps the most apparent difference between VHF and UHF subsystems is in the airborne antenna radiation patterns. Present VHF antennas offer satisfactory coverage for most missiles. However, typical UHF airborne antennas have numerous nulls and lobes.

An antenna array of two to four elements has been used on POGO missiles, A quadraloop array was initially used in 1964. Since then, folded valentines and cavity-backed slots have been used. The most recent antenna procurement was for a four element blade array. No outstanding improvement has been noted in these antenna systems. However, recent manufacturer’s data sheets do indicate a significant improvement in airborne antenna Patterns. Data from one system shows excellent coverage except within a few degrees of the missile thrust-axis[4]. Another system offers approximately hemispherical coverage but may require a major structural modification to the missile [5].

UHF Telemetry Automatic Tracking Systems Results of the aircraft and missile tests have demonstrated that automatic tracking of near-the-horizon targets and automatic tracking of missiles during lift off are critical UHF telemetry tracking problems. An experiment was conducted to simulate multipath and to further investigate its effect on conical scan telemetry tracking systems[6]. During this test, a direct wave and a reflected wave were approximated by two coherent radiation sources. Both sources were radiated simultaneously and the tracking antenna position was recorded. The tracking antenna traced out a path around either source as the relative phase and amplitude of the two signals were varied. These results verified an analytical study which suggested that the antenna could “lock on” either above the target, below the target’s image or anywhere in between.

No direct solution to the multipath tracking problem has been found. Tracking radars have used a diffraction fence around the tracker to provide a shield to the multipath propagation and an inhibiting device which prevents antenna downward motion during the initial launch phase as a means of alleviating the effects. Optical or radar slave tracking aides have also been employed. However, optics may not always be practical because of optical line of sight requirements. Monopulse tracking systems should offer some improvement in this area.

The effects of signal scintillation due to missile rotation and UHF antenna pattern upon conical scan tracking systems were investigated. A test was designed to simulate a spinning missile in flight. For this test a signal was radiated from a POGO missile spinning at rates up to 1,500 rpm and the tracking antenna performance was recorded. The tracking antenna$ lost track at the missile spinning rates of 180 and 900 rpm (3 and 15 Hz). Examination of the tracking error signal at these spinning rates revealed a 30 Hz signal (the tracker conical scanning rate). It should be noted that the results obtained here are unique to the POGO missile and its UHF antenna pattern. However, the results can generally be applied to other systems when the missile spinning rates, airborne antenna patterns, and the tracking system scanning rates are known. The POGO missile simulated test indicated a conical scanning tracking problem can exist. However, for this to occur, the signal scintillation must be of prescribed frequency, magnitude, and duration to override the true target error signal, In fact, WSMR has not experienced this problem during the R&D flight test program.

During reentry tests there is always the possibility of losing track because of plasma blackout, This is especially critical since the time available for reacquisition between reentry and impact is brief. Tracking aides, such as radar chain data and optical slave data, may increase tracking reliability.

Unique Project Support Occasionally, missile projects, such as SPRINT at WSMR, require special instrumentation to satisfy data requirements. The SPRINT is a high performance missile launched from an underground cell. The combination of low signal level due to the cell shielding, large signal variations due to refraction and multipath, and the high missile dynamics create an extremely difficult problem for reliable telemetry data reception. An optical slave tracking system, (developed by the SPRINT system contractor, Bell Telephone Laboratories) was modified to increase the probability of data reception. The system consists of a HERCULES radar pedestal slaved to a SPRINT tracking radar, a four foot S-band antenna and associated RF receiving equipment. The antenna gain is 26 dB and the gain of the TWT preamplifier is 30 dB. The receiving system with a 5.1 dB noise figure is located 5 miles from the SPRINT Launch Site. The system has operated satisfactorily during a SPRINT flight test.

Conclusion The UHF telemetry R&D flight tests have demonstrated that UHF telemetry data can be obtained with a reasonably high degree of reliability. Data obtained from UHF transmission was generally comparable to that obtained from VHF. The 35 dB plasma attenuation encountered during the ATHENA reentry was generally in agreement with the calculated value. The problem of tracking during missile lift off and at low aspect angles can be partially alleviated with optical or radar slave tracking aides. Monopulse tracking systems and polarization and frequency diversity reception may offer additional improvements.

A comprehensive UHF telemetry system training program for range operational personnel is imperative. Finally, close coordination between the range users and the missile engineer will be required to insure reliable UHF telemetry data reception,

Recommendations The numerous VHF to UHF telemetry conversion problems can e minimized through proper system integration and close coordination between the range users and the range operators.

When the data requirements are known in advance, it is preferable to design the airborne antenna system as an integral part of the missile airframe. The remainder of the telemetry system design can be based on commercially available equipment, data requirements, and the telemetry receiving systems available at the test range.

Preliminary data furnished the ranges by range users should include detailed missile dynamic data, such as predicted trajectory, velocity, acceleration and spin rate. At that time, range users should gather information on the location and the number of available receiving systems and detailed system characteristics, such as antenna gain, system noise figure, dynamic range, AGC characteristics, data receiver bandwidth, acquisition or slave modes, tracking schemes (simultaneous or sequential lobing), antenna tracking velocities and accelerations, and servo types and bandwidths.

Once the launch site and other telemetry system parameters have been determined, a computer program should be formulated to compute the relative tracking velocity, acceleration, position, missile aspect angle, and maximum and minimum strength (due to missileborne antenna pattern and missile spinning) as a function of time.

Rearrangement of the ground tracking systems may be necessary to insure reliable telemetry data reception. Mobile tracking systems may be used to supplement the fixed telemetry tracking station for complete coverage. Finally, detailed system performance, such as missile antenna pattern, transmitter power, frequency stability, deviation characteristics, receiver sensitivity, receiver bandwidth, data recording and processing techniques, etc., should be disseminated to cognizant personnel.

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TABLE I
TELEMETRY AUTOMATIC TRACKING ANTENNA CHARACTERISTICS*

Antenna	SCR-584	T9A and T9B	TELTRAC
Date	1962	1964	1966
Frequency Range	1435 to 1535 MHz 2200 to 2300 MHz	2200 to 2300 MHz	1435 to 1535 MHz 2200 to 2300 MHz
System Noise Figure	7.5 dB	7 dB	6 dB
Antenna Size	10 foot parabolic	6 foot parabolic	6 foot parabolic
Antenna Beamwidth	3.3°	4.5°	4.5°
Reflector Gain	33 dB	28 dB	28 dB
Polarization	Right or left hand circular	Right hand circular	Right hand circular
Cross-Over Level	1 dB	1 dB	1 dB
Side Lobe Level	-17 dB	-24 dB	-20 dB
Scan Rate	30 Hz	30 Hz	30 Hz
Preselector Filter	Melab Mod. F-114	Rantec RS 205	Telonic Engineering TTF2250-5-5-EE
Loss	0.5 dB	0.5 dB	0.5 dB
Preamplifiers	Watkins-Johnson TWT WJ-269	International Micro. Corp. ACR-2250-15	Aertech Tunnel Diode, Amplifier Model T5411
Gain	30 dB	20 dB	20 dB
Noise Figure	5.5 dB	4.5 dB	4 dB
Post Amplifier Filters	None	None	Telonic Engineering TTR-2250-5-5EE
Loss	None	None	0.5 dB
Receiver	Defense Electronics TR-711, Direct Reception	Defense Electronics TR-711, Direct Reception at 2200 to 2300 MHz	Defense Electronics TR-711, Direct Reception or Mixer Down-Conversion
Servo System	SCR-584 Radar, Vacuum Tube	T9 Radar, Vacuum Tube	Mostly solid-state
Tracking Velocities AZ	77°/sec	150°/sec	80°/sec
EL	30°/sec	70°/sec	40°/sec
Tracking Mode	Manual Slave Automatic	Manual Slave Automatic	Manual Slave Automatic

*With reference to S-band.

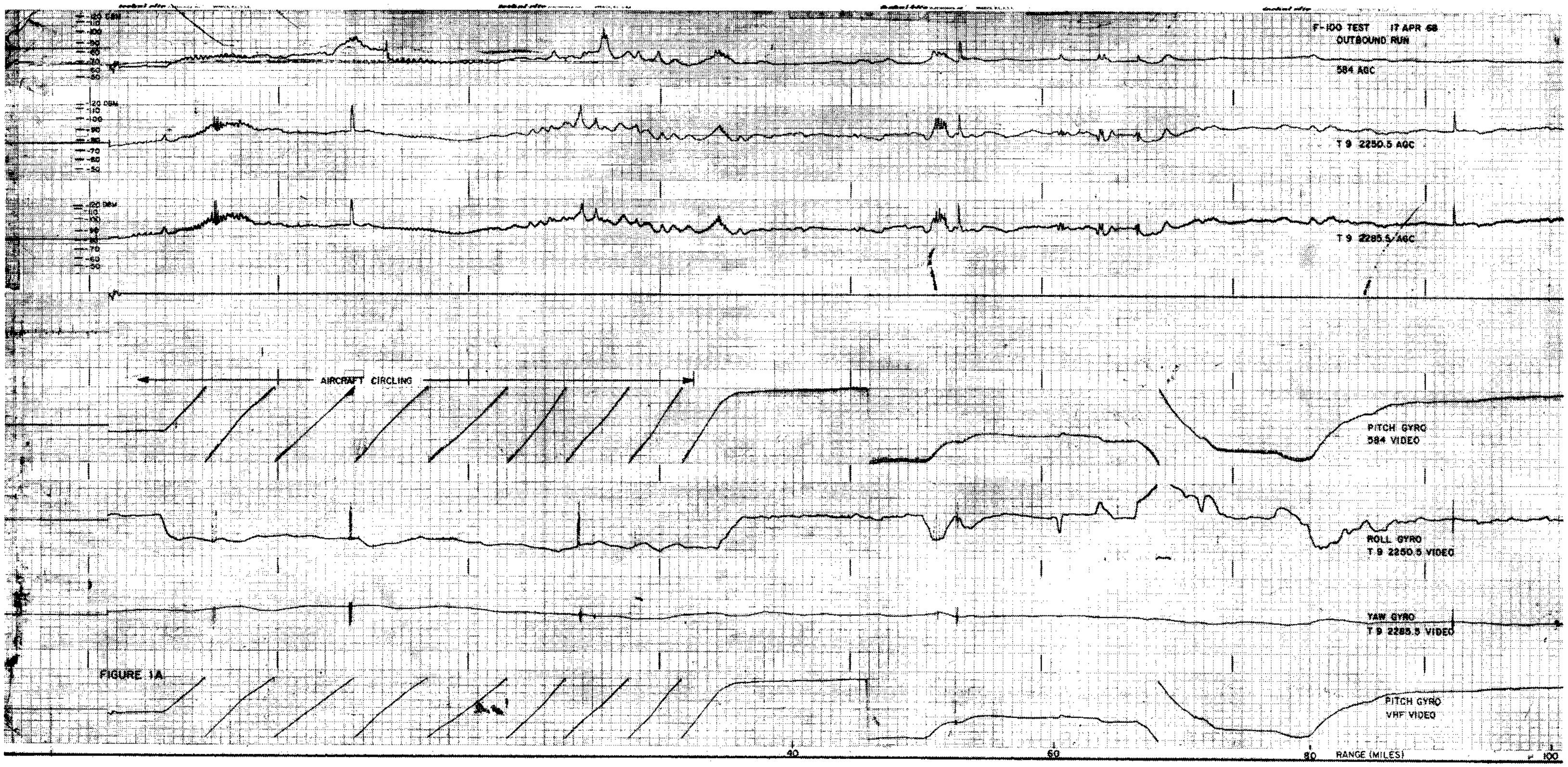

FIGURE IA. F-100 TEST 17 APR 68 OUTBOUND RUN

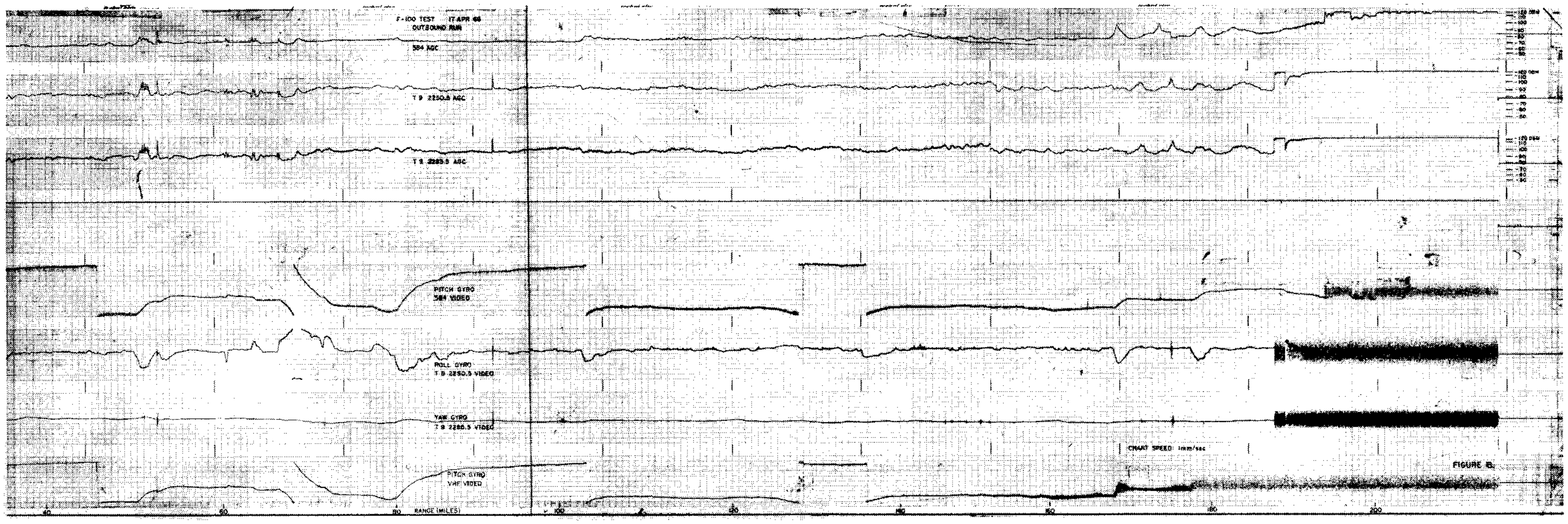

FIGURE 1B. F-100 TEST 17 APR 68 OUTBOUND RUN

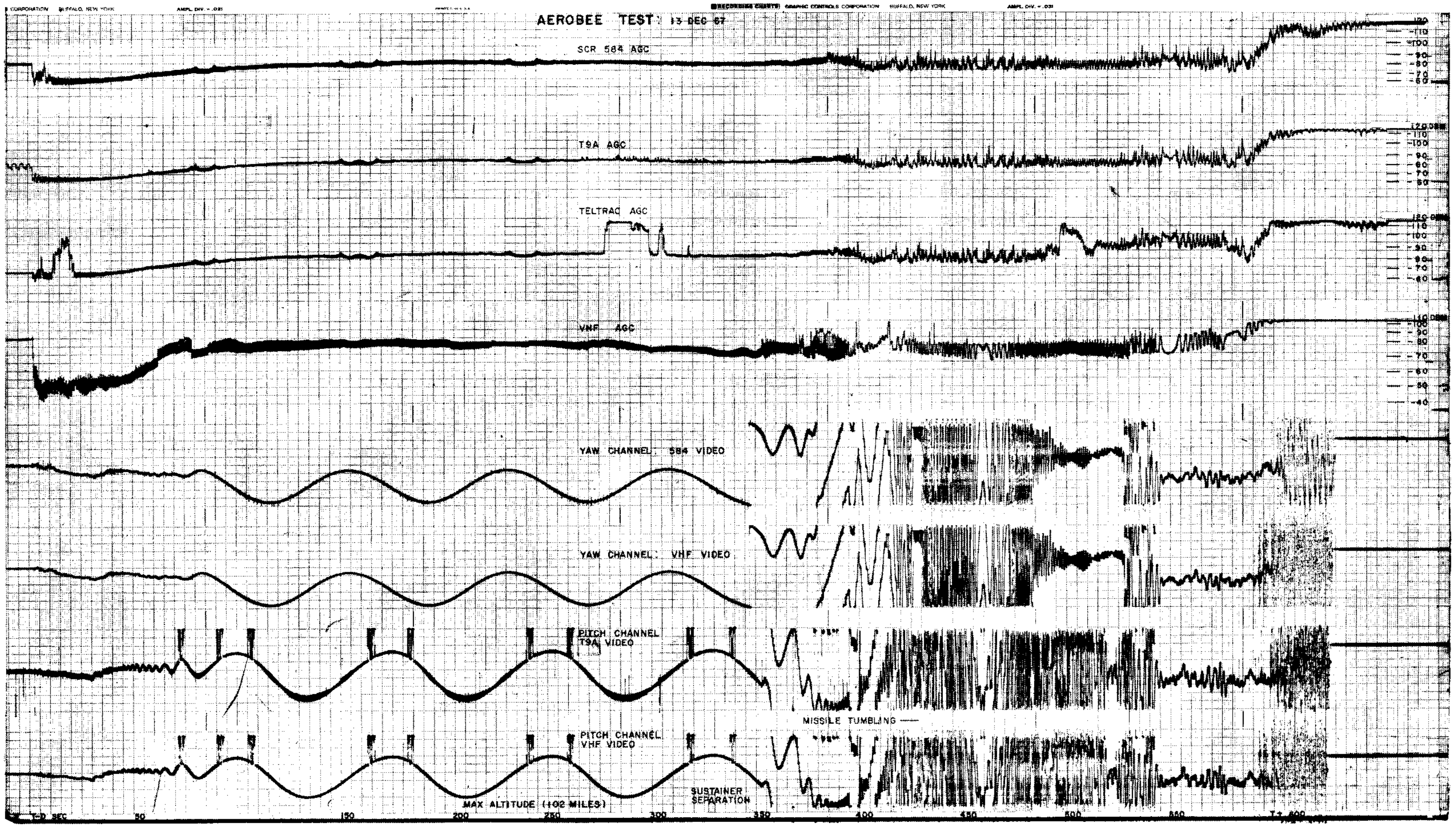

FIGURE 2. AEROBEE TEST: 13 DEC. 67