ROCKET MOTOR PLUME EFFECTS ON TM SIGNALS - MODEL CORROBORATION

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ABSTRACT

This paper presents the interim results of an effort to corroborate analytic model predictions of the effects of rocket motor plume on telemetry signal RF propagation. When space is available, telemetry receiving stations are purposely positioned to be outside the region of a rocket motor's plume interaction with the RF path; therefore, little historical data has been available to corroborate model predictions for specific rocket motor types and altitudes. RF signal strength data was collected during the flight of HERA target missile by White Sands Missile Range (WSMR) using a transportable telemetry receiving site specifically positioned to be within the rocket plume region of influence at intermediate altitudes. The collected data was analyzed and compared to an RF plume attenuation model developed for pre-mission predictions. This work was directed by the US Army Kwajalein Atoll (USAKA)/ Kwajalein Missile Range (KMR) Safety Division.

KEY WORDS

Telemetry, RF Propagation, RF Plume Attenuation, Link Margin Analysis
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INTRODUCTION

This paper presents the interim results of an effort to corroborate analytic and empirical model predictions of the effects of rocket motor plume on telemetry signal RF propagation. RF link margin analysis is extremely important for premission planning and site positioning of critical range safety telemetry and other safety related RF based support instrumentation. This is especially true for the support position selection of mobile sensors in support of hazardous operations where physical space or instrumentation resources are limited and the potential of rocket motor plume attenuation may degrade range safety sensors at specified locations. A detailed understanding of the effects of the missile exhaust plume on RF propagation is important in order to determine the minimum offset locations for such sensors. Current models tend to be overly conservative in the assessment of attenuation and tend to overly restrict operational siting selection.

When space is available, telemetry receiving stations are purposely positioned to be outside the region of a rocket motor's plume interaction with the RF path; therefore, little historical data has been available to corroborate RF attenuation model predictions especially against specific rocket motor types and intermediate altitudes. With the support of the White Sands Missile Range (WSMR), RF signal strength data was collected during the flight of a HERA target missile using a transportable telemetry receiving site specifically positioned to be within the rocket plume region of influence at intermediate altitudes. The collected data was analyzed and compared to an RF plume attenuation model developed for pre-mission predictions. The HERA data, in conjunction with other sources of UHF and S-Band data associated with Aries and Castor rocket motors, has been used to corroborate and fine tune current models.

PHYSICAL CONSIDERATIONS

Several sources were reviewed which have developed theoretical plume attenuation studies and several which have developed empirical data comparisons. A consistent thread through the analytical studies indicates that the predicted attenuation experienced by a direct path from the source to the receiving antenna through free electrons of the plume and the combustion products including aluminum is much greater than that actually experienced in practice. Where the direct propagation path predicts attenuation in the 60 to 100 dB region, experimental data shows maximum attenuation in the 30 to 60 dB region.

For this reason, it is believed that the RF signal reaching the missile or ground station is not in the direct RF path but that predominantly due to diffraction around the plume. Even when the plume is not directly in the RF path, RF losses may be incurred due to Fresnel interference of a reflected signal from the plume interfering constructively or destructively with the direct path. The resultant signal loss is a combination of diffraction and/or Fresnel interference. This effect has been modeled by treating the plume as an opaque strip with associated Fresnel diffraction and interference properties. It is noted that the opaque strip is affected by altitude. Whereas the extent of the plume may be 1 to 1.5 times the exit nozzle at low altitudes, this may expand to 5 to 6 times the exit nozzle diameter at high altitudes.

The aspect angle is defined as the angle from the missile center line axis to the direct line of sight of the RF propagation path. The aspect angle is generally determined from a missile reference point or the center of mass and it may be important to adjust the aspect angle definition due to the length and diameter effects of the missile, as shown in Figure 2, if the length, diameter and antenna positions of the configuration are significant. Missile configurations with high length to diameter ratios tend to be less effected by the need for the use of the adjusted aspect angles.

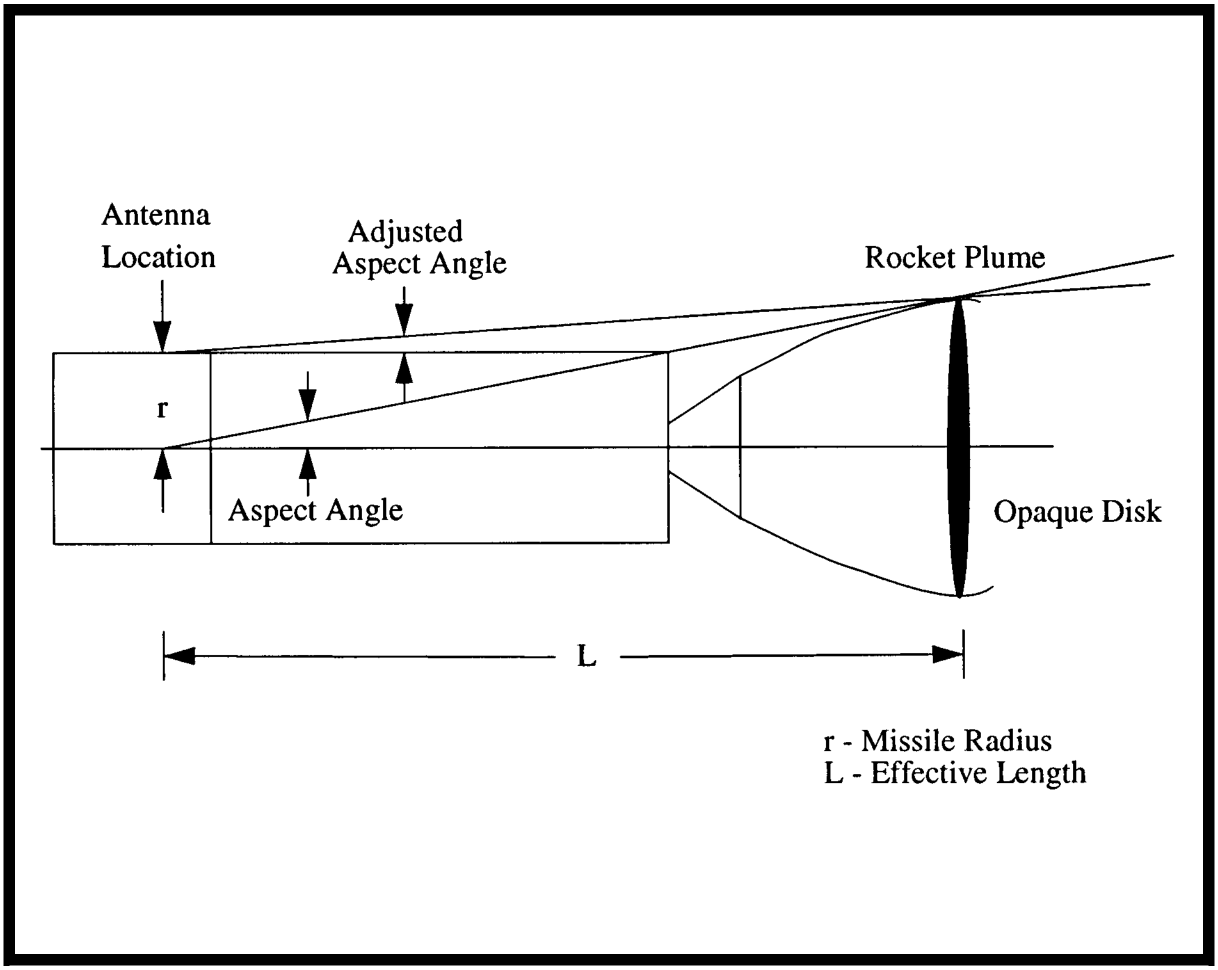


Figure 1- Geometric Configuration

DATA COLLECTION

Telemetry data was collected at WSMR during the 24 April 95 HERA Launch from LC-32 using one of the WSMR Transportable Telemetry Acquisition System (TTAS) for purposes of plume effects analysis. The van was located 2.15 miles to the rear of the launcher site simulating telemetry reception at land limited facilities. The telemetry reception site parameters are given in Table 1. Two telemetry channels were recorded during the mission, RF1 and RF2. Channel RF1 contained the safety related critical telemetry parameters.

The HERA flight configuration consists of a 5 watt transmitter coupled to dual antennas through a hybrid combiner.

Table 1. Telemetry Site Characteristics

RF Reception	Antenna	8' Parabolic Reflector
	Gain	31 dB
	System Temperature (T_s)	400°K
Channel Parameters	RF-1 Frequency	2210.5 MHz
	Modulation	PCM/FM
	IF Bandwidth	1500khz
	RF-2 Frequency	2250.5 MHz
	Modulation	PCM/FM
	IF Bandwidth	2400 kHz
Location*	Latitude	32 22.2244' N (32.37047)
	Longitude	106 24.3820' W (-106.406367)
	Altitude	4009 ft
(*From GPS Receiver)	Distance from LC-32	2.15 miles

The TTAS uses a radscan feed antenna (vertical and horizontal dipoles) with a gain of 31 dB and noise figure of 1.4 dB based on a noise temperature of 400°K. The dynamic pointing error of this antenna is approximately 0.5 and the 3 dB beamwidth is 4°. The antenna feeds a preamplifier which has a gain of 30 dB which in turn provides signals to a 90° hybrid multi-coupler which sums the horizontal and vertical linear polarized signals into an effective left and right hand circularly polarized signal. Between the preamp and the hybrid multi-coupler is approximately 30 feet of RG214 cable with an associated loss of 8 dB. The multi-coupler has a gain of 4 dB and a noise figure of 4 dB. The multi-coupler feeds into the receiver through a cable with 1 dB of loss. The system sensitivity is -115 dBm.

The TTAS telemetry data was provided in the form of analog strip charts with the recorded RHCP and LHCP received signal levels (RSL) for both RF1 and RF2. These signals are shown in Figure 2. These charts were digitized and converted from telemetry units to engineering units for analysis using pre- and post-mission calibrations indicated on the individual strip charts. Since calibration levels changed over the recording interval, a average of the pre- and post-mission calibration levels were used for the analysis.

The maximum difference in the calibration levels were noted as:

RF1 - RHCP	4.7 dB
RF1 - LHCP	2.1 dB
RF2 - RHCP	3.9 dB
RF2 - LHCP	4.8 dB

A composite of the converted data is shown in Figure 3.

DATA ANALYSIS

An RF link margin analysis was conducted using the RFLINK program based on the above telemetry transmitter and receiver parameters. The effects of the plume effluent on the received telemetry signal were also modeled using the TYBRIN developed plume attenuation model for the HERA-B and the measured data used to corroborate the model output. The predicted Received Signal Levels (RSL) are shown in Figure 4 for RF1 RHCP and RF2 LHCP in comparison with the recorded received signal levels. The RF line of sight aspect angle relative to the missile center line is plotted in Figure 5 with the predicted and actual relative RSLs for reference. The link margin analysis used the missile velocity vector as the basis for the aspect angular determination since data for the full six degree of freedom model was not available for this analysis. It is noted that the minimum aspect angle of 4.0° occurred at approximately 75 seconds of flight.

Plume effects are noticeable for aspect angles of less than approximately 9.5 degrees. The severe attenuation at 40 seconds is attributed to an antenna pattern null and the signal variations between approximately 70 to 95 seconds is attributed to missile maneuvering and associated nozzle deflections. These effects are not modeled in this analysis. Burnout of stage 1 and ignition of stage 2 are clearly seen at 60+ seconds and burnout stage 2 results in approximately 13 dB increase in signal level. These features are indicated in Figure 6.

The flight azimuth profile relative to the receiving site during the 70 to 95 second period is shown in Figure 7. The changes in the RF signal during this period can be directly correlated with the motor nozzle during this period. The RF attenuation reflects the nozzle motion during the turn where the nozzle is first pointed toward the receiving site to initiate the turn resulting in a large signal loss and the then away to stop rotation and null turn rates resulting in near nominal RF signal levels.

Since the minimum aspect angles were indicated at no less than 4.0°, the maximum RF attenuation on axis could not be determined; however, with the nozzle deflection data indicated, maximum attenuation values are estimated in the order of 25 dB.

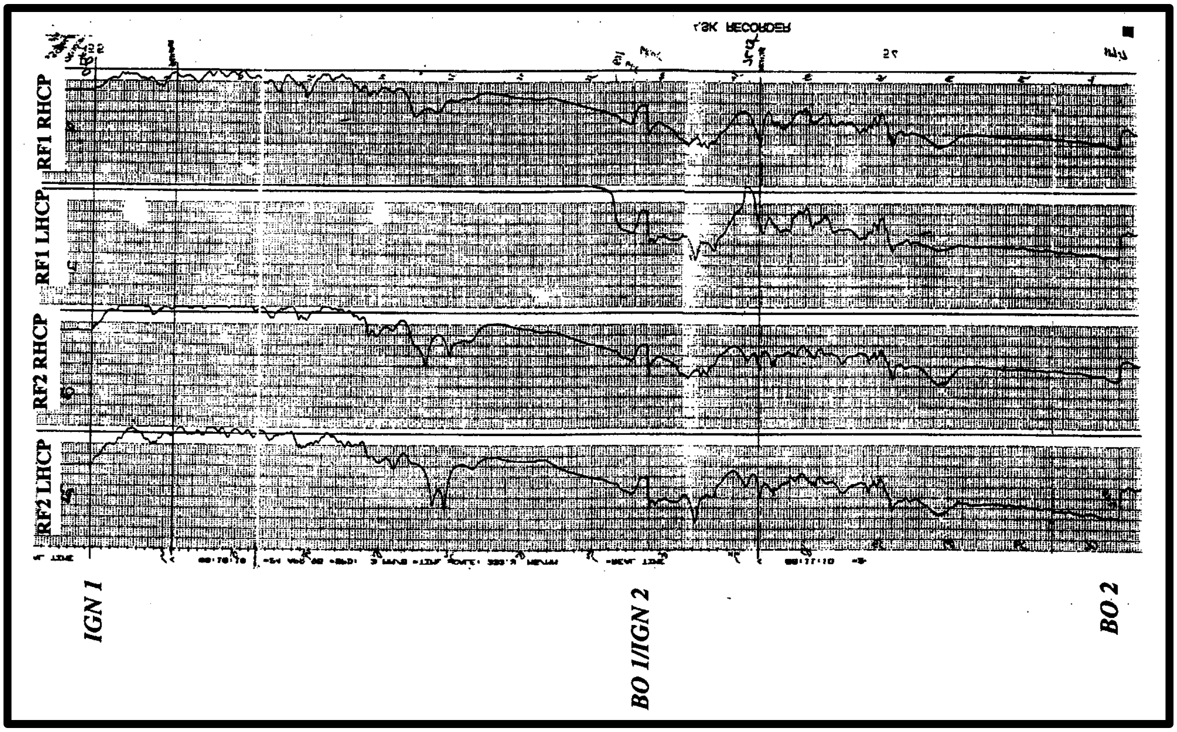
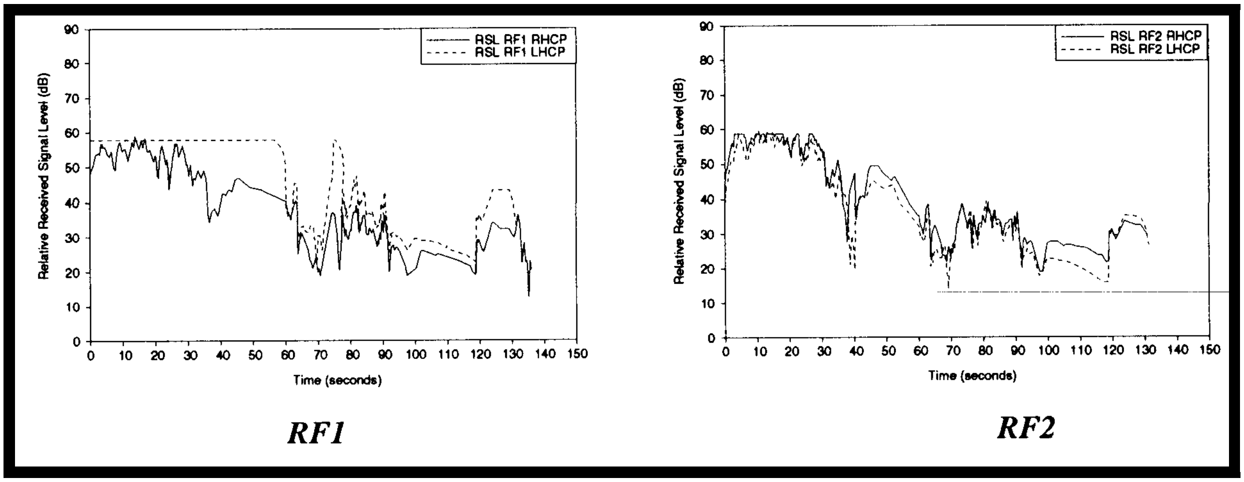
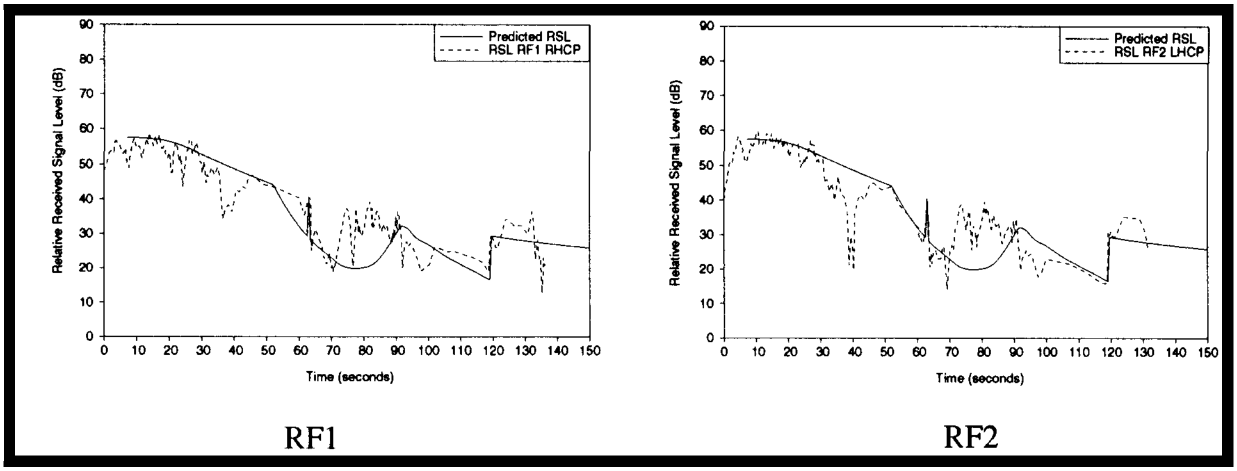


Figure 2- RF1 and RF2 Strip Chart Data



RF1 ***RF2***

Figure 3- RF1 and LHCP Received Signal Level Comparison



RF1 RF2

Figure 4- RF1 RHCP RSL with Predicted Plume Model Levels

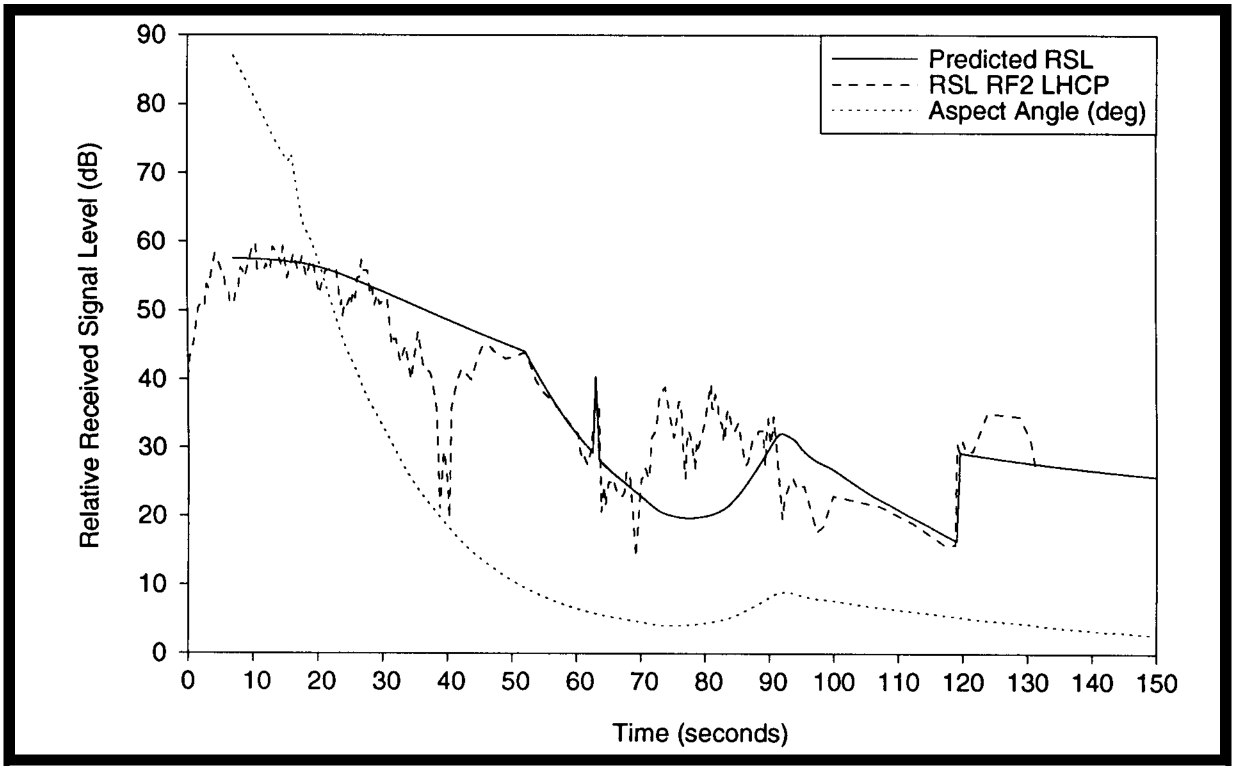


Figure 5- RF2 LHCP Received Signal Level

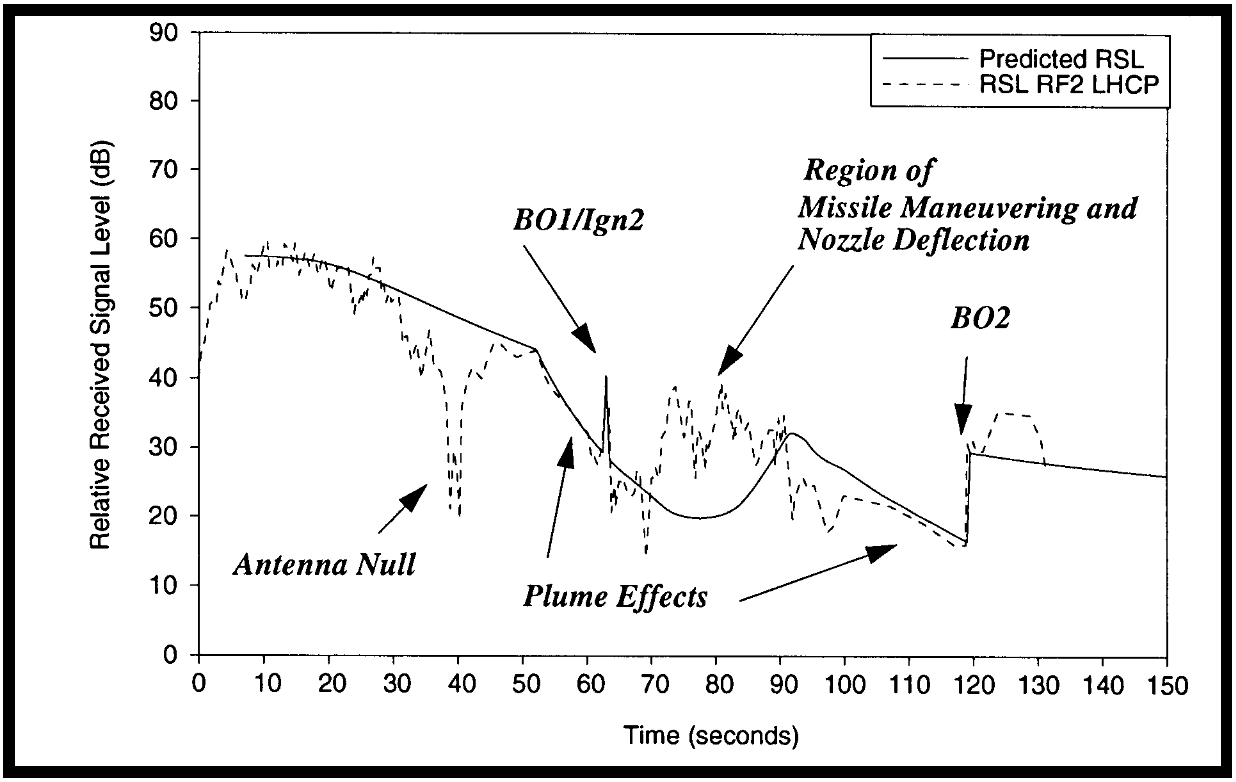


Figure 6- LHCP RSL and Plume Model with Indicated Features

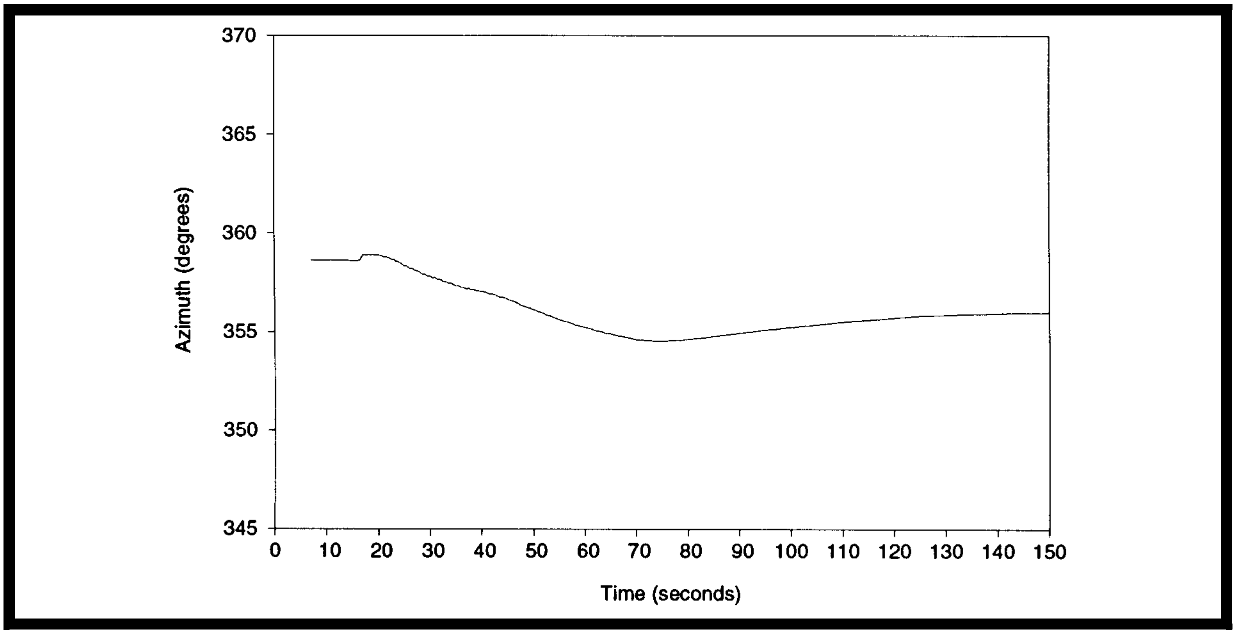


Figure 7- Azimuth Angle- Missile Relative to the TTAS TM Site Location

SUMMARY

The corroboration of RF attenuation models is an important step in being able to position a limited number of TM receivers with the confidence and reliability required for the use of the telemetry data for safety purposes. This is especially important in situations where (1) the physical number of receiving sites may be limited, (2) land limited environments such as that found at remote launch sites limit the geographic dispersion and (3) seaborne instrumentation must be positioned to adequately cover both the prelaunch and launch phases of the test environment. With the effects of the missile plume categorized to finer detail than previously known, the telemetry receiving sites can be selected with improved link margin reliability.

Future planned activities include modeling the missile antenna pattern and nozzle position for use with a full six degree of freedom missile dynamics model.