LAUNCH VEHICLE EXHAUST PLASMA / PLUME EFFECTS ON GROUND TELEMETRY RECEPTION, QRLV-2

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ABSTRACT

This paper discusses the effect of vehicle exhaust plasma/plume on the ability to receive telemetered data via an S-band RF link. The data discussed herein was captured during the launch of the QRLV-2 (Quick Reaction Launch Vehicle) on April 24, 2002 from Kodiak Launch Center, Kodiak, Alaska using Honeywell's BMRST (Ballistic Missile Range Safety Technology) system.

KEY WORDS

Plume attenuation, telemetry reception, exhaust plasma, link margin

INTRODUCTION

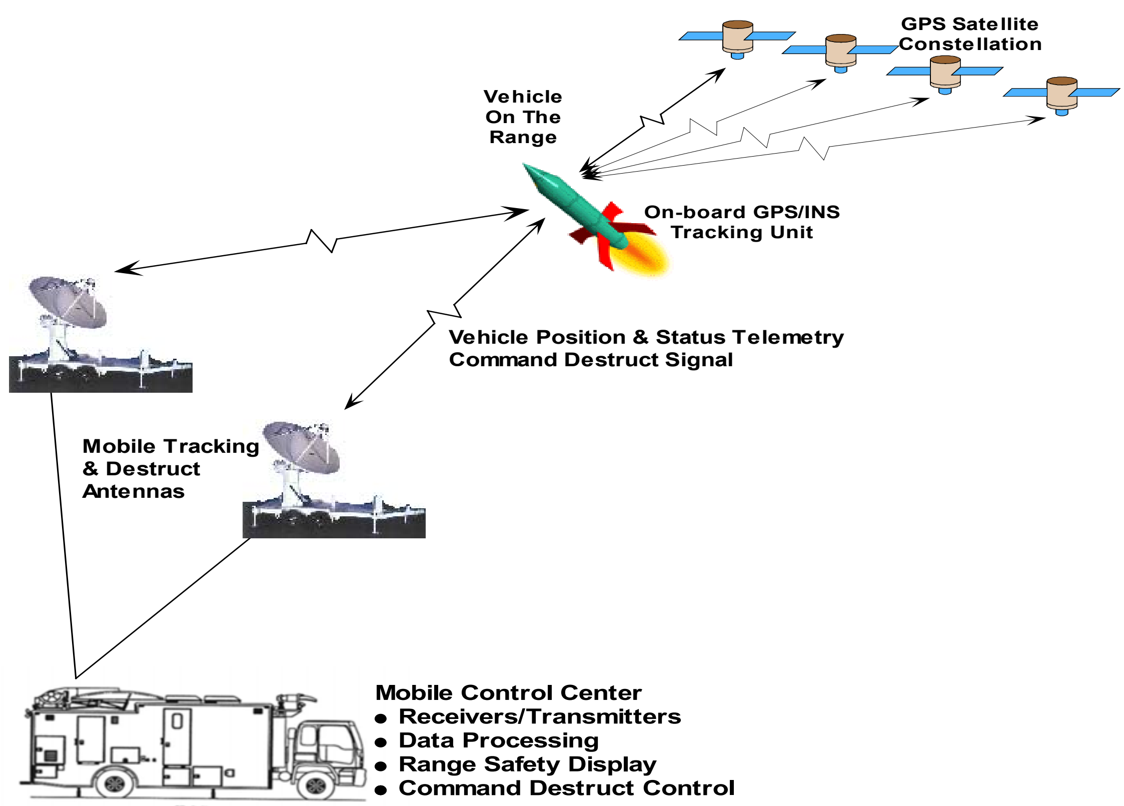
On April 24 2002 at 14:00:00 local, the Quick Reaction Launch Vehicle II (QRLV2) launched from the Kodiak launch complex in Kodiak, Alaska. The BMRST system tracked this vehicle from launch until it went beyond the horizon 403 seconds into the mission. The tracking sources were the vehicle's S-band "PCMB" telemetry stream (TMIG) and the "Honeywell GPS/INS" telemetry stream (GITU). The S-band telemetry streams were decommutated to provide vehicle state information to the mission flight control officers (MFCOs). Additionally a series of IRIG tone test command sequences was executed to demonstrate the ability of the BMRST system to perform the complete range safety function from tracking to command and destruct. During the vehicle's flight from approximately T+30 until motor burnout at T+63 seconds there was expected to be significant attenuation of the S-band signal due to plume. This paper analyzes and presents the data recorded during the plume event.

SYSTEM OVERVIEW

The Honeywell Ballistic Missile Range Safety Technology (BMRST) program, as depicted in Figure 1, is intended to create a mobile, quick reaction range safety system. It is also designed to demonstrate the capabilities of a GPS-based tracking system. The end result is a mobile system that contains all the equipment necessary to receive multiple S-Band telemetry streams, process, record and display the data for the mission flight control officer to verify flight system safety. The system also supports the command destruct function by generating a command uplink through either switchable omni or directional antennas. This system is fully redundant. Although BMRST was configured for two specific S-Band telemetry streams (TMIG and the GPS/INS Tracking Unit, GITU), any single high rate S-Band stream (> 500 Kbps) and low rate S-Band stream (< 200 Kbps) that are compliant with IRIG-106 can be received and processed in the current configuration.

The ground segment of the BMRST is a complete command and tracking system appropriate for use at either the launch site or downrange. It can operate independently of other tracking systems, but can incorporate and display data from another system. It is transportable either by air or ground and contains its own power generating capability. It consists of two dual-band tracking antennas and a mobile control center that contains components to receive and process RF inputs from the antennas, data servers, network components and workstations for computation and data display. It will receive data transmitted from the flight segment (GITU), vehicle telemetry data and data from other tracking sources, process that data and display an instantaneous impact point (IIP) for the launch vehicle. The ground system includes a command/destruct subsystem consisting of a command sequencer / encoder and antennas (integrated with the tracking antennas) for sending commands to the flight termination system.

Figure 1
Honeywell BMRST System



TARGET VEHICLE CONFIGURATION

The Target Test Vehicle (QRLV-02) consisted of a single-stage booster and a non-separating Front Section (FS). The vehicle booster was a M56A1 rocket motor with four fins and aft skirt. The FS consists of a Flight Termination System (FTS) Module, a Payload Module Bus (PMB), and a Shroud. The overall flight vehicle length is approximately 9.14 meters and the total lift-off weight is approximately 6,244 kilograms. The propellant is a Class 1.3 propellant composed of ANP-2864 HLT Mod II Type I and ANP-2862 JM Mod II Type I.

PROPULSION SYSTEM

- ENGINE TYPE: Solid Propellant Motor
- MANUFACTURER: Aerojet
- DESIGNATION: M56A1
- NUMBER OF ENGINES: 1
- SPECIFIC IMPULSE - Isp: 212 lb-sec ± 0.5% @ 77 degrees F
- THRUST - ENG: 46,850 lbf
- THRUST - SEC: Burn Time: ~61 sec

TRACKING SYSTEM CONFIGURATION AND LOCATION

The BMRST system antennas were configured to track the vehicle using the independent S-band streams below:

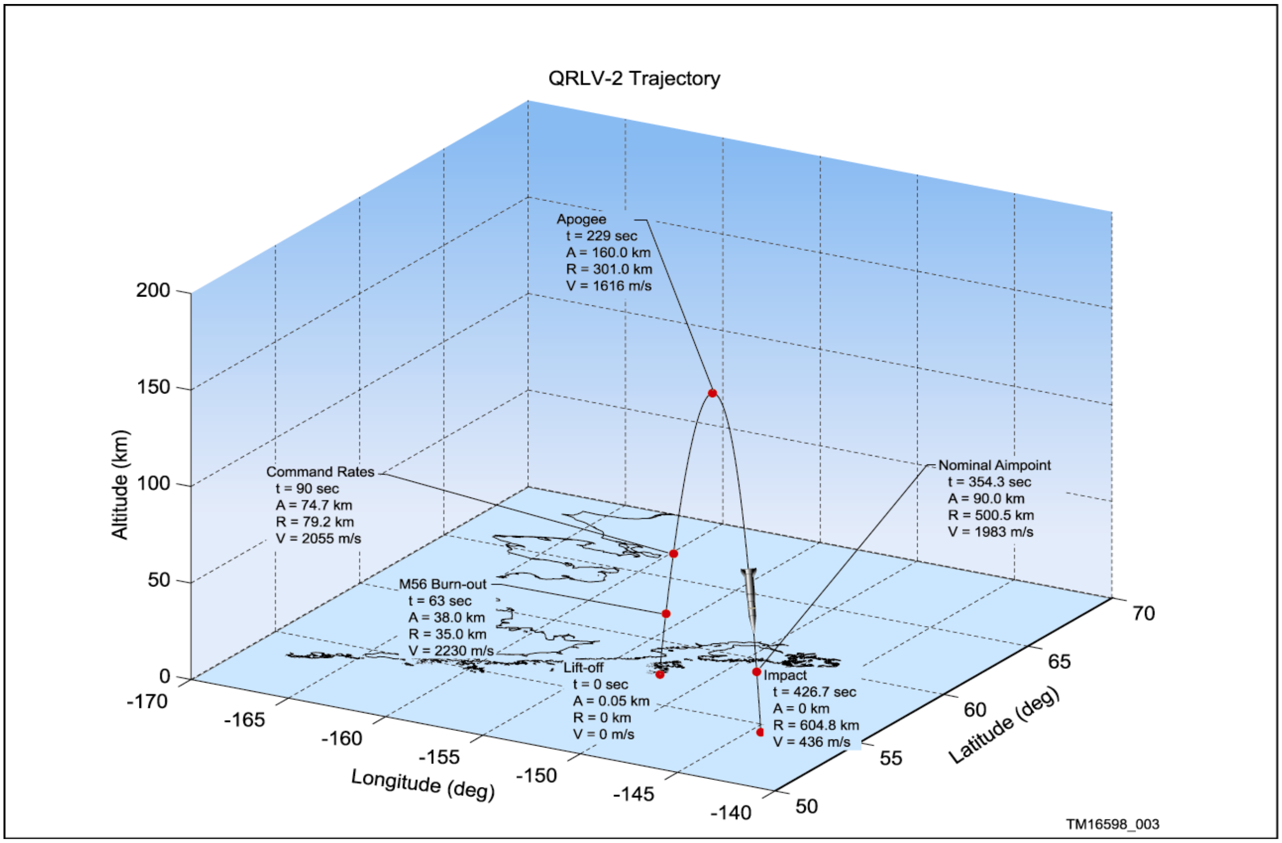
- GITU: 2292.5 MHz, 3.5W vehicle transmitter, antenna gain –15 to 0 dBi for 95% coverage, 56 KHz data rate, PCM-FM
- PCMB: 2233.5 MHz, 10 W vehicle transmitter, antenna gain –15 to 0 dBi for 95% coverage, 500 KHz data rate, PCM-FM

The diameter of the ground system tracking antennas was 4.3 meters, having a gain of 37 dBi and a 3 dB beamwidth of 2.4 degrees. The system incorporates an LNA with a noise figure of approx. 0.40 dB and gain of approx. 36 dB. The system G/T is approximately 14.5 dB/K. The BMRST antennas utilize a dual-feed design, capable of receiving the S-band downlink while simultaneously commanding the vehicle with a 1 KW UHF uplink. The uplink antenna gain is 22 dBi, resulting in an EIRP of +51 dBW.

The vehicle position at the launch pad was Latitude 57.4350° N, Longitude –152.3417° W. Launch occurred at 22:00:00 UTC on 4/24/02 on a 120 deg nominal azimuth. The nominal flight trajectory is shown in Figure 2.

The BMRST system was located at Latitude 57.4536° N, Longitude -152.3790° W, a distance of 3051 meters from the vehicle launch pad. The antennas were pointed at an azimuth of 132.2 degrees and elevation of –0.6 degrees.

Figure 2

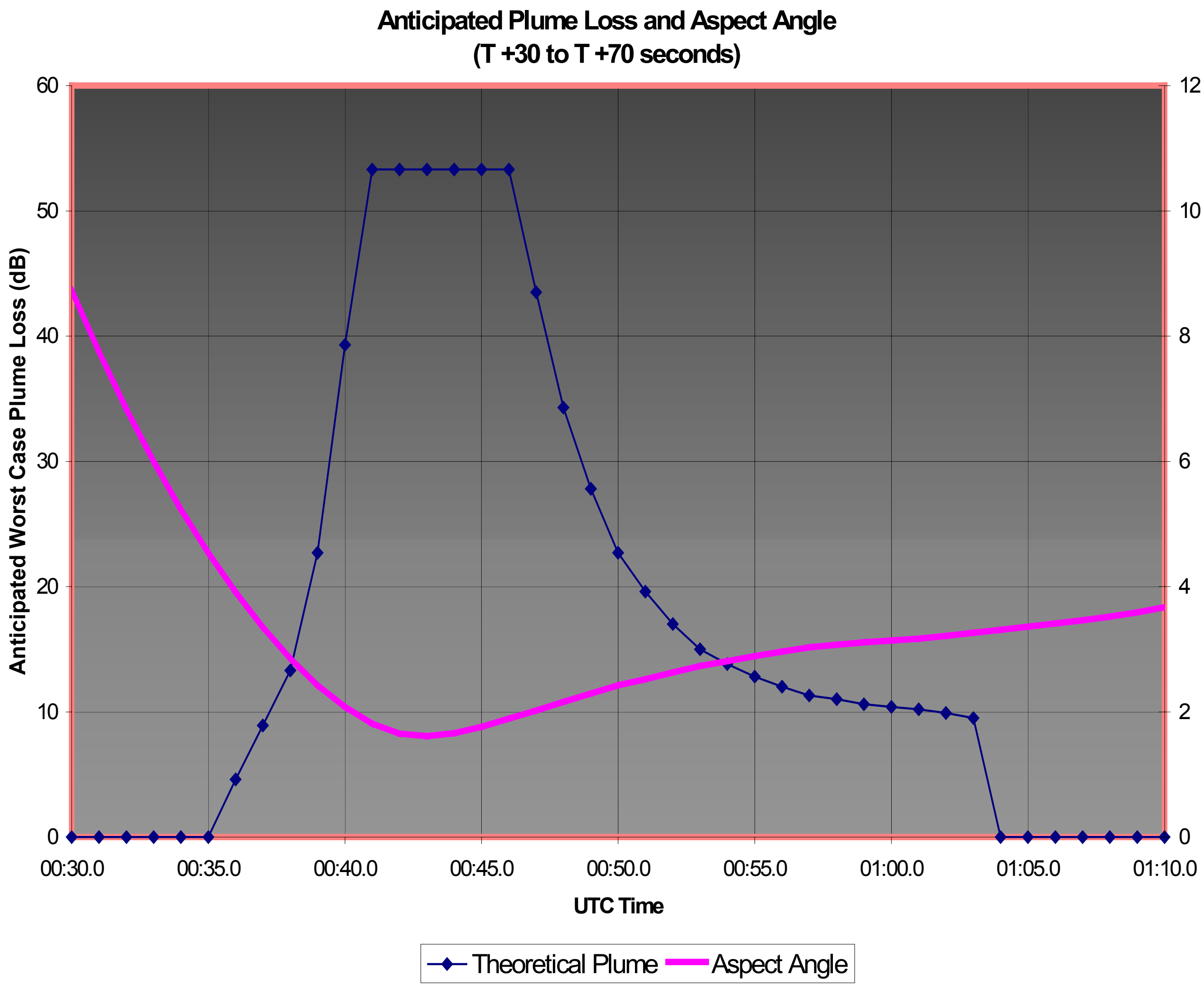


MISSION PLANNING ANALYSIS

Based upon analysis prior to the mission, it was expected that plume would begin to degrade the signal level received by the system at approximately T+30 seconds until motor burnout (T +63 seconds). For reference, an aspect angle zero degrees is looking directly into the aft end of the vehicle and along the primary axis. An angle of 180 degrees is looking down onto the nose cone.

Figure 3 shows theoretical worst case plume loss as a function of aspect angle. This plot was generated from previous measurements on similar rocket motors (Ref 1).

Figure 3



Anticipated Plume Loss and Aspect Angle
(T +30 to T +70 seconds)
Anticipated Worst Case Plume Loss (dB)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
00:30.0
00:35.0
00:40.0
00:45.0
00:50.0
00:55.0
01:00.0
01:05.0
01:10.0
UTC Time
Theoretical Plume
Aspect Angle

MISSION DATA ANALYSIS

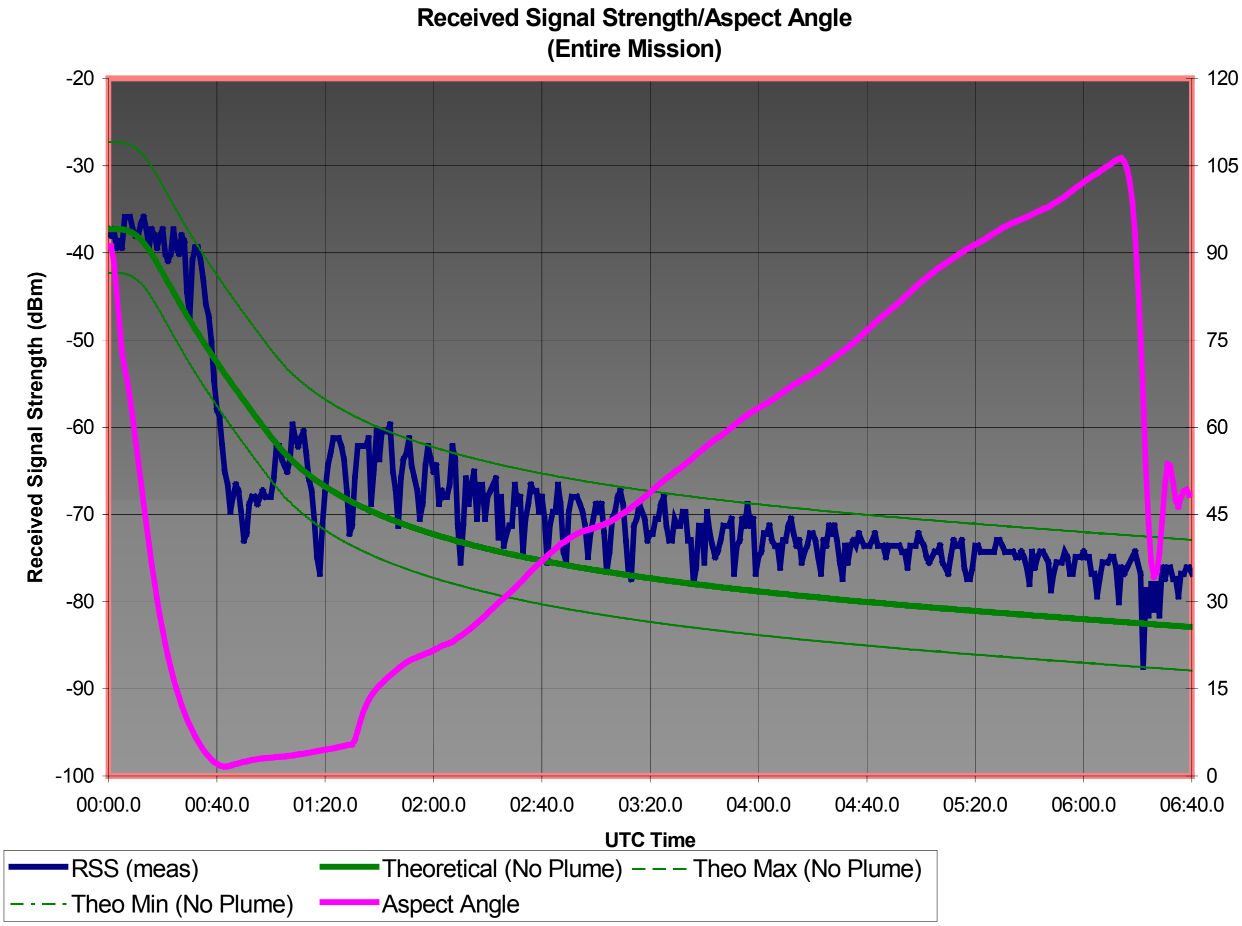
PRE AND POST PLUME PERIOD ANALYSIS

Figure 4 is a plot of the actual received signal strength and aspect angle as a function of time throughout the entire mission. Subsequent analysis of the received signal level prior to launch indicated the vehicle's transmitting antenna was "looking" at the BMRST site with a gain of –10 dBi. Given this data, a theoretical "minimum/maximum expected signal strength envelope" (+10 dB/-5 dB) based upon the vehicle's antenna properties was laid over this data.

As can be seen from the plot in Figure 4, the plume attenuation prior to T +30 is negligible and the only significant signal variation is due to antenna gain variation as a function of vehicle position. Note the total gain variation is less than 15 dB total and stays within the calculated envelope as would be expected.

Referring to Figure 4, it is interesting to note the actual received signal strength variation from time of motor burnout (T +63 seconds) until the end of mission. The figure shows that except for a momentary drop in signal strength at T +78 seconds, the actual signal strength stays within the theoretical envelope of +10/-5 dB as expected. The variation in signal strength is due primarily to vehicle roll and changes in the aspect angle. Effect of multi-path was not considered significant in this analysis. This signal variation range is important to predict accurately in order to calculate the worst case plume effect and is also well in agreement with expected results.

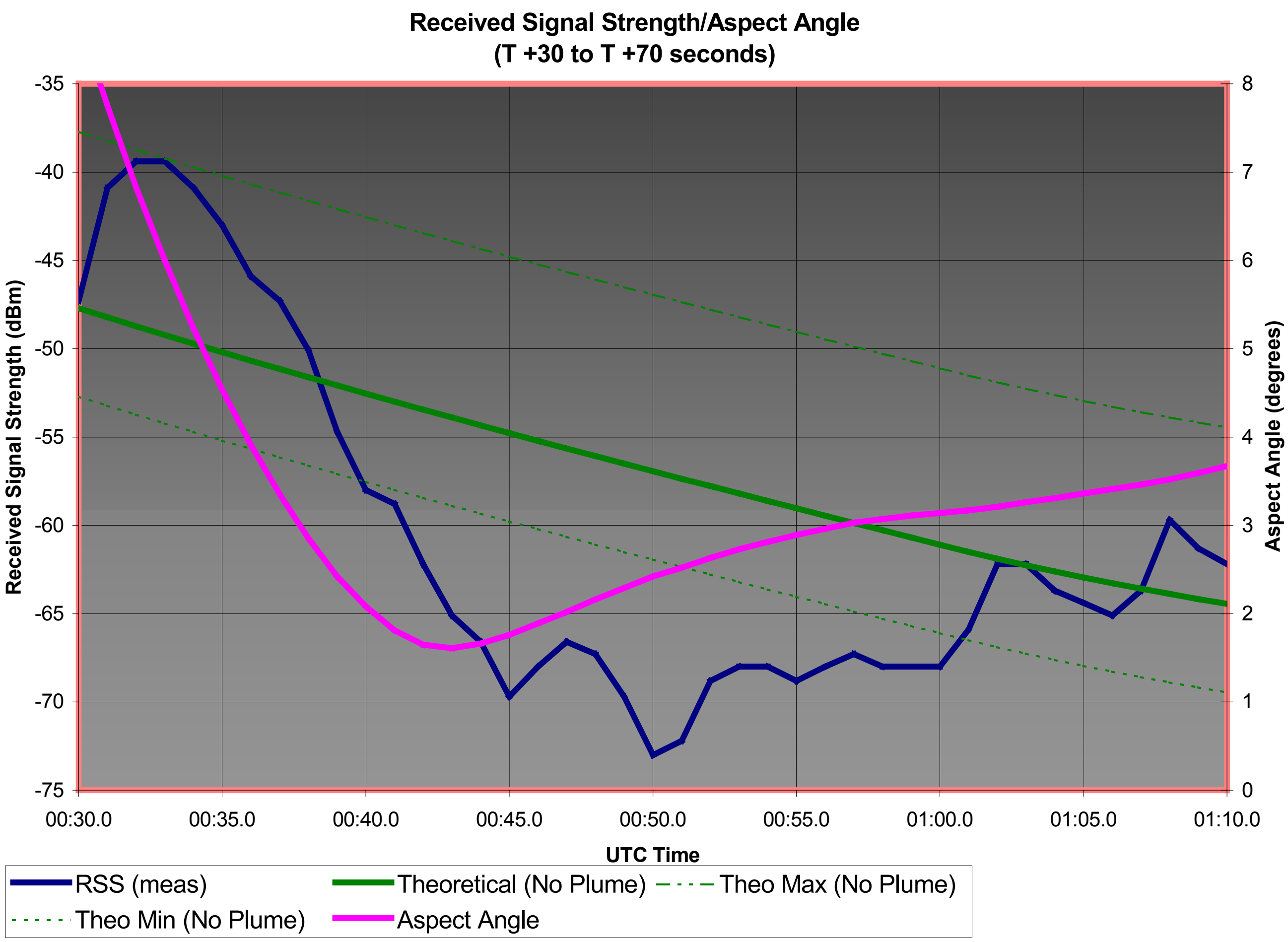
Figure 4



WORST CASE PLUME ANALYSIS

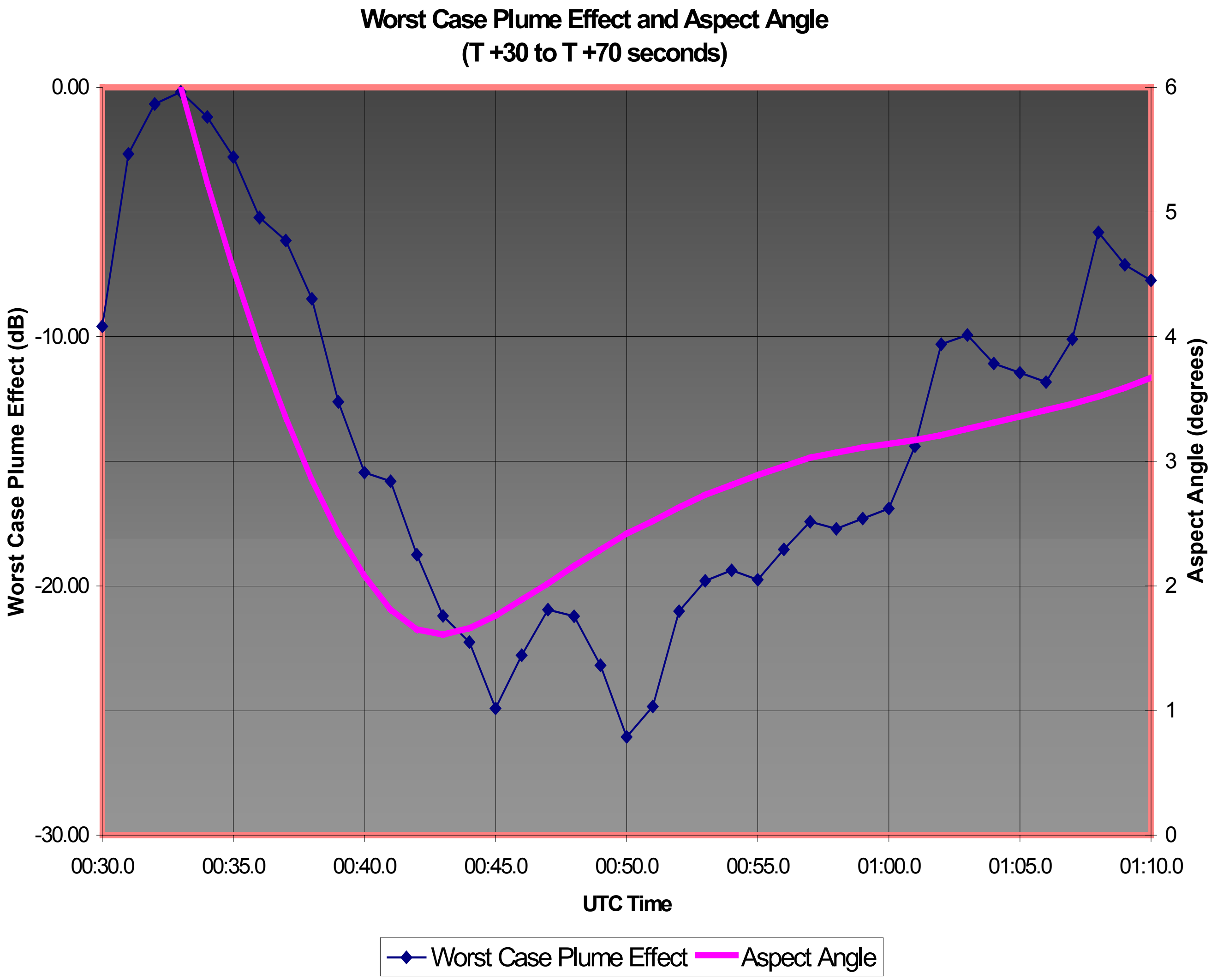
As can be seen from Figure 5, which is an exploded view in time of Figure 4 during the period of maximum plume attenuation, the signal strength drops to below that which would be expected under all conditions without plume. Given the antenna gain variation window of 15 dB, the actual plume attenuation must fall within this window. Therefore, in order to calculate the worst case effect of plume, the difference between the maximum possible signal strength and the actual received signal strength was plotted in Figure 6. The worst case attenuation was 26.1 dB at an aspect angle of 2.4 degrees at T +50 seconds. It is interesting to note that the worst case plume does not appear at the minimum aspect angle (1.6 degrees). Furthermore, it should be noted that there were no telemetry frame drops due to plume during the mission. Finally, the BMRST system was sending a series of experimental test IRIG command tones in the UHF band to the vehicle during the mission. Subsequent analysis has shown that all tones were received and processed by the command receivers throughout the entire mission.

Figure 5



Received Signal Strength/Aspect Angle
(T +30 to T +70 seconds)
Received Signal Strength (dBm)
-35
-40
-45
-50
-55
-60
-65
-70
-75
Aspect Angle (degrees)
8
7
6
5
4
3
2
1
0
00:30.0
00:35.0
00:40.0
00:45.0
00:50.0
00:55.0
01:00.0
01:05.0
01:10.0
UTC Time
RSS (meas)
Theoretical (No Plume)
Theo Max (No Plume)
Theo Min (No Plume)
Aspect Angle

Figure 6


Worst Case Plume Effect and Aspect Angle
(T +30 to T +70 seconds)
0.00
-10.00
-20.00
-30.00
Worst Case Plume Effect (dB)
6
5
4
3
2
1
0
Aspect Angle (degrees)
00:30.0
00:35.0
00:40.0
00:45.0
00:50.0
00:55.0
01:00.0
01:05.0
01:10.0
UTC Time
Worst Case Plume Effect
Aspect Angle

SUMMARY

Plume effect as described in this paper was not as severe as expected in worst case analysis prior to the launch. While some data indicated a possible plume effect of over 50 dB, the worst case plume attenuation seen during the mission was 26.1 dB. The BMRST system was able to track, command, and acquire data throughout the entire mission.

ACKNOWLEGMENTS

Honeywell gratefully recognizes the following individuals and sponsor organizations: AFRL, Space Vehicles Directorate, Dr. Sandra H. Slivinsky; SMC Rocket Systems Launch Program, Business Manager, Dr. Sam Kuennen and Florida Air National Guard, Lt. Col Rembert Schofield.

REFERENCES

1) Plume Attenuation Report for the 16 Jul 96 TCMP Mission, 7 August 1996, Jim E. Noble Operations Control Division