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Unmanned Aviation Systems Models of the Radio Communications Links: Study Results-Appendices Annex 2

Volume 1 & Volume 2

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Unmanned Aircraft Systems Modeling of the Radio Communications Links: Study Results

Annex 2

Volume 1 of 2

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16. Abstract

This report describes the analysis of communications between the Control Station and an Unmanned Aircraft (UA) flying in the National Airspace System (NAS). This work is based on the RTCA SC-203 Operational Services and Environment Description (OSED). The OSED document seeks to characterize the highly different attributes of all UAs navigating the airspace and define their relationship to airspace users, air traffic services, and operating environments of the NAS. One goal of this report is to lead to the development of Minimum Aviation System Performance Standards for Control and Communications. This report takes the nine scenarios found in the OSED and analyzes the communication links.

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Executive Summary

This report describes the analysis of radio communications between the Control Station and an Unmanned Aircraft (UA) flying in the National Airspace System (NAS). It is based on the RTCA SC-203 Operational Services and Environment Description (OSED). The OSED document characterizes the highly different attributes of UA's and define their relationship to airspace users, air traffic services, and operating environments of the NAS. One goal of this report is to lead to the development of Minimum Aviation System Performance Standards for Control and Communications. This report takes the nine scenarios found in the OSED and analyzes the communication links.

The Federal Aviation Administration (FAA) is the authority that grants access into, and operations within, the NAS for all aircraft, including Unmanned Aircraft Systems (UAS). The safe operation of UAS in the NAS must be assured if their full potential is to be realized and supported by the public and Congress.

This report analyzed the radio communication links that are needed for the safe operation of UAS in the NAS. Safe operation, in this sense, can be defined as the availability of the required radio communication links to transmit the information to control the UAS and the return links to allow the pilot to know where the UAS is located at any given moment as well as how the UA is performing.

This report is the end result of work performed jointly between the FAA and the National Aeronautics and Space Administration (NASA)/Kennedy Space Center (NASA KSC). The work was done in support of the RTCA Special Committee 203 (SC-203) Control and Communications Working Group. The RTCA is a federal advisory committee to the FAA. A large part of the specific values used in the simulations came from the working group. Specifically, all of the radio links were modeled based on the formulations completed by the working group.

The research team analyzed all nine scenarios from the RTCA SC-203 OSED. These nine scenarios represent how a UAS would operate in the NAS. Each scenario was created using the Satellite Tool Kit, a modeling and simulation software tool developed by Analytical Graphics, Inc. The flight paths of the UAS were generated based on the OSED description. The UAS dynamics were input into the model. Then each communication asset — such as transmitters, receivers, and antennas — were modeled and placed on the appropriate UA, satellite, or Ground Control Station. The impact on the communication links was analyzed for required signal strength, blockage of links, and availability of the links. Rain attenuation was also introduced, with the results on the links analyzed.

All radio communication links for each of the nine OSED scenarios were analyzed. The radio links needed 6.5 dB Eb/No (energy per bit) to maintain a bit error rate (BER) of 10^{-5} using convolutional coding. A 6 dB safety margin was added to this for all Line of Sight (LOS) links. The goal was to have 12.5 dB Eb/No for all LOS radio links. This was met at the maximum range of 25 nautical miles for the eight scenarios that had LOS. For the single Beyond Line of

Site (BLOS) radio link analyzed, there was no link margin and all links stayed above the 6.5 dB Eb/No.

LOS and BLOS link availability was calculated for all nine scenarios. The BLOS links were constant and never dropped out, thus the availability was 100% for all of the BLOS links analyzed in this report. The table below summarizes the LOS link availability for the eight scenarios that had LOS links (only Scenario 7 did not have an LOS link).

LOS and BLOS Availability by Scenario

Scenario Number	LOS – Command Availability	LOS – Telemetry Availability	BLOS – Command & Telemetry Availability
1	100.00%	100.00%	100.00%
2	100.00%	100.00%	100.00%
3	99.57%	99.78%	100.00%
4	99.87%	99.87%	100.00%
5	100.00%	100.00%	100.00%
6	99.94%	100.00%	100.00%
7	NA	NA	100.00%
8	100.00%	100.00%	100.00%
9	100.00%	100.00%	100.00%

The results of this analysis showed that it's possible to send commands to the UA and have the UA send back the system's health and status with high availability of at least 99.57% (Scenario 3 proved to be the worst case scenario) for command, 99.78% (Scenario 3 proved to be the worst case scenario) for telemetry, and 100% for BLOS.

All of the gaps were due to blockage and not due to the signal falling below the required 12.5 dB. This does not meet the RTCA SC-203 Control and Communications Working Group's stated goal of 99.9% availability. Each UA had two antennas, typically a top and bottom antenna. By placing two antennas on the UA, the availability increases. The top and bottom antenna complement each other; that is, when one antenna loses the signal, the other antenna picks it up. This is called Antenna Diversity, which is defined as "the use of two or more antennas to improve the quality and reliability of a wireless link." This report does not go into how the diversity would be implemented. For instance Scenario 1 has availability of 95.07% for the top antenna and 99.5% for the bottom antenna, when both antennas are used the availability goes to 100%.

The RF links are attenuated by rain; this report analyzed the effects of rain on the RF Links. The rain analysis shows that the higher radio frequencies have higher link attenuation for a given rain rate. When the rain rates increase, the attenuation due to rain also increases for all frequencies. Thus, the 14 GHz link has a higher attenuation for a given rain rate than the 11 GHz link. For the 11 GHz link, the excess margin with no rain was only 1.59 dB because of the lower transmitter power and lower antenna gain on the satellite. Thus, when rain attenuation is added to this link, the excess margin is lost for the 50 mm/hr. (-1.4 dB Margin) and 90 mm/hr. (-2.9 dB Margin) rain rates. The 14 GHz link maintains the margin even at the high rain rates, since this link started with an excess margin of 23.55 dB due to the larger antenna gain of the GCS.

As stated above, the links for command and telemetry can meet an availability of 99.57% for the command link and 99.78% for the telemetry link without rain. When rain attenuation is added, the satellite to UA command link does not meet the link requirements when the rain rates are either 50 mm/hr. or 90 mm/hr. Further study will need to be done to overcome these shortfalls.

1 Introduction

The Federal Aviation Administration (FAA) created the National Airspace System (NAS) in order to provide a safe and efficient airspace environment for civil, commercial, and military aviation. The NAS is composed of a network of air navigation facilities, air traffic control (ATC) facilities, and airports along with the technologies and the rules and regulations to operate the system. In order to meet the anticipated projected demand for manned and unmanned aircraft (UA) operations, the United States Congress established the Joint Planning and Development Office (JPDO) in 2003. The JPDO is responsible for facilitating, coordinating, planning, and implementing the Next Generation Air Transportation System (NextGen), which will leverage existing and emerging technologies to transform the NAS system to meet the projected future demands on the NAS. The technologies include satellite-based navigation systems, digital communications, net-centric operations, advanced automation systems, and substantially improved weather forecasting capabilities. NextGen is being designed to support increased capacity, efficiency, flexibility, and interoperability of manned and unmanned aircraft systems (UAS) while providing increased safety and security. [1]

There are significant differences between manned aircraft and UAS in terms of operations, procedures, and system characteristics. Consequently, UAS do not comply with current aviation procedures and policies, nor is the NAS designed to incorporate the current Sense and Avoid and Control and Communication navigation systems designed for UAS. For these reasons, in 2004, the FAA requested RTCA, Inc.[1] to address standards development for integrating UAS into the NAS, specify how UAS will sense and avoid other aircraft as they navigate, and determine how UAS will navigate and communicate. In response, the RTCA established the RTCA SC-203 Unmanned Aircraft Systems Special Committee.

This report documents the results of a cooperative study conducted by personnel located at the FAA William J. Hughes Technical Center (FAA-WJHTC) and the National Aeronautics and Space Administration's Kennedy Space Center (NASA-KSC). It is a modeling and simulation (M&S) study requested by the RTCA SC 203's Control and Communications Working Group (SC203 CC WG2). In this study, key architectures and operational concepts were modeled to quantify specific parameters to aid the working group in developing UAS control and communications standards. The results documented in this report will help the RTCA to mature the UAS Minimum Aviation System Performance Standards (MASPS) into guidance material for the FAA and UAS industry while also allowing it to be compatible with international aviation standards.

1.1 Background for the Study

Because of the broad range of potential uses for UAS, there is an increasing need for integrating UAS into the NAS. However, current requests for access to the NAS are assessed based on technical and operational specific UAS operations, which are subject to strict limitations when there is any perceived risk to the public. In order to reduce these restrictions, the FAA needs to establish UAS requirements that ensure UAS are able to operate safely in the NAS alongside civilian and defense aircraft.

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[1] RTCA, Inc. is a private non-profit corporation that develops consensus-based recommendations regarding aviation.

Specifically, for UAS control and communications, a number of questions need to be answered.

For example:

- How will a UAS pilot communicate with ATC?
- How will ATC receive a UAS's identification and position data?
- What frequency bands will be specified for UAS and what is the capacity of the frequency band per number of UAS?
- What communication protocols should be utilized?
- What secondary communications should be specified?
- What encryption standards should be incorporated?
- What requirements should be incorporated in the future FAA NAS Voice System?
- What control and communication systems should be certified?
- What latencies, availability, and continuity values permit safe reliable transactions?

The FAA-WJHTC and NASA-KSC team are assessing and quantifying some of these issues at the request of the RTCA's SC203 CC WG2. This work is based on an RTCA document entitled "Operational Services and Environmental Definition (OSED)" [2]. An earlier study modeled the communication links of three OSED scenarios that represent the two architectures referenced in the RTCA UAS Control and Communications Architectures document [3]. The communication links modeled included the command links to the UAS and the telemetry links from the UAS. The voice links were not modeled. The goal of the study was to define the communication links for both LOS links as well as BLOS links. The results show how well the links performed during the dynamics of specific flights for various aircraft under varying conditions. The concept of operations analyzed in this earlier study included satellite navigation and control of aircraft, advanced digital communications, advanced automation capabilities of aircraft control, and enhanced communication connectivity between all NAS components.

This FAA-WJHTC and NASA-KSC study enhances the results of the three OSED scenarios in the previous study and adds the additional six scenarios defined in the OSED document.

1.2 Purpose of the Study

The FAA-WJHTC and NASA-KSC are performing the M&S efforts for the RTCA's SC203 CC WG2 chartered under RTCA SC-203. Key architectures and operational concepts are being modeled to assess concepts and quantify specific parameters to aid the working group in developing UAS Control and Communications (CC) standards. The results of the analysis will help the RTCA to mature the UAS MASPS into guidance material for the FAA and UAS industry while maintaining compatibility with international aviation standards.

The SC203 CC WG2 requires M&S efforts to assess concepts and quantify various approaches. The working group selects the results to be incorporated into white papers that summarize the concepts under review. SC203 CC WG2 cannot finalize MASPS until the spectrum analysis is complete and amount of spectrum assigned to UAS operations has been agreed upon.

The RTCA document DO-264, "Guidelines for Approval of the Provision and Use of Air Traffic Services supported by Data Communications," provides guidance material for stakeholders and approval authorities involved in the operational implementation of the provision and use of air traffic services supported by data communications. There are four major DO-264 required communications performance parameters that will be included in MASPS: availability, integrity, continuity, and availability. These will focus on the development of realistic and achievable performance parameters for the yet to be designed CC links.

The SC203 CC WG2 is working with other SC203 and international CC working groups to incorporate concepts into the common M&S environment, such as:

- Actively working with Sense and Avoid WG, Systems WG, and Safety WG to develop a better understanding of required CC performance to support the SAA function
- Working with the European Organization for Civil Aviation Equipment's (EUROCAE) Working Group 73 on Unmanned Aircraft Systems to ensure a synergistic approach to CC requirements and performance

1.3 Scope of the Document

The scope of the work during this project term was to model the communication links of nine OSED scenarios that represent two Radio Frequency (RF) Link architectures: LOS links and BLOS links, as referenced in the RTCA Architecture document [3].

The work described in this document is based on the OSED and the inputs provided by SC203 CC WG2 on UAS CC. The OSED provides the informational basis for assessing and establishing operational, safety, performance, and interoperability requirements for UAS operations in the NAS. The OSED is identified as an artifact of DO-264 and is part of the coordinated requirements capture process.

The RF communication links that are modeled are the UAS command links as well as the telemetry links. The report does not include specific modeling of voice links nor terrestrial network.

The results show how well the links performed during the dynamics of a simulated flight for various UA under varying conditions.

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2 Methodology

The FAA-WJHTC and NASA-KSC M&S approach was to develop all OSED scenarios for communications link modeling utilizing a common tool, namely the Analytical Graphics, Inc. (AGI) Satellite Tool Kit (STK), version 9.2.2.

STK is a high fidelity fast-time modeling and mission analysis application and software development kit for engineers and analysts. STK models complex systems and subcomponents such as UAS, manned aircraft, satellites, ground vehicles, launch vehicles, and radar systems. STK includes extensive report and graph functions and the ability to export data to Excel.

Nine scenarios were used to validate each UAS model for RF link performance parameters based on the UAS system architecture developed by RTCA's SC203 CC WG2. Simulation runs provide multiple data points over the course of each UA flight. The nine scenario flights provide a variety of conditions that include UA geometry characteristics, realistic antenna patterns, and additional environmental constraints applied to the RF links. Section 2.2, Modeling and Simulation Approach, provides additional details.

M&S analysis will help validate and refine performance values for RTCA's SC203 CC WG2's MASPS. The following sections describe the M&S System Architectures and Modeling and Simulation Approach.

2.1 System Architectures Modeling Overview

The RTCA's SC203 CC WG2 proposed 10 architectures within the RTCA SC203-CC005_UAS Control and Communications Architectures document [3]. Since the 10 architectures had overlapping functionality, RTCA's SC203 CC WG2 focused on architectures from each of the following two categories: UA Relay and UA Non Relay. The following section provides an overview of the architectures modeled for the nine OSED scenarios.

2.1.1 Direct LOS Control Architectures

The Direct Control LOS architecture concept consists of a UA and GCS in direct communication using an LOS RF radio link. A typical radio linked flight would encompass a small UA, low altitude, short range operation (urban environment, surveillance, tracking, mapping, etc.). An additional backup GCS was considered for redundant RF links depending on the situation. Figure 1 and Figure 2 show a high level view of this system architecture.

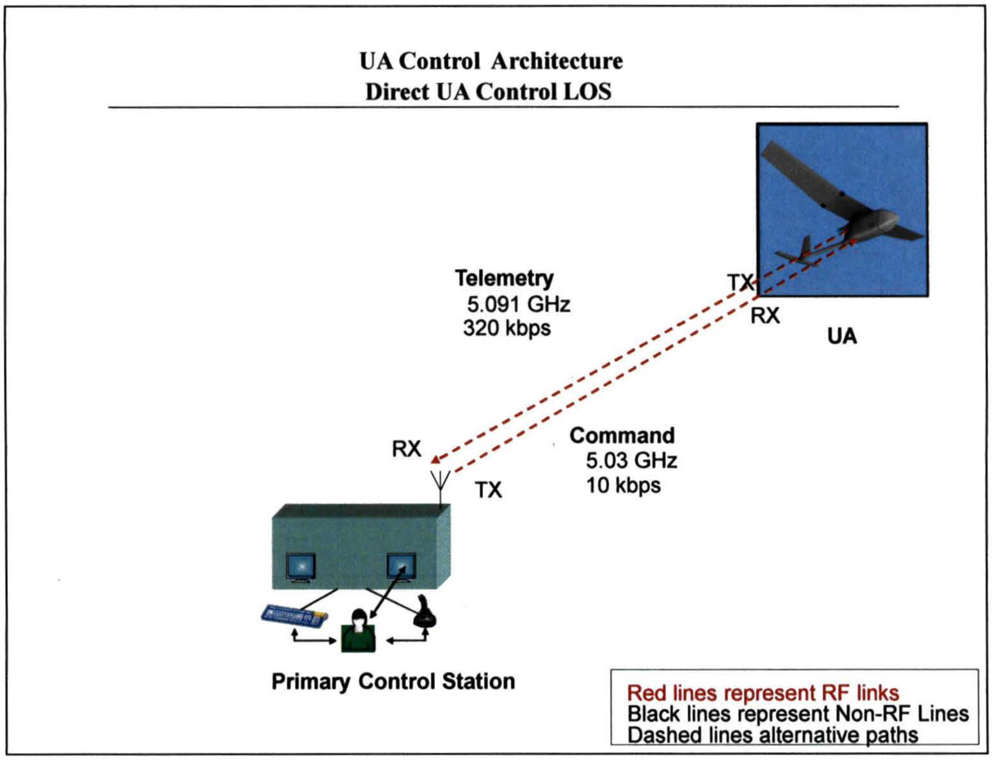


Figure 1. Direct UA Control LOS with Single Control Station

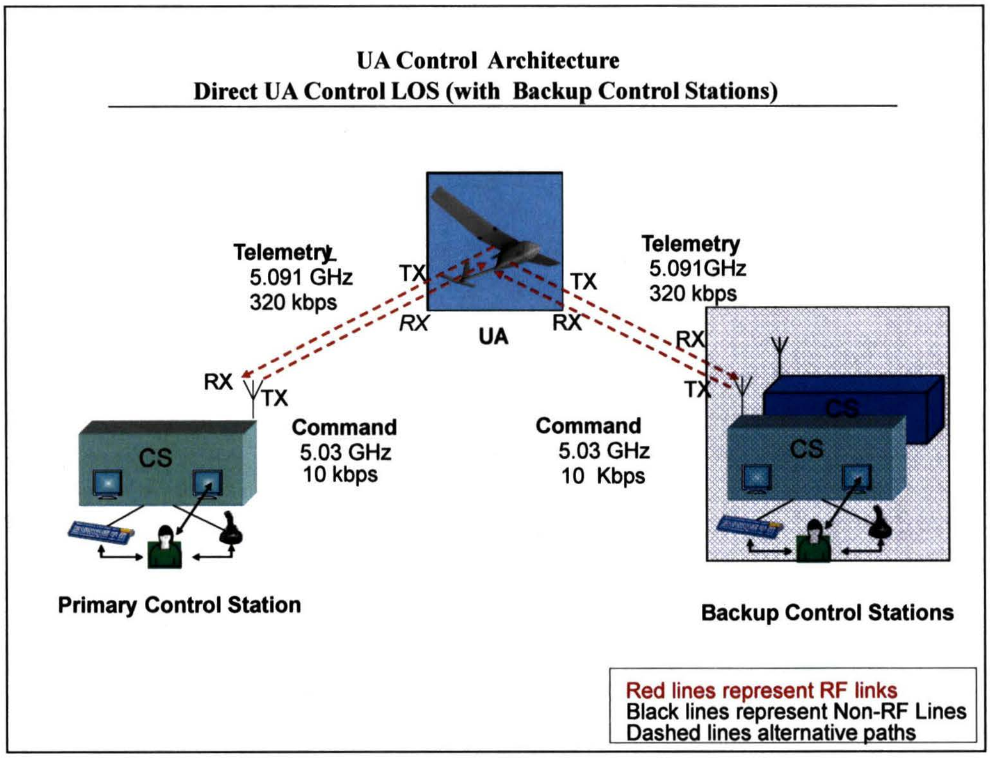


Figure 2. Direct UA Control LOS with Backup Control Stations

2.1.2 Direct LOS/BLOS Control Architecture

Direct LOS/BLOS control architecture consists of an LOS link and BLOS satellite link as the primary control between a UA and the GCS. The LOS RF link tends to be utilized for direct control during take-off and recovery operations. Figure 3 shows a high level view of this system's architecture.

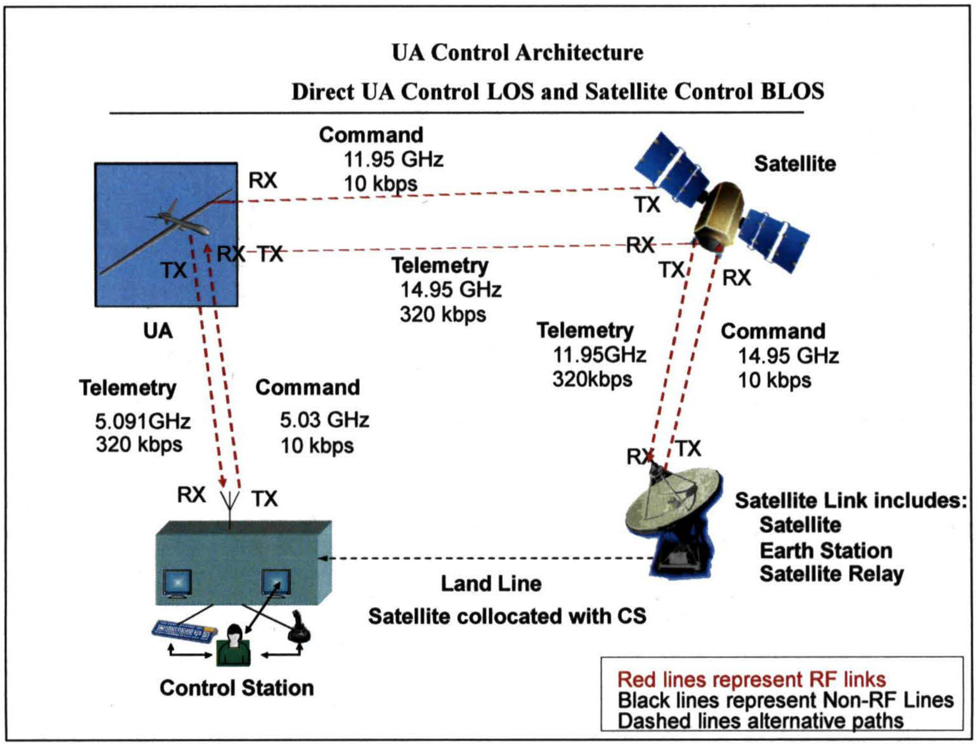


Figure 3. LOS/BLOS Control Architecture

2.1.3 Nationwide Network Control Architecture

The Nationwide Network Control architecture concept consists of a networked control architecture where the UA and GCS access a shared nationwide network maintained by a Communications Service Provider (CSP). The CSP, in turn, maintains an infrastructure of radio towers and (potentially) satellite earth stations which provide connectivity to the UA through a standardized protocol. The CSP network itself can be a combination of wired and wireless links, as required. The LOS and satellite links can each be redundant or the LOS and satellite connections can be used together as a redundant pair, as required. Figure 4 shows a high level view of this system's architecture.

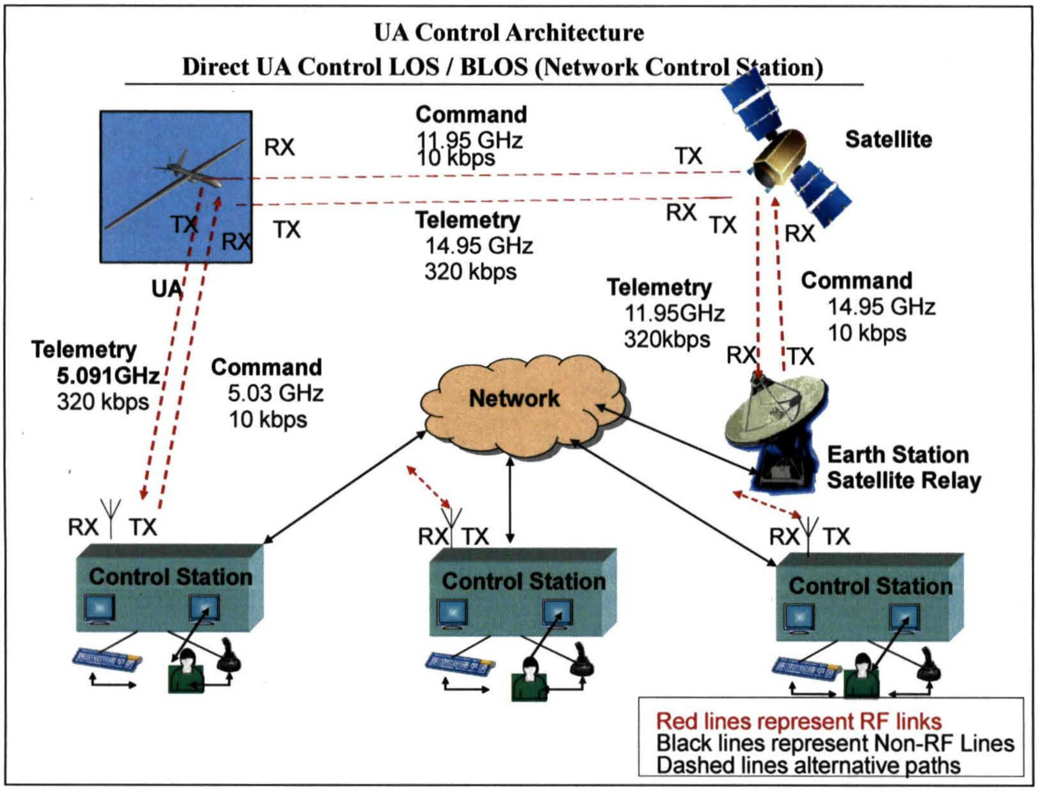


Figure 4. Direct UA Control LOS and BLOS Network Stations

2.1.4 Communications Systems

UAS communication systems encompass LOS and BLOS for command and telemetry. The communication system modeled encompasses:

- Command Link
  - LOS: A 10 kbps link using a Quadrature Phase Shift Key (QPSK)
    - Two UA receive antennas were placed on the top and bottom, configured in the middle of the plane and actual location on the UA when identified by vendor cut-away diagrams.
    - These were half hemispherical antennas
    - One transmit antenna, directional to the UAS from the ground
  - BLOS
    - One UAS directional antenna up to a GEO satellite
    - One directional receive antenna on the GEO
    - One directional transmit antenna on the GEO down to the UA
    - One receive antenna on the UA, top, configured in the middle of the plane
    - These were half hemispherical antennas
- Telemetry Link:
  - This is a 320 kbps link using QPSK. This link uses the same antenna configuration as Command but at different frequencies.

2.2 *Modeling and Simulation Approach*

For this project, the following STK modules were utilized:

- Communications
- Aircraft Mission Modeler
- Atmospheric Absorption Models
    - Gaseous Absorption Model
    - Refraction Model
- Effective Radius Model
- TIREM (Model)

These models are based on industry standard environmental models.

2.2.1 Communications

The STK Communications module allows users to define and analyze detailed communication systems; generate detailed link budget reports and graphs; visualize dynamic system performance in 2D and 3D windows; and incorporate detailed rain models, atmospheric losses, and RF interference sources during analysis. This module uses the Terrain Integrated Rough Earth Model (TIREM), an industry standard for modeling RF propagation, and Terrain.

2.2.2 Aircraft Mission Modeler

The STK Aircraft Mission Modeler propagator for the aircraft object is a premier tool for performing complex, highly accurate, time-based mission analysis for aircraft operations. The Aircraft Mission Modeler features a rapid mission modeling tool that allows users to model specific mission requirements quickly and easily using either the step-by-step graphical user interface or the 3D object editor. Utilizing aircraft-specific characteristics, Aircraft Mission Modeler produces realistic flight paths based upon empirical, airframe-specific deterministic models. In addition to the default aircraft models included with the install, users can customize and add models, as necessary, to fulfill their needs. Table 1 contains the data used in each UA model.

Table 1. Unmanned Aircraft Performance Table

Basic UA Performance Model (3D Model File)					
Description	**Value**	**Description**	**Value**	**Description**	**Value**
Acceleration Built-In Model		***Climb Built-In Model***		***Landing Built-In Model***	
Basic		Ceiling Altitude	25,000 ft	Landing Speed	100 nm/hr
Level Turns		Airspeed	180 nm/hr	Sea Level Ground Roll	1 kft
Turn G	1.1547 G-Sea Level	Altitude Rate	2000 ft/min	Use Aerodynamics/ Propulsion Fuel Flow	Not Specified
Bank Angle	30°	Fuel Flow	500 lb/hr	Fuel Flow	500 lb/hr
Turn Acceleration	11.3237 m/sec^2	Initial Level Off for Acceleration	Not Specified	***Takeoff Built-In Model***	
Turn Radius	Not Specified	Relative Airspeed Tolerance	Not Specified	Takeoff Speed	100 nm/hr
Turn Rate	Not Specified	***Cruise Built-In Model***		Sea Level Ground Roll	1 kft
Climb and Descent Transactions		Ceiling Altitude	25,000 ft	Departure Speed	150 nm/hr
Pull Up G	1.1547 G-Sea Level	Default Cruise Altitude	10,000 ft	Takeoff Climb Angle	3°
Pull Over G	0.75 G-Sea Level	Airspeed	Not Specified	Use Aerodynamics/ Propulsion Fuel Flow	Not Specified
Attitude Transactions		Use Aerodynamics Propulsion Fuel Flow	Not Specified	Acceleration Fuel Flow	500 lb/hr
Roll Rate	20°/sec	Minimum Airspeed	80 nm/hr	Departure Fuel Flow	500 lb/hr
AOA/Pitch Rate	10°/sec	Minimum Flue Flow	600 lb/hr		
Sideslip/Yaw Rate	20°/sec	Maximum Fuel Flow	250 nm/hr		
Aerodynamics		Maximum Flue Flow	600 lb/hr		
Strategy	Not Specified	Maximum Endurance Airspeed	140 nm/hr		
Aircraft Operating Mode	Not Specified	Maximum Endurance Fuel Flow	400 lb/hr		
Lift Factor	1	Maximum Range Airspeed	180 nm/hr		
Drag Factor	1	MaximumRange Fuel Flow	500 lb/hr		
Propulsion		***Descent Built-In Model***			
Strategy	Not Specified	Ceiling Altitude	25000 ft		
Speed Changes		Airspeed	180 nm/hr		
Max Thrust Acceleration	0.5 G-Sea Level	Altitude Rate	-2000 ft/min		
Max Thrust Deceleration	Not Specified	UseAerodynamics Propulsion Fuel Flow	Not Specified		
Density Ratio Exponent	Not Specified	Fuel Flow	500 lb/hr		
Thrust Factor	1	Initial Level Off for Acceleration	Not Specified		
Fuel Factor	1	Relative Airspeed Tolerance	Not Specified		

2.2.3 Atmospheric Absorption Models: ITU-R P.676-5

The STK Gaseous Absorption Model implements the latest ITU-RP676-5 model to interrogate environmental factors that can affect the performance of the RF link as the link passes through earth's atmosphere. The following two options were used in the model.

- Fast approximation method: Uses an empirical curve-fit model valid over the 1-350 GHz frequency range.
- Seasonal/regional atmosphere method: Uses a season and latitude-dependent model.

This ITU model is effective for ground-to-air based scenarios since it is valid to a maximum height of 100 km; all scenarios analyzed are below this height. The fast approximation method was used since the frequency is between 1-350 GHZ. The Seasonal/regional atmospheric method was also used.

2.2.4 Atmospheric Refraction Model: Effective Radius Model

The effective radius model approximates the effects of refraction by assuming that the refractive index decreases linearly with altitude. This is only valid for objects at a low altitude of less than 8-10 km. This approximation leads to a very simple formula for the refracted elevation angle that is akin to computing the elevation angle relative to a scaled Earth surface. The Earth's radius is scaled by the effective radius factor, typically a value between 0.3 and 2 — the most common value is 4/3. (Previous versions of STK used the term "4/3 Earth Radius model" and did not allow the user to set the effective radius directly.) Note that the model does not provide a manner for computing the effect of refraction on the signal path length.

2.2.5 TIREM 3.20

The TIREM adds increased fidelity to the calculation and dynamic modeling of point-to-point and LOS effects for link performance in STK/Communications.

2.2.6 Antenna and Antenna Masks

Antennas are a key component of any communication system. Within STK, there is an ability to put antennas on aircraft and then model the masking of the airframe on the antenna. Realistic antenna patterns were used in this study. The frequencies used in this study were the Radio Spectrum Bands: C band (5 GHz) and Ku band (11 GHz and 14 GHz).

The AzEl (azimuth-elevation) Mask tool restricts visibility of RF links to all surrounding areas of a sensor. The term body masking refers to LOS obstruction caused by the three dimensional model of the parent object of the sensor or other objects in the scenario.

For LOS links, antenna placement on the UA were actual locations identified by the vendor. However, if said identification was unavailable, an antenna was placed on the top and bottom of the UA. For BLOS links, a high gain antenna was used. It was pointed toward the satellite. Likewise, the antenna placed on the satellite was a high gain antenna pointing to the UA. The GCS also had a directional antenna pointing to the UA.

Antennas placed on any UA are blocked due to the masking of the aircraft body on the antenna pattern. STK can calculate this masking and "block" out any communications from the antenna to the other end of the communication link. Figure 5 shows the mask of a top antenna (red) and bottom antenna (yellow).

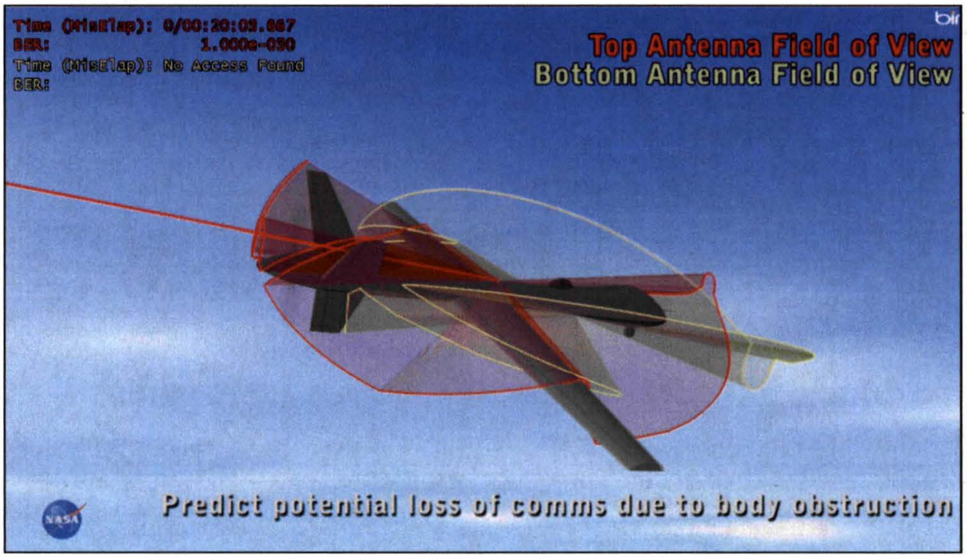


Figure 5. Top and Bottom Antenna Mask

2.2.7 Radio Link Budget

Successful design of radio links involves many factors. A top level link budget analysis is a straightforward exercise and is the first step in determining the feasibility of any given radio system. A link budget calculation is a means to understand the various factors which can be traded off to realize a given cost and level of reliability for a particular communication system. The analysis was done for QPSK modulation with convolutional coding. Energy per bit over noise power spectral density (Eb/No) is how much energy is needed for a specific modulation at a specific Bit Error Rate (BER). This is shown graphically in Figure 6, which shows that for the required BER of 10^{-5}, the Eb/No is 6.5 dB.

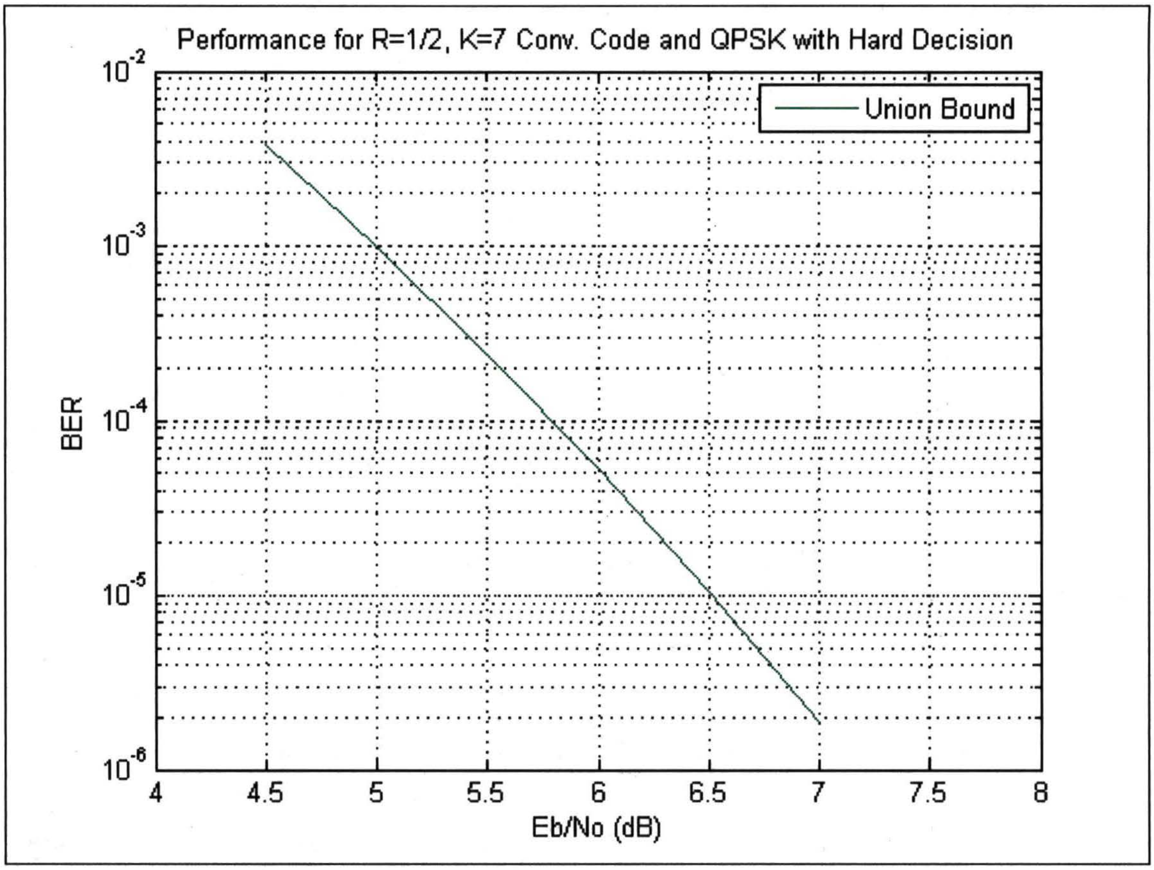


Figure 6. Required Eb/No for a Specific BER Using QPSK with Convolutional Coding

The RF link budgets in Table 2 (Link Margin for LOS) were taken from a MITRE report titled "Link Budgets for Terrestrial UA Control Communications Links" [6]. The LOS link margin, presented in Table 2, is the LOS link margin calculated for a 25 nm range. This value was used in the RTCA document on availability [4] and therefore was used in this analysis. The result of the link analysis shows a total excess margin of 18.5 dB for ground to UA and 6.5 dB for UA to ground.

Table 3 shows the link budget for the BLOS links. The BLOS link has two separate RF links to send the command from the GCS to the UA and two separate RF links for the telemetry from the UA back to the GCS. For long distances the satellite works as a relay sending the command and telemetry over the horizon, where a LOS link would be blocked by the curvature of the Earth for.

- The command link is considered an uplink from the GCS to satellite, then Satellite to UA.
- The telemetry link is considered a downlink from UA to Satellite, then Satellite to the ground station.

As to be expected, the link from the GCS, with its large antenna, was more robust than the link from the satellite to the UA. The excess margin was 21.2 dB for the ground to satellite and -0.65 dB for the satellite to UA. This -0.65 dB barely lowered the BER of 10^{-5}. [2]

Table 4 is the link margin for the telemetry link of BLOS. The excess margin was 11.88 dB for the UA to satellite and 15.14 dB for the satellite to GCS.

Table 2. Link Margin for LOS

	Command	Telemetry
	Ground to UA	UA to Ground
Transmit Power (dBm)	30	32
Transmit Antenna Gain (dB)	28	-10
Transmit Cable Loss (dB)	-2	-2
Transmit EIRP	56	20
Path Loss (dB) (5 GHz, 25 nm)	-138	-138
Atmospheric Loss Margin (dB)	0	0
Multipath Loss Margin (dB)	-20	-20
Receiver Antenna Gain (dB)	-10	28
Receiver Cable Loss (dB)	-2	-2
Received Signal Power (dBm)	-94	-92
Thermal Noise @290 K	-174	-174
Receiver NF (dB)	2	2
Receiver BW (dBHz) (20khz & 320Khz)	43	55
Receiver Noise Power (dBm)	-129	-117
Carrier-to-Noise Ratio (C/N)(dB)	35	23
Implemented Loss Margin	-4	-4
Safety Margin (dB)	6	6
Required C/N (dB) with Convolution Code	12.5	12.5
Excess Margin (dB)	18.5	6.5

Table 3. Link Margin for BLOS Command

	Command 14 GHz	Command 11GHz
	Ground to Satellite	Satellite to UA
Transmit Power (dBm)	21.5	9.2
Transmit Antenna Gain (dB)	59.1	38.2
Transmit Cable Loss (dB)	-2.14	-3.86
Transmit EIRP	78.46	43.54
Path Loss (dB) (5 GHz, 25 nm)	-208.46	-207.17
Atmospheric Loss Margin (dB) Rain	0	0
Receiver Antenna Gain (dB)	39.3	40.08
Receiver Cable Loss (dB)	-1	-0.5
Received Signal Power (dBm)	-91.7	-124.05
Thermal Noise @290 K	-174	-174
Receiver NF (dB)	11.6	1.1
Receiver BW (dBHz) (20khz & 320Khz)	43	43
Receiver Noise Power (dBm)	-119.4	-129.9
Carrier-to-Noise Ratio (C/N)(dB)	27.7	5.85
Implemented Loss Margin	0	0
Required C/N (dB) with Convolution Code	6.5	6.5
Excess Margin (dB)	21.2	-0.65

Table 4. Link Margin for BLOS Telemetry

	Telemetry 14GHz	Telemetry 11GHz
	UA to Satellite	Satellite to GCS
Transmit Power (dBm)	38.9	17.62
Transmit Antenna Gain (dB)	39.67	38.2
Transmit Cable Loss (dB)	-4.17	-2.17
Transmit EIRP	74.4	53.65
Path Loss (dB) (5 GHz, 25 nm)	-209.55	-206.51
Atmospheric Loss Margin (dB) Rain	0	0
Receiver Antenna Gain (dB)	39.7	57.6
Receiver Cable Loss (dB)	-4.17	-1
Received Signal Power (dBm)	-99.62	-96.26
Thermal Noise @290 K	-174	-174
Receiver NF (dB)	1	1.1
Receiver BW (dBHz) (20khz &320Khz)	55	55
Receiver Noise Power (dBm)	-118	-117.9
Carrier-to-Noise Ratio (C/N)(dB)	18.38	21.64
Implemented Loss Margin	0	0
Required C/N (dB) with Convolution Code	6.5	6.5
Excess Margin (dB)	11.88	15.14

2.2.8 Verify Link Budgets with STK and Rain Rates

Microwave signals propagating through the atmosphere are attenuated by vapor, fog, oxygen, rain, and several other gases. The most severe attenuation is caused by rain. An ITU-R rain model based on the most recent revision of ITU-R recommendation, ITU-R P.618, was used for calculating rain attenuation of the RF link. Higher frequency RF Links has higher rain attenuation for the same rain rate. When the rain rates increase, the attenuation due to rain also increases. The LOS links are at 5 GHz and are not affected enough by rain to analyze in this report; the attenuation is close to 0.01 dB. The BLOS links are at 11 GHz and 14 GHz and the RF Link analysis is shown in the previous section. Rain does affect these higher frequency links, the following section will discuss how the BLOS are affected by rain.

In Table 5 and Table 6 below, show the rain attenuation for the BLOS links at 14 GHz (command uplink from ground to satellite) and 11 GHz (command downlink from satellite to UA). The rain analysis was done for rain rates of 10 mm/hr, 50 mm/hr., and 90 mm/hr.

Table 5. Link Budget with Rain Calculation Control Station to Satellite

14 GHz Command From Ground to GEO				
	STK	ITU-R P618-9		
	Ground to Satellite	Rain 10mm/hr	Rain 50mm/hr	Rain 90mm/hr
Transmit Power (dBm)	21.5	21.5	21.5	21.5
Transmit Antenna Gain (dB)	59	59	59	59
Transmit Cable Loss (dB)	-2	-2	-2	-2
Transmit EIRP	78.5	78.5	78.5	78.5
Path Loss (dB) (5 GHz, 25 NM)	-207.03	-207.03	-207.03	-207.03
Atmospheric Rain Loss 5Km Ceiling 99.9% availability	0	-1.3	-4.8	-7
Receiver Antenna Gain (dB)	40.2	40.2	40.2	40.2
Receiver Cable Loss (dB)	-1	-1	-1	-1
Received Signal Power (dBm)	-89.33	-90.63	-94.13	-96.33
Thermal Noise @ 290 K	-174	-174	-174	-174
Receiver NF (dB)	11.6	11.6	11.6	11.6
Receiver BW (dBHz) (20khz & 320khz) 10*log (hz)	43.0103	43.0103	43.0103	43.0103
Receiver Noise Power (dBm)	-119.39	-119.39	-119.39	-119.39
Carrier-to-Noise Ratio (C/N)(dB)	30.0597	28.7597	25.2597	23.0597
Implemented Loss Margin	0	0	0	0
Required C/N (dB) with Convolution Code	6.5	6.5	6.5	6.5
Excess Margin (dB)	23.55	22.25	18.759	16.55

Table 6. Link Budget with Rain Calculation Satellite to UA

11 GHz Command GEO to UA		ITU-R P618-9		
	Satellite to UA	**Rain 10mm**	**Rain 50mm**	**Rain 90mm**
Transmit Power (dBm)	9.2	9.2	9.2	9.2
Transmit Antenna Gain (dB)	38.2	38.2	38.2	38.2
Transmit Cable Loss (dB)	-3.86	-3.86	-3.86	-3.86
Transmit EIRP	43.51	43.51	43.51	43.51
Path Loss (dB) (5 GHz, 25 NM)	-205.36	-205.36	-205.36	-205.36
Atmospheric Rain Loss 5Km Ceiling 99.9% availability	0	-0.7543	-3.0078	-4.5687
Receiver Antenna Gain (dB)	40.54	40.54	40.54	40.54
Receiver Cable Loss (dB)	-0.5	-0.5	-0.5	-0.5
Received Signal Power (dBm)	-121.81	-122.56	-124.82	-126.38
Thermal Noise @ 290 K	-174	-174	-174	-174
Receiver NF (dB)	1.1	1.1	1.1	1.1
Receiver BW (dBHz) (20khz & 320Khz) 10*log (hz)	43	43	43	43
Receiver Noise Power (dBm)	-129.9	-129.9	-129.9	-129.9
Carrier-to-Noise Ratio (C/N)(dB)	8.09	7.3357	5.0822	3.5213
Implemented Loss Margin	0	0	0	0
Required C/N (dB) with Convolution Code	6.5	6.5	6.5	6.5
Excess Margin (dB)	1.59	0.8357	-1.4178	-2.9787

Error! Reference source not found. shows the results of rain attenuation on the command link. As can be seen, the 14 GHz link has higher attenuation for a given rain rate than the 11GHz link. The excess margin is shown here also. The 11 GHz link's excess margin, with no rain, was only 1.59 dB because of the lower transmitter power and smaller antenna gain from the satellite compared to the higher transmitter power and larger gain on the GCS. Thus, when rain attenuation is added to the link, the excess margin is lost for the 50 mm/hr. rain rate (margin of -1.42 dB) and 90 mm/hr. rain rates (margin -2.9 dB). The 14 GHz link maintains the margin even at the high rain rates, since this link started with an excess margin of 23.55 dB.

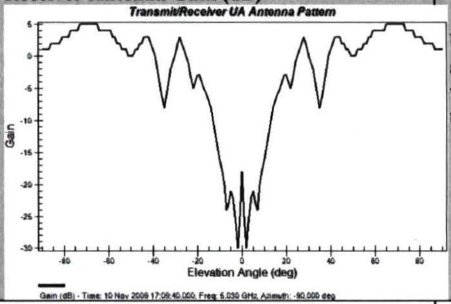
Table 7. Results of Rain Attenuation on the Command Link

			ITU-R P618-9		
		No Rain	Rain 10mm	Rain 50mm	Rain 90mm
11 GHz	**Atmospheric Rain Loss 5Km Ceiling 99.9% availability**	0	-0.7543	-3.0078	-4.5687
	Excess Margin (dB)	1.59	0.8357	-1.4178	-2.9787
14 GHz	**Atmospheric Rain Loss 5Km Ceiling 99.9% availability**	0	-1.3	-4.8	-7
	Excess Margin (dB)	23.55	22.25	18.759	16.55

2.2.9 Comparison of STK to RTCA Report and Real Flight Data

To ensure STK was the right tool and that the proper link budgets were used, it was important to compare the simulated results against real data. The RTCA link budget report [7] was compared to the results in STK. In addition, a test flight was conducted. This real flight data was made available for analysis. T8 shows the comparison of the RTCA link budget report to STK. Figure 7 shows the real flight data compared to the STK scenario results.

Table 8. RTCA Link Budget Report to STK Comparison

	REPORT		**STK**
	Ground to UA		**Ground to UA**
Transmit Power (dBm)	30	**Transmit Power (dBm)**	30
Transmit Antenna Gain (dB)	28	**Transmit Antenna Gain (dB)**	28
Transmit Cable Loss (dB)	-2	**Transmit Cable Loss (dB)**	-2
Transmit EIRP	56	**Transmit EIRP**	56
Path Loss (dB) (5 GHz, 25 nm)	-138	**Path Loss (dB) (5 GHz, 19 nm)**	-135
Atmospheric Loss Margin (dB)	0	**Atmospheric Loss Margin (dB)**	0
Multipath Loss Margin (dB)	0	**Multipath Loss Margin (dB)**	0
Receiver Antenna Gain (dB)	-10	**Receiver Antenna Gain (dB)** 	-5 Used -5 here as a typical value during the flight.
Receiver Cable Loss (dB)	-2	**Receiver Cable Loss (dB)**	-2
Received Signal Power (dBm)	-94	**Received Signal Power (dBm)**	-86
Thermal Noise @290 K	-174	**Thermal Noise @290 K**	-174
Receiver NF (dB)	2	**Receiver NF (dB)**	2
Receiver BW (dBHz) (20khz)	43	**Receiver BW (dBHz) (20khz)**	43
Receiver Noise Power (dBm)	-129	**Receiver Noise Power (dBm)**	-129
Carrier-to-Noise Ratio (C/N)(dB)	35	**Carrier-to-Noise Ratio (C/N)(dB)**	43
Implemented Loss Margin	-4	**Implemented Loss Margin**	-4
Safety Margin (dB)	6	**Safety Margin (dB)**	6
Required C/N (dB) with Convolution Code	12.5	**Required C/N (dB) with Convolution Code**	12.5
Excess Margin (dB)	18.5	**Excess Margin (dB)**	26.5

The excess margin for the calculated link is 18.5 dB from the RTCA Link Budget report, whereas using STK the calculated excess margin is 26.5 dB. The total difference is 8 dB and can be explained by the following: STK used an antenna gain of -5 dB and the RTCA report used -10 dB for the antenna gain a difference of 5 dB. The RTCA report had a path of 25 Nautical miles which yielded a loss of 138 db and STK had a path of 19 nautical miles and a loss of 135 dB a difference of 3 dB..

A scenario was set up in STK that mirrored the test flight. Antenna patterns were modeled based on real antennas and the transmitters and receivers were modeled based on real hardware. The antenna pattern for the receive antenna is shown in Table 7. The simulated GCS was modeled after the real GCS. Global Positioning System coordinates were taken at the site and used for the simulation. Figure 7 shows a comparison of the flight test data compared to the simulated data.

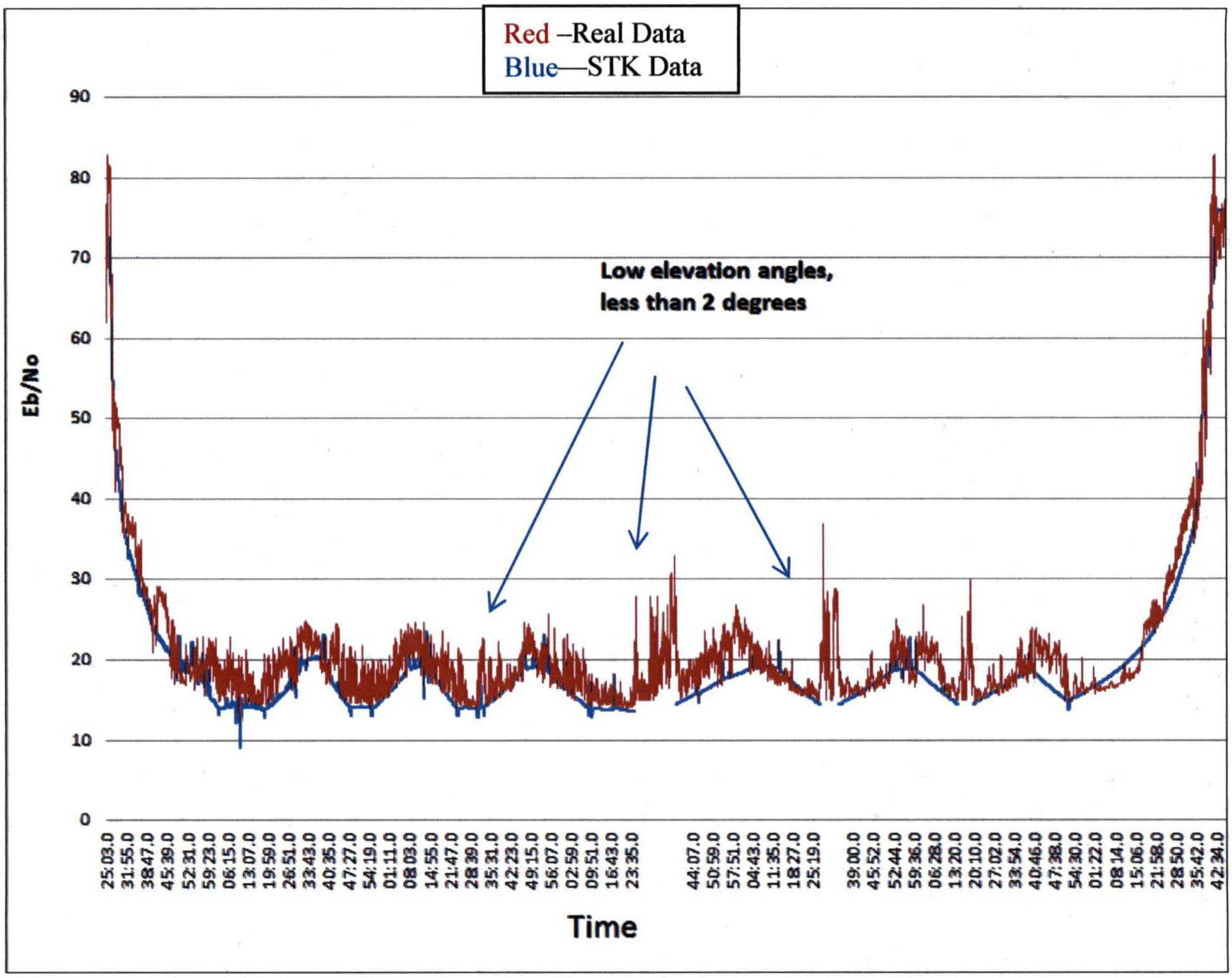


Figure 7. Real Flight Data Compared to STK Simulated Data

The propagation model used in STK is ITU-R-P676-5. This model implements the latest update to the ITU-R atmospheric absorption loss model. The maximum height for this model is 100 km.

The flight path was such that the UA went down range and performed six box maneuvers, which correspond to the six peaks and valleys in the graph. At the start of the flight, the comparison between the two sets of data shows no difference. As the UA goes down range, the STK data (blue) does not fluctuate while the real data (red) has fluctuations of about 5 dB. It is normal for an RF link to vary. This is called fading. Fading is caused by reflections and absorptions as the radio wave moves along its path. The larger fluctuation did not occur until the UA was down range and at a low elevation angle to the GCS; this was probably due to reflections off the body of the UA.

When the UA was far down range at lower elevation angles, the STK data dropped out, while the real data did not drop out but had many errors (shown in Figure 7 as large spikes). All of the drop outs occurred over a very large range of 163 km and where the elevation angle was less than 1°.

Overall, the STK data followed that of the real data but at a lower level. This was probably due to either a lower antenna gain or lower transmitter power in the STK model compared to the real antenna gain or real transmitter power.

STK propagation models were in line with the real test data. The rest of the report is based on the STK modeling of the RF links. This comparison provides confidence that the results in this report are accurate.

2.2.10 Assumptions

This report details the RF communications links of UAS in the NAS as different scenarios described in the OSED. Real world modeling of RF communication systems is very complex and time-consuming. This report does not analyze the lower levels of a communication system such as data protocols or data formatting.

Assumptions within this report follow:

- Antenna patterns were modeled with realistic external files imported into STK
- Antenna locations were placed on top and bottom center of the UA and provided locations from vendors and online diagrams
- The link budgets were modeled with a -5 dB gain for worst case nulls.
- All nine aircraft were modeled with the same flight dynamics. This is a time-consuming process and for this report the authors did not think the flight dynamics would change the communications links
- The link budgets are based on inputs from the RTCA's SC203 CC WG2's paper: "UAS Control and Communications Link Performance – Availability." [4]
- Rain rates used were none, 1 mm/hr., 10 mm/hr., 50 mm/hr., and 90 mm/hr.

2.2.11 Limitations

Modeling radio communications has many variables that are not being considered in this analysis, such as refraction of the UAS body and multipath, which are too complex to model in a timely manner. In most radio communications modeling, a link margin is added to compensate for items that cannot be modeled very well. Thus, for land mobile communications, there is an additional 30 dB added to the link for margin. The following links have a 6 dB Link Margin for the LOS links. Satellite to stationary ground links are very well understood and usually only have a margin of a couple of dB. This report had no link margin for BLOS.

Another limitation is the handoff from LOS to BLOS or links between UA and multiple GCS. This report does not cover these types of situations. Handoffs are important because there are human-in-the-loop delays that could influence the delivery of command and control signals to a UA. An example of this type of delay is the intentional handoff between two GCS creating an actual lost link. It is possible to model this type of scenario within fast-time simulations and include human delays within the results. Further investigation is required to determine the different types of hand-offs within the UAS, human delays, and delay values.

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3 Scenario Analysis

The following scenario analysis is based on STK physics-based software geometry engine version 9.2.2. STK. STK's internal analysis algorithms accurately take into account time dynamics for all scenario objects (e.g., UA, aircraft, and satellites) based on position, orienttion, and propagation algorithms. For this study, external models were used for all transmitters, receivers, and antenna patterns based on commercial off the shelve hardware. The antenna patterns were used in all nine scenarios. See Figure 8 for an overview of the RF links, LOS, BLOS, and corresponding antenna patterns.

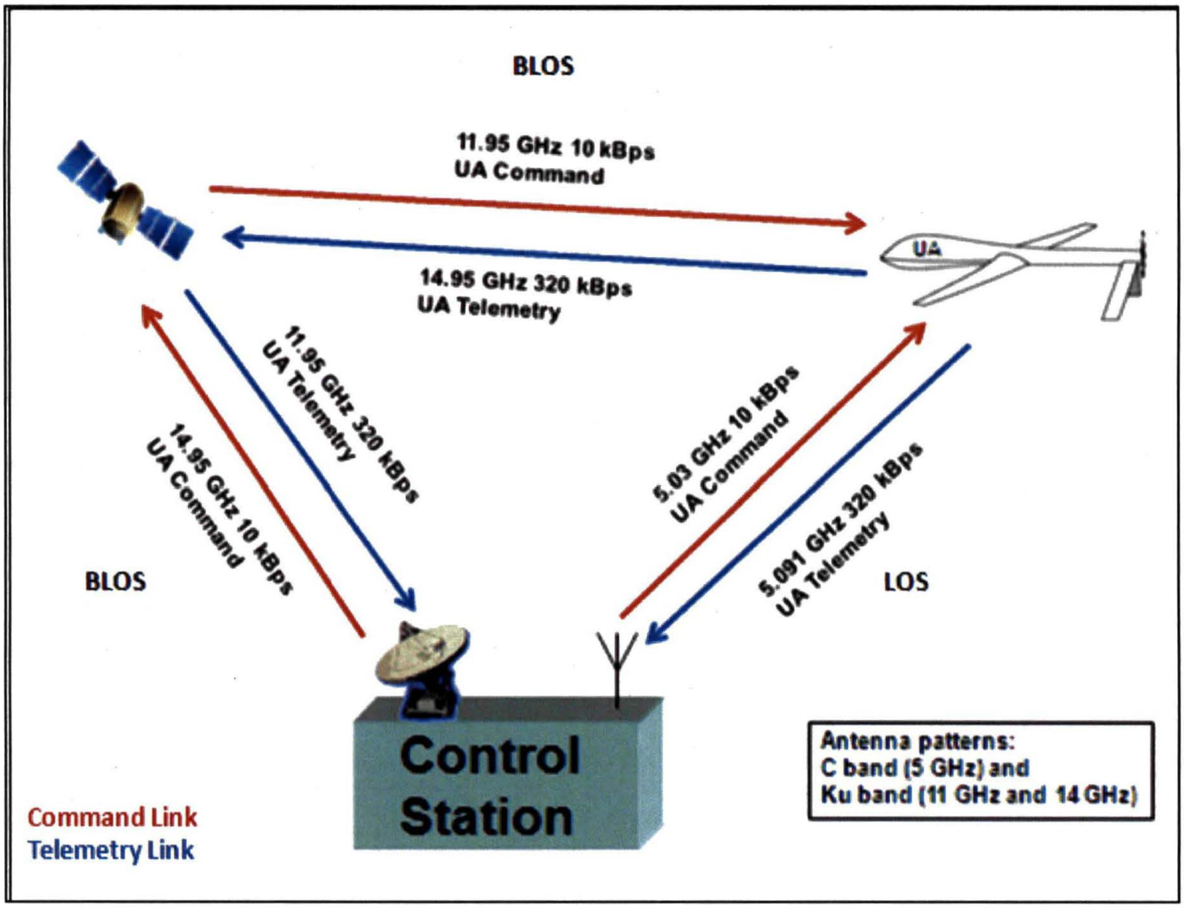


Figure 8. Overview of RF Links

The scenario results consist of the following analysis:

- Access Time
    - The Access Time Tool determines when two or more objects are able to "see" each other, be it LOS or RF communications that can go over the horizon.
    - The use of constraints applied to the link between objects provides additional fidelity to the results. These constraints are defined as properties of the objects between which access is being calculated.

  - The light time delay and directionality of the signal transmission are considered when computing the times between objects.
  - The effect of refraction is also considered for objects during access/analysis computation. Atmospheric Absorption model ITU-R P676-5 was used as a global value for all nine scenarios.

- Gap Analysis
  - Determines the time intervals during the scenario when at least one point does not have access between the assigned objects.
- Bit Error Rate
  - BER is the probability (bits in error divided by total number of bits sent) that a bit is in error (i.e., a zero is transmitted but a one is received).
  - STK uses table lookup from a .mod file to extract a BER given an Eb/No. STK interpolates the table, as necessary, to determine the appropriate BER for a particular bit energy level.
- Link Budget Analysis
  - A link budget report can include many link parameters associated with the selected receiver or transmitter. For this analysis, the link budget results consist of the results for three parameters: Effective Isotropic Radiated Power (EIRP), Eb/No, and EBR.
  - Transmitter EIRP: This is the signal strength at the output transmitter. This value is the product of the transmitter power and the transmitter gain in the link and direction with the inclusion of user-defined post-transmit gains and losses. Unit of measure is dBM.
  - Receiver Eb/No: Receive signal strength. The energy per bit to noise ratio (Eb/No), where Eb is the EPB and No = kT (Boltzmann's constant * system temperature).
- Availability
  - Availability is a Required Communication Performance. The probability that the communication system between the two parties is in service when it is needed.

3.1 Overall Results

LOS and BLOS link availability was calculated for all nine scenarios. For the non-rain links, the BLOS links were constant and never dropped out, thus the availability was 100%. For the rain analysis of the BLOS, the 14 GHz links stayed above the link margin and also had 100% availability. The 11 GHZ BLOS links for the 50 mm/hr. rain rate had 4.5 dB Eb/No, availability of about 50%. For the 90 mm/hr. rain rate, the Eb/No was 3.6 dB, while the availability of about 0% was due to the large amount of errors. Tables 9.1 and 9.2, along with Tables 10.1 and 10.2, summarize the LOS link availability for the eight scenarios that had LOS links (only Scenario 7 did not have an LOS link). The LOS availability for command and telemetry links was almost identical due to the fact that they both used the same antenna. The loss of the RF link was due to blockage of the airframe from the antenna on the UA to the antenna on the GCS. For the command links, the worst availability was 99.57%. For the telemetry links, the worst availability was 99.78%. All of the gaps were due to blockage and not due to the signal falling below the required 12.5 dB.

Table 9.1 LOS Scenario Gap Analysis – Scenarios 1-4 Command

COMMAND	Scenario 1		Scenario 2		Scenari0 3	UA1	UA2		Scenario 4	
	Bottom	Top	Left	Right	Bottom	Top	Bottom	Top	Bottom	Top
Total Scenario Time (Sec)	4366.739	4366.739	7684.832	7684.832	52853.13	52853.1	52578.689	52578.7	8229.955	8229.955
Total Number of Gaps	8	12	8	7	124	231	119	229	12	13
Minimum Gap Duration (Sec)	0.035	0.039	0.01	2.149	0.132	0.076	0.132	0.071	2	0
Maximum Gap Duration (Sec)	198.556	4.3	4.329	13.071	75	817.369	51	817.132	41	2879
Average Gap Duration (Sec)	26.914	1.795	1.062	6.634	9.464	220.915	8.948	205.988	13.667	591.462
Total Gap Duration (Sec)	215.315	21.539	8.5	46.441	1173.501	51031.3	1064.814	47171.2	164	7689
Gaps < 1 Second	2	6	6	0	11	66	8	69	0	1
Gaps 1-2 Seconds	1	2	0	0	0	47	2	49	2	0
Gaps 2-4 Seconds	2	3	1	3	6	0	4	0	4	0
Gaps 4-8 Seconds	2	1	1	2	25	4	27	7	0	0
Gaps 8-15 Seconds	0	0	0	2	77	2	76	0	1	0
Gaps 15-30 Seconds	0	0	0	0	4	0	1	0	3	1
Gaps 30-60 Seconds	0	0	0	0	0	3	1	0	2	1
Gaps > 60 Seconds	1	0	0	0	1	109	0	104	0	10
Availability (%)	95.069	99.507	99.889	99.396	97.78	3.447	97.975	10.285	98.007	6.573
	Combined 100%		Combined 100%		Combined 99.566%				Combined 99.866%	

Table 10.2 LOS Scenario Gap Analysis – Scenarios 5-9 Command

COMMAND	Scenario 5		Scenario 6		7	Scenario 8		Scenario 9	
	Bottom	Top	Bottom	Top	No LOS	Bottom	Top	Bottom	Top
Total Scenario Time (Sec)	4879.721	4879.721	1212.977	1212.977		12527.242	12527.242	21400	21400
Total Number of Gaps	4	3	3	2		2	2	3	7
Minimum Gap Duration (Sec)	0.026	0.001	0.637	10		4.41	2.554	6	34
Maximum Gap Duration (Sec)	15	1739	248.58	39		1123.012	1352.101	1010	9080
Average Gap Duration (Sec)	4.83	638.667	87.08	24.5		563.711	677.328	372.333	2633.857
Total Gap Duration (Sec)	19.321	1916.001	261.24	49		1127.422	1354.655	1117	18437
Gaps < 1 Second	2	1	1	0		0	0	0	0
Gaps 1-2 Seconds	0	0	0	0		0	0	0	0
Gaps 2-4 Seconds	1	0	0	0		0	1	0	0
Gaps 4-8 Seconds	0	0	0	0		1	0	1	0
Gaps 8-15 Seconds	1	0	1	1		0	0	0	0
Gaps 15-30 Seconds	0	0	0	0		0	0	0	0
Gaps 30-60 Seconds	0	0	0	1		0	0	0	1
Gaps > 60 Seconds	0	2	1	0		1	1	2	6
Availability (%)	99.604	60.735	78.463	95.96		91	89.186	94.78	13.846
	Combined 100%		Combined 99.94%			Combined 100%		Combined 100%	

Table 11.1 LOS Scenario Gap Analysis – Scenarios 1-4 Telemetry

TELEMETRY	Scenario 1		Scenario 2		Scenario3	UA1	UA2		Scenario 4	
	Bottom	Top	Left	Right	Bottom	Top	Bottom	Top	Bottom	Top
Total Scenario Time (Sec)	4366.739	4366.739	7684.832	7684.832	52853.13	52853.1	52578.689	52578.7	8229.955	8229.955
Total Number of Gaps	7	13	8	7	125	231	119	231	12	13
Minimum Gap Duration (Sec)	0.022	0.04	0.01	2.149	0.132	0.076	0.132	0.071	2	0
Maximum Gap Duration (Sec)	198.558	4.251	4.329	13.072	73.117	816.744	49.781	816.587	41	2879
Average Gap Duration (Sec)	30.422	1.832	1.062	6.635	8.507	220.6	8.058	203.902	13.667	591.462
Total Gap Duration (Sec)	212.954	23.814	8.5	46.444	1063.329	50958.7	958.908	47101.5	164	7689
Gaps < 1 Second	2	6	6	0	12	66	10	69	0	1
Gaps 1-2 Seconds	1	3	0	0	0	47	0	49	2	0
Gaps 2-4 Seconds	1	3	1	3	13	0	13	0	4	0
Gaps 4-8 Seconds	2	1	1	2	21	4	19	7	0	0
Gaps 8-15 Seconds	0	0	0	2	74	2	75	0	1	0
Gaps 15-30 Seconds	0	0	0	0	4	0	1	0	3	1
Gaps 30-60 Seconds	0	0	0	0	0	3	1	0	2	1
Gaps > 60 Seconds	1	0	0	0	1	109	0	106	0	10
Availability (%)	95.123	99.455	99.889	99.396	97.988	3.584	98.176	10.417	98.007	6.573
	Combined 100%		Combined 100%		Combined 99.777%				Combined 99.866%	

Table 12.2 Continue LOS Scenario Gap Analysis - Scenarios 5-9 Telemetry

TELEMETRY	Scenario 5		Scenario 6		7	Scenario 8		Scenario 9	
	Bottom	Top	Bottom	Top	No LOS	Bottom	Top	Bottom	Top
Total Scenario Time (Sec)	4880.042	4880.042	1212.977	1212.977		12527.242	12527.242	21400	21400
Total Number of Gaps	4	3	2	2		2	2	4	7
Minimum Gap Duration (Sec)	0.289	0.001	10	10		4.41	2.557	5.626	32.681
Maximum Gap Duration (Sec)	15	1739	39	39		1122.214	1351.11	1008.224	9078.021
Average Gap Duration (Sec)	4.908	638.667	24.5	24.5		563.312	676.834	294.268	2632.826
Total Gap Duration (Sec)	19.634	1916.001	49	49		1126.624	1353.667	1177.07	18429.78
Gaps < 1 Second	2	1	0	0		0	0	0	0
Gaps 1-2 Seconds	0	0	0	0		0	0	0	0
Gaps 2-4 Seconds	1	0	0	0		0	1	0	0
Gaps 4-8 Seconds	0	0	0	0		1	0	1	0
Gaps 8-15 Seconds	1	0	1	1		0	0	0	0
Gaps 15-30 Seconds	0	0	0	0		0	0	0	0
Gaps 30-60 Seconds	0	0	1	1		0	0	0	1
Gaps > 60 Seconds	0	2	0	0		1	1	3	6
Availability (%)	99.598	60.738	95.96	95.96		91.007	89.194	94.5	13.88
	Combined 100%		Combined 100%			Combined 100%		Combined 100%	

3.2 Scenario Results

The following subsections provide a written description of the scenarios and the results. Section 3.2.1 contains supporting figures and tables. All other figures and tables for Scenarios 2 through 9 will be contained in Volume 2 of 2 of this report.

3.2.1 Scenario 1 Results

OSED Scenario 1 demonstrates the use of a UAS for the support of a law enforcement operation. In this scenario, a Raven — a small, hand-launched, electrically-powered, fixed wing UAS — supports a police operation in the Los Angeles area. The scenario assumes that the UAS is integrated into a specially equipped UAS air unit police cruiser. The officers, consisting of a pilot and a support person, are trained in the UAS launch, recovery, and operations, which includes communication with ATC.

In this scenario, police are called to investigate a suspect car observed leaving a crime scene. The police are told that the car was last seen near Culver City heading toward the southbound on-ramp to the San Diego Freeway. Officers in the UAS Air Unit police cruiser inform dispatchers that they will launch their UA to begin assisting in the search. Operation of the UA is in Class D airspace below 500 feet MLS (440ft AGL), well below air traffic pattern altitude. The RF command and telemetry links for this scenario consist of LOS between the UA and the GCS (the GCS for this scenario is a stationary police cruiser). The flight consists of a launch and recovery two miles southeast of the Los Angeles International Airport. Areas of interest covered by this scenario include low altitude urban operations, Class D and Class B airspace, special VFR, and random tracking activities.

The analysis for the rest of the report will deal with signal strength in the form of Eb/No and availability, where Eb/No is defined as "the measure of signal to noise ratio for a digital communication system." Availability is defined as "Present and ready for use."

As stated previously, a 6.5 dB Eb/No is needed for a BER of 10^{-5} (see Figure 6). For the LOS, a 6 dB link margin was chosen to overcome fading. Thus, in order to have the link "available," the Eb/No has to be above 12.5 dB (6.5+6). If the Eb/No falls below the required 6.5 dB, the BER gets worse and errors become a problem; this is what happens on cell phones when the voice gets garbled and finally the call drops out. The rest of this section has charts showing the Eb/No for the duration of the flight. Each chart has a line drawn at 12.5 dB Eb/No.

The other consideration for availability is antenna blockage. The antennas that are placed on the aircraft must "see" the ground antenna for LOS or "see" the GEO antenna for BLOS. If the antennas cannot see each other, this is considered a drop out and the link is not available.

Figure 9 shows the results for LOS command while Figure 10 shows the results for LOS telemetry. Both figures show that throughout the flight, there was a very strong link. In Figure 9 and Figure 10 below, there are spikes in the Eb/No as the UA did various banks and pitches; this is due to the antenna pattern gain changing with respect to the GCS. The links are above the necessary 12.5 dB. This is true for both the command as well as the telemetry links shown in Figure 9 and Figure 10 shows a large drop out of the bottom antenna due to blockage of the fuselage.

The telemetry, like the command, stays well above the required 12.5 dB. The telemetry link margin is about 12 dB lower than the command link margin; this is due to the higher data rate of 320 kbps compared to 20 kbps for the command link.

The receiver bandwidths of 20 Khz for command and 320 Khz for telemetry are used in the link calculations. The 20 khz badwidth adds 43 dB of noise to the system while the 320 khz bandwidth adds 55 dB of noise to the system. Thus, the command link has less noise or more link margin than the telemetry link.

Table 13 for the command link shows a total of eight gaps for the bottom antenna and 12 gaps for the top antenna; this provides an availability of 95.07% and 99.51%, respectively. If both antennas are combined, the availability increases to 100%. The top and bottom antenna complement each other; that is, when one antenna loses the signal, the other antenna picks it up. This is called Antenna Diversity, which is defined as "[the use of] two or more antennas to improve the quality and reliability of a wireless link." This report does not go into how the diversity would be implemented.

Table 14 for the telemetry link shows a total of seven gaps for the bottom antenna and 13 gaps for the top antenna; this provides availability of 95.12% and 99.46%, respectively. If both antennas were to be set up as a diversity system, the availability would increase to 100%. This mirrors the command link.

Table 15 and Table 16 show what the UA was doing when there were gaps in the link. As can be seen, all of the drop outs were due to the maneuvering of the UA.

To summarize, all links were above the 12.5 dB Eb/No required. All links had 100% availability.

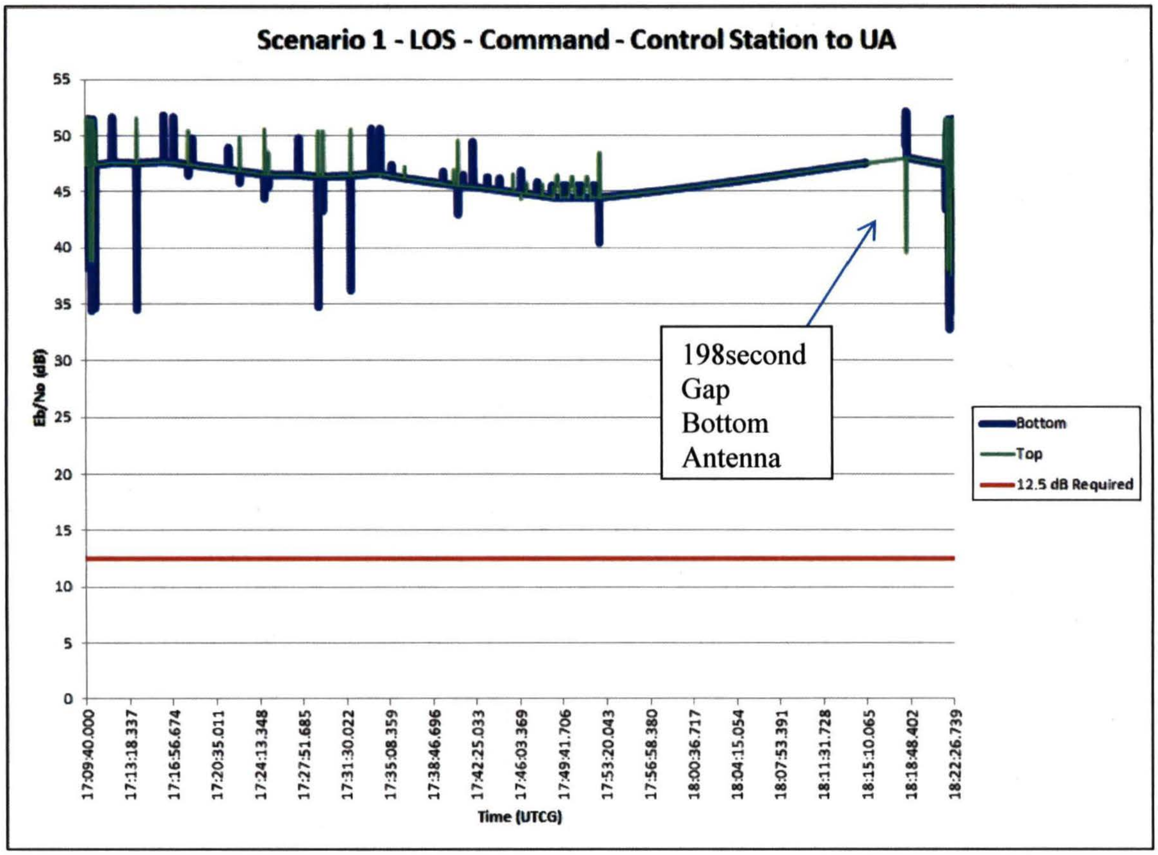
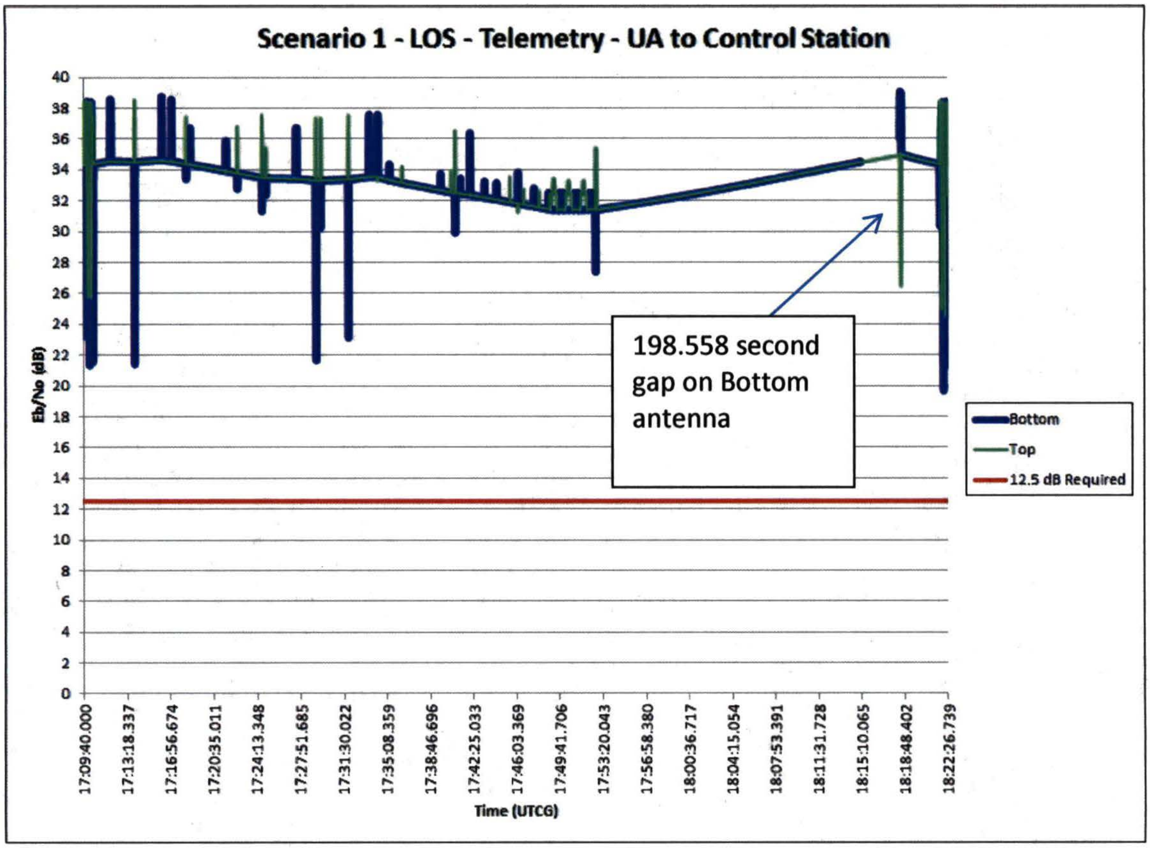


Figure 9. LOS - Command - Control Station to UA

Table 13. Scenario 1 - LOS Command - Control Station to UA - Gap Analysis

Scenario 1 - LOS - Command - Control Station to UA - Gap Analysis			
	Bottom	Top	Combined Gap Overlap
Total Scenario Time (Sec)	4366.739	4366.739	4366.739
Total Number of Gaps	8	12	0
Minimum Gap Duration (Sec)	0.035	0.039	0
Maximum Gap Duration (Sec)	198.556	4.3	0
Average Gap Duration (Sec)	26.914	1.795	0
Total Gap Duration (Sec)	215.315	21.539	0
Gaps < 1 Second	2	6	0
Gaps 1-2 Seconds	1	2	0
Gaps 2-4 Seconds	2	3	0
Gaps 4-8 Seconds	2	1	0
Gaps 8-15 Seconds	0	0	0
Gaps 15-30 Seconds	0	0	0
Gaps 30-60 Seconds	0	0	0
Gaps > 60 Seconds	1	0	0
Availability (%)	95.07%	99.51%	100



198.558 second gap on Bottom antenna

Figure 10. Scenario 1 – LOS - Telemetry - UA to Control Station

Table 14. Scenario 1 - LOS - Telemetry - UA to Control Station - Gap Analysis

	Bottom	Top	Combined Gap Overlap
Total Scenario Time (Sec)	4366.739	4366.739	4366.739
Total Number of Gaps	7	13	0
Minimum Gap Duration (Sec)	0.022	0.04	0
Maximum Gap Duration (Sec)	198.558	4.251	0
Average Gap Duration (Sec)	30.422	1.832	0
Total Gap Duration (Sec)	212.954	23.814	0
Gaps < 1 Second	2	6	0
Gaps 1-2 Seconds	1	3	0
Gaps 2-4 Seconds	1	3	0
Gaps 4-8 Seconds	2	1	0
Gaps 8-15 Seconds	0	0	0
Gaps 15-30 Seconds	0	0	0
Gaps 30-60 Seconds	0	0	0
Gaps > 60 Seconds	1	0	0
Availability (%)	**95.123**	**99.455**	**100**

Table 15. Scenario 1 - LOS - Command Telemetry - Control Station to UA - Gap Analysis - Bottom

Gap Start Time (UTCG)	Gap End Time (UTCG)	Gap Duration (Sec)	Blockage
10 Nov 2009 17:09:40.057	10 Nov 2009 17:09:42.398	2.341	Banking Left
10 Nov 2009 17:10:09.521	10 Nov 2009 17:10:09.556	0.035	Banking Left
10 Nov 2009 17:52:43.882	10 Nov 2009 17:52:49.610	5.728	Banking Right
10 Nov 2009 18:15:06.129	10 Nov 2009 18:18:24.685	198.556	Fuselage Blockage
10 Nov 2009 18:21:47.560	10 Nov 2009 18:21:51.884	4.324	Banking Right
10 Nov 2009 18:21:52.258	10 Nov 2009 18:21:52.294	0.036	Nose Blockage
10 Nov 2009 18:22:04.304	10 Nov 2009 18:22:07.406	3.102	Banking Left
10 Nov 2009 18:22:22.740	10 Nov 2009 18:22:23.933	1.193	Banking Left

Table 16. Scenario 1 - LOS - Command/Telemetry - Control Station to UA - Gap Analysis - Top

Gap Start Time (UTCG)	Gap End Time (UTCG)	Gap Duration (Sec)	Blockage
10 Nov 2009 17:09:47.600	10 Nov 2009 17:09:48.100	0.5	Nose Blockage
10 Nov 2009 17:09:49.600	10 Nov 2009 17:09:49.700	0.1	Nose Blockage
10 Nov 2009 17:11:50.900	10 Nov 2009 17:11:54.800	3.9	Banking Right
10 Nov 2009 17:16:10.800	10 Nov 2009 17:16:14.400	3.6	Banking Right
10 Nov 2009 17:18:33.800	10 Nov 2009 17:18:34.700	0.9	Banking Right
10 Nov 2009 17:21:36.500	10 Nov 2009 17:21:37.100	0.6	Banking Right
10 Nov 2009 17:27:29.500	10 Nov 2009 17:27:31.500	2	Tail Blockage
10 Nov 2009 17:33:35.400	10 Nov 2009 17:33:39.200	3.8	Fuselage Blockage
10 Nov 2009 17:34:17.200	10 Nov 2009 17:34:21.500	4.3	Propeller Blockage
10 Nov 2009 17:42:07.200	10 Nov 2009 17:42:08.800	1.6	Banking Right
10 Nov 2009 18:22:15.600	10 Nov 2009 18:22:15.800	0.2	Banking Left

3.2.2 Scenario 2 Results

OSED Scenario 2 demonstrates the use of a UAS for marine monitoring. In this scenario, a ScanEagle — a small, fixed-wing reciprocating UAS — is used by the Department of Interior (DOI) for a marine fisheries protection and monitoring operation in the Dry Tortugas Marine Sanctuary. The Dry Tortugas National Park is situated within Warning Area W-174B and the Tortugus Military Operations Area (MOA). A DOI patrol vessel stationed at the Key West Naval Air Station Boca Chica (NQX) is responsible for monitoring operations in a radius of approximately 100 nm surrounding NQX. The operations of the UA take place in Class E airspace and are operated under Defense Visual Flight Rules due to its crossing the United States and Cuban Air Defense Identification Zone. The RF command and telemetry links for this scenario consist of both LOS and BLOS. LOS is between the UA and the mobile GCS, which is a moving DOI patrol vessel. BLOS is between the GCS to the satellite and back to the UA. The flight consists of a launch and recovery that takes place aboard the vessel en route to Dry Tortugas Marine Sanctuary.

In Scenario 2, the UA had two antennas placed on the winglets. The results were almost identical from the left or right antenna. All LOS Eb/No were above the required 12.5 dB link. The minimum LOS Eb/No was 37 dB, which is 25 dB above the link margin. The BLOS links were above the necessary 6.5 dB, but were only 5 dB and 2 dB above the margin for command and telemetry BLOS links, respectively.

The availability was high for this scenario. For both the command and telemetry link, there is a 99.89% availability for the left antenna and 99.40% for the right antenna. Like Scenario 1, where the top and bottom antennas were combined through the use of Antenna Diversity, the resulting availability was 100%.

The gap analysis shows why there were drop outs. For this scenario, all drop outs were due to the body of the aircraft blocking the link to the command antenna on the ground. The specific reason for the blockages is shown in the appendix, as are the Eb/No charts. There were no blockages for BLOS and the availability was 100% for BLOS links.

To summarize, all links were above the 12.5 dB Eb/No required. All links had 100% availability.

3.2.3 Scenario 3 Results

OSED Scenario 3 demonstrates the use of a UAS for environmental sensing. In this scenario, an Aerosonde — a medium, fixed-wing reciprocating UAS — supports Environmental Protection Agency (EPA) efforts to monitor coal emissions in the vicinity of Steubenville, Ohio. The mission takes place mid-week while plants are in operation. The EPA plans are for 12 hours of coverage, from 6:00 am to 6:00 pm, using two aircraft simultaneously. Each aircraft flies an incrementally stepped altitude grid, with vertical separation of 500 feet operating on two separate VFR flight plans. The launch and recovery site and controlling stations are based at Jefferson County Airport outside of Steubenville. The flight plans and grid will be coordinated with ATC. The operation of the UA will be conducted at 1,500 to 4,500 feet AGL (3,500 feet to 6,500 feet MSL) in a pattern that allows maximum exposure to smokestacks and coal emissions. The flights will be operated under VFR. The RF command and telemetry links for this scenario consist of both LOS and BLOS, with the BLOS/satellite used as the primary control link due to low altitude requirements and possible LOS issues.

In Scenario 3, the UA had two antennas placed on the top and bottom of the UA; this is the same for both of the two UA. All LOS Eb/No were above the required 12.5 dB link. The Eb/No showed a saw tooth time wave form. This was due to the UA making a continuous box maneuver. First, the UA moved away from the GCS and then back toward the GCS. The minimum LOS Eb/No was 52 dB, which is 40 dB above the link margin needed for the command link.

The telemetry link had a minimum of 37 dB, which is 25 dB more than needed for the minimum link margin. The BLOS links were above the necessary 6.5 dB. For the GCS to the GEO, the minimum Eb/No was 31 dB, well above the necessary 6.5 dB. This was due to the large ground antenna. The command link from the GEO to the UA was only 11.5 dB due to the small receiver antenna on the UA. The telemetry link mirrored the command link for the BLOS but at a lower level due to the higher data rate of the telemetry link.

The availability was high for this scenario. There are two UAs for this scenario with similar but slightly different results for;

For Command

- UA1 had availability of 97.78% for the bottom antenna and 3.45% for the top antenna
- UA2 had availability of 97.98% for the bottom antenna and 10.29% for the top antenna.

For Telemetry

- UA1 had availability of 97.99% for the bottom antenna and 3.48% for the top antenna
- UA2 had availability of 98.18% for the bottom antenna and 10.42% for the top antenna.

When the total combined availability for both UAs is calculate the result is

- Command link 99.57%,
- Telemetry link 99.78%.

This lower availability when compared to the other previous scenarios is due to the constant maneuvering of the UA and the resulting blockage of the body of the UA in relation to the GCS.

The gap analysis shows why there were drop outs. For this scenario, all drop outs were due to the body of the aircraft blocking the link to the command antenna on the ground.

The specific reason for the blockages is shown in the appendix, as are the Eb/No charts. This chart is larger due to the constant box maneuver and body blockage.

There were no blockages for BLOS and the availability was 100% for BLOS links.

To summarize, all links were above the 12.5 dB Eb/No required. The command availability was 99.57% and the telemetry availability was 99.78%.

3.2.4 Scenario 4 Results

OSED Scenario 4 demonstrates the use of a UAS for media and traffic reporting. In this scenario, a Firescout — a large, turbine vertical take-off and landing UAS — supports media and traffic reports in the Denver metropolitan area. The flight takes place during mid-week morning commuting hours. The base of operations is Rocky Mountain Metropolitan Airport, a Class D airport located 10 miles northwest of downtown Denver. The flight route follows predetermined waypoints near major highway intersections. Orbit maneuvers of 15-minute duration are planned at each intersection. Once in flight, adjustments to the flight route are made to cover a developing traffic situation. The RF command and telemetry links for this scenario consist of both LOS and BLOS between the UA and the company-owned GCS.

In Scenario 4, the UA had two antennas placed on the top and bottom of the UA. All LOS Eb/No were above the required 12.5 dB link. The command Eb/No chart shows a typical chart for a UA that goes down range and then returns. The Eb/No started high at 85 dB and then went down to 50 dB for the minimum Eb/No, 37 dB more power than needed to maintain the link margin. The top and bottom antenna had similar results. The telemetry looked the same but with lower power due to the higher data rates.

The BLOS links were above the necessary 6.5 dB for the GCS to the GEO. The minimum Eb/No is 31 dB, well above the required 6.5 dB. This is due to the large ground antenna. The command link from the GEO to the UA was only 11.5 dB due to the small receiver antenna on the UA. The telemetry link mirrored the command link for the BLOS but at a lower level due to the higher data rate of the telemetry link. The UA to GEO has 9 dB Eb/No and the GEO to GCS is 9.7 dB Eb/No.

The availability was high for this scenario. For the command link, the top antenna has an availability of 6.57% and the bottom antenna has an availability of 98.01%. If both antennas are combined, the availability goes to 99.87%. The telemetry link had the same results.

The gap analysis shows why there were drop outs. For this scenario, all drop outs were due to the body of the aircraft blocking the link to the command antenna on the ground. The bottom antenna had 12 gaps and the top antenna had three gaps for the command link and the telemetry links.

The specific reason for the blockages is shown in the appendix, as are the Eb/No charts.

There were no gaps for BLOS and the availability was 100% for all BLOS links.

To summarize, all links were above the 12.5 dB Eb/No required: For LOS, the links availability was 99.87% for both command and telemetry. All BLOS links had 100% availability.

3.2.5 Scenario 5 Results

OSED Scenario 5 demonstrates the use of a UAS for cargo delivery. In this scenario, a Caravan — a turboprop conversion UAS — is used for an air cargo delivery of natural gas replacement parts from a distributor in Sacramento, California to an energy company located near Brawley in southern California. The flight is 440 nm, with two hours and 30 minutes flight time. The UAS is operated by a major cargo delivery company and is supported by dispatchers, a maintenance crew, a ground operational crew, and communications specialists referred to as support element personnel. These personnel are both company and contract workers based throughout the United States. The main operations center, including the pilot's GCS and all control communications and dispatch facilities for the flight, are located in Bakersfield, California. The RF command and telemetry links for this scenario consist of both LOS and BLOS between the UA and company-owned GCS.

Scenario 5 was a little different since it used two LOS GCS and a BLOS satellite link. The first LOS chart is the command to Sacramento. The UA left the Sacramento Mather Airport and traveled down range until LOS was lost. This encompassed a total of 51 nm, which was 26 nm further down range than the link budgets in Section 2 were set up for. This link started high at over 90 dB for Eb/No. It quickly fell off as the UA went down range. The UA lost the signal from the Sacramento GCS due to the low elevation angle and then lost LOS. The Eb/No at this point was at 42 dB, well above the necessary 12.5 dB. The next LOS was when the UA came within range of Bakersfield, at which time the Eb/No was at 32 dB and the range was about 90 nm. As the UA got closer to Bakersfield, the Eb/No peaked at 70 dB Eb/No and fell off again as the UA started to go away or down range from Bakersfield.

The telemetry link followed the same pattern with a lower Eb/No of 72 dB for the Sacramento to UA link and 55 dB Eb/No for Bakersfield.

The BLOS link followed the same pattern as the other scenarios: 30 dB for GCS to GEO, 11 dB for GEO to UA for the command link, 9 dB for the telemetry link from the UA to the GEO, and 20 dB for the GEO to GCS link. All links were above the required 6.5 dB Eb/No.

The availability was high for this scenario. For the command link, there was 100% availability, 99.60% for the bottom antenna, and 60.74% for the top antenna. The telemetry link had a combined availability of 100%. For the bottom antenna, it was 99.60% and for the top antenna it was 60.74%. This lower availability on the top antenna was due to the low elevation angle between the GCS and the UA, which caused more blockage of the airframe; thus, the top antenna was not used as much as the bottom.

The gap analysis shows why there were drop outs. For this scenario, all drop outs were due to the body of the aircraft blocking the link to the command antenna on the ground. There is a long drop out but that is because the UA went BLOS and was not used in the calculations for availability. The specific reason for the blockages is shown in the appendix, as are the Eb/No charts. There were no blockages for BLOS and the availability was 100% for BLOS links.

To summarize, all links were above the 12.5 dB Eb/No required for LOS and above the 6.5 dB required for the BLOS. For LOS, the links availability was 100% for both command and telemetry. All BLOS links had 100% availability.

3.2.6 Scenario 6 Results

OSED Scenario 6 demonstrates the use of a UAS for border surveillance and tracking. In this scenario, a Predator B — a turboprop UAS owned and operated by the United States Customs and Border Patrol — performs border surveillance and unplanned aerial work tracking border incursions on the northern border of the United States. The base of operations is Syracuse Hancock International Airport, a Class C airport located four miles northeast of Syracuse, New York. The flight is a routine operation taking place at night, but with the expectations of some unplanned aerial work if and when any border incursions or smuggling operations are observed. The RF command and telemetry links for this scenario consist of both LOS and BLOS between the UA and GCS. LOS is used for the take-off and landing phase of the flight. At a point in time, the LOS links fades out and BLOS takes over. BLOS is also used during en route and aerial work.

In Scenario 6, like Scenario 5, the UA was on a long-range mission and went down range and over the horizon beyond LOS, thus it had the LOS link drop outs. This link started high at over 90 dB for Eb/No, but quickly fell off as the UA went down range. The US took off from Syracuse and went up to Northern Maine. The UA did not lose the signal from the GCS until it was down range 125 miles, at which point the UA went below the horizon. The Eb/No at this point was 32 dB, well above the necessary 12.5 dB required.

The BLOS link followed the same pattern as the other scenarios: 31 dB for GCS to GEO; for the GEO to UA there was 11 dB at the start of the flight, going down to 10.5 dB Eb/No. For the telemetry link, the UA to the GEO had an Eb/No of 9 dB. From the GEO to the GCS, the Eb/no was 20 dB, well above the necessary 6.5 dB.

The availability was high for this scenario, though not 100%. For the command link, there was 99.94% availability: 78.46% for the bottom antenna and 95.96% for the top antenna. The telemetry link had a combined availability of 100%: 95.96% for the bottom antenna and 95.96% for the top antenna.

The gap analysis shows why there were drop outs. For this scenario, all drop outs were due to the body of the aircraft blocking the link to the command antenna on the ground. The specific reason for the blockages is shown in the appendix, as are the Eb/No charts. There were no blockages for BLOS and the availability was 100% for BLOS links.

To summarize, all links were above the 12.5 dB Eb/No required for LOS and above the 6.5 dB required for the BLOS. For LOS, the availability is 99.94% for the command link and 100% for the telemetry link. All BLOS links had 100% availability.

3.2.7 Scenario 7 Results

OSED Scenario 7 demonstrates the use of a UAS for hurricane research. In this scenario, a NASA Global Hawk — a turbojet UAS — flew over two storms to collect remote sensing data and deploy dropsondes for research and forecasting purposes. In this scenario, a tropical depression is intensifying off the coast of Africa and predicted to be a tropical storm within 12 hours. In addition, a Category 2 hurricane is located northeast of Puerto Rico and moving west by northwest. The flight used two primary pilot positions: the Launch and Recovery pilot and the Mission Commander (MC) pilot. The pilot in control of the aircraft is designated as the PIC. There is a transfer of MC pilots during the en route and aerial work portions of the flight due to the long duration of the mission. The flight takes place in early September from 12:00 pm to 11:00 am the next day. Weather conditions are normal. This scenario covers an IFR flight in controlled airspace, warning areas, restricted airspace, and oceanic airspace, as well as flight and coordination within domestic and foreign flight information region airspace. The RF command and telemetry links for this scenario consist of BLOS for two GCS: NASA Wallops Flight Facility, Virginia; and NASA Global Hawk Operation Center, Dryden, California.

Scenario 7 only had BLOS. The BLOS link followed the same pattern as the other scenarios: 29 dB for GCS to GEO. For the GEO to UA, there was an 11 dB Eb/No. These two links fluctuated by a couple of dB due to the UA moving away from the GEO and back toward the GEO. For the telemetry link, the Eb/No was lower due to the higher data rate and added noise at these higher data rates. The UA to GEO was between 6.7 dB and 7.0 dB The GEO to GCS was 20 dB, well above the necessary 6.5 dB.

To summarize, the link from the UA to the GEO was only 6.7 dB Eb/No, above the required 6.5 dB, but barely. The other links were all higher. There were no gaps for BLOS and the availability was 100% for BLOS links.

3.2.8 Scenario 8 Results

OSED Scenario 8 demonstrates the use of a UAS for mining exploration. In this scenario, a WDL 1B — a conversion airship UAS — explores an area in the southern part of Ohio and portions of northern West Virginia. This part of the country has been very productive over the last 100 years regarding the amount of coal that has been mined. As the coal became depleted, new techniques and equipment have been developed to find new sources of coal to be mined.

Specialty sensors aboard this airship are heavy, sensitive, and require very slow steady speeds and low altitudes to effectively scan the terrain for low-density rock formations. Wingfoot Lake Airship Base (4OH6) does not have a control tower. The Akron Canton Regional Airport, located approximately seven miles away, is the ATC authority for the airship base. A mix of general aviation, commuter, airline, and cargo operations use the airspace around 4OH6. Departure procedures typically involve radar vectors to an initial waypoint or navigational fix. In this scenario, the airship is flown at an altitude of 5,000 feet MSL and average airspeed of 45 kts. The total flight time in the scenario is 13 hours. Under IFR, the airship follows a victor airway from the Akron area to southern Ohio, where the IFR flight plan is cancelled and VFR flight following is requested. The airship is flown to the start of its grid pattern area, where it is handed off to a mission pilot who flies the aircraft autonomously. Upon completion of the operation (approximately eight hours later), ATC clearance is requested and the airship returns to the

Akron area on an IFR flight plan that was placed in the ATC system prior to the aircraft's early morning departure. The RF command and telemetry links for this scenario consist of both LOS and BLOS between the UA and company GCS.

In Scenario 8, the UA was on a long-range mission. The command link started at 52 dB Eb/No when at the Akron Canton Regional Airport, then dropped down to 37 dB Eb/No on loss of signal as the UA went over the horizon at 75 miles. The telemetry link followed the same pattern except at a lower level, of 40 dB at the start of the flight, down to 26 dB on loss of signal as the UA went over the horizon.

The BLOS link followed the same pattern as the other scenarios for BLOS: the Eb/No was 30 dB for the GCS to GEO and Eb/No 11 dB for the GEO to UA. For the telemetry link, the UA to the GEO had an Eb/No of 9 dB; from the GEO to the GCS, the Eb/No was 20 dB. All of these Eb/No were well above the necessary 6.5 dB Eb/No.

The availability was high for this scenario, though not 100%. For the command link, there was 100% availability: 91.0% for the bottom antenna and 89.19% for the top antenna. The telemetry link had a combined availability of 100%. For the bottom antenna, the availability was 91.0% and for the top antenna it was 89.19%.

For this scenario all drop outs were due to the body of the aircraft blocking the link to the command antenna on the ground. The specific reason for the blockages is shown in the Appendix as are the Eb/No charts.

To summarize, all links were above the 12.5 dB Eb/No required for LOS and above the 6.5 dB required for the BLOS. For LOS, the availability of the links was 100% for the command link and 100% for the telemetry link. All BLOS links had 100% availability.

3.2.9 Scenario 9 Results

OSED Scenario 9 demonstrates the use of a UAS for agricultural/environmental monitoring. In this scenario, a Global Observer — a High Altitude Long Endurance (HALE) UAS — supports an agricultural/environmental monitoring operation in the midwest of the United States. The Global Observer is owned and operated by a company that leases its service to the Department of Agriculture. The company owns and operates numerous HALE UAS and leases them to other commercial and government clients for routine and on-demand services.

The takeoff and climb to altitude takes place during early morning hours in order to minimize any negative effects of the slow airspeed and climb rate of the Global Observer on normal air traffic. The base of operations is a privately-owned airport located north of Las Vegas. The takeoff takes place in July around 4:00 am. The climb out route follows a prearranged flight path that has been coordinated with local ATC so as to avoid busy airways and other areas of known concentrations of air traffic.

Depending on local air traffic conditions, either a circling, straight ahead, or combination of maneuvers is used during climb out. Adjustments to the climb route are made to deal with developing air traffic situations. Once above FL500, the Global Observer is given permission to fly straight to the area of operation. Aerial work takes place over a five-day period. Areas of interest covered by this scenario include private airport operations, integration of a slow flying/climbing UAS in controlled airspace, limited aircraft maneuverability, prolonged five-day flights in Class E airspace above FL600, and en route only qualified pilots when pre-programmed missions are being flown at 65,000 feet MSL. The RF command and telemetry links for this scenario consist of BLOS for the company-owned GCS.

In Scenario 9, the UA is on a long-range mission and went down range and over the horizon, thus the LOS link dropped out. This link started high at over 97 dB for Eb/No, then it quickly fell off as the UA went down range. The UA lost the signal from the GCS due to the low elevation. As the UA went over the horizon, the Eb/No at that point was at 25 dB, well above the necessary 12.5 dB. When the UA came back in range at 90 miles the Eb/No was at 25 dB. As the UA got closer to the GCS, the Eb/No peaked at over 100 dB Eb/No, the highest for any of the nine scenarios. The telemetry link followed a similar pattern except at a lower level: 78 dB at start of flight, down to 10 dB on loss of signal, picked it up at 10 dB, and then the Eb/No was 87 dB on landing. Even though the Eb/No was below the required 12.5 dB, the range of 90 nm is beyond what is to be expected of an LOS link

The BLOS link followed the same pattern as the other scenarios: 30 dB for GCS to GEO, for the GEO to UA there was an 11 dB at the start of the flight going down to 10.5 dB Eb/No. For the telemetry link, the UA to the GEO had an Eb/No of 9 dB and from the GEO to the GCS, the Eb/No was 20 dB, well above the necessary 6.5 dB.

The availability was high for this scenario at 100%.

The command link had a combined availability of 100%:

- bottom antenna availability 94.78%
- top antenna availability 13.85%

The telemetry link had a combined availability of 100%:

- bottom antenna availability 94.5%
- top antenna availability 13.88%

This lower availability for the top antenna was due to the constant turning of the UA and body of the UA blocking the link between the GCS and itself, especially at the low elevation angles as the UA went down range.

The gap analysis describes why there were drop outs. For this scenario, all drop outs were due to the body of the aircraft blocking the link to the command antenna on the ground. The specific reason for the blockages is shown in the appendix, as are the Eb/No charts.

To summarize, all links were above the 12.5 dB Eb/No required for LOS and above the 6.5 dB required for the BLOS. For LOS, the link availability was 100% for the command link and 100% for the telemetry link. All BLOS links had 100% availability.

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4 Conclusion

This report is the end result of over two years of work conducted jointly between the FAA and NASA KSC. The work was done in support of the RTCA SC-203 Control and Communications Working Group. A large part of the specific values used in the simulation came from the working group. All of the radio links were modeled based on the formulations completed by the working group. STK was selected as the tool of choice due to demonstrated NASA KSC experience utilizing this tool for past communication systems development. Part of this report confirmed the validity of this tool. The tool was validated through the comparison of data collected during a test flight against STK-simulated data. STK communication models were found to be in line with real data collected during live test flights on various aircraft — see Section 2.2.5. The STK results were close to the static link margins that were calculated, as seen in Sections 2.2.3 and 2.2.4.

The stated goal of the RTCA is to have availability of 99.9%; this analysis fell just short of that stated goal for LOS and exceeded that goal for BLOS. Each scenario had only one GCS that the UA was communicating with. If another GCS were included in these scenarios, the availability would be well over the calculated 99.57% worst case for command and 99.78% worst case for telemetry.

This report analyzed Radio Communications Links for the RTCA S203 OSED Scenarios. This report showed link margins (which incorporated realistic antennas, transmitters, and receivers), rain attenuation, gaps in coverage, and availability. This report was done with STK using the Communication Modules for the Radio Links and Aircraft Mission Modeler for the flight Dynamics of the UA.

The results of this analysis show that it is possible to send commands to the UA and have it send back the system's health and status with high availability of at least 99.852% for command, 99.717% for telemetry, and 100% for BLOS. If another GCS were added, the LOS links would exceed the 99.9% availability.

The biggest difference of the command link when compared to the telemetry link was the data rate. The command link was 10 kbps and the telemetry link was 320 kbps. The command and telemetry links were modeled with the antennas at the same location. The command link Eb/No values were found to be less than the telemetry Eb/No values. This is because the higher data rate of the telemetry signal has more noise added to the RF signal power, thus having lower Eb/No.

The frequencies used were C-Band at 5 GHz for the LOS and Ku-band of 14 GHz and 11 GHz. All antennas were based on realistic antennas. The links for the LOS are shown below.

- LOS Antennas
  - Command
    - GCS to UA 5.03 GHz at 10 kbps Antenna Gain 28 dB
  - Telemetry
    - UA to GCS 5.091 GHz at 320 kbps Antenna Gain 0 dB nominal

- BLOS antennas
    - Command
        - GCS to GEO 14.9 GHz at10 kbps Antenna Gain 59 dB
        - GEO to UA 11.95 GHz at 10 kbps Antenna Gain 38 dB
    - Telemetry
        - UA to GEO 14.95 GHz at 320 kbps Antenna Gain 39 dB
        - GEO to GCS 11.95 GHz at 320 kbps Antenna Gain 38 dB

All Radio Communication Links for the nine OSED Scenarios were analyzed. The Radio Links needed a 6.5 dB Eb/No to maintain a BER rate of 10^{-5}. A 6 dB safety margin was added to this for all LOS links. Thus, the goal was to have 12.5 dB Eb/No for all LOS Radio Links; this was met at the maximum range of 25 nm for eight of the scenarios that had LOS (Scenario 7 did not have LOS). For BLOS, there was no link margin and all BLOS links stayed above the 6.5 dB Eb/No.

Rain attenuation was added to the links using the ITU-R P618-9 rain model. Rain rates of 1 mm/hr, 5mm/hr, 50mm/hr, and 90 mm/hr were used. The 11 Ghz command link maintained the needed performance of at least 6.5 dB Eb/No for the 10 mm/hr rain rate. For the higher rain rate, the link fell below the 6.5 dB required. This failure was on the link to the UA from the GEO; this can be attributed to the small size of the antenna on the aircraft. The telemetry link from the GEO to the GCS had excess margin of 16.55 dB even at the high rain rate of 90 mm/hr; this also can be attributed to the large antenna of the GCS.

All of the gaps or drop outs were due to the body of the UA blocking the LOS link to the GCS. In STK, it is possible to set up a "body mask" and exclude any links that are not within the LOS from the exact placement of the antenna on the UA to the GCS. For example, if the antenna is on the bottom of the UA when the UA is taking off climbing and the Control Station is directly behind the UA, the bottom antenna will be blocked. In general, C-band needs LOS in order to close a radio link. STK does not calculate reflection off the body of the UA, be it either constructive or destructive interference. This is why another antenna was added to the top of the UA. This antenna closed the link as the UA climbed. This is called antenna diversity, which is widely used in RF Radio Communications.

All the gaps and individual scenario availability are shown below for LOS. The BLOS did not have any gaps and all had 100% availability. For the LOS links, the best availability was 100% while the worst was 99.57% for the command link of Scenario 3; the worst telemetry availability was 99.78%, also from Scenario 3. The scenarios are very different so there was no clear way to combine them into an overall scenario. Any further research should be directed to increasing the availability of Scenario 3.

Table 175 shows the length of the gaps added up for all nine scenarios. This is an important table because it gives the length of each gap as well as how many gaps there were for all scenarios.

Table 17. Length of Gaps

Combined - LOS - Command - Control Station to UA

	Bottom	Top	Combined
Total Scenario Times (Sec)	165733.3	165733.3	165733.3
Total Number of Gaps	283	508	511
Gaps < 1 Second	30	143	458
Gaps 1-2 Seconds	5	99	48
Gaps 2-4 Seconds	18	7	0
Gaps 4-8 Seconds	57	14	3
Gaps 8-15 Seconds	156	4	0
Gaps 15-30 Seconds	8	2	0
Gaps 30-60 Seconds	3	6	1
Gaps > 60 Seconds	6	233	1

Combined - LOS - Telemetry - UA to Control Station

	Bottom	Top	Combined
Total Scenario Times (Sec)	165733.6	165733.6	165733.6
Total Number of Gaps	283	511	272
Gaps < 1 Second	32	143	267
Gaps 1-2 Seconds	3	100	0
Gaps 2-4 Seconds	33	7	0
Gaps 4-8 Seconds	45	14	3
Gaps 8-15 Seconds	152	4	0
Gaps 15-30 Seconds	8	2	0
Gaps 30-60 Seconds	4	6	1
Gaps > 60 Seconds	6	235	1

Table 16 provides an availability summary of all nine scenarios for both LOS and BLOS. Also included in Table 16 are both Command and Telemetry availability.

Table 18. Availability Summary Table

Scenario Number	LOS – Command Availability	LOS – Telemetry Availability	BLOS – Command & Telemetry Availability
1	100.00%	100.00%	100.00%
2	100.00%	100.00%	100.00%
3	99.57%	99.78%	100.00%
4	99.87%	99.87%	100.00%
5	100.00%	100.00%	100.00%
6	99.94%	100.00%	100.00%
7	NA	NA	100.00%
8	100.00%	100.00%	100.00%
9	100.00%	100.00%	100.00%

5 Acronyms and Abbreviations

4OH6	Wingfoot Lake Airship Base
AGI	Analytical Graphics, Inc.
AGL	Above Ground Level
ATC	Air Traffic Control
BER	Bit Error Rate
BLOS	Beyond Line of Sight
CAASD	Center for Advanced Aviation System Development
CC	Control and Communication
CRCP	Continuity
CS	Control Station
CSP	Communications Service Provider
dB	Decibel
dBM	Power ration in decibels
DOI	Department of Interior
DVFR	Defense Visual Flight Rules
Eb	Energy per bit
Eb/No	Energy per bit over noise power spectral density
EIRP	Equivalent Isotropically Radiated Power
EPA	Environmental Protection Agency
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FL	Flight Level
GEO	Geosynchronous orbit satellite
HALE	High Altitude Long Endurance
Hr	Hour
IFR	Instrument Flight Rules
IRCP	Integrity
ITU-R	International Telecommunications Union Radio Section
JPDO	Joint Planning Development Office
kbps	Kilobits per second
km	Kilometers
KSC	Kennedy Space Center
LEO	Low Earth Orbit
LOS	Line of Sight
M&S	Modeling and Simulation
MASPS	Minimum Aviation System Performance Standards
MC	Mission Control
MEO	Medium Earth Orbit
Mm	Millimeter
MOA	Memorandum of Agreement
MS	Mission Support
MSL	Mean Sea Level
NAS	National Airspace System
NASA	National Aviation and Space Administration
No	Noise power spectral density
NextGen	Next Generation Air Transportation System
OSED	Operational Services and Environmental Definition[2]
QPSK	Quadrature Phase-Shift Keying

PIC	Pilot in Control
RF	Radio Frequency
RTCA	Radio Technical Commission for Aeronautics
SAA	Sense and Avoid
SC-203	RTCA Unmanned Aircraft Systems Special Committee
SC203 CC WG2	RTCA SC-203 Control and Communications Working Group
STK	Satellite Tool Kit
TIREM	Terrain Integrated Rough Earth Model
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UHF	Ultra High Frequency
VFR	Visual Flight Rules
VHF	Very High Frequency
WG	Working Group
WJHTC	William J. Hughes Technical Center

6 References

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Unmanned Aviation Systems Modeling of the Radio Communications Links: Study Results - Appendices

Annex 2

Volume 2 of 2

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15. Supplementary Notes

16. Abstract

This report describes the analysis of communications between the Control Station and an Unmanned Aircraft (UA) flying in the National Airspace System (NAS). This work is based on the RTCA SC-203 Operational Services and Environment Description (OSED). The OSED document seeks to characterize the highly different attributes of all UAs navigating the airspace and define their relationship to airspace users, air traffic services, and operating environments of the NAS. One goal of this report is to lead to the development of Minimum Aviation System Performance Standards for Control and Communications. This report takes the nine scenarios found in the OSED and analyzes the communication links.

17. Key Words National Airspace System, NAS, NextGen, Unmanned Aircraft Systems, UAS, Communications, Radio Frequency	**18. Distribution Statement** This report is approved for public release and is on file at the William J. Hughes Technical Center, Aviation Security Research and Development Library, Atlantic City International Airport, New Jersey 08405. This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161.

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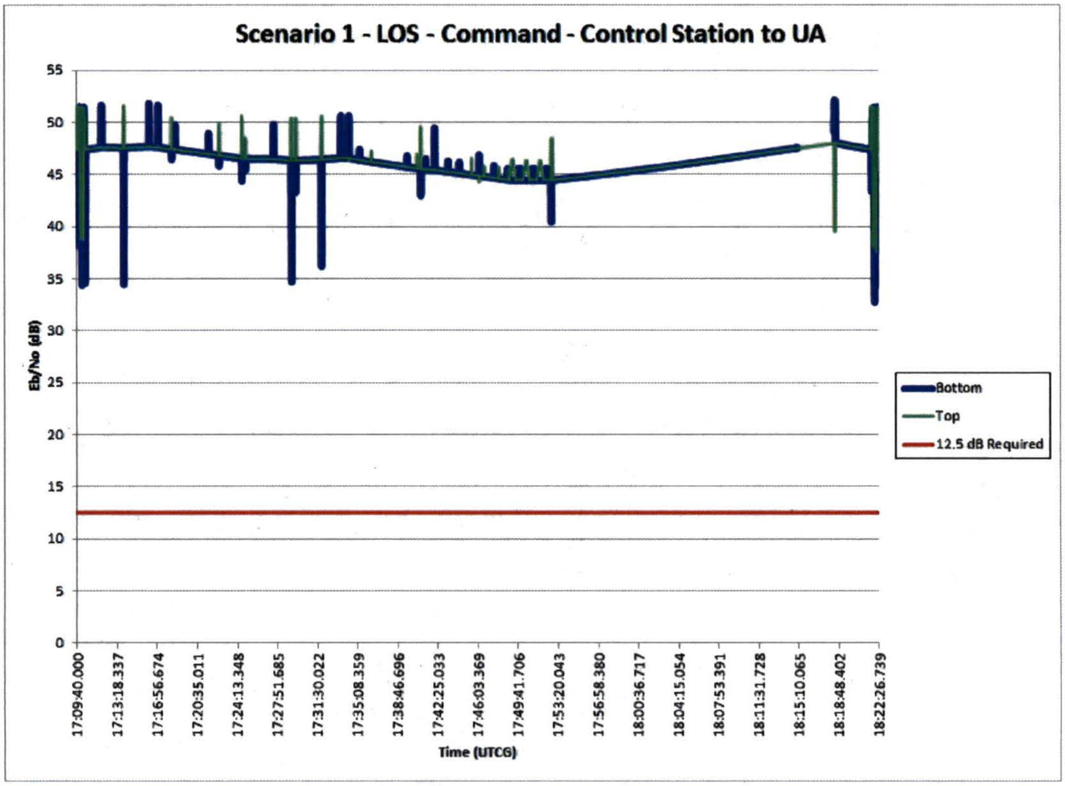
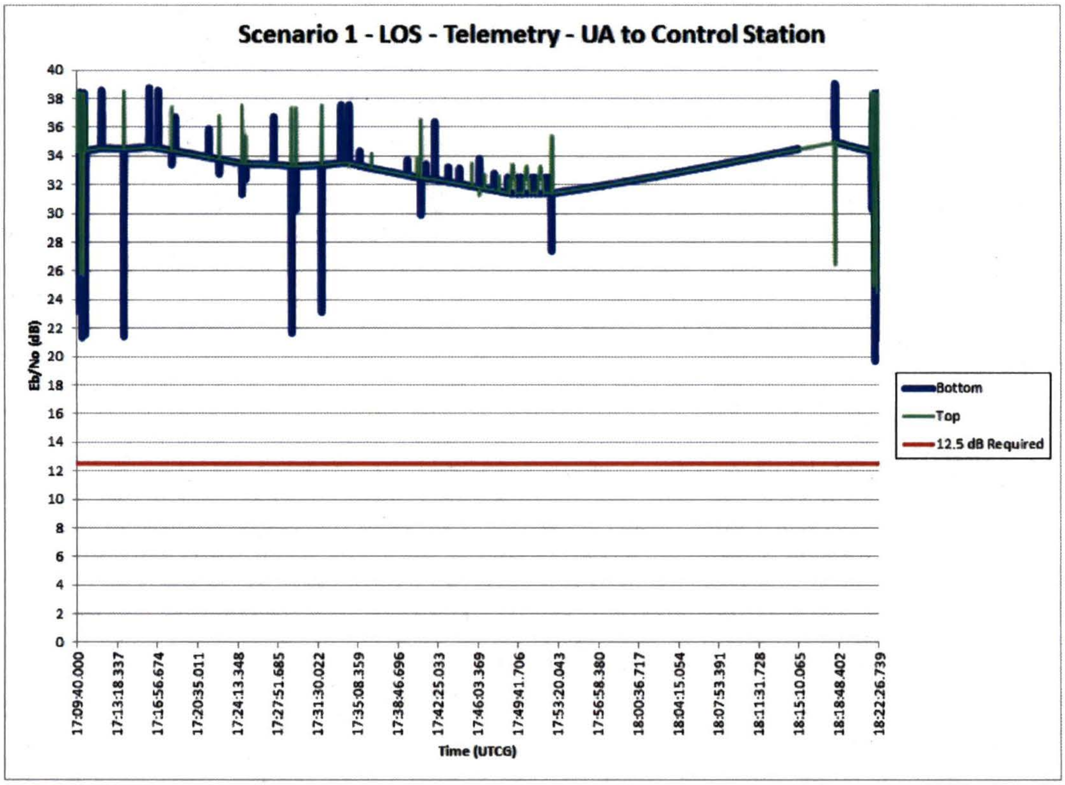
A. Study Results for Scenario 1





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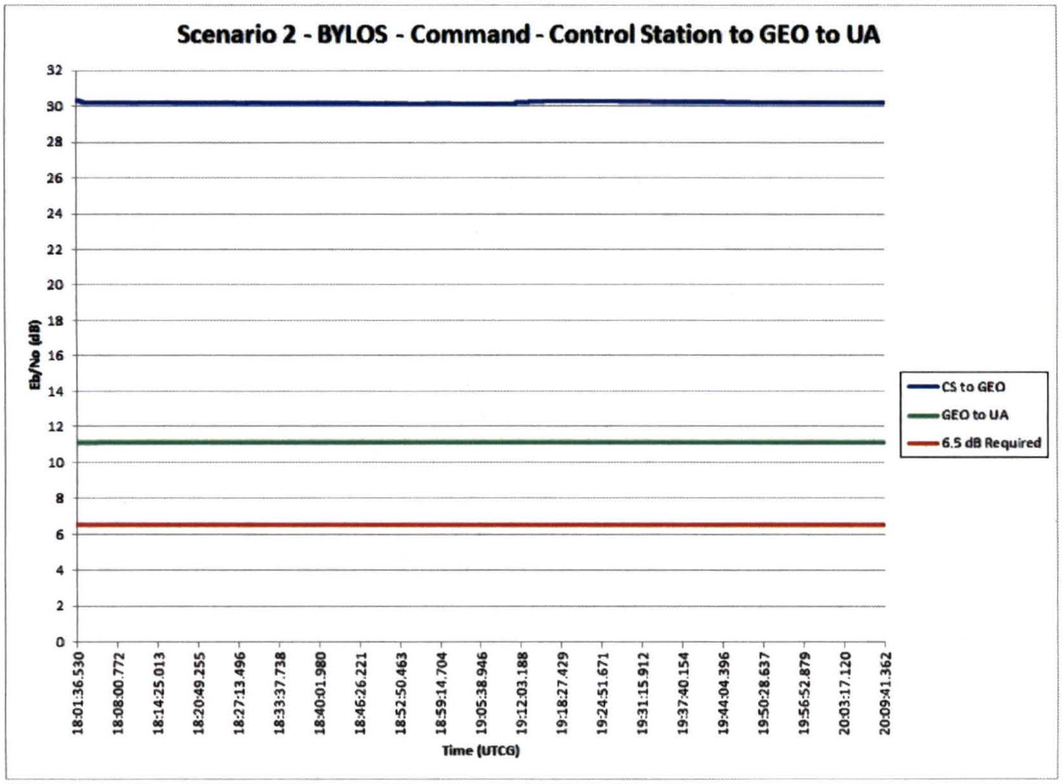

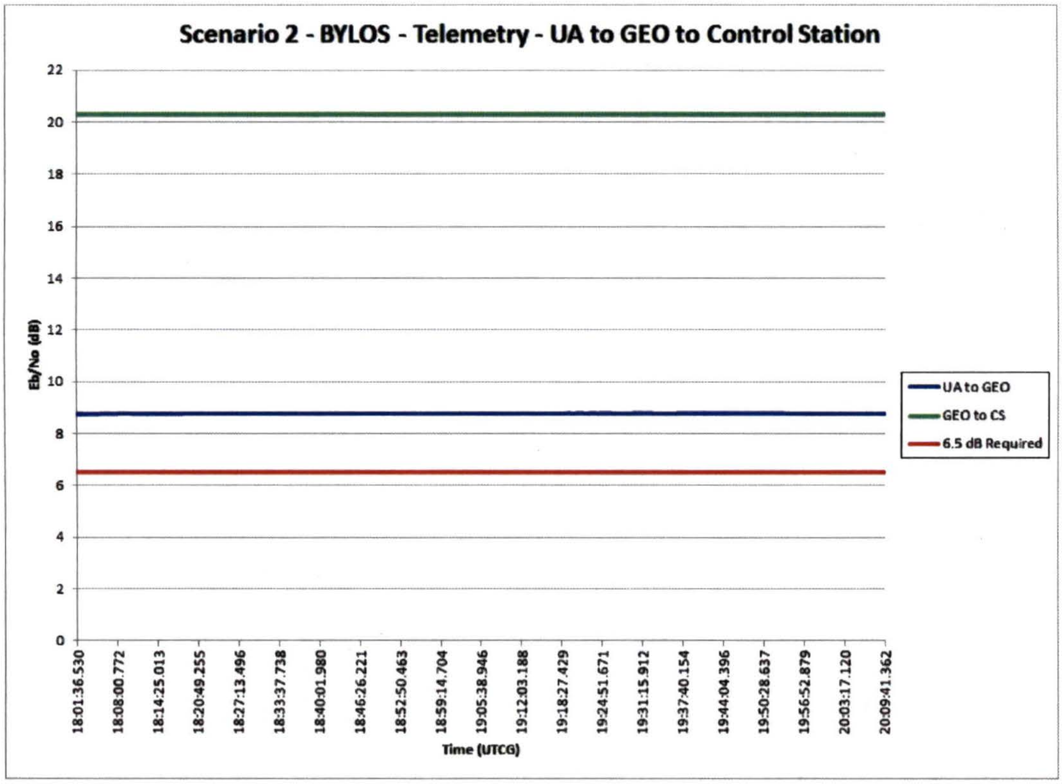

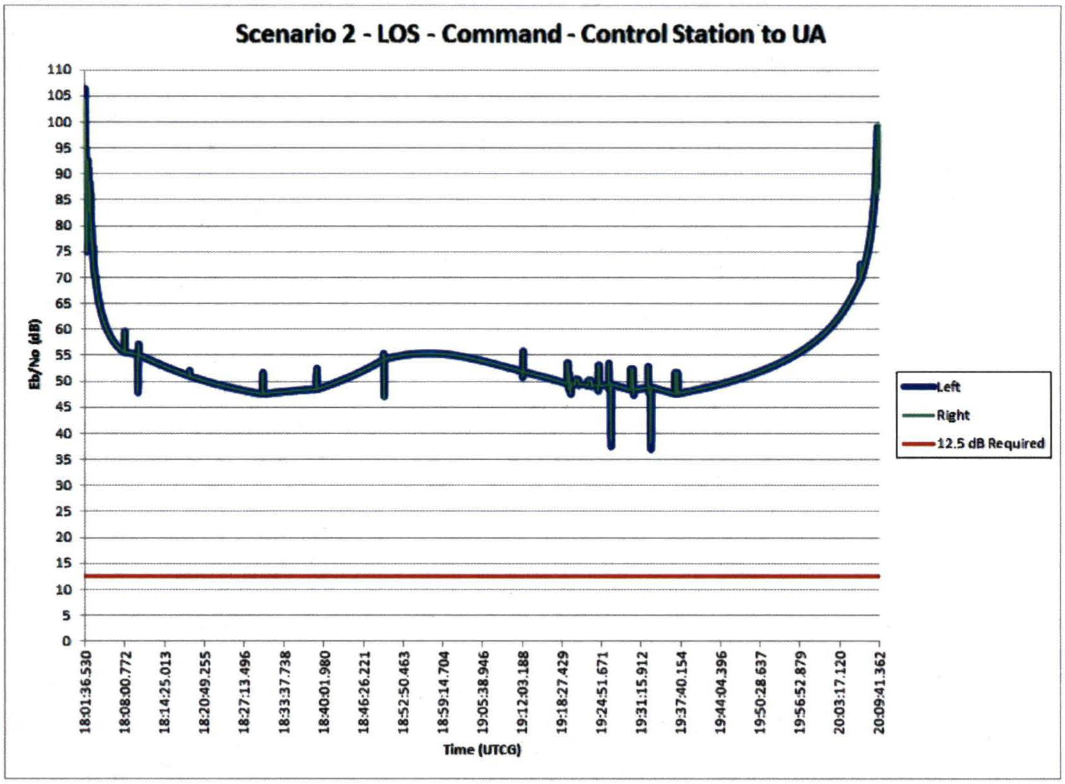
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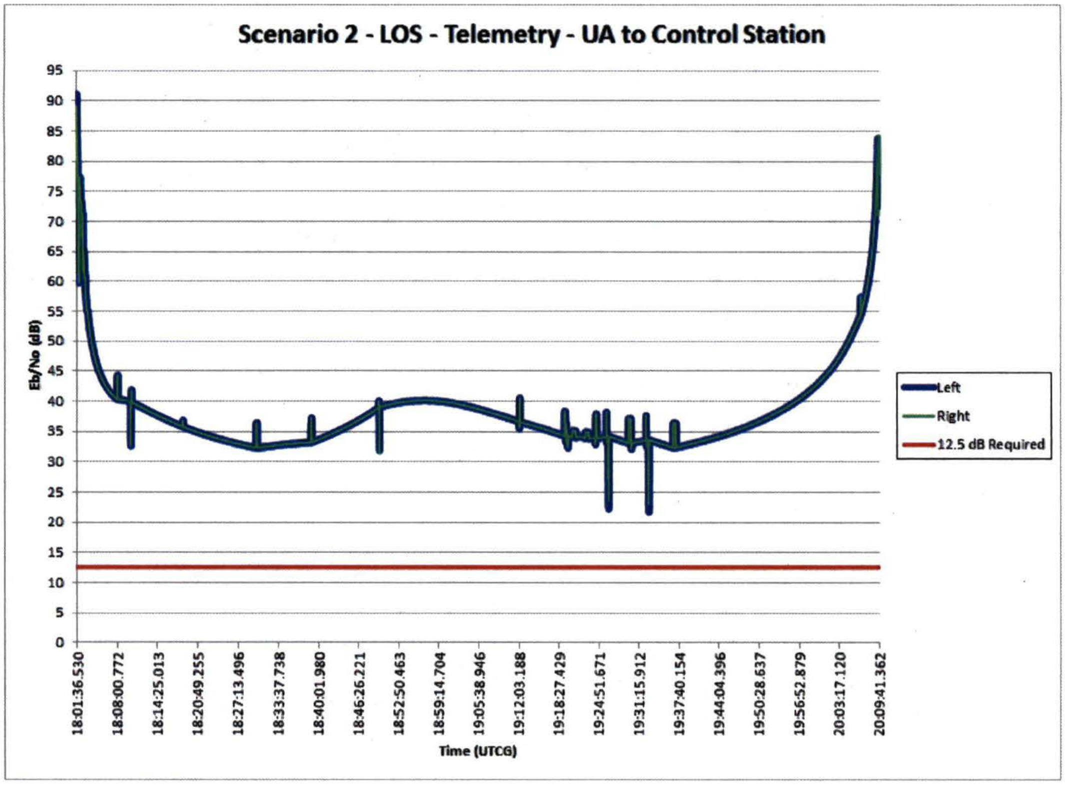
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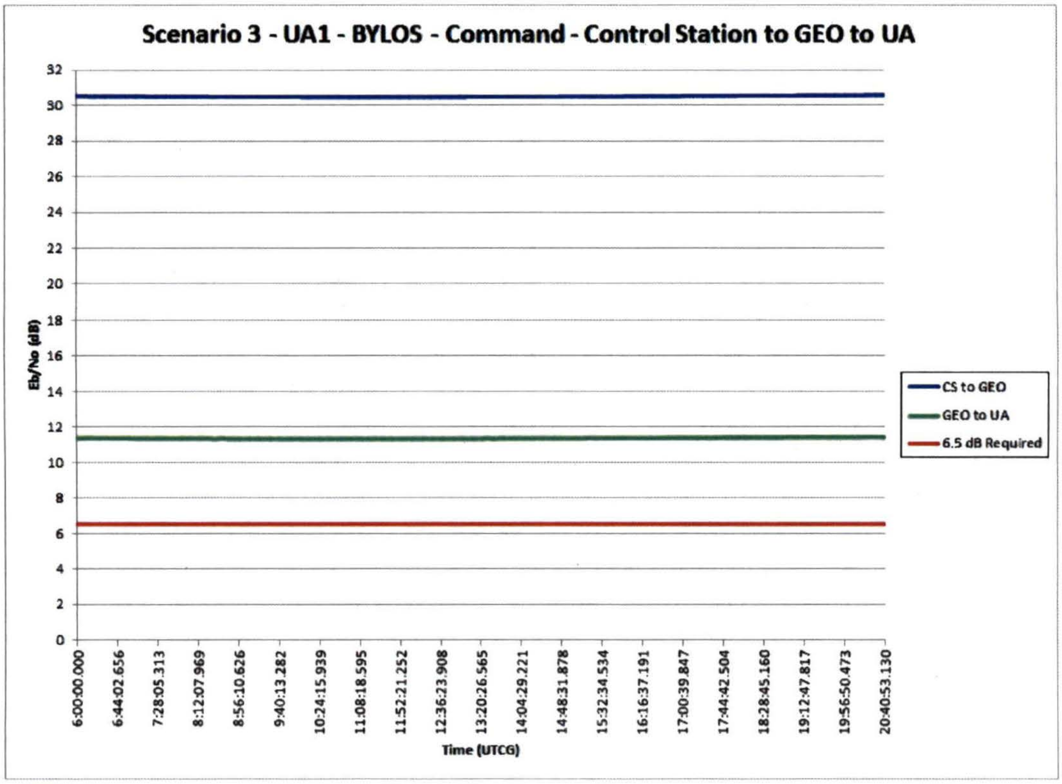

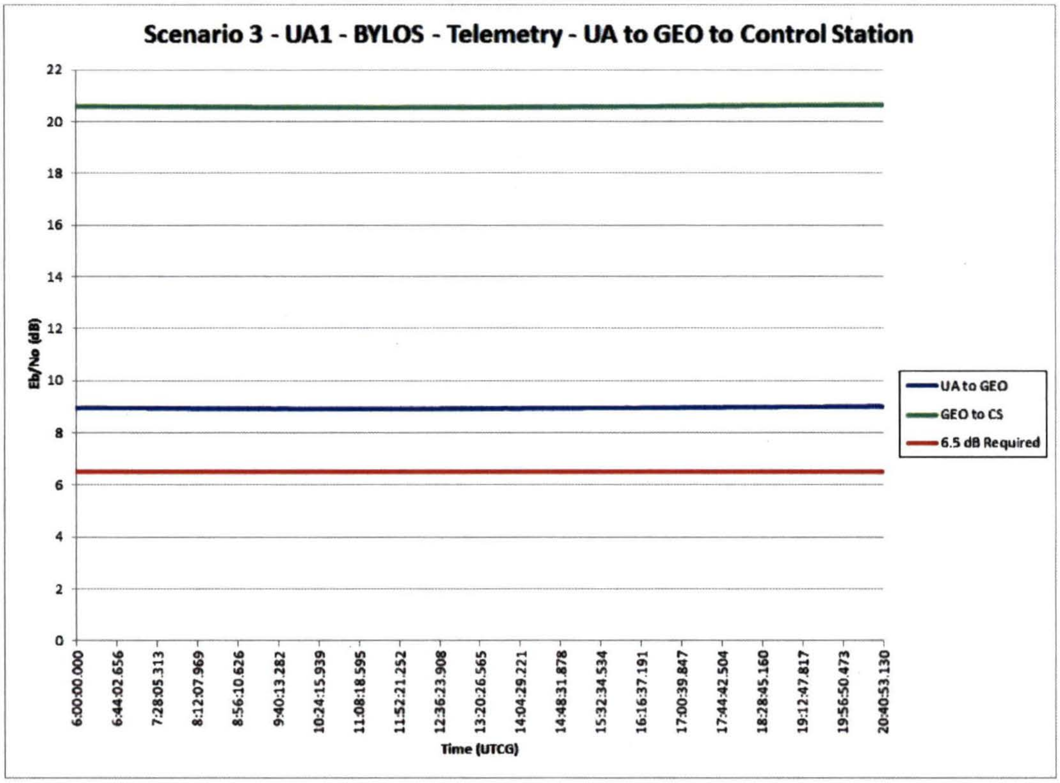

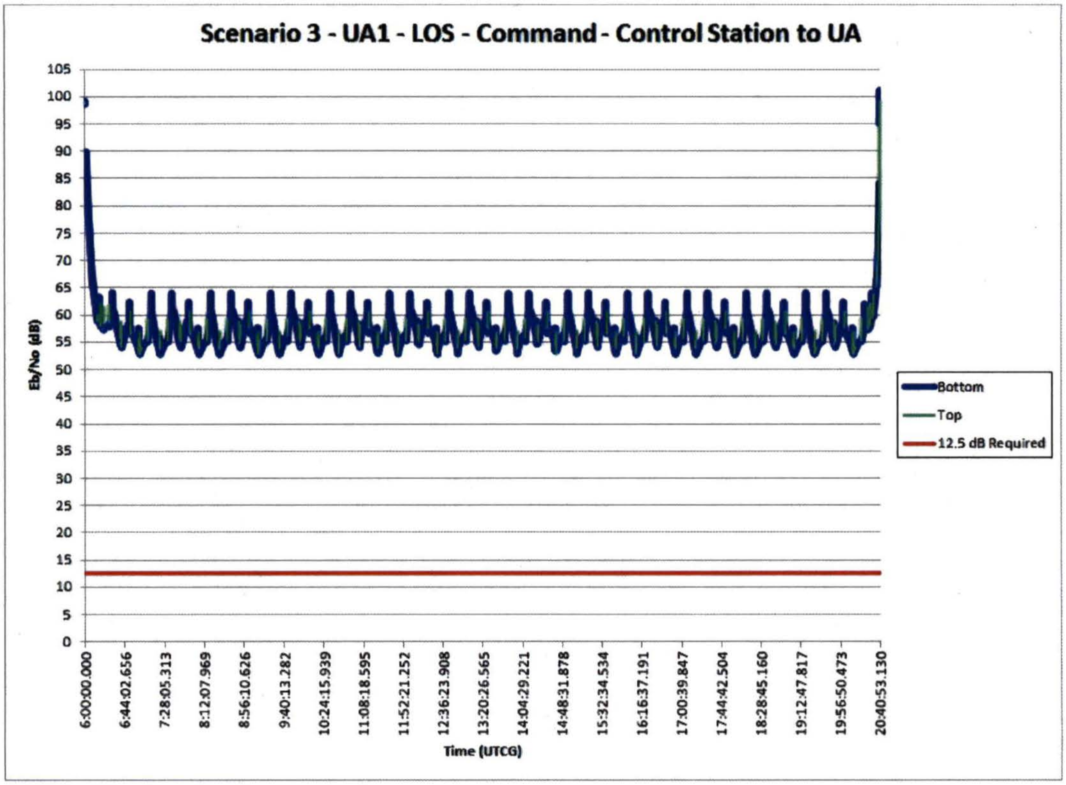
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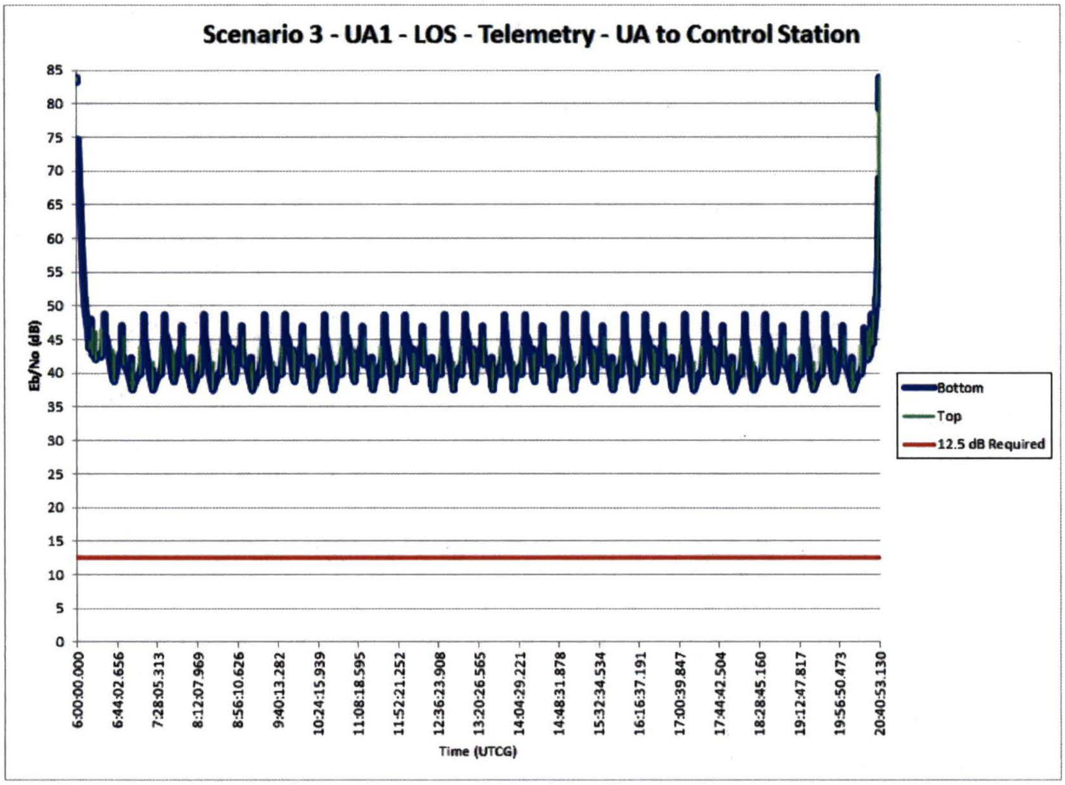
Eb/No (dB)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
6:00:00.000
6:44:02.656
7:28:05.313
8:12:07.969
8:56:10.626
9:40:13.282
10:24:15.939
11:08:18.595
11:52:21.252
12:36:23.908
13:20:26.565
14:04:29.221
14:48:31.878
15:32:34.534
16:16:37.191
17:00:39.847
17:44:42.504
18:28:45.160
19:12:47.817
19:56:50.473
20:40:53.130
Time (UTCG)
Bottom
Top
12.5 dB Required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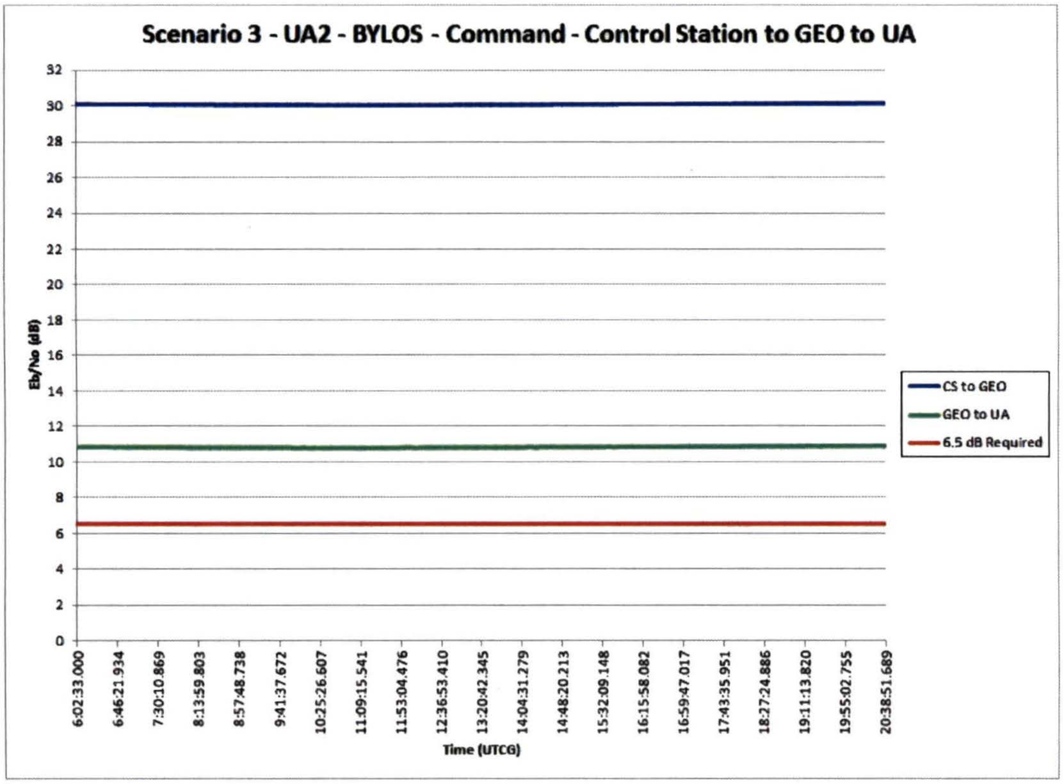
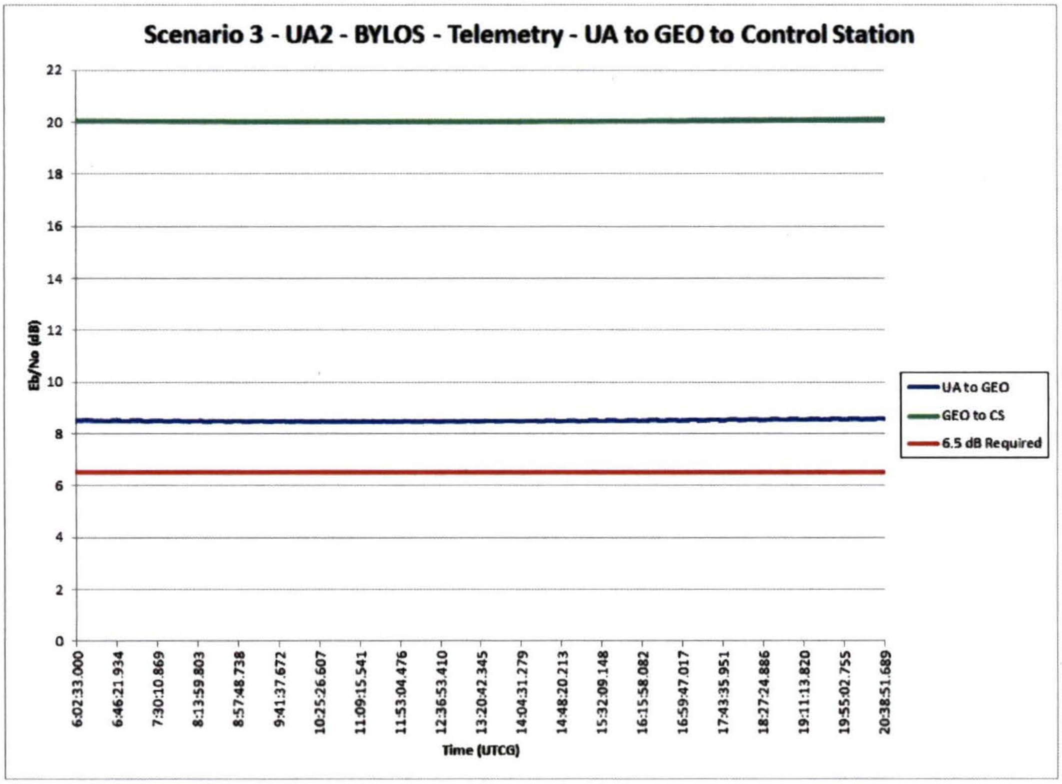
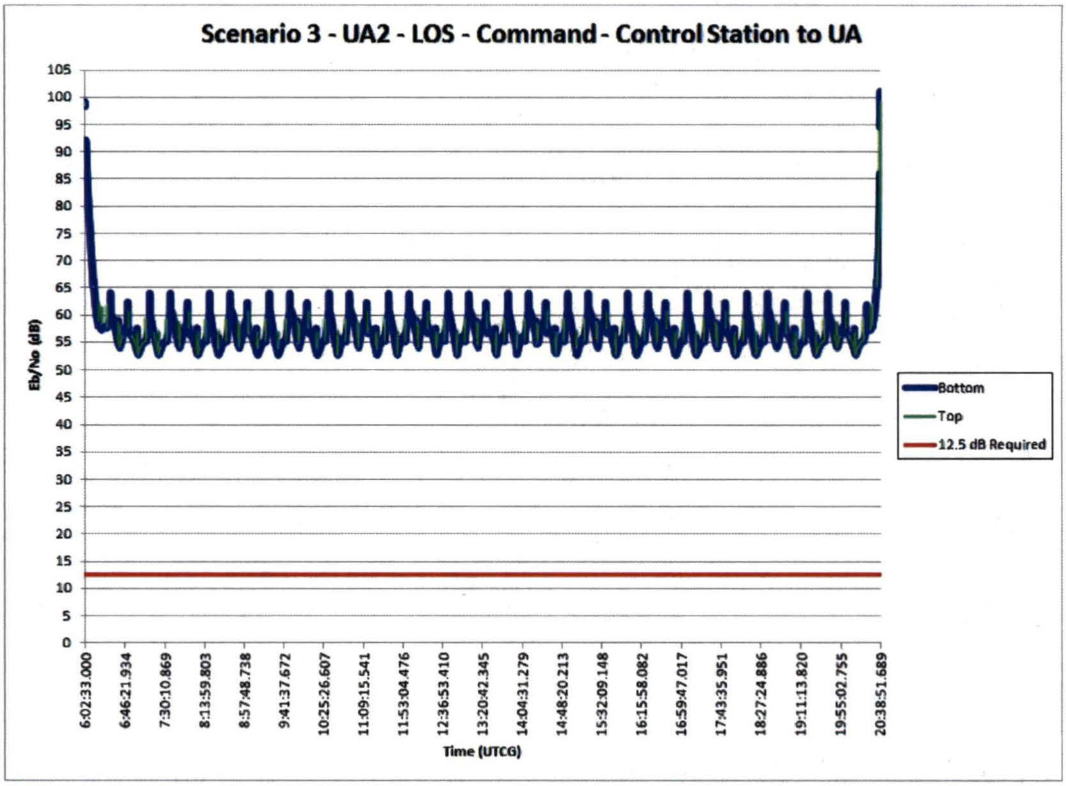
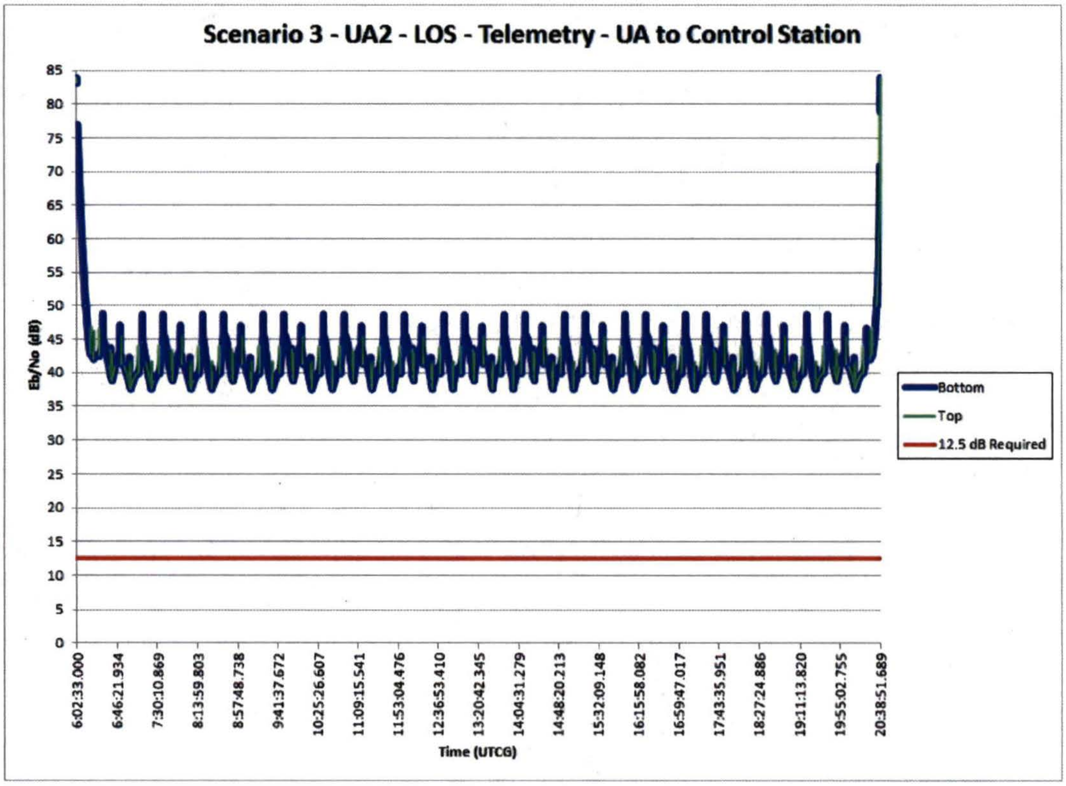
Eb/No (dB)
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
6:00:00.000
6:44:02.656
7:28:05.313
8:12:07.969
8:56:10.626
9:40:13.282
10:24:15.939
11:08:18.595
11:52:21.252
12:36:23.908
13:20:26.565
14:04:29.221
14:48:31.878
15:32:34.534
16:16:37.191
17:00:39.847
17:44:42.504
18:28:45.160
19:12:47.817
19:56:50.473
20:40:53.130
Time (UTCG)
Bottom
Top
12.5 dB Required

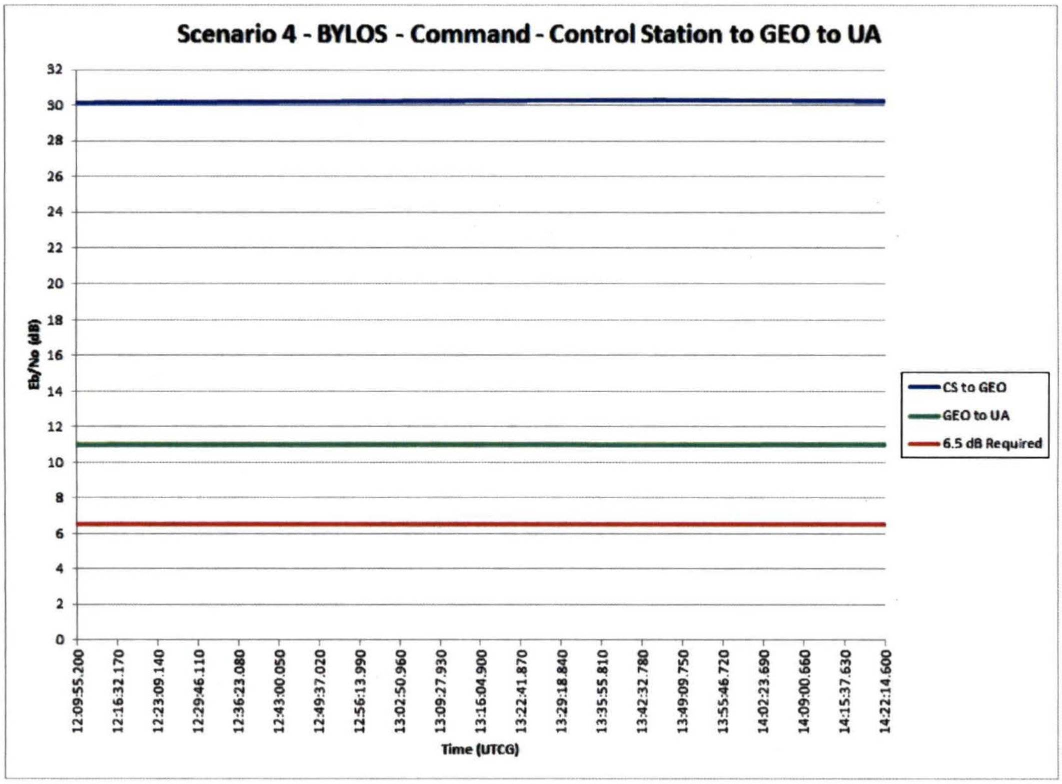

Scenario 3 - UA2 - BYLOS - Command - Control Station to GEO to UA
Eb/No (dB)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6:02:33.000
6:46:21.934
7:30:10.869
8:13:59.803
8:57:48.738
9:41:37.672
10:25:26.607
11:09:15.541
11:53:04.476
12:36:53.410
13:20:42.345
14:04:31.279
14:48:20.213
15:32:09.148
16:15:58.082
16:59:47.017
17:43:35.951
18:27:24.886
19:11:13.820
19:55:02.755
20:38:51.689
Time (UTCG)
CS to GEO
GEO to UA
6.5 dB Required

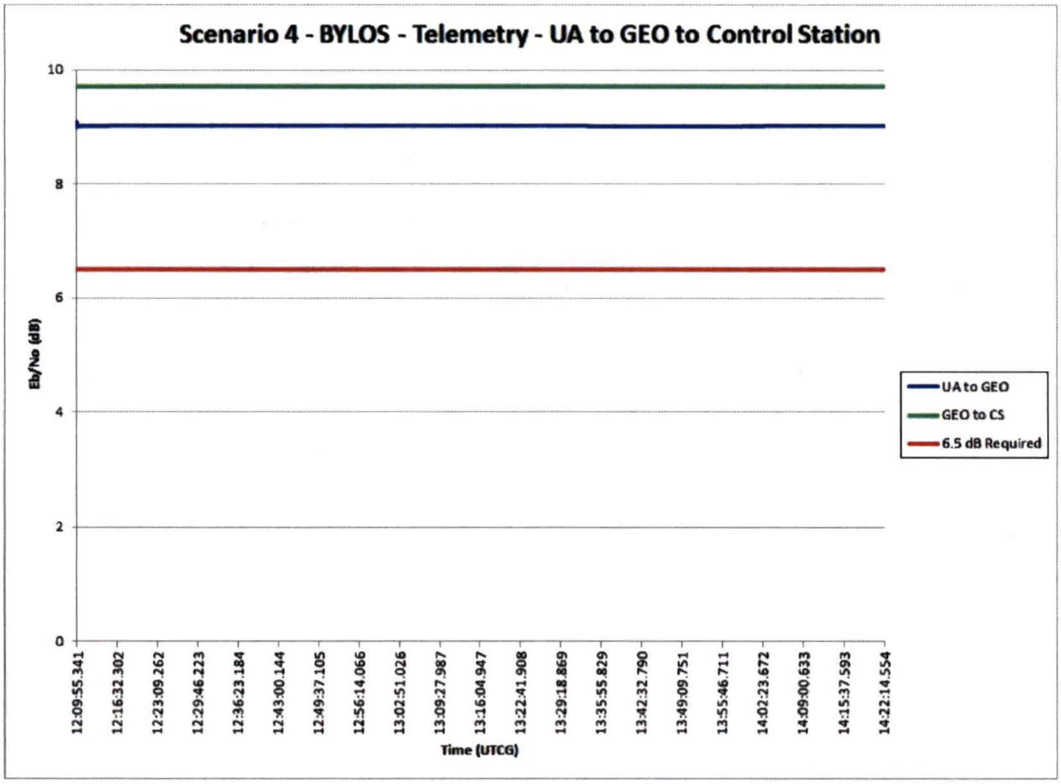

Scenario 3 - UA2 - BYLOS - Telemetry - UA to GEO to Control Station
Eb/No (dB)
22
20
18
16
14
12
10
8
6
4
2
0
6:02:33.000
6:46:21.934
7:30:10.869
8:13:59.803
8:57:48.738
9:41:37.672
10:25:26.607
11:09:15.541
11:53:04.476
12:36:53.410
13:20:42.345
14:04:31.279
14:48:20.213
15:32:09.148
16:15:58.082
16:59:47.017
17:43:35.951
18:27:24.886
19:11:13.820
19:55:02.755
20:38:51.689
Time (UTCG)
UA to GEO
GEO to CS
6.5 dB Required

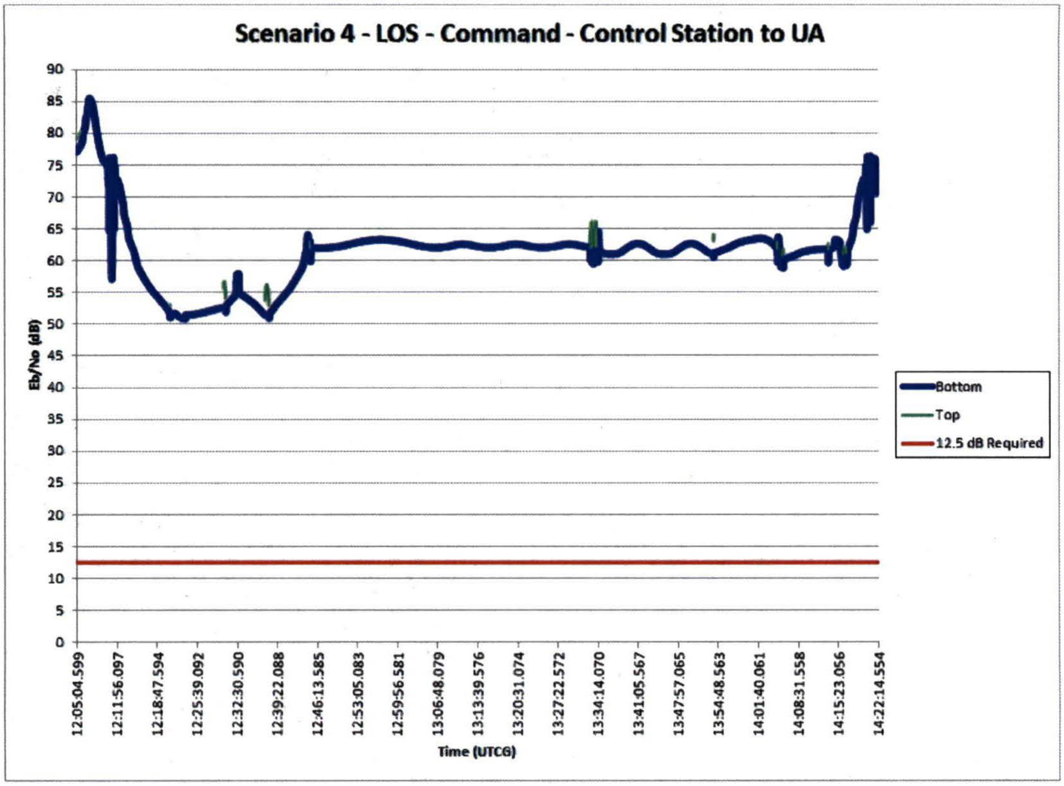

Scenario 3 - UA2 - LOS - Command - Control Station to UA
Eb/No (dB)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
6:02:33.000
6:46:21.934
7:30:10.869
8:13:59.803
8:57:48.738
9:41:37.672
10:25:26.607
11:09:15.541
11:53:04.476
12:36:53.410
13:20:42.345
14:04:31.279
14:48:20.213
15:32:09.148
16:15:58.082
16:59:47.017
17:43:35.951
18:27:24.886
19:11:13.820
19:55:02.755
20:38:51.689
Time (UTCG)
Bottom
Top
12.5 dB Required

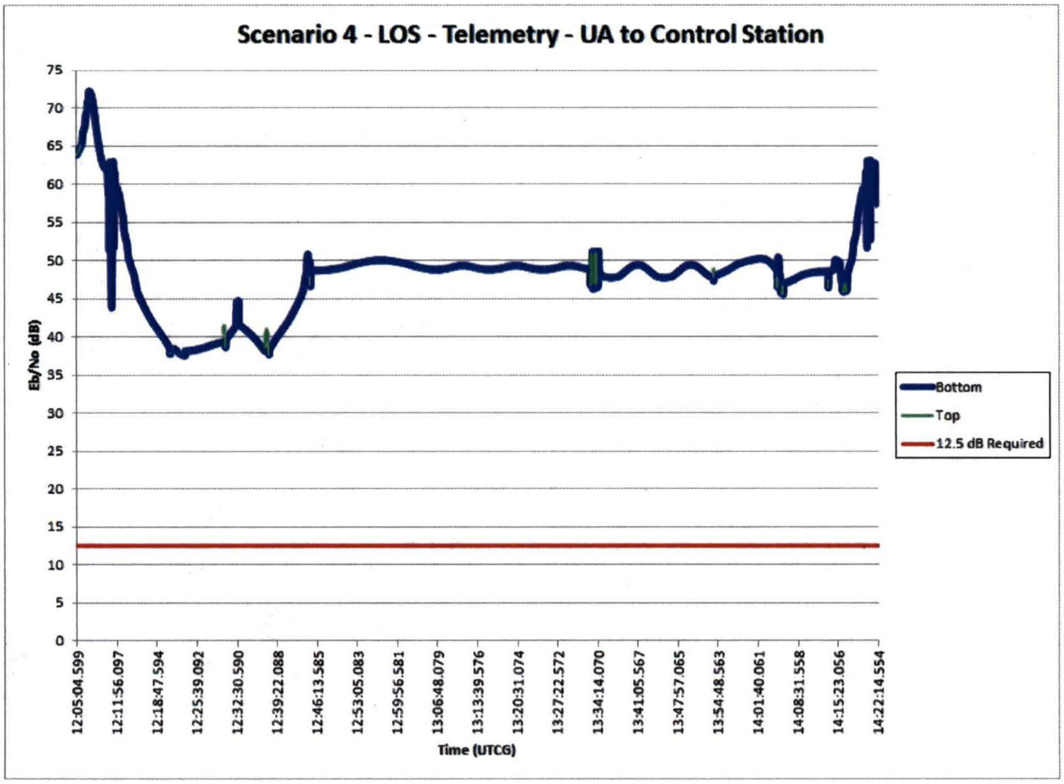

Scenario 3 - UA2 - LOS - Telemetry - UA to Control Station
Eb/No (dB)
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
6:02:33.000
6:46:21.934
7:30:10.869
8:13:59.803
8:57:48.738
9:41:37.672
10:25:26.607
11:09:15.541
11:53:04.476
12:36:53.410
13:20:42.345
14:04:31.279
14:48:20.213
15:32:09.148
16:15:58.082
16:59:47.017
17:43:35.951
18:27:24.886
19:11:13.820
19:55:02.755
20:38:51.689
Time (UTCG)
Bottom
Top
12.5 dB Required

D. Study Results for Scenario 4

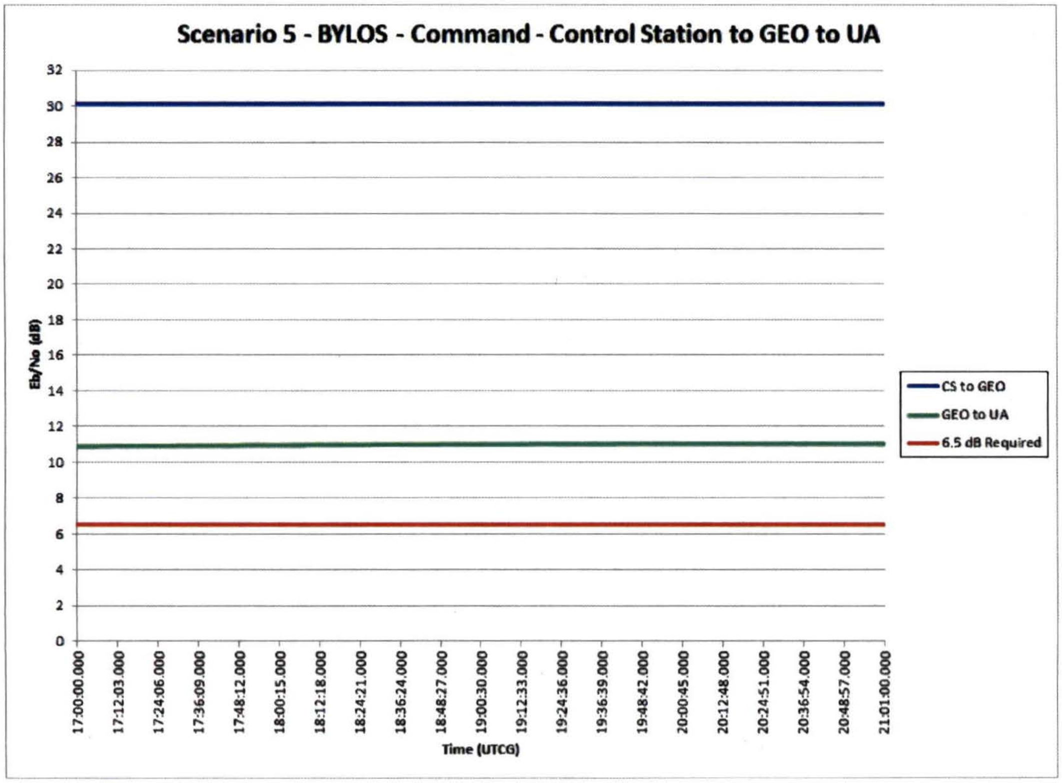


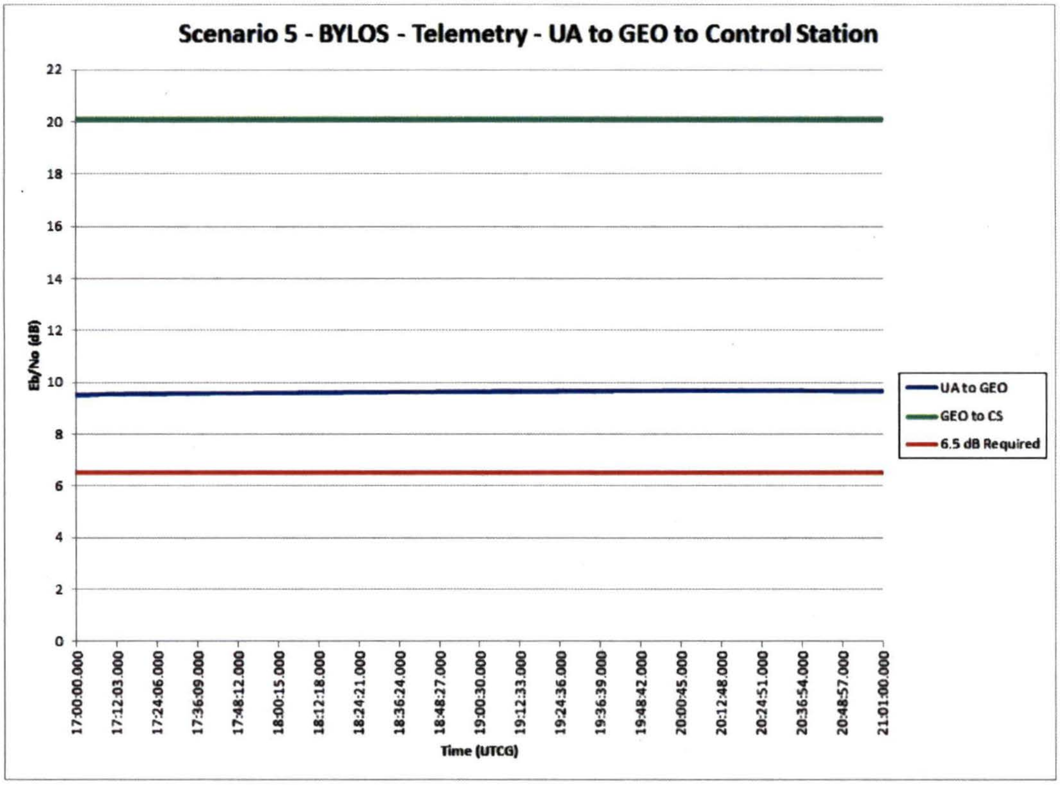


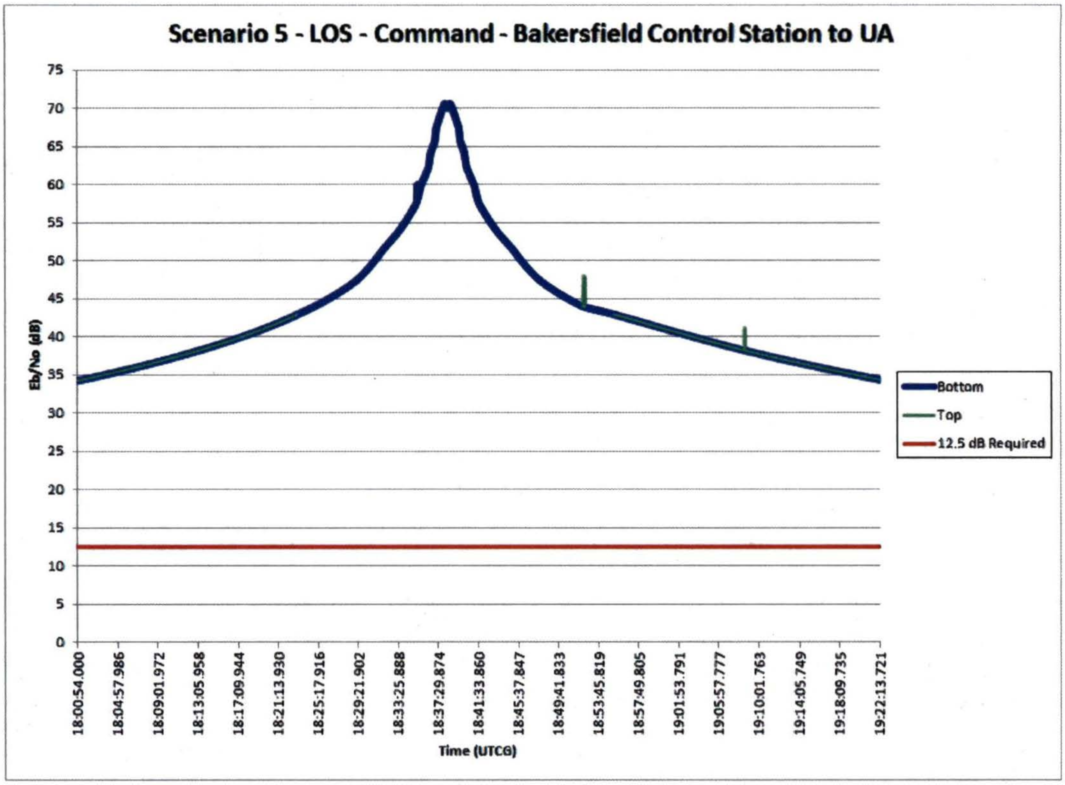

Scenario 4 - LOS - Command - Control Station to UA
Eb/No (dB)
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
12:05:04.599
12:11:56.097
12:18:47.594
12:25:39.092
12:32:30.590
12:39:22.088
12:46:13.585
12:53:05.083
12:59:56.581
13:06:48.079
13:13:39.576
13:20:31.074
13:27:22.572
13:34:14.070
13:41:05.567
13:47:57.065
13:54:48.563
14:01:40.061
14:08:31.558
14:15:23.056
14:22:14.554
Time (UTCG)
Bottom
Top
12.5 dB Required

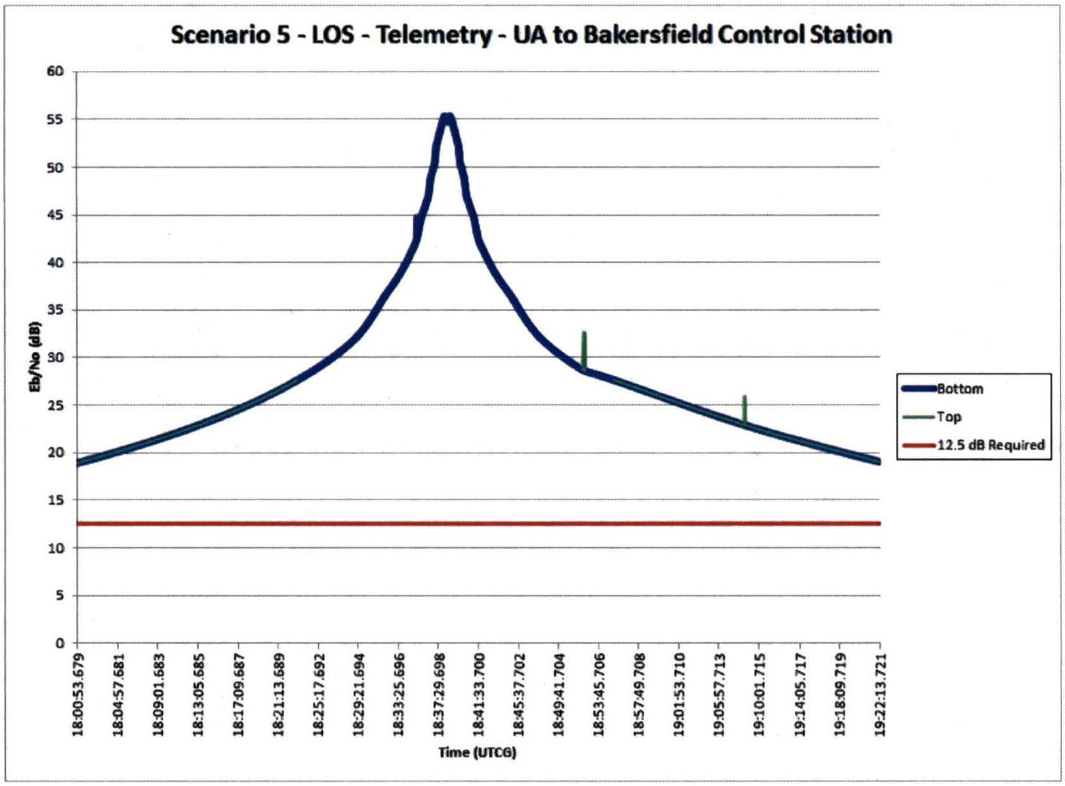

Scenario 4 - LOS - Telemetry - UA to Control Station
Eb/No (dB)
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
12:05:04.599
12:11:56.097
12:18:47.594
12:25:39.092
12:32:30.590
12:39:22.088
12:46:13.585
12:53:05.083
12:59:56.581
13:06:48.079
13:13:39.576
13:20:31.074
13:27:22.572
13:34:14.070
13:41:05.567
13:47:57.065
13:54:48.563
14:01:40.061
14:08:31.558
14:15:23.056
14:22:14.554
Time (UTCG)
Bottom
Top
12.5 dB Required

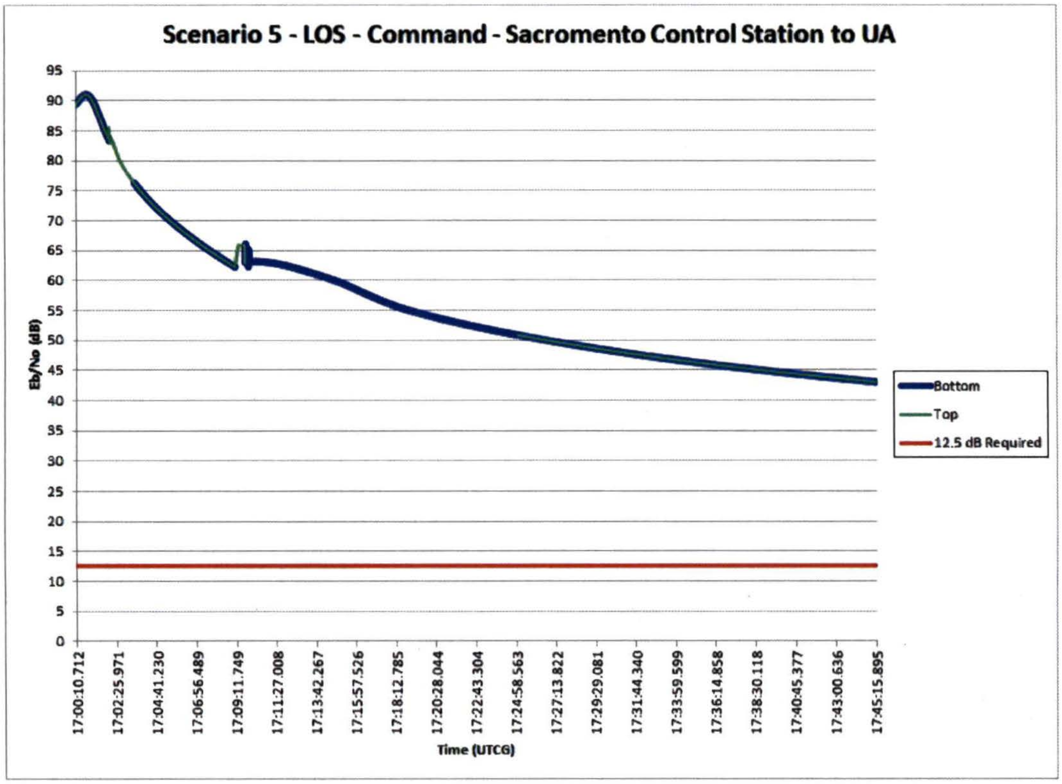
E. Study Results for Scenario 5

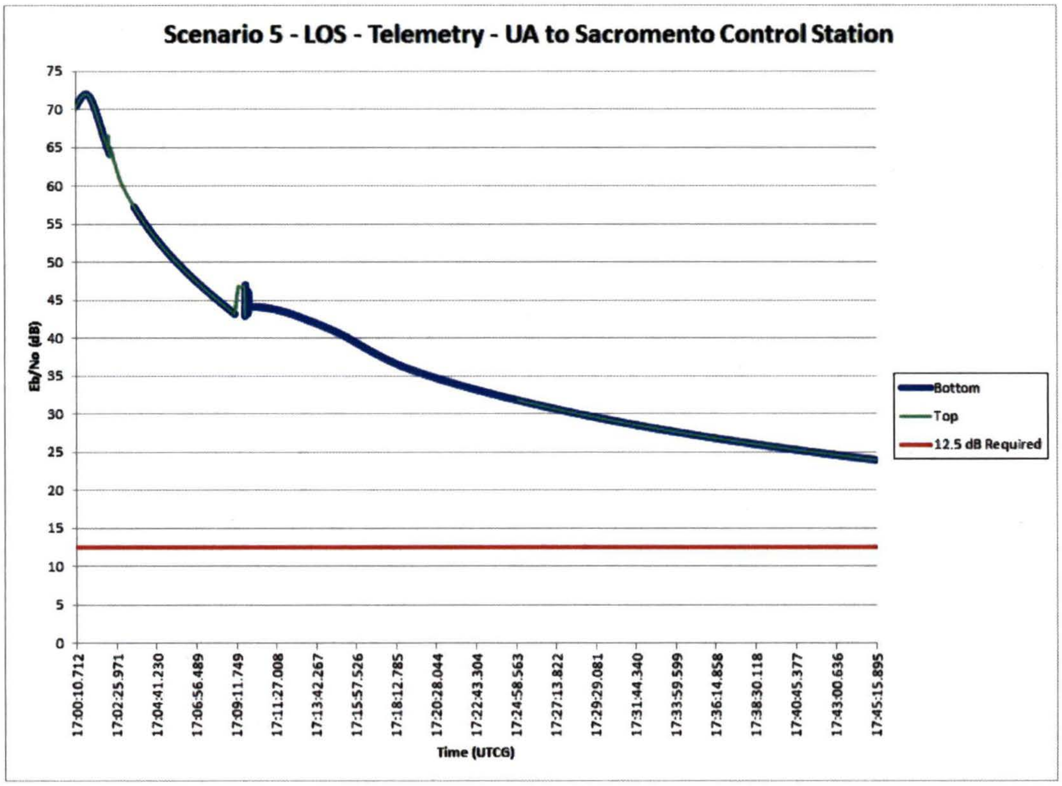




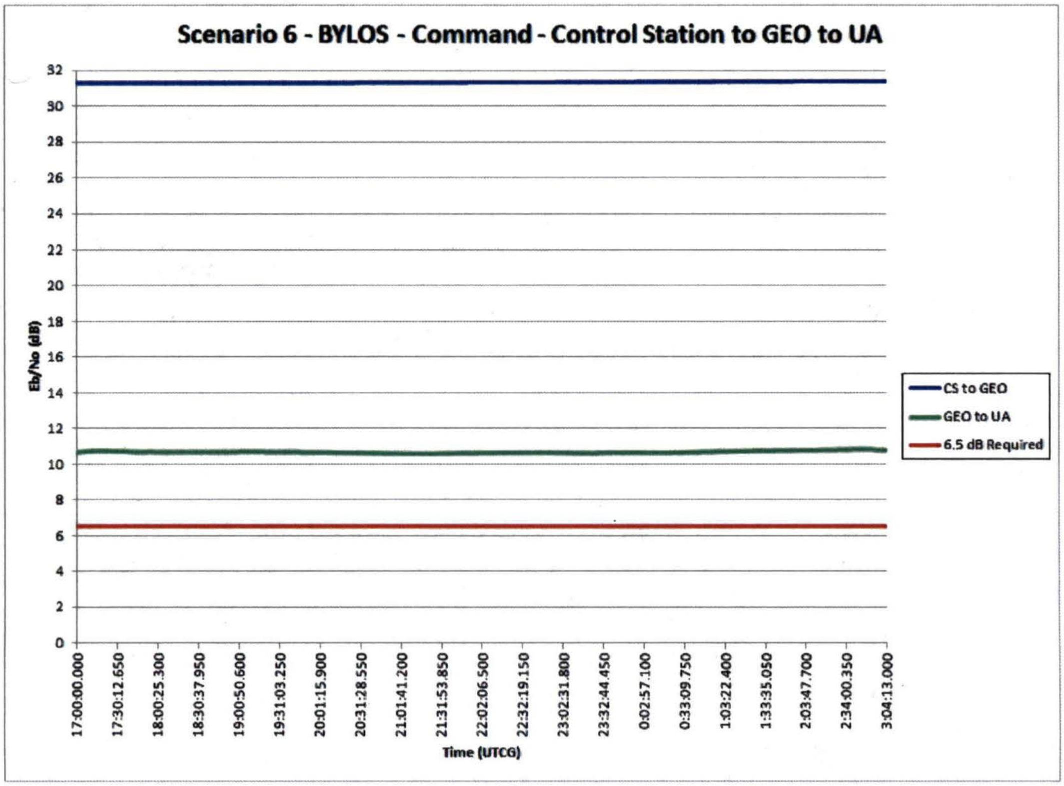

Scenario 5 - LOS - Command - Bakersfield Control Station to UA
Eb/No (dB)
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
18:00:54.000
18:04:57.986
18:09:01.972
18:13:05.958
18:17:09.944
18:21:13.930
18:25:17.916
18:29:21.902
18:33:25.888
18:37:29.874
18:41:33.860
18:45:37.847
18:49:41.833
18:53:45.819
18:57:49.805
19:01:53.791
19:05:57.777
19:10:01.763
19:14:05.749
19:18:09.735
19:22:13.721
Time (UTCG)
Bottom
Top
12.5 dB Required


Scenario 5 - LOS - Telemetry - UA to Bakersfield Control Station
Eb/No (dB)
60
55
50
45
40
35
30
25
20
15
10
5
0
18:00:53.679
18:04:57.681
18:09:01.683
18:13:05.685
18:17:09.687
18:21:13.689
18:25:17.692
18:29:21.694
18:33:25.696
18:37:29.698
18:41:33.700
18:45:37.702
18:49:41.704
18:53:45.706
18:57:49.708
19:01:53.710
19:05:57.713
19:10:01.715
19:14:05.717
19:18:09.719
19:22:13.721
Time (UTCG)
Bottom
Top
12.5 dB Required

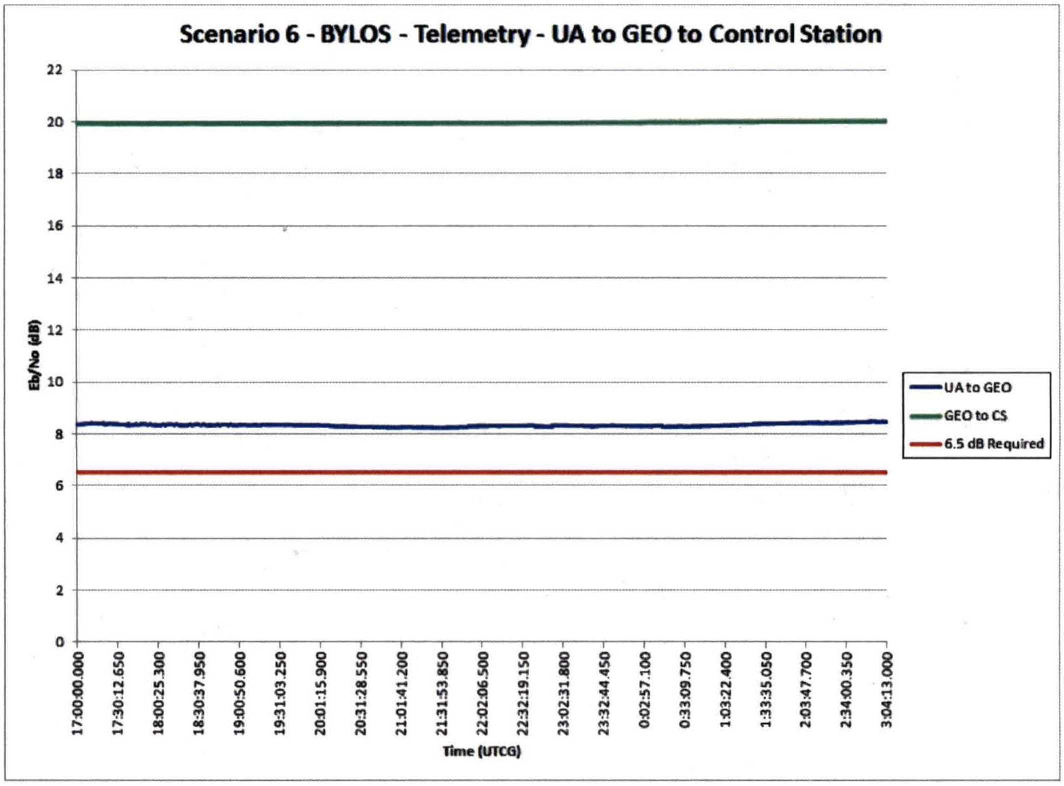

Scenario 5 - LOS - Command - Sacromento Control Station to UA
Eb/No (dB)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
17:00:10.712
17:02:25.971
17:04:41.230
17:06:56.489
17:09:11.749
17:11:27.008
17:13:42.267
17:15:57.526
17:18:12.785
17:20:28.044
17:22:43.304
17:24:58.563
17:27:13.822
17:29:29.081
17:31:44.340
17:33:59.599
17:36:14.858
17:38:30.118
17:40:45.377
17:43:00.636
17:45:15.895
Time (UTCG)
Bottom
Top
12.5 dB Required


Scenario 5 - LOS - Telemetry - UA to Sacromento Control Station
Eb/No (dB)
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
17:00:10.712
17:02:25.971
17:04:41.230
17:06:56.489
17:09:11.749
17:11:27.008
17:13:42.267
17:15:57.526
17:18:12.785
17:20:28.044
17:22:43.304
17:24:58.563
17:27:13.822
17:29:29.081
17:31:44.340
17:33:59.599
17:36:14.858
17:38:30.118
17:40:45.377
17:43:00.636
17:45:15.895
Time (UTCG)
Bottom
Top
12.5 dB Required

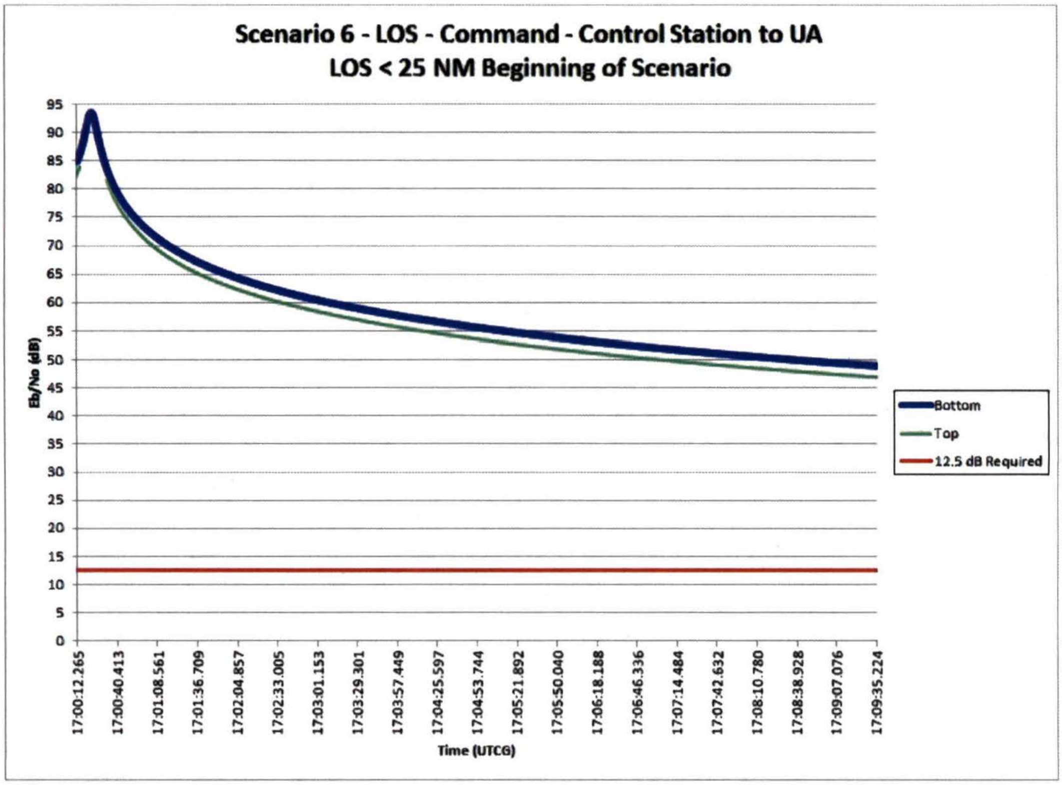
F. Study Results for Scenario 6

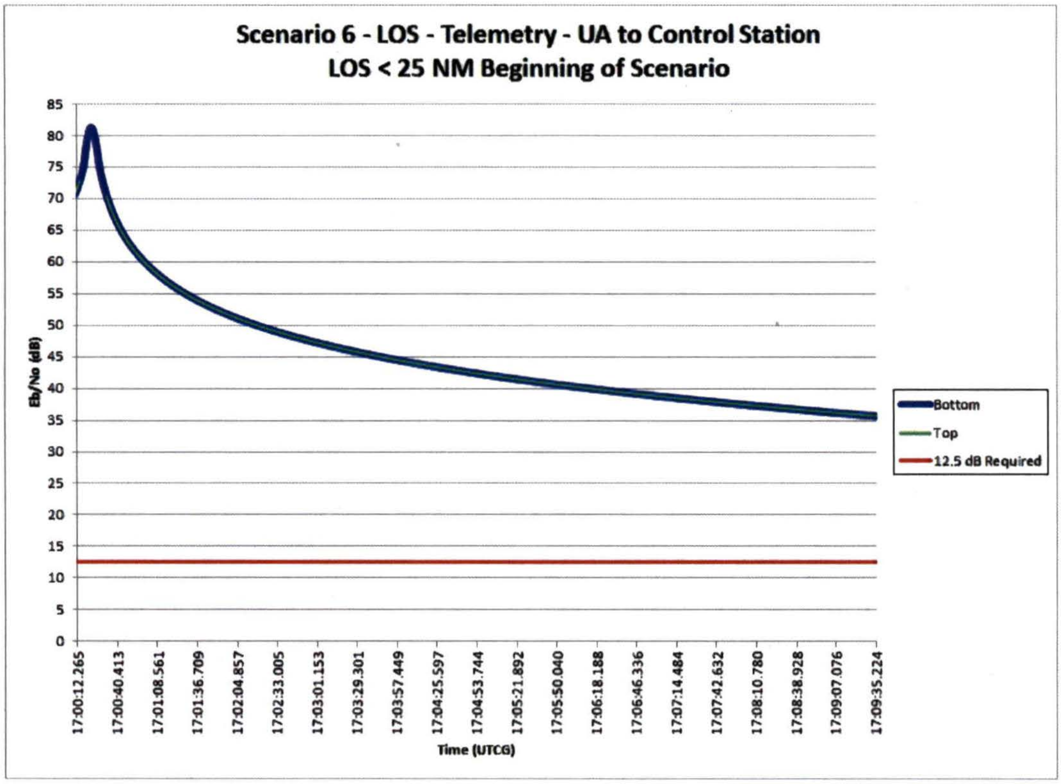


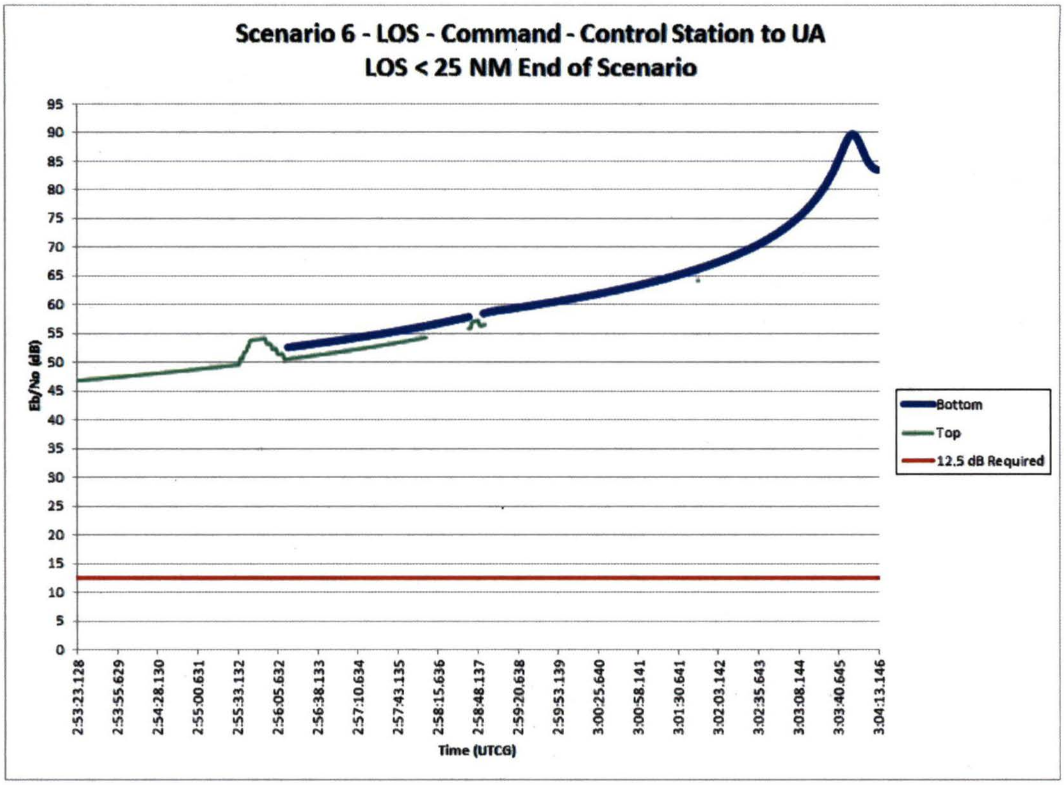
Scenario 6 - BYLOS - Command - Control Station to GEO to UA

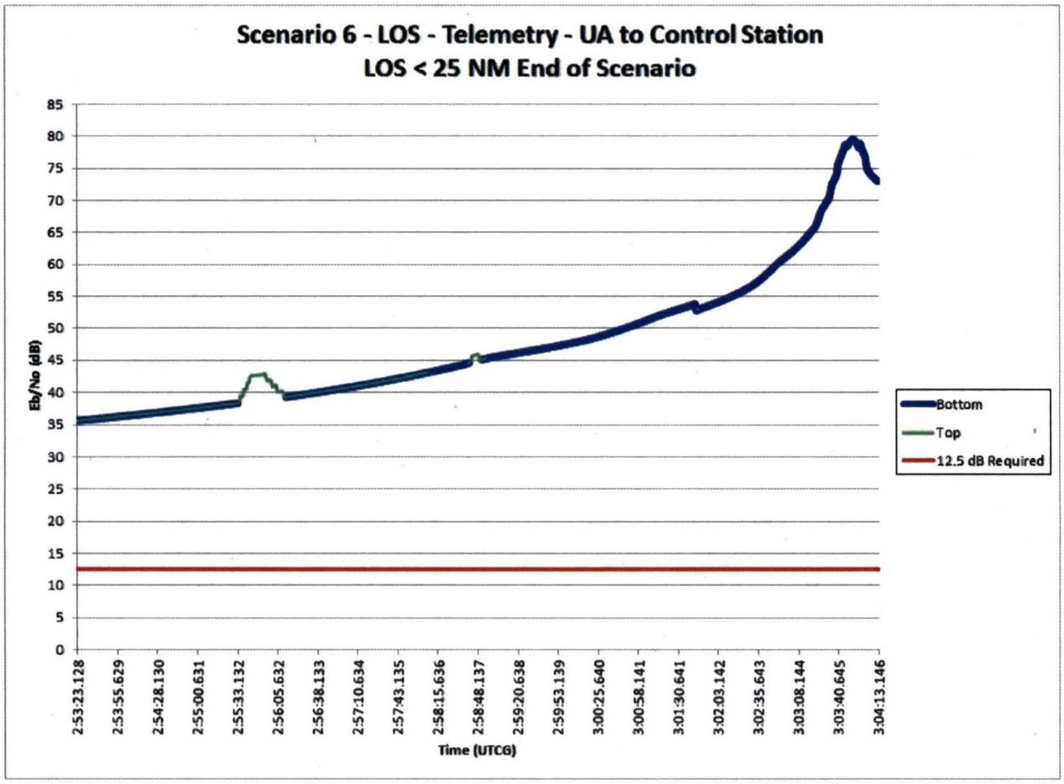


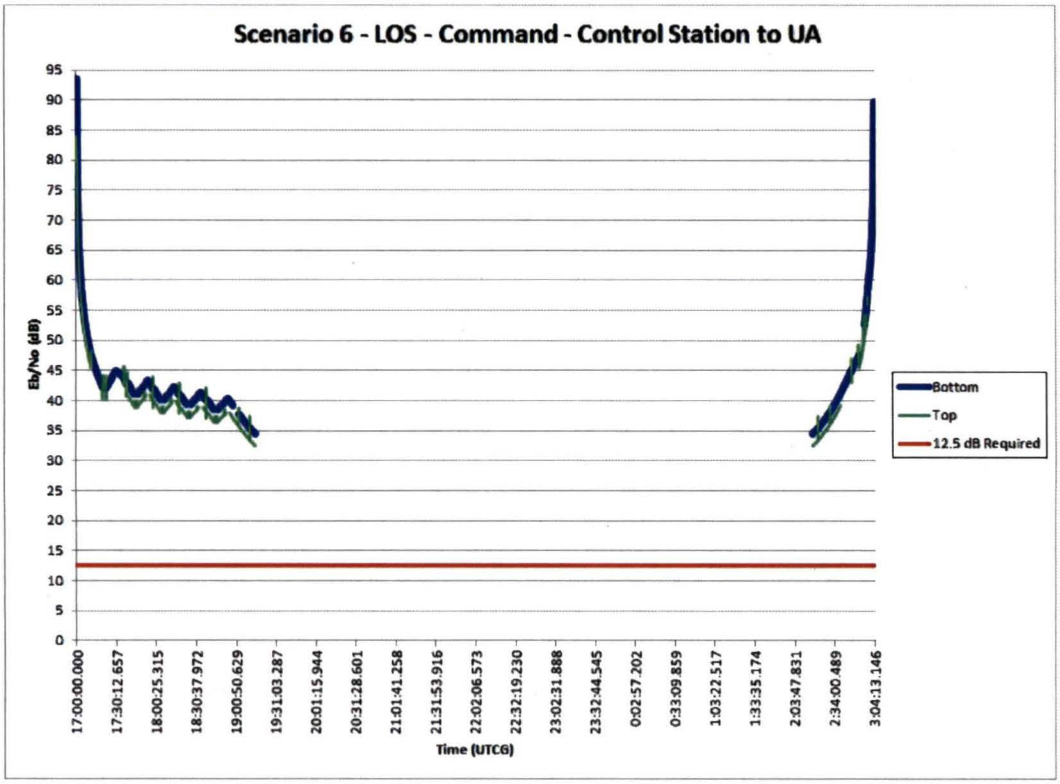
Scenario 6 - BYLOS - Telemetry - UA to GEO to Control Station

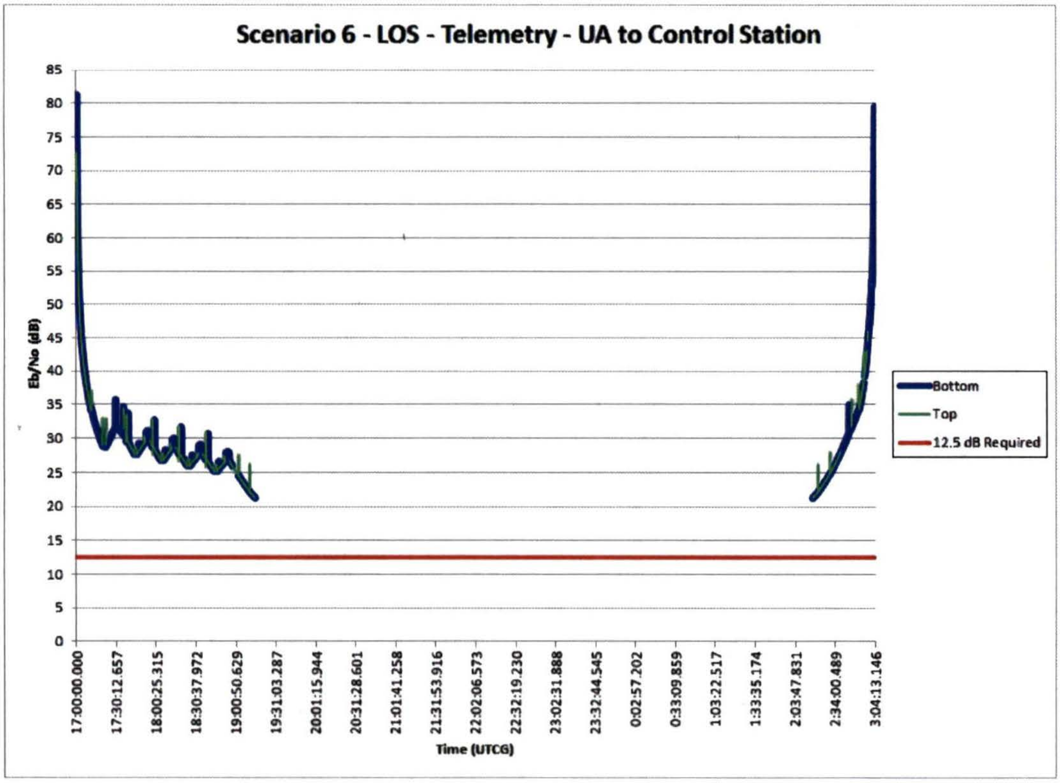

Scenario 6 - LOS - Command - Control Station to UA
LOS < 25 NM Beginning of Scenario
Eb/No (dB)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
17:00:12.265
17:00:40.413
17:01:08.561
17:01:36.709
17:02:04.857
17:02:33.005
17:03:01.153
17:03:29.301
17:03:57.449
17:04:25.597
17:04:53.744
17:05:21.892
17:05:50.040
17:06:18.188
17:06:46.336
17:07:14.484
17:07:42.632
17:08:10.780
17:08:38.928
17:09:07.076
17:09:35.224
Time (UTCG)
Bottom
Top
12.5 dB Required


Scenario 6 - LOS - Telemetry - UA to Control Station
LOS < 25 NM Beginning of Scenario
Eb/No (dB)
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
17:00:12.265
17:00:40.413
17:01:08.561
17:01:36.709
17:02:04.857
17:02:33.005
17:03:01.153
17:03:29.301
17:03:57.449
17:04:25.597
17:04:53.744
17:05:21.892
17:05:50.040
17:06:18.188
17:06:46.336
17:07:14.484
17:07:42.632
17:08:10.780
17:08:38.928
17:09:07.076
17:09:35.224
Time (UTCG)
Bottom
Top
12.5 dB Required

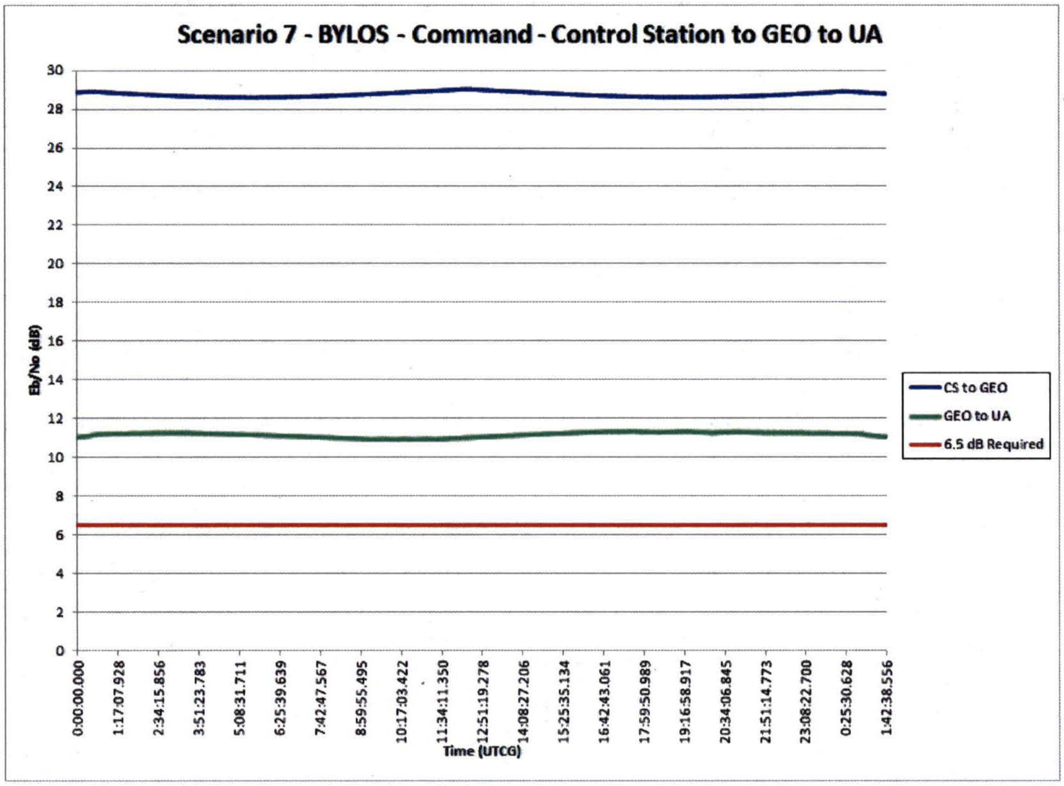

Scenario 6 - LOS - Command - Control Station to UA
LOS < 25 NM End of Scenario

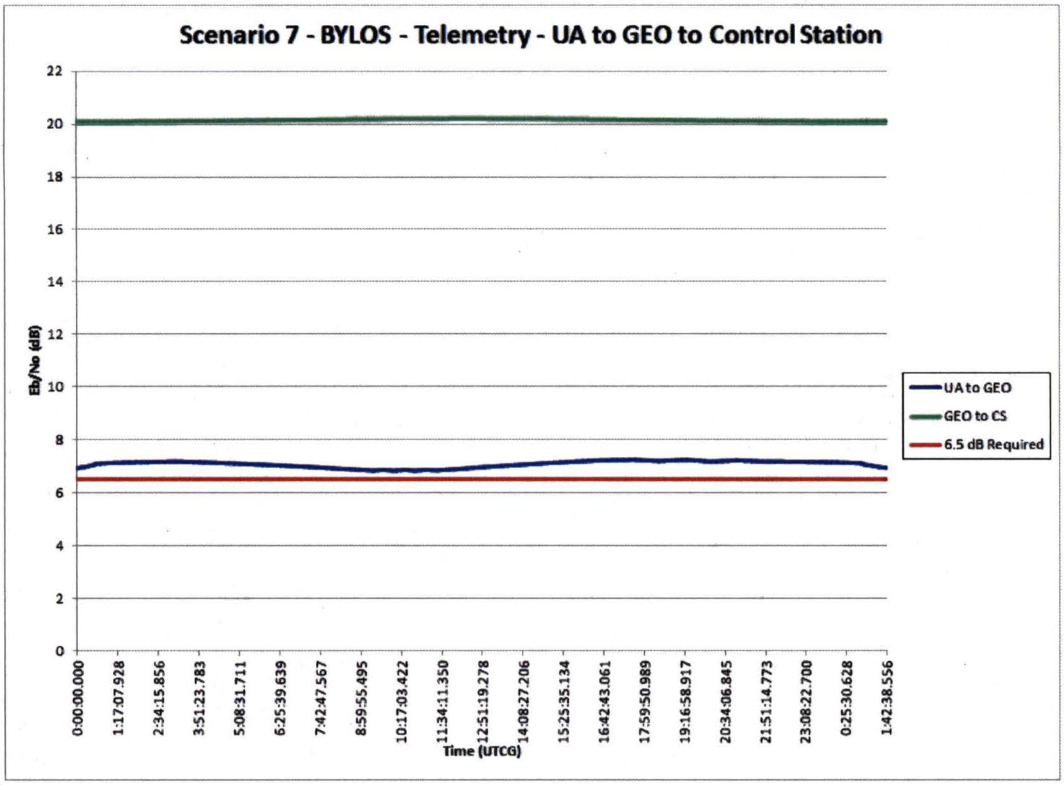

Scenario 6 - LOS - Telemetry - UA to Control Station
LOS < 25 NM End of Scenario


Scenario 6 - LOS - Command - Control Station to UA

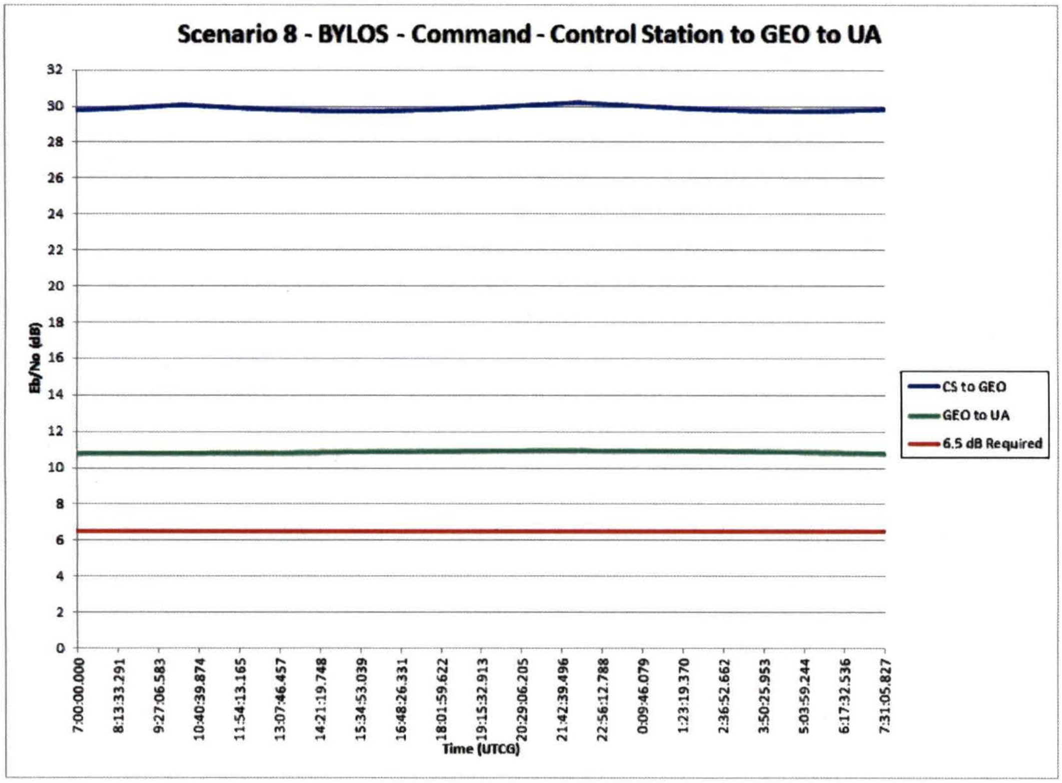

Scenario 6 - LOS - Telemetry - UA to Control Station

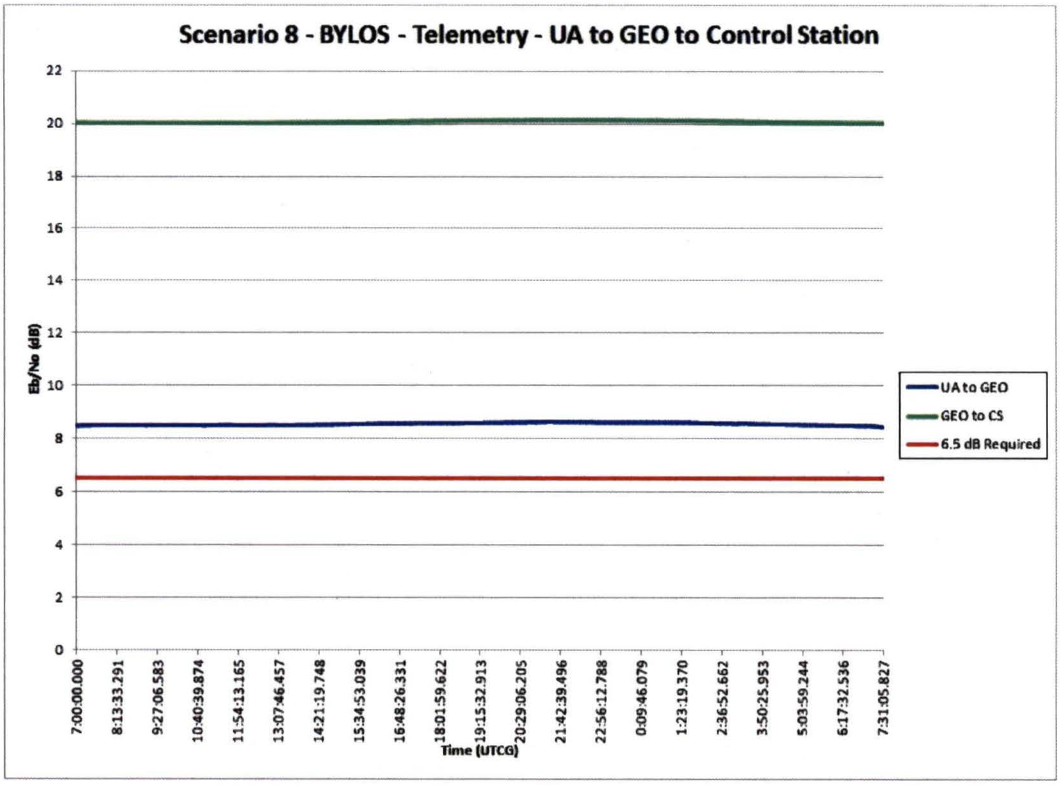
G. Study Results for Scenario 7

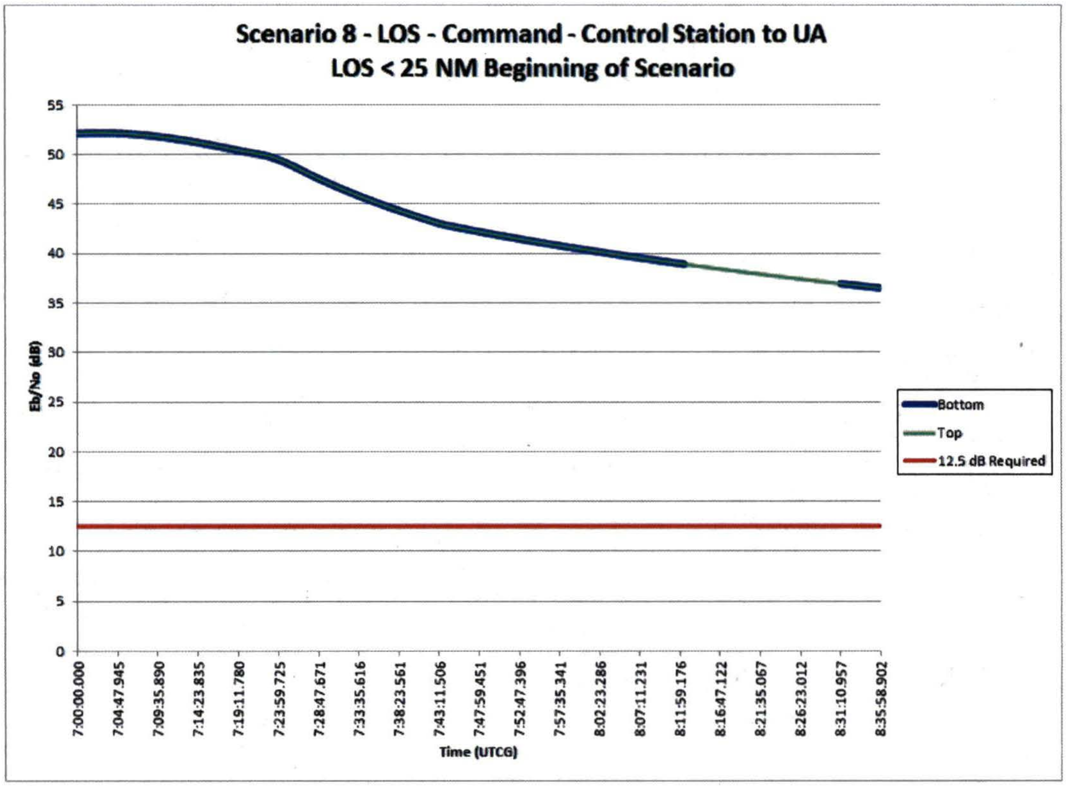

Scenario 7 - BYLOS - Command - Control Station to GEO to UA


Scenario 7 - BYLOS - Telemetry - UA to GEO to Control Station

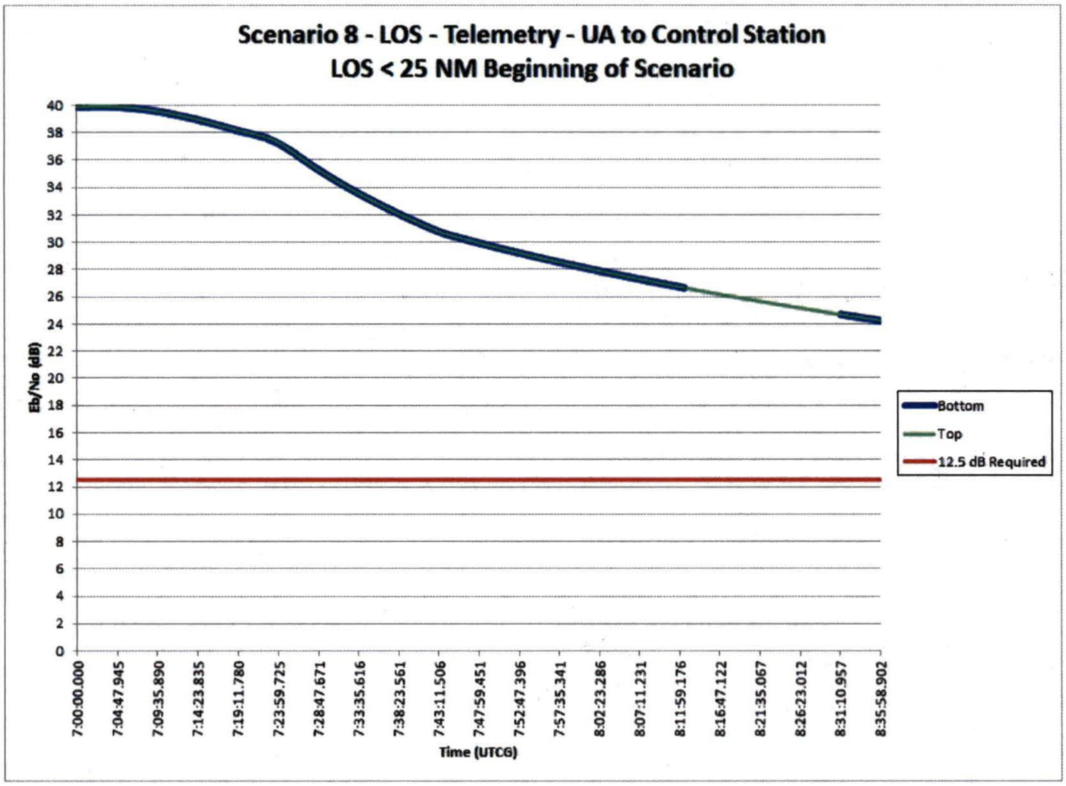
H. Study Results for Scenario 8


Scenario 8 - BYLOS - Command - Control Station to GEO to UA

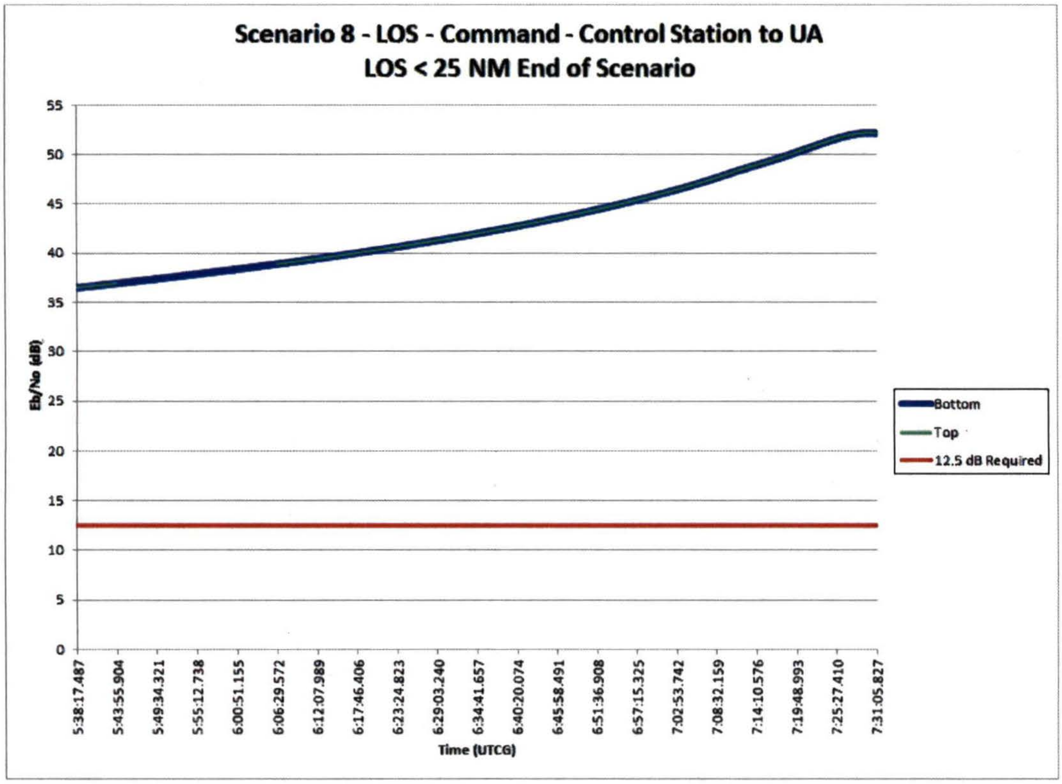

Scenario 8 - BYLOS - Telemetry - UA to GEO to Control Station

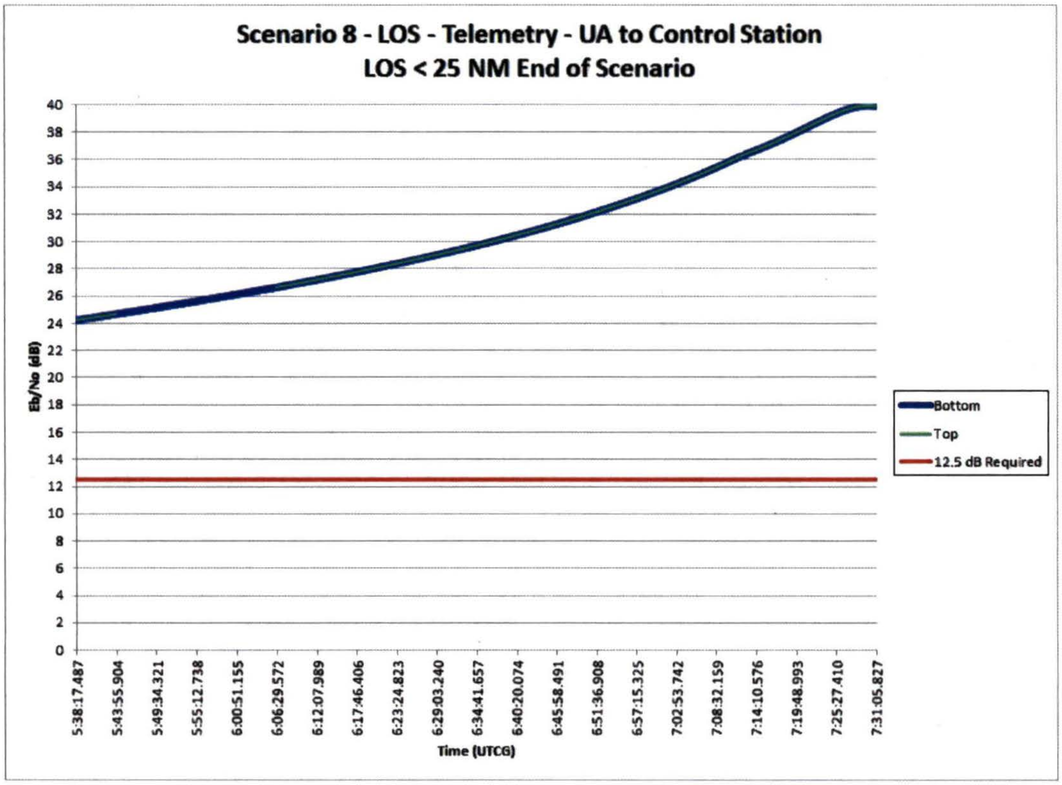


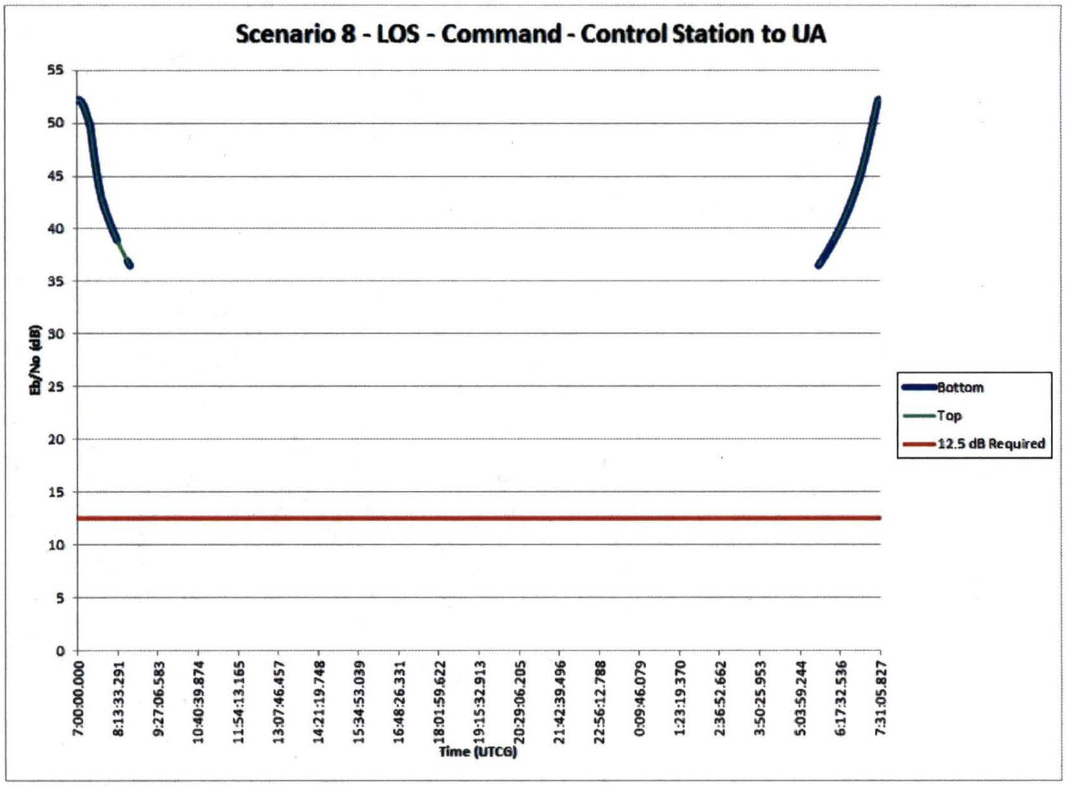
Scenario 8 - LOS - Command - Control Station to UA
LOS < 25 NM Beginning of Scenario

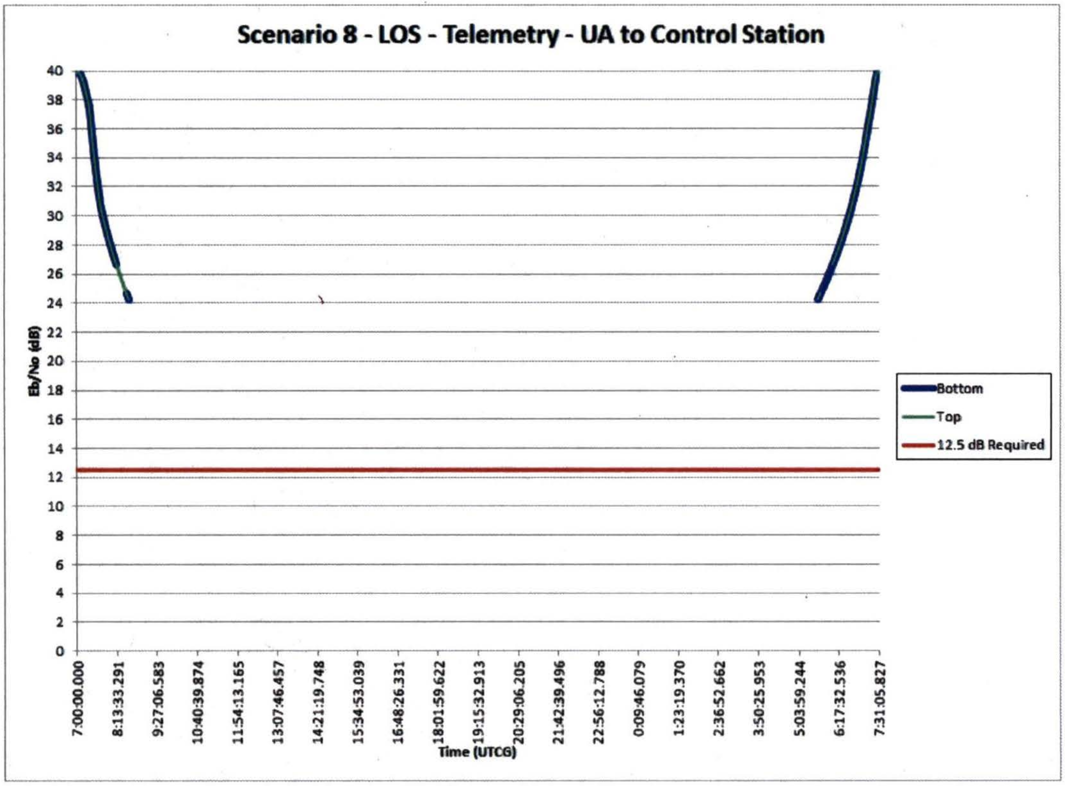


Scenario 8 - LOS - Telemetry - UA to Control Station
LOS < 25 NM Beginning of Scenario

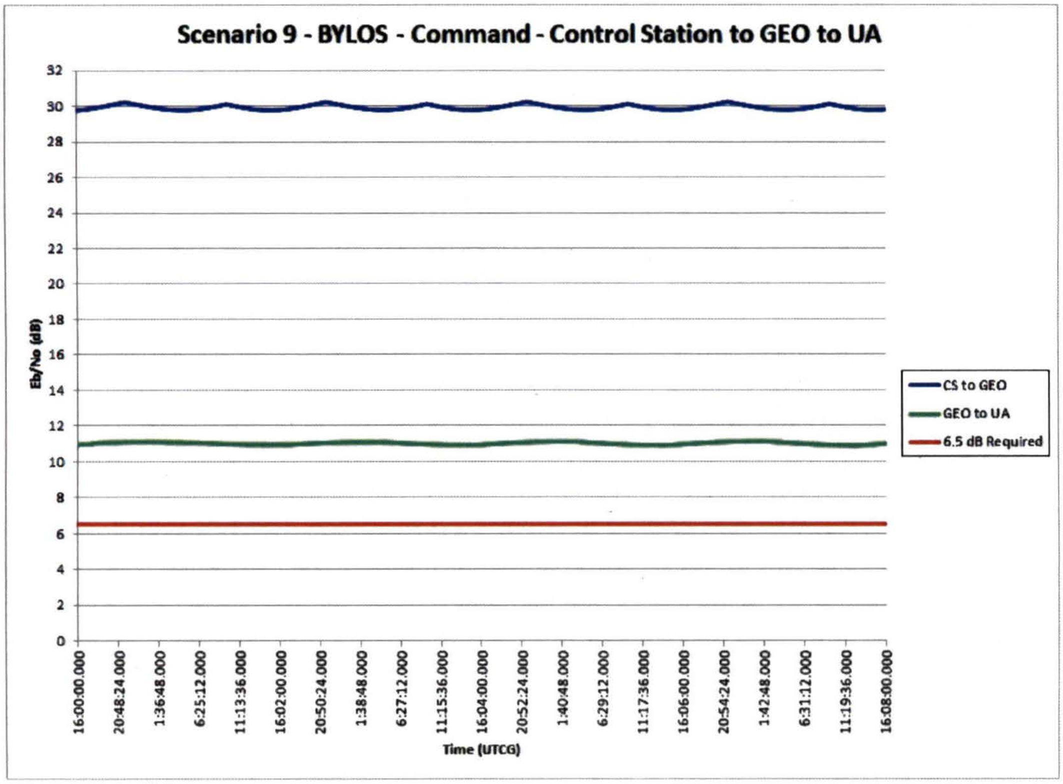

Scenario 8 - LOS - Command - Control Station to UA
LOS < 25 NM End of Scenario
Eb/No (dB)
55
50
45
40
35
30
25
20
15
10
5
0
Time (UTCG)
5:38:17.487
5:43:55.904
5:49:34.321
5:55:12.738
6:00:51.155
6:06:29.572
6:12:07.989
6:17:46.406
6:23:24.823
6:29:03.240
6:34:41.657
6:40:20.074
6:45:58.491
6:51:36.908
6:57:15.325
7:02:53.742
7:08:32.159
7:14:10.576
7:19:48.993
7:25:27.410
7:31:05.827
Bottom
Top
12.5 dB Required

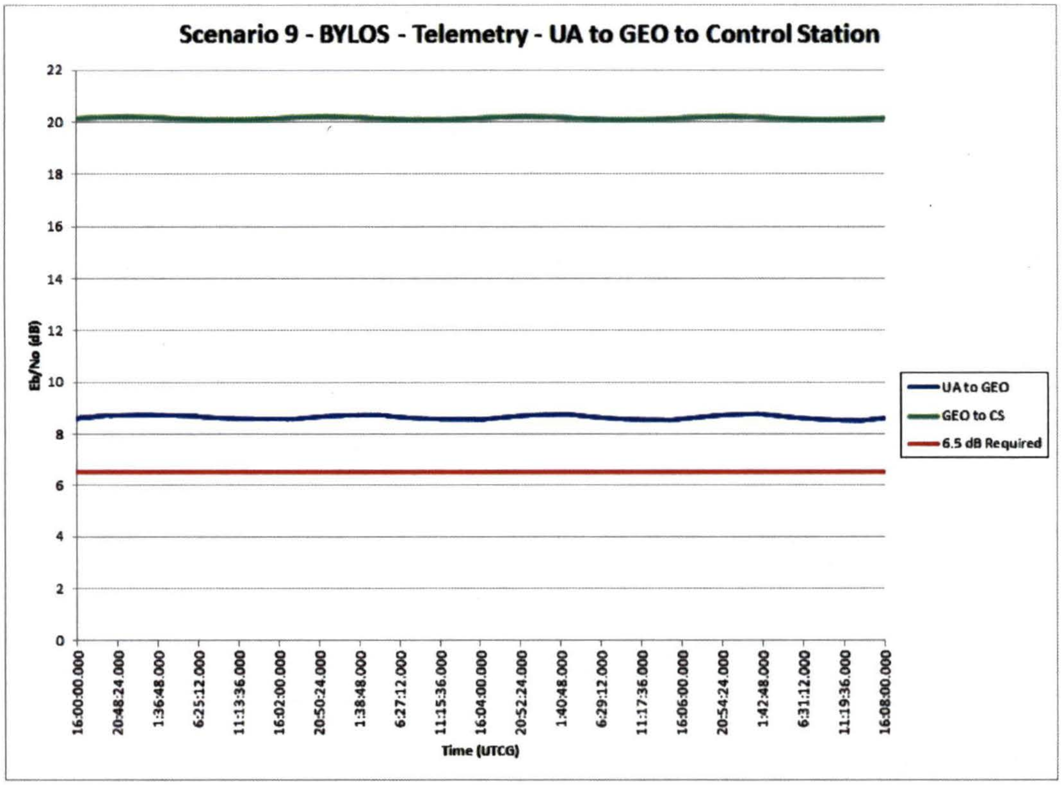

Scenario 8 - LOS - Telemetry - UA to Control Station
LOS < 25 NM End of Scenario
Eb/No (dB)
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Time (UTCG)
5:38:17.487
5:43:55.904
5:49:34.321
5:55:12.738
6:00:51.155
6:06:29.572
6:12:07.989
6:17:46.406
6:23:24.823
6:29:03.240
6:34:41.657
6:40:20.074
6:45:58.491
6:51:36.908
6:57:15.325
7:02:53.742
7:08:32.159
7:14:10.576
7:19:48.993
7:25:27.410
7:31:05.827
Bottom
Top
12.5 dB Required

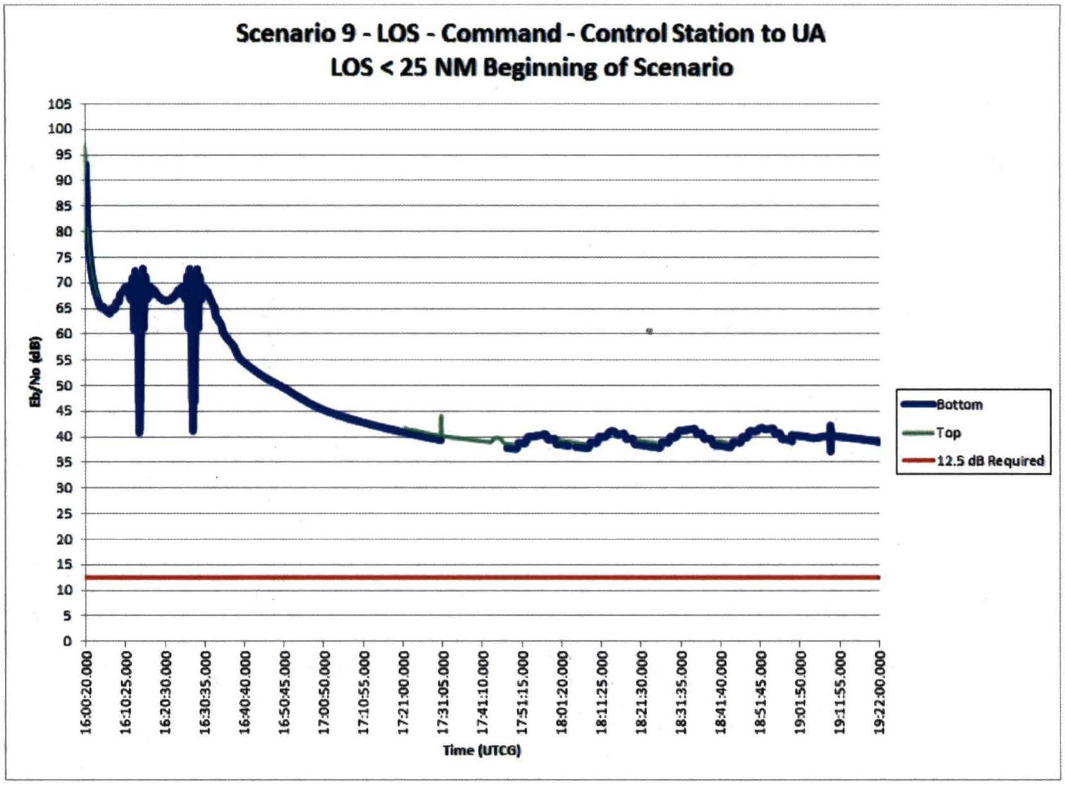

Scenario 8 - LOS - Command - Control Station to UA
Eb/No (dB)
55
50
45
40
35
30
25
20
15
10
5
0
7:00:00.000
8:13:33.291
9:27:06.583
10:40:39.874
11:54:13.165
13:07:46.457
14:21:19.748
15:34:53.039
16:48:26.331
18:01:59.622
19:15:32.913
20:29:06.205
21:42:39.496
22:56:12.788
0:09:46.079
1:23:19.370
2:36:52.662
3:50:25.953
5:03:59.244
6:17:32.536
7:31:05.827
Time (UTCG)
Bottom
Top
12.5 dB Required

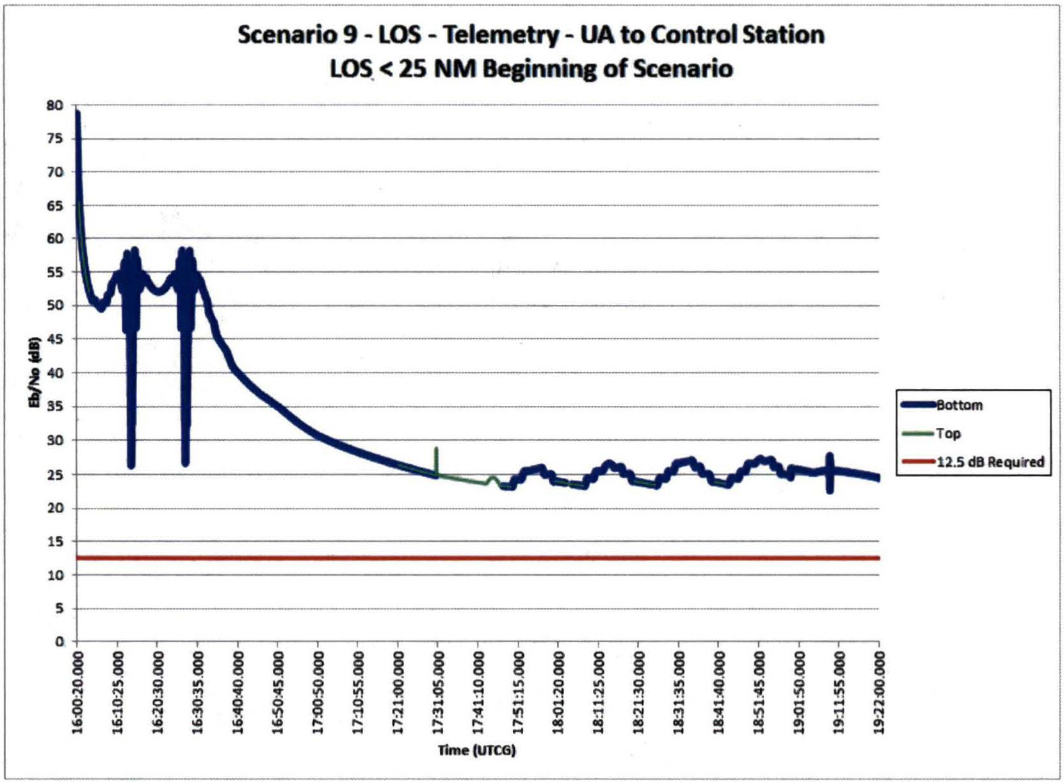

Scenario 8 - LOS - Telemetry - UA to Control Station
Eb/No (dB)
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7:00:00.000
8:13:33.291
9:27:06.583
10:40:39.874
11:54:13.165
13:07:46.457
14:21:19.748
15:34:53.039
16:48:26.331
18:01:59.622
19:15:32.913
20:29:06.205
21:42:39.496
22:56:12.788
0:09:46.079
1:23:19.370
2:36:52.662
3:50:25.953
5:03:59.244
6:17:32.536
7:31:05.827
Time (UTCG)
Bottom
Top
12.5 dB Required

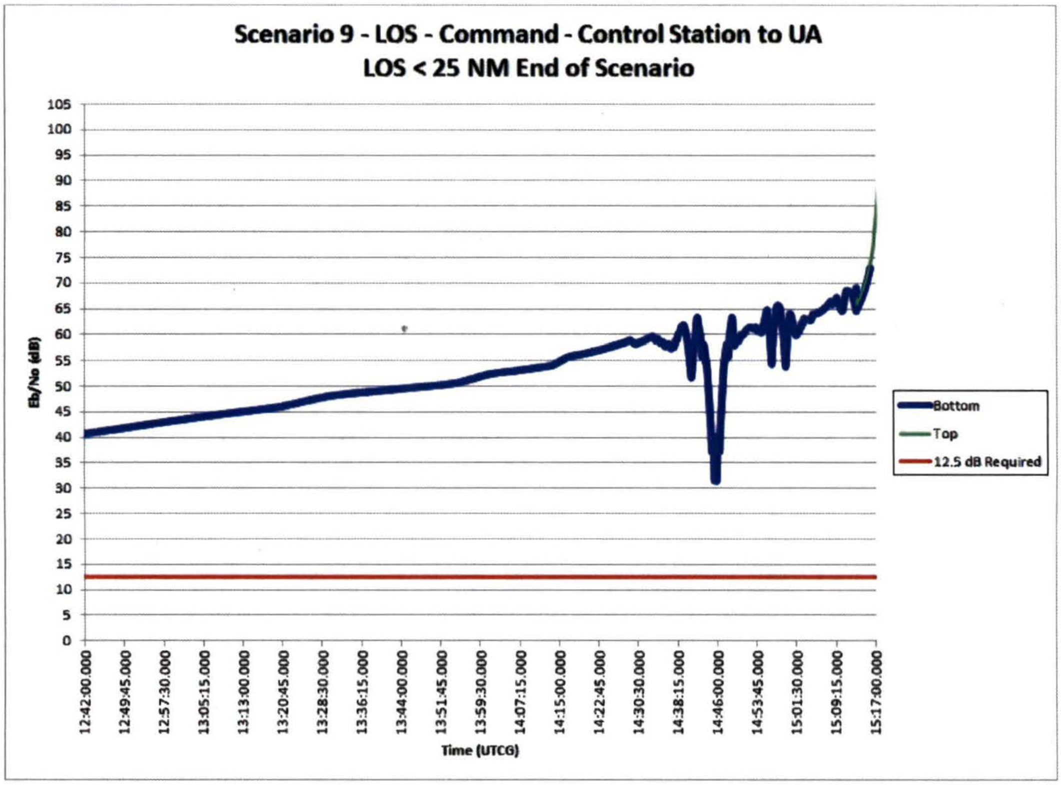
I. Study Results for Scenario 9


Scenario 9 - BYLOS - Command - Control Station to GEO to UA

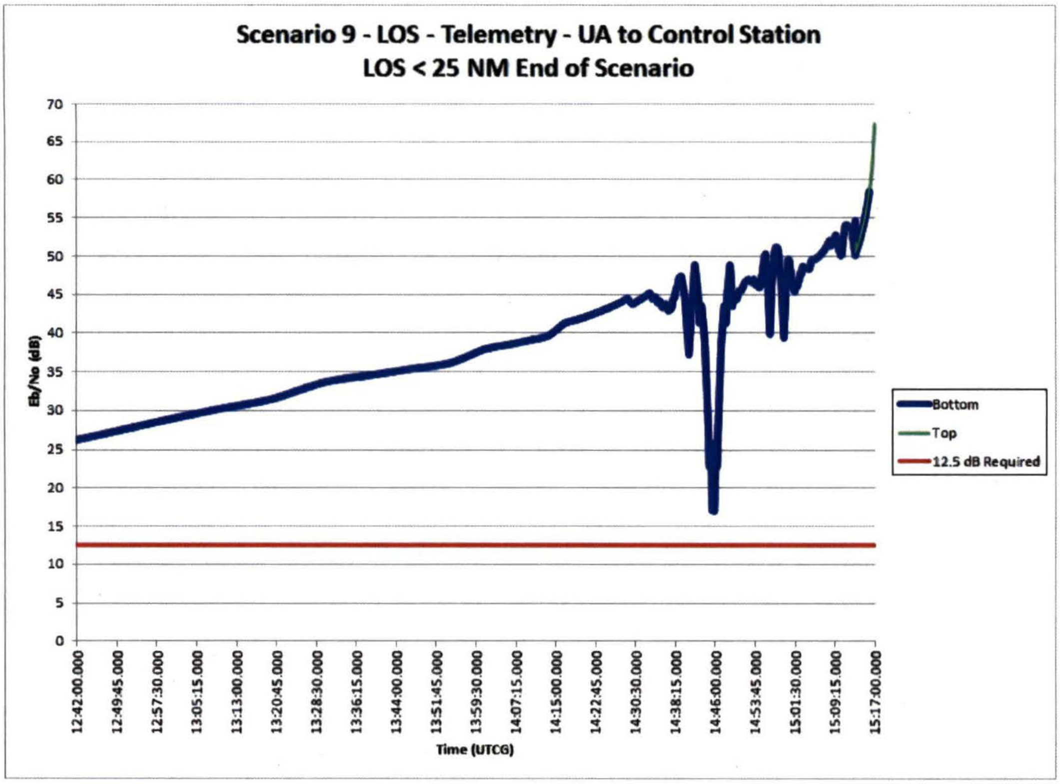

Scenario 9 - BYLOS - Telemetry - UA to GEO to Control Station


Scenario 9 - LOS - Command - Control Station to UA
LOS < 25 NM Beginning of Scenario
Eb/No (dB)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
16:00:20.000
16:10:25.000
16:20:30.000
16:30:35.000
16:40:40.000
16:50:45.000
17:00:50.000
17:10:55.000
17:21:00.000
17:31:05.000
17:41:10.000
17:51:15.000
18:01:20.000
18:11:25.000
18:21:30.000
18:31:35.000
18:41:40.000
18:51:45.000
19:01:50.000
19:11:55.000
19:22:00.000
Time (UTCG)
Bottom
Top
12.5 dB Required

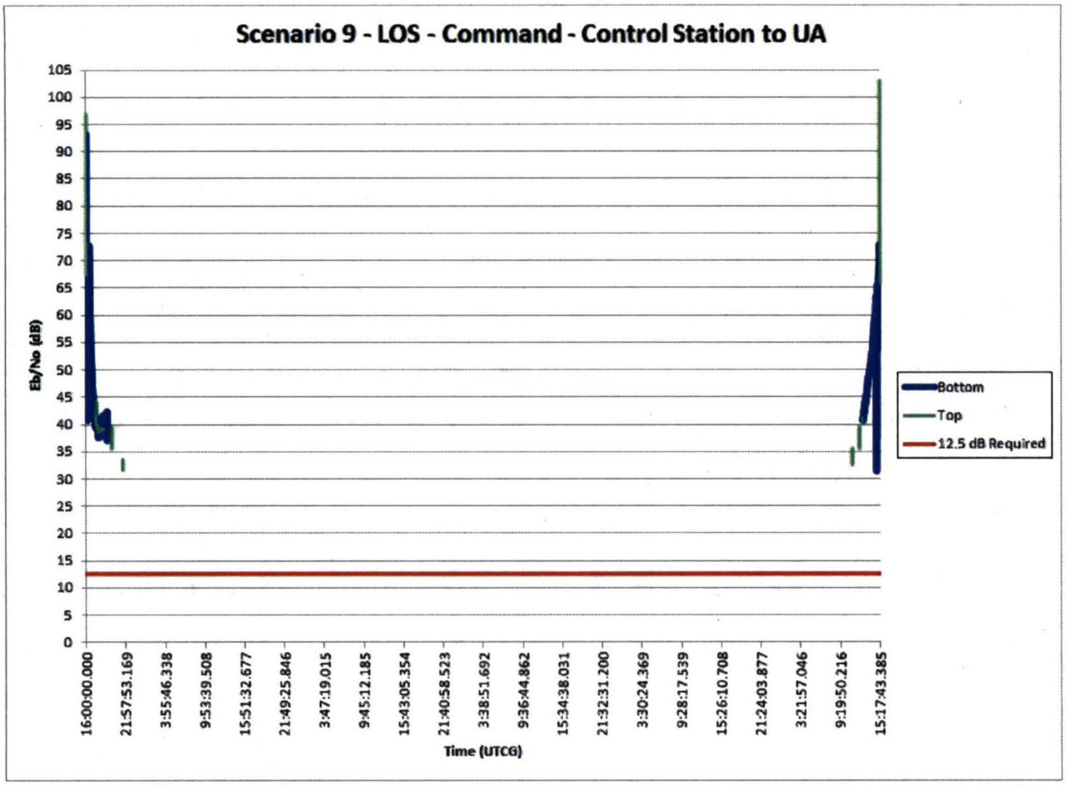

Scenario 9 - LOS - Telemetry - UA to Control Station
LOS < 25 NM Beginning of Scenario
Eb/No (dB)
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
16:00:20.000
16:10:25.000
16:20:30.000
16:30:35.000
16:40:40.000
16:50:45.000
17:00:50.000
17:10:55.000
17:21:00.000
17:31:05.000
17:41:10.000
17:51:15.000
18:01:20.000
18:11:25.000
18:21:30.000
18:31:35.000
18:41:40.000
18:51:45.000
19:01:50.000
19:11:55.000
19:22:00.000
Time (UTCG)
Bottom
Top
12.5 dB Required



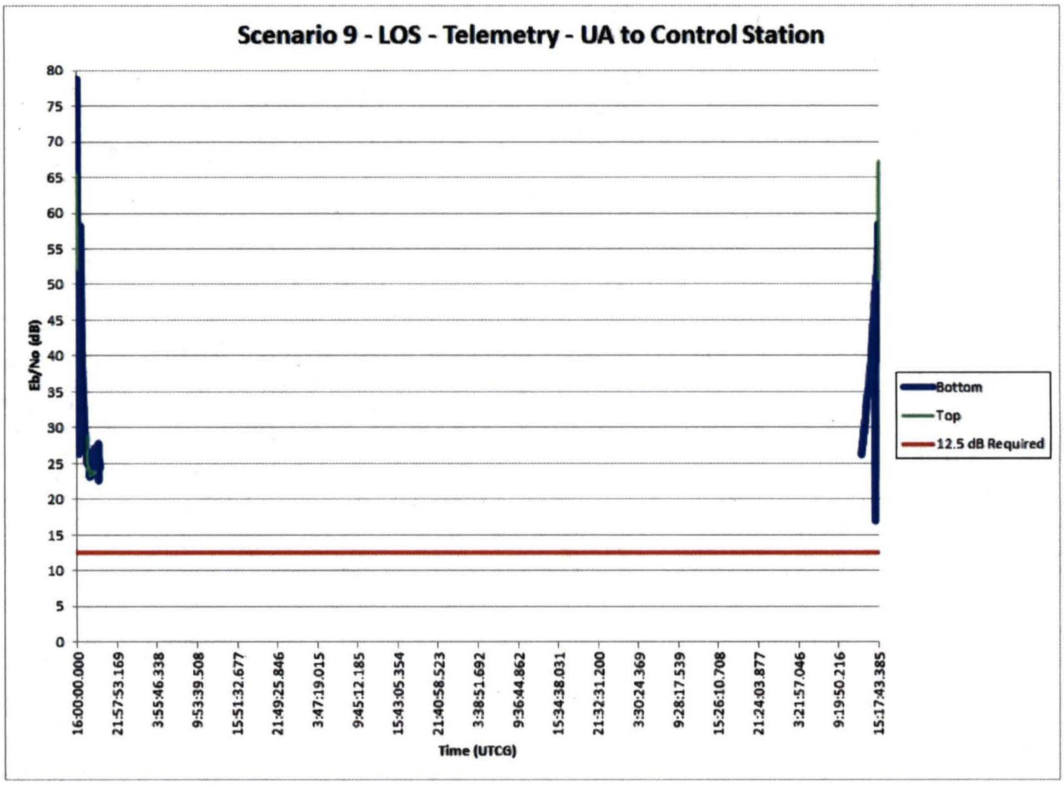
Scenario 9 - LOS - Command - Control Station to UA
LOS < 25 NM End of Scenario



Scenario 9 - LOS - Telemetry - UA to Control Station
LOS < 25 NM End of Scenario



Scenario 9 - LOS - Command - Control Station to UA



Scenario 9 - LOS - Telemetry - UA to Control Station

DTFACT-10-X-00003
KCA-4269 Rev. Basic

INTERAGENCY AGREEMENT (IA)

BETWEEN THE

FEDERAL AVIATION ADMINISTRATION (FAA) RESEARCH AND TECHNOLOGY DEVELOPMENT OFFICE (R&TD)

AND THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) KENNEDY SPACE CENTER (KSC)

FOR

UNMANNED AIRCRAFT SYSTEMS (UAS) ANALYSIS, MODELING, SIMULATION, AND DEMONSTRATION ACTIVITIES TO ADVANCE UAS INTEGRATION IN THE NATIONAL AIRSPACE SYSTEM (NAS)

ARTICLE 1. PARTIES

This Agreement is entered into by the Federal Aviation Administration (FAA) Research and Technology Development Office (R&TD), Routing AJP-6, 800 Independence Avenue, SW, Washington, D.C., 20591, and the National Aeronautics and Space Administration (NASA) Kennedy Space Center (KSC) located at Mail Code NE-I1, Kennedy Space Center, FL 32899. FAA and NASA may be individually referred to as a Party or Partner and collectively referred to as the Parties or Partners.

ARTICLE 2. SCOPE

A. Purpose and Implementation

This IA is consistent with the intent of the Memorandum of Understanding (MOU) between the Parties concerning "A Partnership to Achieve Goals in Aviation and Space Transportation" (FNA/11), dated May 15, 2006.

The purpose of this IA between the Parties is to conduct research related to integrating Unmanned Aircraft Systems (UAS) into the National Airspace System (NAS), and to identify potential requirements for the FAA Next Generation Air Transportation System (NextGen).

The Parties will execute one (1) Annex concurrently with this IA. Subsequent Annexes are authorized under this IA consistent with the purpose and terms of this Agreement.

Each Annex will detail the specific purpose of the proposed activity, statement of work (SOW) including responsibilities, schedule and milestones, and any personnel, property or facilities to be utilized under the task.

B. Background

Within the aviation community, interest in using UAS for a broad range of purposes has been rapidly increasing, making UAS access to the NAS a priority. Current requests for access to the NAS are subject to technical and operational assessments of the specific UAS operation in question based on interim approval guidance. UAS operations are subject to operational limitations when there is any perceived risk to the public. It is a growing imperative within the UAS community, including public and civil users, to reduce these restrictions and to support more routine access in order to improve and advance integration of UAS into the NAS.

Therefore, validated operational standards and policies are required. The Parties have joined resources to conduct research and development activities that will support the investigation of UAS-NAS integration issues.

NASA KSC is interested in supporting the FAA effort to facilitate the integration of UAS operations to supplement NASA and Air Force missions as part of the NASA-Air Force Memorandum of Agreement (MOA) on Next Generation Range Technology Development. Future Range operations will integrate manned and unmanned aircraft systems in the NAS enabling higher launch rate operations. This NAS integration will require optimal operational procedures and standards for the interaction between UAS operations/flight management systems with air traffic managers/controllers for both the nominal and off-nominal flight scenarios.

The Parties will work together on research and development activities to evaluate parameters, operations, and procedures that define acceptable UAS behavior while maintaining the highest level of safety. This includes investigating methods that support the integration of UAS into the NAS without causing delays, capacity reduction, or placing current users at risk.

Researchers at NASA KSC have already started conducting UAS research using modeling techniques to study communications link performance and other command and control design considerations. The FAA has conducted studies and is developing advanced UAS modeling capabilities that will be integrated into their extensive NAS simulation environment to evaluate UAS operations in the NAS. The purpose of this partnership is to utilize the highly specialized skills, experience, and unique capabilities of NASA KSC and the FAA R&TD Office to research issues that will support the development of standards for the safe integration of UAS in the NAS.

C. Objectives

Specific goals and objectives include (but are not limited to):

1. Conduct research and provide data to support the development of standards, procedures, and tools to facilitate safe and efficient UAS operations in the NAS.
2. Investigate Air Traffic Management (ATM) and Air Traffic Control (ATC) operational issues associated with integrating UAS operations into the NAS.
3. Provide data to contribute confidence in the UAS safety case.
4. Provide a platform for validation of Radio Technical Commission for Aeronautics (RTCA, Inc.) SC-203 UAS performance requirements now under development.
5. Use the NASA KSC and FAA modeling and simulation (M&S) environments to plan and support potential UAS flight demonstration and test activities.
6. Provide data to support the identification of UAS requirements for NextGen.
7. Provide support for UAS simulation and demos.

Where support provided by this Agreement involves transfer of funds between the Parties will be governed by appropriate procedures and policies as set forth in both federal acquisition and individual agency regulations, incorporating FAA and NASA accounting and appropriation codes.

D. Roles and Responsibilities

1. NASA KSC will use reasonable efforts to:

    a. Provide operational and technical expertise and work with the FAA R&TD Office to accomplish objectives listed in Section C above.
    b. Provide expertise and technical support to the FAA R&TD in developing UAS modeling scenarios, integrating those scenarios with ATM/ATC data and systems, and use those capabilities to conduct research.
    c. Participate in simulation and demonstration activities.

2. FAA R&TD will use reasonable efforts to

    a. Provide operational and technical expertise, and provide resources and funding to NASA KSC when needed, to accomplish objectives listed in Section C above.
    b. Provide expertise and technical support to NASA KSC to develop and integrate UAS modeling capabilities with ATM/ATC data and systems, and use those capabilities to conduct research.

3. All Parties will use reasonable efforts to:

    a. Share capabilities and resources to accomplish objectives listed in Section C above.
    b. Jointly prepare plan (with revisions as needed) for developing modeling capabilities and a distributed test bed to evaluate UAS operations.

c. Develop and enhance each other's capabilities to conduct UAS research.
d. Jointly prepare reports, briefings, and other intellectual materials that document the strategies, methodologies, results and products developed under this agreement.
e. Participate in collaborative research, development, and technology demonstration and flight test activities, and share data and results from those activities.

ARTICLE 3. EFFECTIVE DATE AND TERM

This Agreement is effective on the date of the last signature of the parties and shall continue in effect for a period of five (5) years, or until earlier terminated by the parties, as provided herein.

ARTICLE 4. REPORTING REQUIREMENTS

A. Both Parties will prepare and co-author the technical reports, technical presentations, and other reporting items as required in the SOWs.

B. Bi-weekly teleconferences. More frequent calls as needed to support engineering and M&S activities.

C. On-site meetings as needed (quarterly at a minimum) at NASA KSC or FAA William J. Huges Technical Center (WJHTC).

ARTICLE 5. USE AND RELEASE OF TECHNICAL DATA, PROTECTION, AND SECURITY OF INFORMATION

A. No information, oral or written, concerning the results or conclusions made pursuant to this Agreement shall be published or released to the public without the prior written approval of the FAA Contracting Officer.

B. It is the intent of the Parties that the information and data exchanged in furtherance of the activities under this Agreement will be exchanged without Federal-use restrictions unless required by national security issues or otherwise agreed to by the Parties for specifically identified information or data.

C. The Parties agree that they will take appropriate measures to protect proprietary, privileged, classified, or otherwise confidential information that may come into their possession as a result of this Agreement.

D. Release of information associated with joint activities carried out under this Agreement will appropriately recognize each Party and will be coordinated between the Parties in advance of the release.

ARTICLE 6. INTELLECTUAL PROPERTY

Unless otherwise agreed by the Parties, custody and administration of inventions made as a consequence of, or in direct relation to, the performance of activities under this Agreement will remain with the respective inventing party. In the event an invention is made jointly by employees of the Parties or an employee of a Party's contractor, the Parties will consult and agree as to future actions toward establishment of patent protection for the invention.

ARTICLE 7. LEGAL AUTHORITY

A. This Agreement is entered into on behalf of the FAA under the authority of Sections 226 and 227 of the FAA Reauthorization Act of 1996, 49 U.S.C. §106 (l)(6) and (m).

B. This Agreement is entered into on behalf of NASA under authority of Sections 203 (c)(5) and (c)(6) of the National Aeronautics and Space Act of 1958, as amended, 42 U.S.C. 2473(c)(5) and (c)(6).

ARTICLE 8. POINTS OF CONTACT

A. Federal Aviation Administration

1. Technical Representatives:

Albert Schwartz (609) 485-4226
FAA William J. Hughes Technical Center, AJP-65
Atlantic City International Airport, NJ 08405
albert.schwartz@faa.gov

Richard VanSuetendael (321) 867-2133
FAA R&TD Field Office, AJP-641
Mail Stop: FAA
Kennedy Space Center, FL 32899
richard.vansuetendael@faa.gov

2. Administrative Representative:

Susan Conry (757) 864-2011
FAA R&TD Field Office, AJP-641
Mail Stop 221
NASA Langley Research Center
Hampton, VA 23681-2199
susan.l.conry@faa.gov

B. National Aeronautics and Space Administration, Kennedy Space Center

1. Business Office Official:

Taya Stokes NASA KSC Program Planning & Analysis Team Resources Management Branch Mailcode: NE-I1 Kennedy Space Center, FL 32899 Taya.R.Stokes@nasa.gov	(321) 867-1630

2. Technical Representatives:

Jennifer Murray NASA Kennedy Space Center KSC UAS Project Lead Advanced Systems Branch Mail Stop: NE-E9 Kennedy Space Center, FL 32899 jennifer.murray@nasa.gov	(321) 867-6673
Richard Birr NASA Kennedy Space Center RF Communications Lead - UAS Advanced Systems Branch Mail Stop: NE-E9 Kennedy Space Center, FL 32899 richard.b.birr@nasa.gov	(321) 867-6301

ARTICLE 9. FUNDING AND PAYMENT

A. Schedule

Projected funding is subject to availability and FAA prioritization. The following table presents estimates and is for planning purposes only.

FAA Funding	FY-2010	FY-2011	FY-2012	FY-2013	FY-2014	TOTAL ($)
To KSC	$184,500					$184,500
TOTAL ($)						

B. Funding

1. Funds in the amount of $184,500 are hereby obligated to this Interagency Agreement in accordance with the work described in Annex No. I.

   FAA Purchase Request Number: CT-10-00204-51

   Obligation is chargeable to Appropriation Code: 1209CT0049 / 00.WB1050 / 31XXX / CTG531T000 / 12182A0090 / 1A08C0

   Funding for this Appropriation expires: 9/30/2011

2. In no event will NASA transfer any U.S. Government funds to Party under this Agreement. Center Management and Operations (CMO) charge is waived due to the benefits of the collaborative work effort in this Agreement.

3. NASA will not provide services or incur costs beyond the funds obligated under this agreement. Although NASA has made a good faith effort to accurately estimate its costs, it is understood that NASA provides no assurance that the proposed effort under this Agreement will be accomplished for the above estimated amount.

   Should the effort cost more than the estimate, the FAA will be advised by NASA as soon as possible. NASA shall notify the FAA when 75% of the funds obligated have been incurred under the agreement so that the FAA does not run into a cost overrun situation. The FAA shall pay all costs incurred and have the option of canceling the remaining effort, or providing additional funding in order to continue the proposed effort under the revised estimate. Should the Agreement be terminated, or the effort completed at a cost less than the agreed-to estimated cost, NASA shall account for any unspent funds within (1) year after completion of all effort under this Agreement, and promptly thereafter, return any unspent funds to the FAA.

4. Notwithstanding any other provision of this Agreement, all activities under or pursuant to this Agreement are subject to the availability of funds, and no provision of this Agreement shall be interpreted to require obligation or payment of funds in violation of the Anti-Deficiency Act, Title 31 U.S.C. 1341.

C. Method of Payment

Both Parties will comply with the intra-governmental transaction data and reconciliation requirements contained in Office of Management and Budget (OMB) Memorandum M-07-03, "Business Rules for Intra-governmental Transactions." Transfer of funds will be accomplished using the Department of the Treasury's Intra-governmental Payment and Collection (IPAC) System.

1. Federal Aviation Administration:

- IPAC Agency Locator Code (ALC): 69001104
- Business Partner Network (BPN) number:
    - 928338656 (Headquarters, Washington, DC)
    - 020057782 (William J. Hughes Technical Center, Atlantic City, NJ)
    - 809772007 (IPAC Accounts Payable Branch, Oklahoma City, OK)
- Treasury Account Symbol (TAS): 690/18107
- Business Event Type Code (BETC): DISB

2. National Aeronautics and Space Administration:

- IPAC Agency Locator Code (ALC): 80004904
- Business Partner Network (BPN) number: DUNS# 031708360
- Treasury Account Symbol (TAS): 8010/110122
- Business Event Type Code (BETC): COLL

D. Financial Points of Contact

1. Federal Aviation Administration:

Glenn Hansen (609) 485-6532
Business Analyst
FAA William J. Hughes Technical Center, AJP-912
Atlantic City International Airport, NJ 08405
glenn.hansen@faa.gov

2. NASA Financial Point of Contact:

Marilyn Davidson (321) 867-2772
NASA Kennedy Space Center
Office of Chief Financial Officer / GG-B
Marilyn.A.Davidson@nasa.gov

E. Upon termination or expiration of this Agreement, any FAA funds which have not been spent or obligated for allowable expenses prior to the date of termination, and are not reasonably necessary to cover termination expenses, shall be returned to the FAA.

ARTICLE 10. LIMITATION OF FUNDS

A. The FAA's liability to make payments to NASA and NASA's obligation to perform under this Agreement is limited to the amount of funds obligated hereunder, including written modifications/revisions to this Agreement.

B. All activities under or pursuant to this Agreement are subject to the availability of appropriated funds, and no provision herein shall be interpreted to require obligation or payment of funds in violation of the Anti-Deficiency Act, 31 U.S.C. § 1341.

C. The total cost of this Agreement, including all annexes and modifications, shall not exceed $2,000,000.00. No provision herein shall be interpreted to require obligation or payment of funds in excess of this funding ceiling without a properly executed written modification/revision specifically raising the funding ceiling.

ARTICLE 11. ANNEXES AND MODIFICATIONS

A. This Agreement takes precedence over any Annexes. In the event of a conflict between the IA and any Annex concerning the meaning of its provisions, and the rights, obligations and remedies of the Parties, this Agreement is controlling.

B. Annexes shall not modify terms of this Agreement.

C. Each Annex will state the duration of the Annex, but no Annex will exceed two (2) years in duration.

D. Annexes and/or modifications to this Agreement shall be in writing and signed by the approvers of this agreement acting within the scope of their authority. No oral statement by any person shall be interpreted as modifying or otherwise affecting the terms of this Agreement. All requests for interpretation or modification shall be made in writing.

E. The FAA and NASA Technical Representatives (TRs) identified in Article 8 are responsible for the technical administration of this Agreement. The TRs are not authorized to make any changes that impact the cost, schedule, or performance of this Agreement without the written consent of both parties.

ARTICLE 12. TERMINATION

Either Party may unilaterally terminate this Agreement or any Annex(es) by providing 30 calendar days written notice to the other Party. Termination of an Annex does not terminate this Agreement. However, the termination or expiration of this Agreement also constitutes the termination of all outstanding Annexes. In the event of such termination, the Party will be obligated to reimburse NASA for all costs for which the Party was responsible and that have been incurred in support of this Agreement up to the date the termination notice is received by the non-terminating Party. Both Parties will seek to mitigate the effect of such termination, if possible, and will enter into discussions for that purpose.

ARTICLE 13. DISPUTES

Where possible, disputes will be resolved by informal discussion between the Parties. If the Parties are unable to resolve any disagreement through good faith negotiations; disputes must be resolved pursuant to the procedures and standards of the Business Rules for Intragovernmental Transactions described in the U.S. Treasury Financial Manual, Volume 1, Bulletin 2007-03, Section VII.

ARTICLE 14. LIABILITY AND RISK OF LOSS

Each party agrees to assume responsibility for its own risks associated with activities undertaken in this Agreement.

ARTICLE 15. PRIORITY OF USE

Any schedule or milestone in this Agreement is estimated based upon the Parties' current understanding of the projected use of NASA test facilities and equipment by NASA personnel. In the event NASA's projected usage changes, Party shall be given reasonable notice of that change, so that the schedule and milestones may be adjusted accordingly. The Parties agree that NASA usage of the test facilities, equipment, and personnel shall have priority over the usage planned in this Agreement. Should a conflict arise, NASA in its sole discretion shall determine whether to exercise that priority. Likewise, should a conflict arise as between two commercial users, NASA, in its sole discretion, shall determine the priority as between the two users. This Agreement does not obligate NASA to seek alternative government property or services under the jurisdiction of NASA at other locations.

ARTICLE 16. COMPLIANCE WITH LAWS AND REGULATIONS

The Parties shall comply with all applicable laws and regulations including, but not limited to, safety, security, export control, and environmental laws and regulations. Access by each Party to the other's facilities or property, or to an Information Technology (IT) system or application, is contingent upon compliance with each Party's security and safety policies and guidelines including, but not limited to, standards on badging, credentials, and facility and IT system/application access.

ARTICLE 17: SIGNATORY AUTHORITY

The signatories to this Agreement covenant and warrant that they have authority to execute this Agreement. By signing below, the undersigned agrees to the above terms and conditions.

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
KENNEDY SPACE CENTER

BY:__________________________
Patrick A. Simpkins, D.B.A.
Director, Engineering Directorate
Mail Code: NE

Kennedy Space Center, FL 32899
Phone: (321) 867-7770
Fax: (321) 867-4246
Patrick.A.Simpkins@nasa.gov

DATE:________________________

FEDERAL AVIATION
ADMINISTRATION (FAA)

BY:__________________________
William Zeiger
Contracting Officer
FAA William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405
Phone: (609) 485-4389
Fax: (609) 485-4088
William.Zeiger@faa.gov

DATE:________________________

ANNEX NO. 1

BETWEEN THE

FEDERAL AVIATION ADMINISTRATION (FAA) RESEARCH AND TECHNOLOGY DEVELOPMENT OFFICE (R&TD)

AND

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) KENNEDY SPACE CENTER (KSC)

FOR

MODELING & SIMULATION (M&S) OF UNMANNED AIRCRAFT SYSTEMS CONTROL AND COMMUNICATION ACTIVITIES

In accordance with the terms and conditions set forth in Interagency Agreement no. DTFACT-10-X-00003 (KCA-4269 Rev. Basic), dated June 2010, the Parties hereby agree as follows:

ARTICLE 1. PURPOSE

The purpose of this annex is to document the current work between NASA KSC and the FAA R&TD to support M&S of UAS Control and Communication activities based on current and perceived UAS architectures for use within the NAS.

ARTICLE 2. RESPONSIBILITIES

A. Both parties will use reasonable efforts to:

1. Participate in the design, development, and review of the Analytical Graphics, Inc. (AGI) Satellite Tool Kit (STK) UAS Control and Communication.
2. Establish a current UAS baseline for M&S (unmanned aircraft minimum performance values based on classification of large, medium, and small). This will be in support of, and coincide with, related RTCA SC-203 efforts.
3. Analyze, using constructive Monte Carlo modeling techniques, the RTCA SC-203 concept architectures that support UAS Control and Communication. Scenario Use Cases/Attributes found in the RTCA SC-203 Operational Services and Environment Definition (OSED) will be used to define future M&S efforts needed to assess system

interaction and validate assumptions. The results will support RTCA SC-203 and FAA Control and Communications for NextGen activities. Examples: control/communication in sense and avoid situations, radio frequency (RF) interference (RFI), electrical magnetic interference (EMI), ground-based obstructions.

B. The FAA will use reasonable efforts to:

  1. Acquire UAS flight data to establish and determine minimum operational performance values from RTCA SC-203 as well as existing documentation and other resources (Example: manufactures, venders, customers, DoD). Some data may require modification to avoid proprietary information being released.

ARTICLE 3. STATEMENT OF WORK

The work activities presented above will be conducted in two phases:

1. Phase 1**:** Data Collection and Initial Baseline Scenarios
   1. Prepare Test Plan.
   2. Develop M&S UAS control and communication architectures scenarios using STK Unmanned Aircraft (UA) default model parameters and data. Create additional UA models as needed.
   3. Acquire data, OSED, other RTCA documents from RTCA SC-203 Control and Communications work group (CC), manufacturers, public domain, and other sources as needed. Incorporate UAS system level minimum requirements (i.e., UAS operational performance characteristics and system control and communication parameters) as they relate to M&S for the different UA classes and airspace classes.
   4. Integrate use cases from RTCA SC-203 OSED and other sources with RTCA SC-203 CC control and communication architectures scenarios.
   5. Incorporate and validate minimum requirements baseline scenario(s) with STK M&S and other tool(s) as needed.
   6. Complete initial analysis of UAS control and communication architectures to include end-to-end system latencies evaluation.
   7. Generate VDF files for Partner access to STK.
   8. Prepare Phase 1 results briefing.

2. Phase 2**:** Utilize constructive, Monte Carlo, and other modeling techniques to baseline STK scenarios from Phase 1. Parties in cooperation with RTCA SC-203 CC group will determine specific requirements/criteria/events for M&S activities.

   1. Examples of analyses to be performed include, but are not limited to, the following:
      a. Access coverage analysis
      b. Dynamic / link performance analysis

   c. System-level interference analysis
   d. Sub-system analysis
   e. Interference analysis
   f. Sense and Avoid analysis
   g. RF environment modeling
   h. Transmitter / Receiver / Antenna / Sensors analysis
   i. EMI / RFI analysis
   j. Extended modulation types and coding
   k. Spread spectrum support Customizable database of RF payloads and environmental effects

2. Prepare final report and results briefing.

ARTICLE 4. MILESTONES AND DELIVERABLES

Milestone	Date
Phase 1 Start	June 7, 2010
Draft Test Plan	July 2, 2010
Final Test Plan	July 30, 2010
Phase 1 Results Briefing	November 1, 2010
Phase 1 Completion	January 7, 2011
Phase 2 Start	July 6, 2010
Draft Report	December 30, 2010
Phase 2 Completion	January 14, 2011
Final Report	January 28, 2011

Deliverable	Responsibility	Due Date
Final Report	NASA KSC and FAA R&TD	January 28, 2011
Consolidate all M&S UAS control and communication architectures (use cases) scenarios developed in STK	NASA KSC and FAA R&TD	November 1, 2010
Consolidate all supporting data, software, and scripts	NASA KSC and FAA R&TD	November 1, 2010

ARTICLE 5. PROPERTY AND/OR FACILITIES TO BE UTILIZED

N/A

ARTICLE 6. SIGNATORY AUTHORITY

The signatories to this Annex covenant and warrant that they have authority to execute this Annex. By signing below, the undersigned agrees to the above terms and conditions.

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
KENNEDY SPACE CENTER

BY:__________________________
Patrick A. Simpkins, D.B.A.
Director, Engineering Directorate
Mail Code: NE

Kennedy Space Center, FL 32899
Phone: (321) 867-7770
Fax: (321) 867-4246
Patrick.A.Simpkins@nasa.gov

DATE:________________________

FEDERAL AVIATION
ADMINISTRATION (FAA)

BY:__________________________
William Zeiger
Contracting Officer
FAA William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405
Phone: (609) 485-4389
Fax: (609) 485-4088
William.Zeiger@faa.gov

DATE:________________________