U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

STATUS REPORT: ASSESSMENT OF COMPATIBILITY OF PLANNED LIGHTSQUARED ANCILLARY TERRESTRIAL COMPONENT TRANSMISSIONS IN THE 1526-1536 MHZ BAND WITH CERTIFIED AVIATION GPS RECEIVERS

Redacted Version Cleared for Public Release

JANUARY 25, 2012

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Executive Summary

The Federal Aviation Administration (FAA) has worked with LightSquared since August 2011 to evaluate the compatibility of certified aviation receivers with the planned LightSquared ancillary terrestrial component (ATCt) network using a signal broadcast in the 1526-1536 MHz band.

The assessment in this report is based on FAA performance standards. Unlike most other GPS devices, certified aviation GPS receivers have interference rejection requirements specified by the FAA and harmonized internationally. Aircraft antenna characteristics are also specified. The use of these specifications precludes the need to individually test every aviation device, and allows the assessment to be accomplished through analysis which estimates the LightSquared interference present at the aircraft GPS receiver, and then compares that level to the specified rejection limits.

To predict the interference at the aircraft, the FAA has developed a set of propagation models that build upon testing conducted by the mobile satellite services and cellular communications industries for terrestrial applications. Unfortunately, aircraft operate at altitudes where no significant research on propagation has been conducted. Addressing this gap has been the primary focus of the FAA and LightSquared activities though several technical issues remain unresolved, which would require additional resources. While variations in the FAA and LightSquared models affect the scope of impact, they do not affect our fundamental conclusions.

Two primary conclusions can be drawn from the analysis work done to-date:

Conclusion 1: *The proposed ATCt network is not compatible with FAA requirements for operations dependent on GPS receivers at low altitudes in the vicinity of the ATCt transmitters*.

The incompatibility is primarily focused at lower altitude aviation operations, including impacts to navigation and automatic dependent surveillance – broadcast (ADS-B) for fixed-wing aircraft and helicopters. Of special concern is the impact to terrain awareness and warning systems (TAWS) used by the fixed-wing and helicopter communities to reduce the risk of controlled flight into terrain. This technology uses GPS position in conjunction with a database of terrain to alert the flight crew of potentially unsafe trajectories and was mandated for commercially-operated turbine aircraft with 6 seats or more after the Cali, Columbia accident. TAWS is considered by many in the airplane safety community as the single most important safety device introduced to prevent commercial fatal accidents in the last 20 years. This technology has also been voluntarily adopted in general aviation as part of GPS-based navigation systems. This technology has particular advantage for helicopter operations at low altitudes and outside of FAA-established routes. Many operators of helicopters have voluntarily installed it, and the FAA has proposed mandating it for certain helicopter operations.

Conclusion 2: *The variations in local propagation environments preclude adoption of any readily-implementable mitigation for this interference*.

LightSquared has proposed to address this issue through a combination of site-by-site tailoring of their network density and operating parameters plus neutral third-party

verification. Prior to initiating any attempt to implement such a solution, site-by-site analyses to account for differences in signal blockage and reflections would be required and the remaining technical issues on the specific propagation models would need to be resolved. If, however, these conditions could be accomplished, maintaining the in-air power level limit presents a severe challenge, as the surrounding environment, LightSquared's network, and aviation operations are all dynamic and continue to change (e.g., helicopter MediVac or search-and-rescue need to be able to operate anywhere, or an adjacent building is constructed which creates a new signal reflection).

Therefore, the FAA believes that the LightSquared approach will not ensure the current safety levels and has significant concerns in ensuring the efficacy of modulating density and power levels on a site-by-site basis while reacting to future changes in LightSquared's deployment *or* aviation operations. In addition, the FAA must maintain oversight and surveillance of critical national airspace equipment and operations and the FAA resources needed to perform this function do not exist.

This Report represents the FAA views on the progress and outcome of the joint analysis. In the interest of transparency, LightSquared was provided with draft copies of the report and were provided an opportunity to comment or otherwise present their analysis and conclusions. That reaction is provided in its entirety as an Appendix to this report. However, it must be stressed that the views in that Appendix are those of LightSquared and its contractors, and its inclusion does *not* represent concurrence by the FAA.

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1. Scope and Requirements

1.1 LightSquared Configuration

This compatibility assessment analysis is only applicable to a single 10 MHz Long Term Evolution (LTE) channel (referred to as 10L) centered at 1531 MHz. Other key configuration details are listed in Section 2.

1.2 Certified Aviation Receivers

This analysis addresses all receivers compliant with the requirements[1] of:

- Federal Aviation Administration (FAA) Technical Standard Order (TSO)-C145, Airborne Navigation Sensors Using The Global Positioning System Augmented By The Satellite Based Augmentation System. This standard invokes RTCA/DO-229, *Minimum Operational Performance Standards for GPS/Wide Area Augmentation System Airborne Equipment*.
- TSO-C146, Stand-Alone Airborne Navigation Equipment Using The Global Positioning System Augmented By The Satellite Based Augmentation System. This standard invokes RTCA/DO-229, *Minimum Operational Performance Standards for GPS/Wide Area Augmentation System Airborne Equipment*.
- TSO-C161, Ground Based Augmentation System Positioning and Navigation Equipment. This standard invokes RTCA/DO-253, *Minimum Operational Performance Standards for GPS/Local Area Augmentation System Airborne Equipment*.
- TSO-C196, Airborne Supplemental Navigation Sensor for Global Positioning System Equipment Using Aircraft-Based Augmentation. This standard invokes RTCA/DO-316, *Minimum Operational Performance Standards for GPS/Aircraft-Based Augmentation System Airborne Equipment*.

Note that many receivers were designed to comply with the Radio Frequency interference (RFI) environments defined within these standards even though they were certified to an earlier standard (TSO-C129a[2]), and therefore are also addressed by this analysis. This analysis does not specifically address receivers that comply only with TSO-C129a. However, that category of receivers was designed to be lower-performance narrowband receivers and should exhibit reduced impacts from the LightSquared signal. As a result, if the receivers assessed under this analysis should prove compatible with the LightSquared network, the FAA accepts any residual risk that some early-generation GPS receivers, not tested to RTCA/DO-229, RTCA/DO-253, and RTCA/DO-316, may experience harmful interference from operation of that system.

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[1] Where specifications are referenced, the latest version as of January 2012 is assumed.

[2] TSO-C129, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)

This analysis also does *not* address non-certified avionics, such as portable GPS devices, electronic flight bags, etc. These devices are not developed to an FAA standard and, therefore, must be tested to evaluate susceptibility rather than rely on analysis. The analysis methods identified in this document could be used to determine the expected received power levels for non-certified devices to assess devices tested for L1 interference susceptibility.

1.3 Tracking and Acquisition Thresholds

The tracking and acquisition thresholds for GPS receivers are defined in TSO-C145, TSO-C146, TSO-C161, and TSO-C196. These standards invoke industry standards developed through RTCA: RTCA/DO-229, RTCA/DO-253, and RTCA/DO-316. The radio frequency aspects of these three standards are identical, and the relevant characteristics were first published in 1996 and invoked by the FAA in May of 1998.

The passband for this equipment is from 1565.42 MHz to 1585.42 MHz. Adjacent-band rejection requirements are specified for continuous waveform (CW) RFI below and above the GPS band, and all equipment is designed and tested to ensure that these requirements are met. The complete requirements are defined in Appendix C, RTCA/DO-229, which was first published in 1996. The same requirements are harmonized internationally (ICAO SARPs Annex 10 Volume I, paragraph 3.7.4) since 2001. For convenience, the CW filter rejection curve is shown in Figure 1-1. The adjacent-band rejection is enabled by filtering in the antenna and the receiver. As an example, for a CW signal at 1531 MHz 92.4 dB of rejection is designed into the aviation standards.

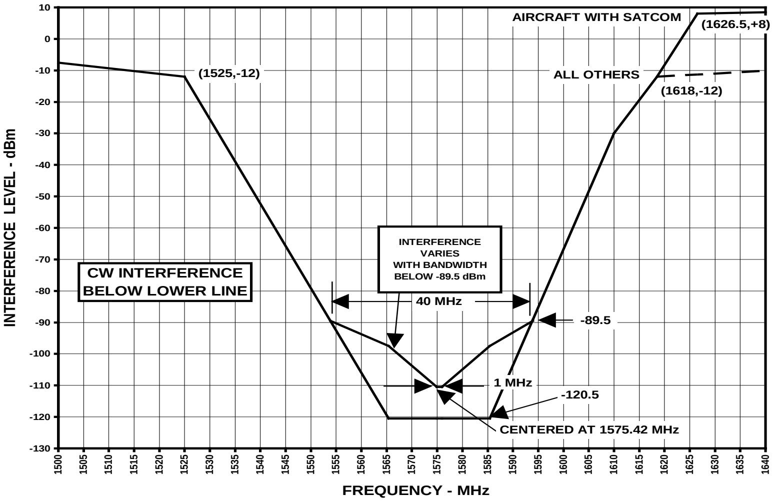

Figure 1-1 Out-of-band CW Interference Rejection Levels

The curve only specifies rejection of CW interference. Results from testing a limited number of certified receivers has indicated that tolerable interference levels are nearly equivalent for CW and a 10 MHz broadband noise signal centered at 1531 MHz. The resulting tolerable interference level (receiver specification test condition) for tracking GPS signals is -28.1 dBm.

Historically, the international aviation community has applied a 6 dB safety margin to aviation interference thresholds. This safety margin reflects the criticality of aviation use of GPS and recognizes that there are a number of real-world effects and future expected interference sources that are not captured in the modeling. With the safety margin applied, the resulting threshold for the mean aggregate RF interference power at the receiver is then -34.1 dBm.

The FAA also evaluated whether the 6 dB of safety margin could be reconsidered for GPS tracking in the presence of the LightSquared interference based upon the fidelity of the modeling being used to evaluate compatibility. Two factors were considered to dominate the need for the margin: one, the fact that aircraft are not always operating in level flight, and two, that the probability of loss of tracking needs to be considered against the GPS system performance requirements. The reliability of the positioning service is specified in terms of continuity (see Section 2.3.3 of the WAAS Performance Standard[3]). The more stringent requirement is the en route through non-precision approach requirement where the service is defined from the surface of the earth to 100,000 feet (see Section 3.1). The associated continuity requirement is 10^{-5} per hour.

Loss of positioning can be caused by many factors, such as failure of avionics on an aircraft, failure of a GPS satellite, and failure within the supporting ground systems (GPS and WAAS control segments). There is no system allocation for interference above the specified interference environment (i.e., the rejection mask depicted in Figure 1-1). While recognizing that some allowance must be made in order to apply a probability for the LightSquared/GPS analysis, it is important that the LightSquared contribution is small when compared to other factors contributing to the loss of continuity. As such, it was determined that the LightSquared contribution should not exceed one-tenth of the total requirement (i.e., 10^{-6} per hour) for the purposes of this analysis.

Another consideration is the ability for the aviation receiver to acquire GPS satellite signals. Acquisition is normally accomplished prior to takeoff and, under ideal circumstances, is not needed during flight. However, power interruptions on the aircraft or loss of GPS due to aggregate radio frequency (RF) interference (possibly unrelated to LightSquared) requires that the aircraft be capable of GPS acquisition while airborne. Since acquisition is more demanding on the receiver than tracking, the receiver standards specifications require operation with a 6 dB lower interference test condition than in the

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[3] "WAAS continuity is defined as the probability that the WAAS SIS performance level will continue to be available throughout one flight hour for en route through LNAV operations or 15 seconds for LNAV/VNAV, LPV, and LP operations given that the service was available at the beginning of the specific exposure time, unless the loss of service was the subject of a prior notice to airmen (NOTAM). For en-route operations, this is defined as a probability of loss of service per hour. For approach operations, this is defined as a probability of loss of service over any 15 second period. WAAS continuity is directly dependent on GPS SPS SIS continuity because both are required in order to provide the service. For LPV operations, additional external effects, such as ionospheric storms, can interrupt the service. "

tracking case. As a result, the acquisition test threshold is -34.1 dBm and applying a safety margin would then result in an interference threshold at -40.1 dBm. Rather than apply this limit directly, the FAA determined that the analysis should account for a maximum probability of 10^{-3} that the interference exceeds -34.1 dBm. This approach *discounts* the additional risk to acquisition that occurs during banking or other real-world effects, but does consider that acquisition would likely become possible at some point as the aircraft continues to fly out of the area of peak interference.

Based on these considerations, the required thresholds are:

<u>Tracking</u>:

- Mean interference level must be at or below –34.1 dBm for an aircraft at level attitude. This reflects a 6 dB margin below the receiver susceptibility of -28.1 dBm to account for non-modeled effects and random events.
- Probability of interference level exceeding –30.1 dBm must be $\leq 10^{-6}$ in any hour of flight, considering aircraft banking and pitching. This preserves a 2 dB margin in RF interference for non-modeled effects other than LightSquared.

<u>Acquisition</u>:

- Probability of interference level exceeding -34.1 dBm must be $\leq$ 0. 001 for an aircraft at level attitude.

Note: The relationship of the 10^{-6} per hour requirement to the RF interference analysis is an unresolved issue. The correlation time of the LightSquared interference is expected to be short relative to an hour, which would suggest that there are many independent events occurring in an hour of operation – each of which represent a risk of loss of GPS. Should GPS be lost at any of those intervals, the ability to reacquire will be delayed until the aircraft can be in level flight and exit the area of higher interference. For a helicopter operating at low levels, it may be necessary to evaluate instantaneous power levels at lower probabilities in order to account for the number of independent events. IFR clearance may be essential to maneuvering out of the affected area and the pilot may be inhibited or unable to perform IFR flight due to the loss of GPS navigation and ATC may be unable to provide surveillance. As a result, the aircraft trajectory becomes critical in relating the 10^{-6} per hour to a propagation model's predicted instantaneous power. Neither the FAA nor LightSquared has identified a method to resolve this issue. The results in this report consider only the instantaneous 10^{-6} probability. This issue would require resolution in order to fully complete a compatibility assessment.

1.4 Area of Aviation Operation

GPS is ubiquitous and aviation has embraced it for a wide variety of applications. The GPS Standard Positioning System Performance Standard (GPS PS) specifies the coverage provided by GPS as:

> The terrestrial service volume for the baseline 24-slot constellation and expandable 24-slot constellation coverage comprises the entire near-Earth region which extends from the

> surface of the Earth up to an altitude of 3,000 km above the surface of the Earth which is not physically obscured by localized obstructions. [4]

In addition, the FAA has invested over $1B in an augmentation to GPS, the Wide Area Augmentation System, to meet stringent aviation standards for performance integrity. The coverage requirement for WAAS is defined in the WAAS Performance Standard, and is defined for various regions within the footprint of the WAAS geostationary satellites. The relevant zone for this evaluation is the conterminous United States, which is defined as:

> **Zone 1** - Zone 1 is defined as the region from the surface up to 100,000 feet above the surface of the 48 contiguous states, extended to 30 nautical miles (nm) outside of its borders. [5]

The proposed LightSquared EIRP (62 dBm) in the 1526-1536 MHz band exceeds the aviation certified GPS receiver tracking threshold (-28.1 dBm, see Section 1.3) for that band by 92.1 dB even without accounting for safety margin. It is not readily apparent that it is feasible to retain the current coverage of GPS for aviation with any LightSquared deployment. In an effort to resolve this issue and find a reasonable path forward, the FAA evaluated the uses of certified GPS avionics to identify those locations where impacts to GPS would be unacceptable. This Section summarizes those operations and identifies the locations where the interference thresholds should be applied for the purpose of this study.

Certified GPS receivers are used to support three main functions: navigation, surveillance (automatic dependent surveillance-broadcast or ADS-B) and terrain awareness and warning systems (TAWS).

The navigation function must be provided in all areas of normal aircraft[6] operation. 14 CFR 91.119 provides the general framework for operating areas, and additional insight is provided by 14 CFR 77.13 which defines surfaces around airports where obstructions *may* be considered hazards to navigation. The lowest altitudes are those associated with approach and landing operations to any airport or heliport.

The surveillance function must be provided wherever ATC separation services are applied. The ADS-B program requirement is to provide ADS-B surveillance in the areas where current secondary radars provide coverage, and the FAA is evaluating cost-effective expansions of surveillance to lower altitudes. The ability of ADS-B to provide surveillance at lower altitudes has been a primary benefit of the ADS-B program to the general aviation community. Due to the nature of these requirements, the altitudes vary significantly across the country. However, surveillance coverage is a subset of navigation coverage so this condition is not constraining.

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[4] Global Positioning System Standard Positioning Service Performance Standard, 4th Edition, September 2008, Section 3.3.2.

[5] Global Positioning System Wide Area Augmentation System Performance Standard, 1st Edition, 31 October 2008, Section 3.1.

[6] The term ‘aircraft’ includes both airplanes and rotorcraft.

The TAWS function provides a key safety enhancement designed to alert the flight crew of operation *outside* of the normal envelope of safe operations. The FAA mandated this system for many airplane operators (e. g., 14 CFR 121.354) following the Cali, Columbia accident. The standards for TAWS are defined in TSO-C151b. In commercial aircraft, TAWS includes a GPS-based function to look forward along the projected flight path and identify hazardous terrain, as well as an alerting capability based on radio altitude that is independent of the GPS function. The TAWS equipment in general aviation aircraft typically does not include alerting based on radio altitude and is completely dependent on GPS. The alerting that would occur depends on the aircraft trajectory, the terrain, the proximity to the airport, and details of the alerting algorithms implemented by each equipment supplier. This analysis uses the FAA standard and does not consider the radio altitude alerting.

The GPS-based alerting technology has been adapted for rotorcraft and the standards for that are defined in TSO-C194. Unlike commercial aircraft, helicopters routinely operate close to the ground and their alerting depends entirely on GPS-based positioning. The FAA has proposed that helicopter TAWS (HTAWS) be mandatory equipment for some rotorcraft operators as minimum safety equipment[7].

One issue that has surfaced is how to treat LightSquared towers that are at or above the altitudes associated with TAWS and HTAWS as it is not possible to comply with the aviation threshold immediately adjacent to the transmitter. For HTAWS, the equipment is required to contain a database of obstacles which is used to provide collision avoidance alerting for the obstacle. The FAA does *not* specify the characteristics of obstacles which must be contained in the database, this is determined by the HTAWS manufacturer as part of their system design. After consulting with several vendors, the FAA determined that it is reasonable to assume that HTAWS vendors will include identified obstacles that are 100’ above ground level (AGL) or higher. Since helicopters will avoid flying to those obstacles identified in the database, some exclusion zone around transmitters located on those obstacles is reasonable. The HTAWS alerting thresholds vary depending on manufacturer design, helicopter speed and altitude. After consulting with vendors and considering the nature of helicopter operations, the FAA suggested that disruptions to GPS may be acceptable for HTAWS within 500' laterally from the LightSquared transmitter and extending up to 100' above the top of obstacles in the database. This allowance remains to be coordinated with the users who would be impacted within the exclusion zone.

For TAWS, the equipment is not required to contain an obstacle database and the FAA does not have any requirements for this optional capability. For those models that do have such a database, they include identified obstacles that are 200’ AGL or higher and lower obstacles close to airports if they pose a threat to normal operations. Considering the TAWS thresholds and fixed wing operations, the FAA proposed to extend the HTAWS exclusion zone to TAWS, with the exception that obstacles shorter than 200' are not expected to be in the aircraft database more than 7.5 NM to an airport. This allowance

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[7] Air Ambulance and Commercial Helicopter Operations, Part 91 Helicopter Operations, and Part 135 Aircraft Operations; Safety Initiatives and Miscellaneous Amendments, Federal Register: October 12, 2010 (Volume 75, Number 196).

has not been coordinated with the users who would be impacted within the exclusion zone.

For obstacles that would be too low to be included in the respective TAWS/HTAWS databases, GPS function must be supported without exclusion to the coverage requirements detailed below. It is important to recognize that this exclusion zone applies only to the coverage requirements for TAWS and HTAWS and does not apply to navigation of aircraft approaching or departing airports or helipads.

Additional details for fixed and rotary-wing (helicopter) areas of aviation operations, aviation GPS required functions, TAWS/HTAWS standards and helicopter specific operations are provided in Appendix A. It should be noted that the FAA has not made operational and safety assessments for the additional areas of consideration identified in Appendix A Section 6 “Residual Operational Risks” and these risks have not been coordinated with the users who would be impacted.

The FAA identified current airports and heliports on the following website http://www.faa.gov/airports/airport_safety/airportdata_5010/ (Select data downloads, Airport Facility Data).

The resulting coverage requirements where GPS tracking and acquisition thresholds must be met consistent with the three criteria identified in Section 1.3 are as follows, illustrated in Figure 1-2 and Figure 1-3.

These coverage requirements do not protect all current aviation operations that use GPS but provide a reasonable approximation of the critical areas where GPS must be protected. Additional discussion of the operations that would be affected is provided in Appendix A. Again, the potential impacts outside of the region defined below have not been coordinated with the users who would be impacted.

1. For fixed-wing airplane operations:[8]
    a. At airports with a runway 3,200' or longer: Above a 100 to 1 (run over rise) sloping surface extending from the nearest point of the nearest runway to 100' AGL at a horizontal distance of 10,000' away. Some regions of interference above this surface may be acceptable but would have to be evaluated on a case-by-case basis considering the traffic in the vicinity in order to make that determination.
    b. At airports with a runway less than 3,200': Above a 50 to 1 (run over rise) sloping surface extending from the nearest point of the nearest runway to 100' AGL at a horizontal distance of 5,000' away. Some regions of interference above this surface may be acceptable but would have to be evaluated on a case-by-case basis considering the traffic in the vicinity in order to make that determination.
    c. Between 5000’/10000’ and 7.5 NM of any airport: At and above 100' AGL.
    d. Between 7.5 NM and 15 NM to any airport: At and above 300' AGL.

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[8] The first two subparagraphs apply the surface for requiring notice to the FAA of potential hazards to navigation, allowing for penetrations that would be evaluated on a case-by-case basis. See 14 CFR 77.13, (a)(2)(i) and (ii). Subparagraphs c) through e) apply the requirements for TAWS, see TSO-C151b, Table A-2.

e. Outside of 15 NM to any airport: At and above 500' (AGL).

Fixed-wing banking and pitch requirements, applicable to the tracking analysis with a 2 dB safety margin:

a. At and above 300' AGL, aircraft bank in excess of 25 degrees (e. g. circling approach) and routinely change their pitch for approach and departure operations. The FAA uses a receiver antenna tilt of up to 25 degrees for interference analysis in this report.

b. At and above 100', but below 300' AGL, aircraft can bank in excess of 15 degrees and routinely change their pitch for approach and departure operations. The FAA uses a receiver antenna tilt of up to 15 degrees for interference analysis in this report.

c. Below 100' AGL, banking is aircraft and operator dependent. A typical aircraft pitch is up to 6 degrees nose-up leading into the flare for landing and up to 15 degrees bank for crosswind landings. The FAA uses a receiver antenna tilt of up to 6 degrees for interference analysis in this report.

In order to accommodate LightSquared transmitters that are mounted on towers where the tower may be included in the TAWS obstacle database, an exclusion zone is permissible as follows:

  a. For transmitters within 7.5 NM of an airport, if they are mounted on an obstacle that is taller than 100’ AGL, then an exclusion zone that is the intersection of a cylinder centered on the obstacle (500’ in radius and extending 100’ above the top of the obstacle) and the region below the obstacle clearance surfaces (as defined by the FAA Orders in the 8260 series) for all instrument procedures. The exclusion zone extends down to the minimum altitude where coverage would be required by paragraph 1c, d, or e above. The FAA must also retain the ability to publish new instrument procedures and establish new airports without undue constraints.

  b. For transmitters more than 7.5 NM away from any airport, if they are mounted on an obstacle that is taller than 200’ AGL, then an exclusion zone that is a cylinder centered on the transmitter (500’ in radius and 100’ above the top of the obstacle), but not above 1000’ AGL (including effects of falling terrain). The exclusion zone extends down to the minimum altitude where coverage would be required by paragraph 1c, d, or e above.

For helicopter operations**:** [9]

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[9] The first subparagraph applies the surface for requiring notice to the FAA of potential hazards to navigation, allowing for penetrations that would be evaluated on a case-by-case basis. See 14 CFR 77.13, (a)(2)(iii). Subparagraph b) considers helicopter operations and the requirement for HTAWS for a slow rate of descent, see *Minimum Operational Performance Standards for Helicopter Terrain Awareness and Warning System Airborne Equipment*, RTCA/DO-309, March 13, 2008, Table 2-3

a. Above a 25 to 1 (run over rise) sloping surface extending from the nearest point of the nearest runway or landing surface to 100' AGL at a horizontal distance of 2,500' away. Some regions of interference above this surface may be acceptable, but would have to be evaluated on a case-by-case basis considering the traffic in the vicinity in order to make that determination.

b. Beyond a horizontal distance of 2500' from any airport or heliport: at and above 100' above ground level (AGL).

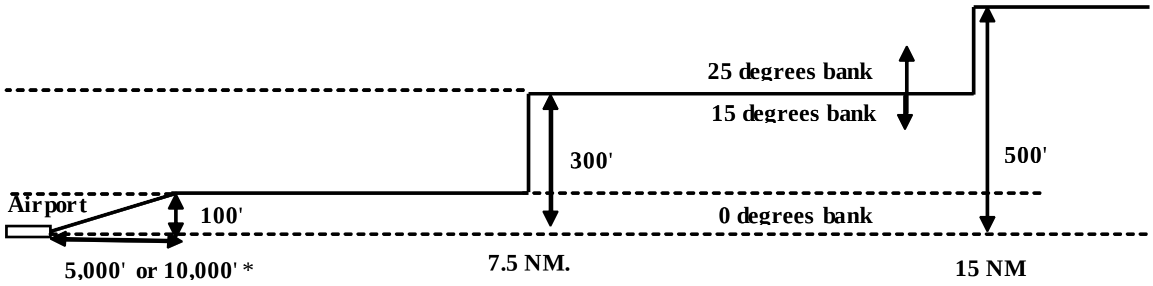
Helicopter banking and pitch requirements, applicable to the tracking analysis with a 2 dB safety margin:

a. Helicopter banking requirements at and above 25' AGL: helicopter pilots bank and pitch in excess of 25 degrees. The FAA uses a receiver antenna tilt of 25 degrees for interference analysis in this report.

b. Below 25' AGL, helicopter pitch and bank can be assumed to be 15 degrees.

In order to accommodate LightSquared transmitters that are mounted on towers where the tower is included in the HTAWS obstacle database, an exclusion zone is permissible. If they are mounted on an obstacle that is taller than 100’ AGL, then an exclusion zone is defined that is the intersection of a cylinder centered on the obstacle (500’ in radius and extending 100’ above the obstacle) and the region below the obstacle clearance surfaces (as defined by the FAA 8260 series orders) for all instrument procedures. The exclusion zone extends down to 100’ AGL. The FAA must also retain the ability to publish new instrument procedures or establish new heliports without undue constraints.

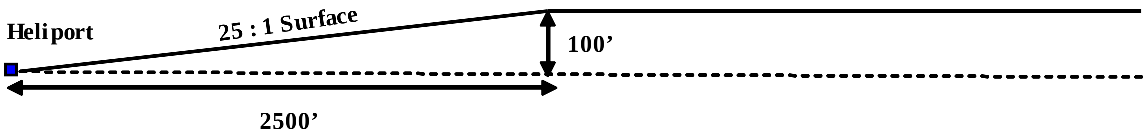
The following illustrations are not drawn to scale.



Fixed-wing GPS area of coverage maximum floor

*** 5,000' if runway is less than 3200’ and 10,000' if greater than 3200’**

25 degrees for helicopter interference analysis at any altitude



Helicopter GPS area of coverage maximum floor

Figure 1-2. Surfaces Above which GPS Coverage Must be Assured

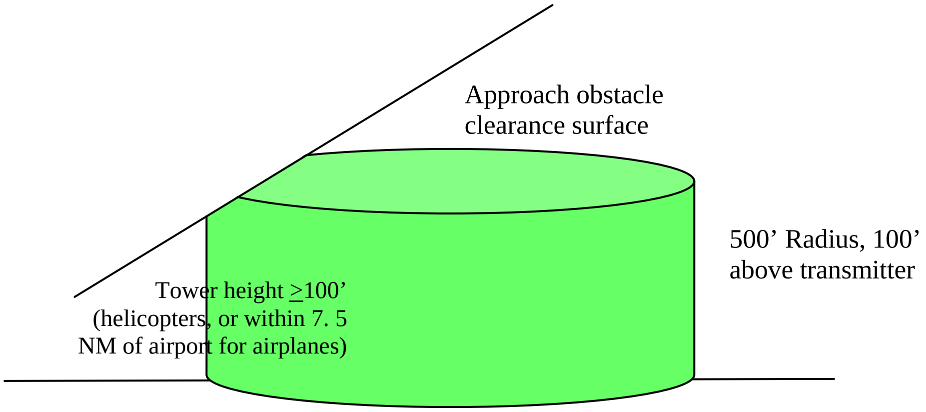


Figure 1-3. Example Exclusion Area around LightSquared Tower

Helicopter operations, including HTAWS, provide the most stringent constraints in terms of the area of GPS reception. For fixed-wing airplanes, the low-altitude constraints are most significant in the vicinity of airports: within ~ 3 NM for navigation and 15 NM for TAWS.

These coverage requirements differ from the current United States Government and FAA specifications for GPS and WAAS, which do not include any exclusion zones where GPS coverage is not provided. The FAA has proposed these boundaries to protect the majority of operations and safety systems, but they do not provide complete protection. This proposal has not been coordinated with the users who would be impacted by interference inside and below the FAA proposed exclusion zones.

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2. Transmitter and Receiver Component Assumptions for Analysis

2.1 Transmit Antenna

LightSquared has provided characteristics for two base station antenna models:

- Argus HPX308R
- Tongyu TDJ-151717DE-65F[10]

Figure 2-1 is a picture of the Argus antenna panel mounted on a test stand. As is the Tongyu antenna, the Argus antenna is a vertical array of cross-polarized (+/-45º with respect to the horizon) elements designed to produce a beam that is broad in its horizontal dimension and narrow in its vertical dimension.

Figure 2-1. Argus HPX308R-J1 Antenna

The two antenna models' electrical characteristics are very similar as summarized in Table 2-1, and either model may be used for each LightSquared base station. For the purposes of this Report, no physical down tilt and 2º electrical down tilt was presumed for each antenna (i.e., the antenna panel is mounted on the tower with the longest dimension oriented perpendicular to the local horizon, and the antenna is electrically configured to provide peak gain 2º below the local horizon).

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[10] Gain patterns were provided by LightSquared via e-mail (M. Aliani to C. Hegarty on April 15, 2011), in two Excel files: (1) "Argus HPX308R-J1_65_2°EDT 1559 MHz MFR pattern. xlsx" and (2) "Tongyu TDJ-151717DE_65_2°EDT 1559 MHz MFR pattern. xlsx". Polarization data was supplied in two e-mails: (1) "Argus_Antenna_Polarization_Plotsv2. xls" via e-mail (S. Dutta to FAA team on Sept 2, 2011), and (2) "TongYu_antenna_polarization_plots. xlsx" (M. Aliani to FAA team on Sept 7, 2011). "

Table 2-1. LightSquared Antenna Characteristics

Model	Peak Gain (dBi)	Horizontal Beamwidth (deg)	Vertical Beamwidth (deg)
Argus	16.94	64.6	8.8
Tongyu	16.5	66.9	8.1

The gain patterns for each antenna, with 2º of electrical down tilt, were provided by LightSquared and are shown in Figure 2-2 and Figure 2-3.

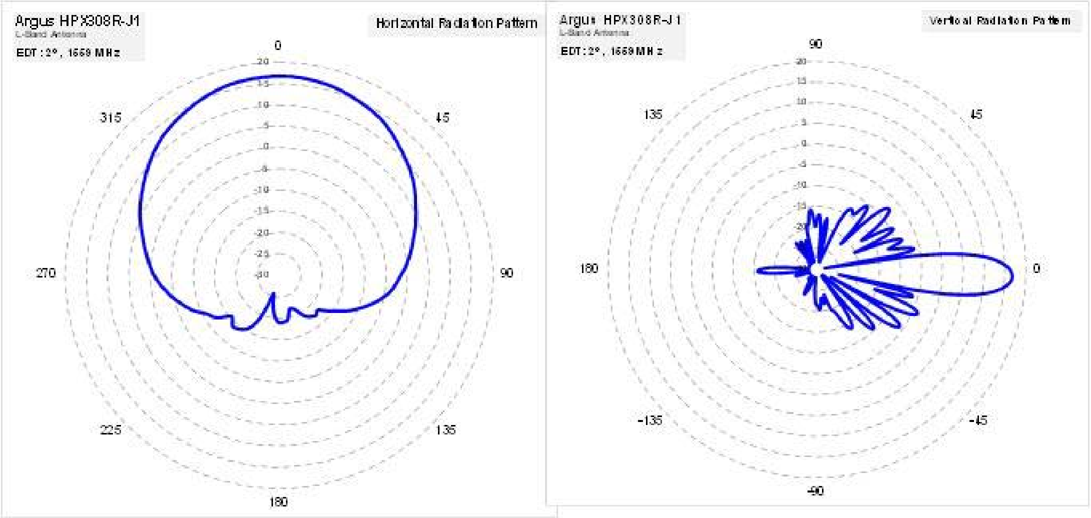

Figure 2-2. Horizontal (left) and Vertical (right) Gain Patterns for Argus HPX308R Antenna with 2º Electrical Down tilt

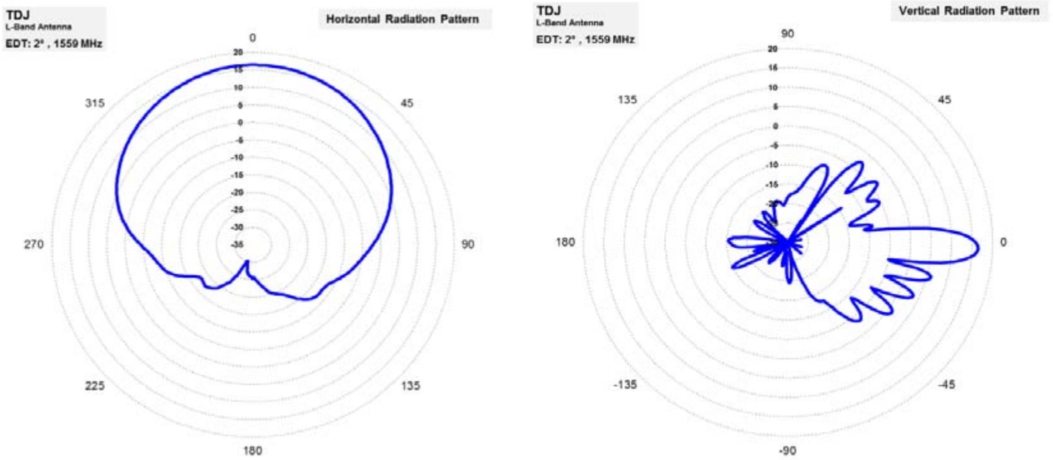

Figure 2-3. Horizontal (left) and Vertical (right) Gain Patterns for Tongyu TDJ-151717DE-65F Antenna with 2º Electrical Down tilt

Polarization measurements were also provided by LightSquared. These measurements, showing how the overall gain patterns of each antenna are split between horizontally and vertically polarized (HPOL and VPOL, respectively) components, are plotted in Figure 2-4 and Figure 2-5 below and were used in the received power calculations discussed throughout this report. Both antennas exhibit very close to a 50-50 power split between HPOL and VPOL within their main beam, but significantly differing power splits for some off-boresight directions.

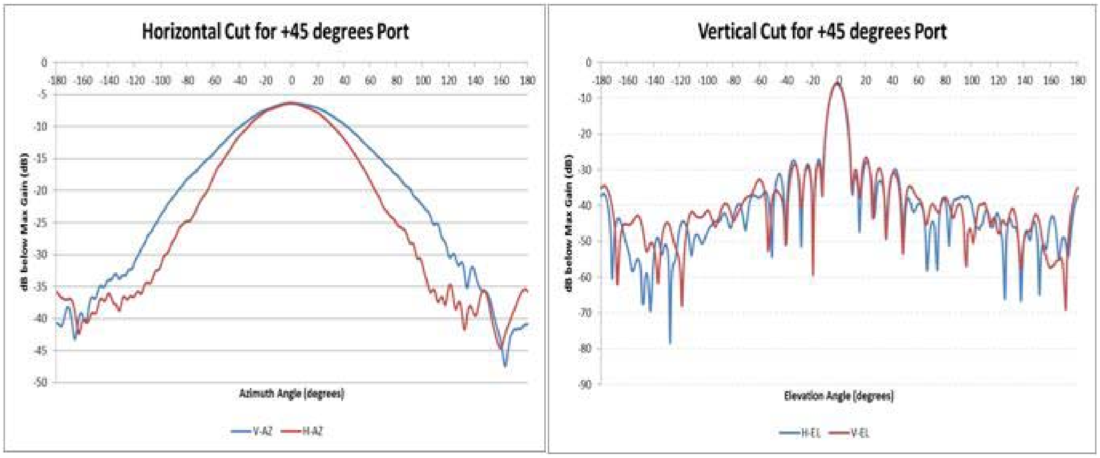

Figure 2-4. Polarization Measurements for Argus Antenna (+45° Port only; -45° Port Patterns are Similar)

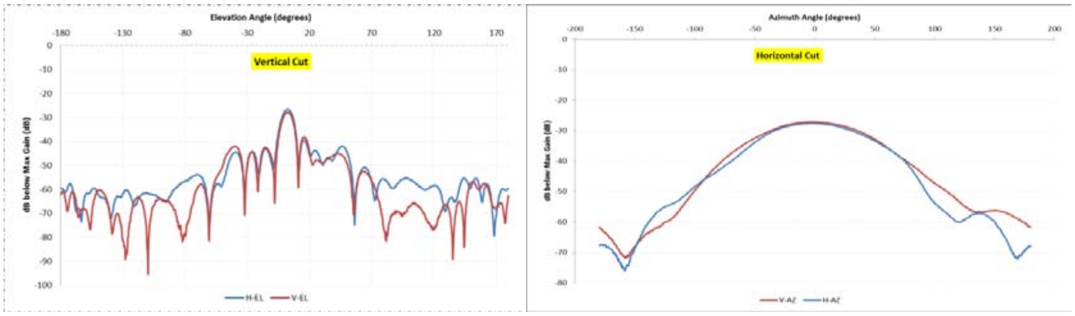

Figure 2-5. Polarization Measurements for Tongyu Antenna

2.2 Network Density/Arrangement

LightSquared provided a set of base station data for sites throughout the United States (See Figure 2-6). Three sectors (three transmitters and three antennas) would be implemented at a typical site, with the antennas pointing in three different compass directions and mounted on a tower. Figure 2-7 shows a typical cellular base station tower similar to what might be expected for some LightSquared sites, where one of the antennas depicted for each sector would transmit the LightSquared signal.

Figure 2-6. Base Station Locations [***Redacted***]

Figure 2-7. Typical Cellular Base Station Tower

The antenna heights vary from site to site. The distribution of heights in AGL is shown in Figure 2-8. Two sites are only 0.3 m AGL. One of these is on a steep hillside in California, and the other is in the Lincoln Tunnel connecting New Jersey and Manhattan. The tallest site is 152.4 m (500 ft) and is located in New Castle, Pennsylvania.

It is important to note that the base station height AGL does not necessarily relate to "effective altitude" as seen by nearby aircraft. For example, the 0.3 m (1 foot) AGL antenna in California discussed above is on a steep hill that rises 150 feet above a valley floor that begins just 500 feet to its East. In this case then an aircraft at 150 feet AGL in the valley would see that antenna at "eye level" (i.e., approximately in the main beam of the LightSquared antenna). As a result, it is apparent that this effective altitude must be accounted for in the LightSquared analyses.

Figure 2-8. Distribution of Candidate LightSquared Sites vs Height AGL **[*Redacted*]**

2.3 LightSquared Transmit Power

For this study, each base station sector is assumed to be transmitting only a single Long Term Evolution (LTE) signal at 1526 – 1536 MHz with an effective isotropic radiated power (EIRP) of 62 dBm. This EIRP is below the 72 dBm level conditionally authorized by the Federal Communication Commission (FCC), but consistent with current LightSquared plans. The emissions of the base station in the band 1559 – 1610 MHz are presumed to be below -100 dBW/MHz, consistent with Federal Communication Commission (FCC) regulations applicable to LightSquared.

2.4 Network Loading

For this study, 100% loading was assumed for each base station. To protect safety-critical aviation systems, the FAA would not be able to assume a reduction in EIRP due to network loading unless such a reduction was enforced through the FCC authorization.

2.5 Receiver Antenna

Figure 2-9 and Figure 2-10 show the assumed maximum airborne antenna gain patterns for the lower and upper hemisphere, respectively. For each hemisphere, two gain patterns are shown corresponding to horizontally polarized (HPOL) and vertically polarized (VPOL) signals. The VPOL pattern is from RTCA document DO-327. For this study, the HPOL pattern is assumed to be equal to the VPOL pattern for elevation angles at or above 45º, which is appropriate since airborne antennas are nominally right hand circularly polarized. Below 45º, the HPOL pattern is assumed to fall off relative to the VPOL pattern up to a maximum difference of 6 dB for the horizon and below. The HPOL pattern – as agreed by LightSquared – was derived using engineering judgment, polarization data measurements described in RTCA DO-235B, and with the conservatism appropriate for the protection of safety-critical equipment.

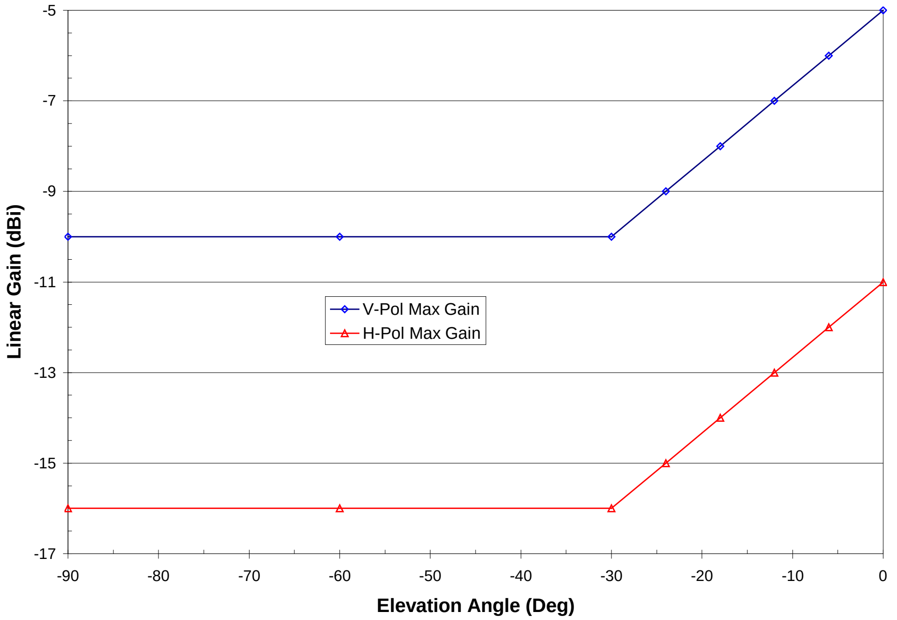

Figure 2-9. Airborne Antenna Lower Hemisphere Maximum Gain Patterns
(G_{VPOL} = -10 dBi for $-90° \leq el < -30°$; = $-10 + (5 + el/6)$ for $-30° \leq el \leq 0°$)
(G_{HPOL} = -16 dBi for $-90° \leq el < -30°$; = $-16 + (5 + el/6)$ for $-30° \leq el \leq 0°$)

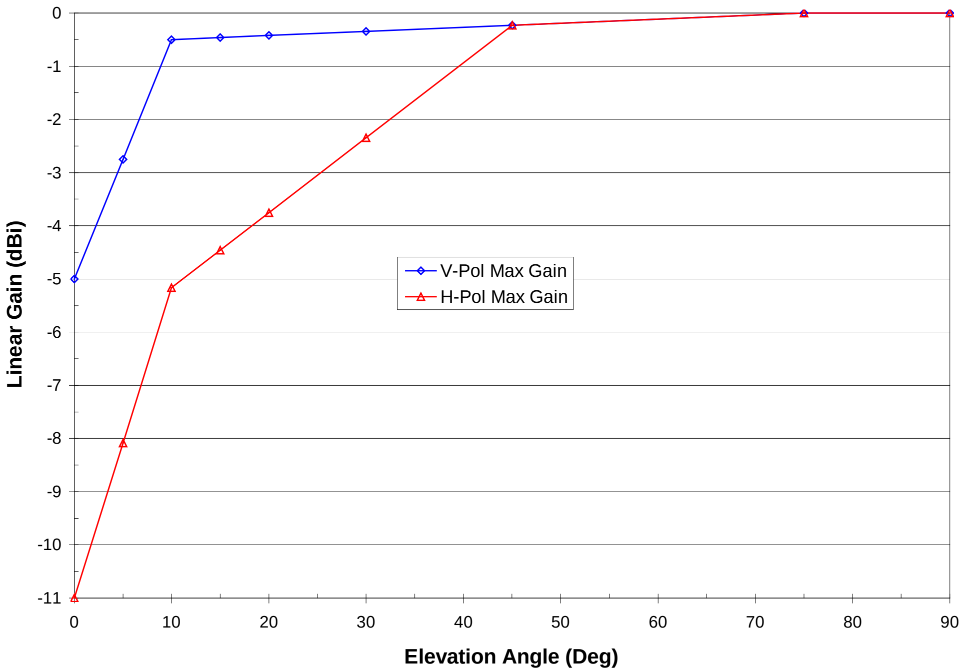

Figure 2-10. Airborne Antenna Upper Hemisphere Maximum Gain Patterns
(G_{VPOL} = 0 dBi, $75° \leq$ el; = -0.5+0. 0077(el-10), $10° \leq$ el $\leq 75°$; = -5+0.45•el, $0 \leq$ el $< 10°$)
($G_{HPOL} = G_{VPOL}$, $45° \leq$ el ≤ 90; = G_{VPOL} – (6*(45-el)/45), $0° \leq$ el $\leq 45°$)

3. Analysis Models, Methods, and Results

To evaluate the potential impact of aggregate interference from LightSquared ancillary terrestrial component (ATCt) towers to airborne GPS receivers, it is necessary to first model the propagation environment between each of the interfering towers and the GPS receive antenna. The models used in this Report draw from previous research as applicable and have been refined from those used in the recent RTCA study (RTCA/DO-327 [3-1]) as described in the following subsections. Using these models, the potential impact of LightSquared interference has been evaluated for several specific scenarios and results are presented in Sections 3.2 through 3.5**.**

3.1 Path Loss Models

For this analysis, several different path loss models were used as appropriate for the various operational scenarios that were evaluated. In line-of-sight propagation conditions at radio frequencies near the GPS L1 carrier, the radio horizon value (distance at which a direct radio wave from a transmitter can reach a receiver) depends, in general, on the aircraft GPS and radio frequency interference (RFI) source antenna heights and the amount of atmospheric refraction along the path. This Report uses the 4/3 Earth approximation for the refractive effect on the radio horizon. With this approximation, the radius of the radio horizon, in meters, is given by:

$$R_0 = 4124\left(\sqrt{h_A} + \sqrt{h_E}\right)$$

where h_A is the height of the aircraft antenna and h_E is the height of the emitter antenna (in meters). For determining which emitters are within radio line of sight, terrain and building topology is not considered.

The following subsections present the deterministic and probabilistic path loss models that were used within this analysis.

3.1.1 Deterministic Models

Deterministic models, including: (1) the free space path loss model, and (2) the two-ray path loss model predict a single path loss value for a given transmitter-receiver scenario that has no variability. Such models have the benefit of simplicity but are only accurate if there is a clear line-of-sight path between the RFI source and aircraft and simultaneously either no significant secondary paths (for the free space model) or one single, well-behaved secondary path (for the two-ray model). Reference [3-1] recommended the use of the free-space path loss model for ‘high altitude’ scenarios (aircraft above 1800’) and the two-ray model for very low-level operations when the aircraft is close to a tower and over a flat surface.

The free space path loss model is given by:

$$L_P = 20\log_{10}\left(4\pi d / \lambda\right)$$

where L_P is the path loss in dB, d is the distance in meters between the aircraft antenna and base station antenna, and λ is the wavelength in meters (= 0.1958 for 1531 MHz).

The well-known two-ray model is described in RTCA DO-327 as well as many textbooks on radio propagation. For this study, the two-ray model formulation from DO-327 was used with one modification. The modification was the inclusion of the treatment of horizontally polarized signals as well as vertically polarized signals. DO-327 presumed that the LightSquared base station emissions were vertically polarized, whereas in this study (as noted in Section 2.1) the cross-polarization characteristics of the proposed LTE antennas were employed.

Using the free-space path loss model, Figure 3-1 shows the area where the -34.1 dBm tracking threshold described in Section 1.3 would be exceeded by a single 62 dBm LightSquared sector at 100' (30 m) AGL. The x-axis and y-axis pertain, respectively, to the aircraft antenna distance from the sector and height of the aircraft antenna above ground. The figure assumes that the aircraft is level with respect to the local horizon.

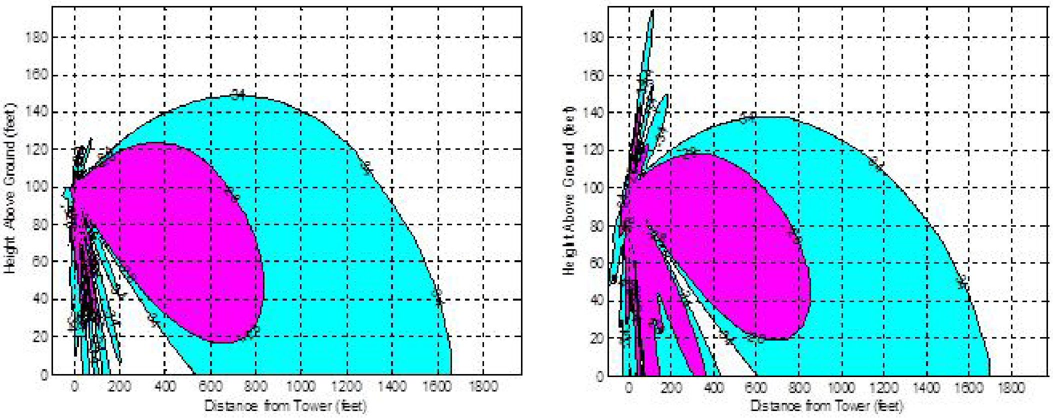

Figure 3-1. Received Power Contour Using Free-Space Model for 100'
Sector with Argus Antenna (left) and Tongyu Antenna (right) for an aircraft in level flight

Figure 3-2 illustrates the variability of received power with aircraft attitude. The left plot in the Figure is the Argus result from Figure 3-1 with the sector antenna at 100' (30 m) AGL and the aircraft level. The right plot shows the increase in affected area if the aircraft is tilted 25º towards the tower (e.g., a banking fixed-wing aircraft or a helicopter with this amount of pitch). The affected area roughly doubles in distance due to the increase in gain of the airborne antenna towards the emitter.

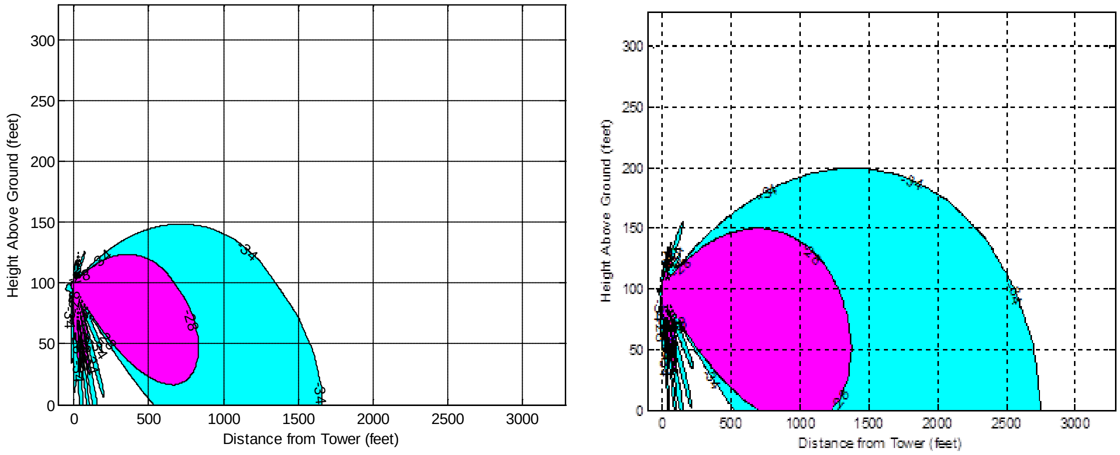

Figure 3-2. Variability of Received Power with Aircraft Attitude using the Free-space Model
Aircraft in Level Flight on Left, Aircraft with 25º Bank or Pitch on Right

Figure 3-3 shows the received power for the tallest proposed LightSquared tower (500'), assuming the aircraft is banked 25 towards the tower.

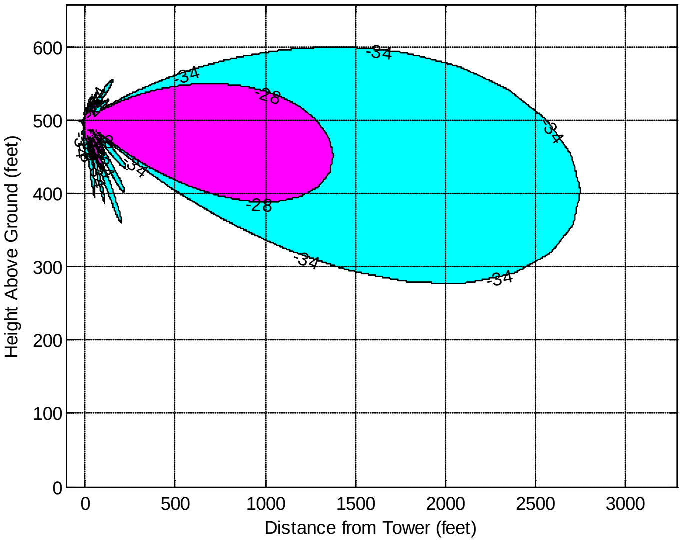

Figure 3-3. Received Power for Aircraft with 25º Bank and 500' LightSquared Tower Using Free-Space Model (Argus Antenna)

Received power contours using the two-ray model are shown in Figure 3-4 for a level aircraft and Figure 3-5a for an aircraft with 25º bank or pitch towards the tower. For each Figure, the Argus antenna was assumed and the ground reflection was modeled using the electrical characteristics of smooth concrete. Figure 3-5b shows received power contours using the same assumptions used to create Figure 3-5a except that the Tongyu (rather than Argus) antenna pattern was used.

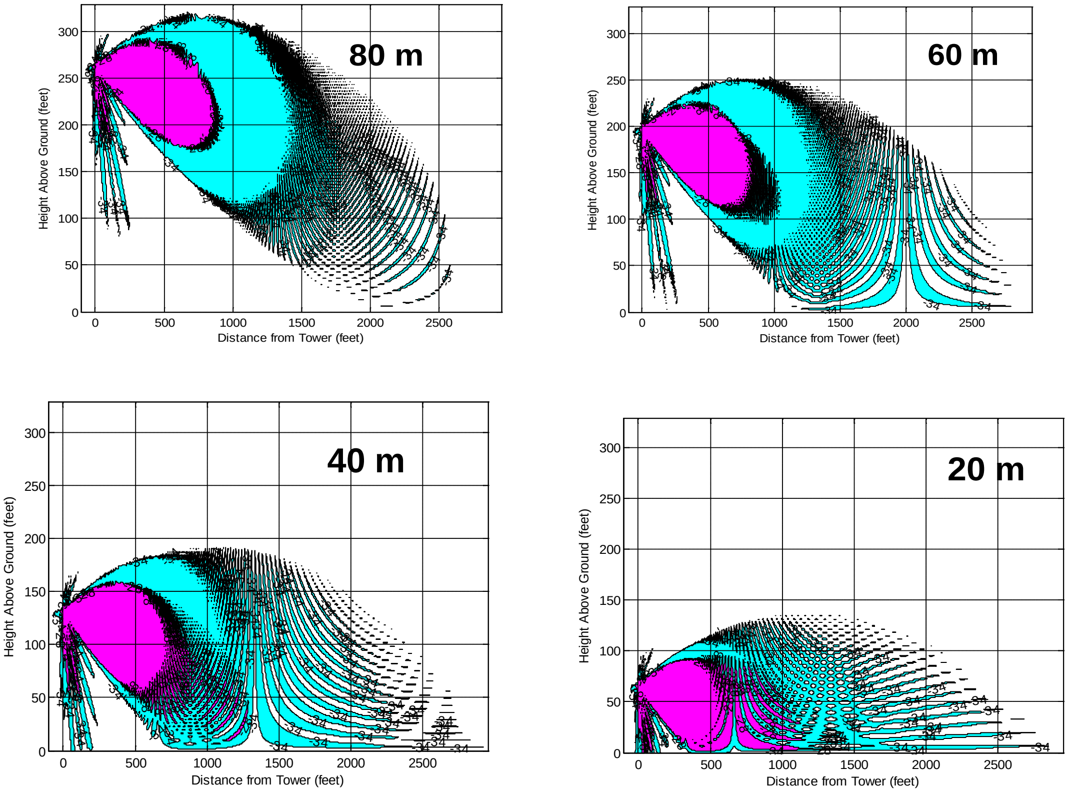

Figure 3-4. Received Power using the Two-Ray Model. Aircraft in Level Flight Various Base Station Antenna Heights (as indicated upon each plot)

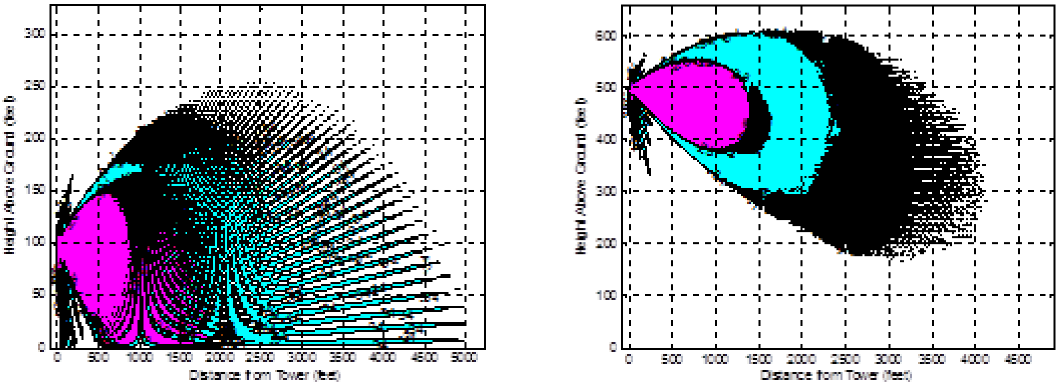

Figure 3-5a. Received Power using the Two Ray Model Aircraft with 25° Bank or Pitch towards Tower. 100’ Tower (left) and 500’ Tower (right). Argus Antenna

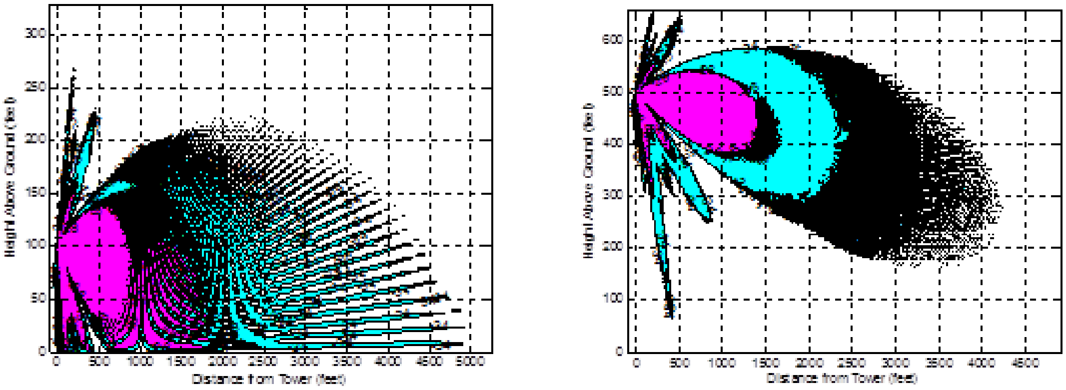

Figure 3-5b. Received Power using the Two-Ray Model Aircraft with 25°
Bank or Pitch Towards Tower. 100’ Tower (left) and 500’ Tower (right). Tongyu antenna

3.1.2 Probabilistic Models

A deterministic model is not appropriate for many scenarios. For instance, there may be obstructions between the base station and aircraft that completely or partially block the line-of-sight path. In such situations, the received power from secondary paths (reflections) becomes non-negligible and impossible to deterministically characterize in practice. In fact, in an urban environment many of the reflecting surfaces may be moving (e. g., vehicular traffic, skyscrapers moving due to wind). Received power from secondary paths may also be non-negligible when the transmitter antenna gain in the direction of the aircraft is very low as compared to the transmitter antenna gain in the direction of a reflected path. Thus, propagation environments in which emissions undergo scattering, reflections, and absorption prior to arriving at the receive antenna are typically analyzed using a probabilistic model. In a probabilistic path loss model the received power from each interference source is a random variable with a median value and some random distribution around the median.

Most of the development of probabilistic models has been done either by the terrestrial cellular radio community or as a result of propagation research done in the development of mobile satellite services (MSS). Unfortunately, in evaluating LightSquared aggregate interference to aircraft GPS receivers, the heights of the respective antennas – in particular the aircraft antennas – are such that much of the prior probabilistic propagation model research does not readily apply. The analyses in this Report use isotropic path loss models from prior research that have been adapted to the specific LightSquared RFI scenarios. The adaptations are supported by the most appropriate portions of path loss measurement data available from the literature and adjustments when necessary based on engineering judgment. Generally this means that at short distances between the aircraft nadir point and cell tower base some results from the MSS research are used while at longer distances, and hence lower elevation angles, results from the cellular radio community are applicable. For intermediate distances, a "linear fit" between the two types of models is typically used.

As noted in Section 3.1.1, for aircraft at higher altitudes (e.g. greater than 1800 - 2000 feet), clear line of sight conditions to the primary RFI sources usually prevail so that free space path loss may be used. The ‘ideal’ propagation model would automatically transition from free space path loss to a probabilistic model as aircraft altitude changes. By using the so-called "extended Suzuki" distribution (a generalization on the research by the cellular radio community) at lower aircraft altitudes where a probabilistic propagation model must be used, in theory it is possible to develop a generic propagation model that transitions smoothly between probabilistic and deterministic (free space path loss) propagation as aircraft altitude increases. The development of such a generic model was attempted but the resulting model was found to be deficient at the lower aircraft altitudes primarily due to the fact that LightSquared-to-aircraft *aggregate* interference is very dependent on aircraft and cell tower position, as well as the surrounding topography (terrain) and morphology (building structures).

3.1.2.1 Probabilistic Model Background

Since the propagation models are site specific, the general form of the model will be described herein. For all of the low-altitude en route and terminal airspace example scenarios involving fixed wing aircraft, it is assumed that an aircraft is approaching a metropolitan airport located in a substantially suburban setting with an urban area in the vicinity but at some distance away. Thus the probabilistic propagation model for these scenarios must be able to transition from the inclusion of a substantial line of sight component at shorter distances between aircraft nadir and an interfering cell tower, to one in which there is no line of sight propagation as this distance increases. Probabilistic models have been developed for surface-level analyses by the cellular radio community that include the effects of fast- (frequency-selective) as well as slow-fading but omit a line of sight component.

One such model, developed by H. Suzuki, suggested that the statistics of the received mobile radio signal can be described by a mixture of Rayleigh and log-normal distributions [3-2]. The resulting distribution function for the envelope of the received signal, which later came to be known as the "Suzuki distribution", is valid for those environments in which there is no line of sight component. In an extension to that model [3-3], the statistics of the received signal from a single emitter in a fading environment also provides for a strong line of sight component. Basically it replaces the Rayleigh component in the Suzuki distribution with a Rician distribution which can degenerate to the Rayleigh if the Rician K factor is set to zero. This more flexible representation is known as the “extended Suzuki distribution.” This distribution assumes the envelope of the received interference can be expressed as the product of two random processes, i.e.,

$$\eta(t) = \xi(t)\lambda(t) \tag{1}$$

where $\xi(t)$ has a Rician distribution (may be the sum of several Rician random variables in the case of frequency selective fading for wideband signals) and $\lambda(t)$ is log-normal distributed. The "extended Suzuki" probability density function is given by:

$$p_{\eta}(z) = (z/(\sqrt{2\pi}\psi_{o}\sigma))\int_{0}^{\infty}(1/y^{3})Exp[-((z/y)^{2}+\rho^{2})/(2\psi_{o})]I_{o}[z\rho/(y\psi_{o})]Exp[-(\ln(y)-\mu)^{2}/(2\sigma^{2})]dy\,. \tag{2}$$

Because of its ability to include a line of sight component, the "extended Suzuki distribution" has been selected for the probabilistic propagation model in this Report.

In the case of the LightSquared 10 MHz bandwidth signal where frequency selective fading will occur, the dimensionless fast fading function ($\xi^{2}(t)$) has a non-central Chi-squared distribution given by,

$$p_{\xi^2}(x) = (1/(2\psi_{o}(r)))Exp[-(x+\rho^{2}(r))/(2\psi_{o}(r))](x/\rho^{2}(r))^{(k/4-1/2)}I_{(k/2-1/2)}[(\rho(r)/\psi_{o}(r))\sqrt{x}] \tag{3}$$

where $I_{(k/2-1/2)}[\square]$ is a modified Bessel function of order (k/2-1/2) with k typically set to 10. The parameters ρ and ψ_o vary with distance *r* between aircraft nadir and cell tower and are scenario dependent.

As in [3-2], the slow fading power, $\lambda^2(t)$, is log-normal distributed with parameters $\mu(r)$ and $\sigma(r)$, both of which vary with distance *r* and are scenario dependent. Following the description given in [3-1] we have $\mu(r) = \ln\,[P_o G_{xmt}(\theta_{elev}(r), a_{az}) PL(r) G_{rcv}(\phi_{elev}(r))]$ where P_o is the interfering source emitted power, *PL(r)* the isotropic median path loss for a source at lateral separation range, *r*, $G_{xmt}(\ )$ the interfering emitter antenna gain, $\theta_{elev}(r)$ the transmit elevation angle and a_{az} the azimuth angle toward the receive antenna, $G_{rcv}(\ )$ the receive antenna gain, and $\phi_{elev}(r)$ the receive elevation angle toward the interfering emitter antenna. From the mean of a log-normal distribution as well as (3) above, it is readily shown that the mean received power from a single emitter, $\overline{P}(r) = E[\xi^2(t)\lambda^2(t)]$, is given by:

$$\overline{P}(r) = (k\psi_o(r) + \rho^2(r))Exp[\sigma^2(r)/2 + \mu(r)]\,. \qquad (4)$$

3.1.2.2 General “Extended Suzuki” Model Scenario Dependent Parameters

The "extended Suzuki" model requires that the four quantities, $\psi_o(r), \rho^2(r), \sigma(r)$, and $\mu(r)$, be defined. The parameter $\mu(r)$ is determined by the median path loss model $PL(r)$ for which the lateral separation range *r* from aircraft nadir to ATCt cell tower is generally broken into four segments in accordance with break points in range. Certain of these break points also impact the definition of $\psi_o(r), \rho^2(r)$, and $\sigma(r)$. The segments are concatenated to be continuous across the boundaries and the segment formulations account for the changing nature of the propagation as separation range increases.

Considering the topology and morphology, the median path loss break points are determined by the following guidelines (see RTCA DO-327, Appendix B [3-1]):

- At short ranges a two-ray median path loss model is used up to the range r_1 where the vertically polarized component reflection coefficient is at minimum magnitude. This break point varies with aircraft antenna height.
- Beyond r_1, the median path loss is extended in a continuous manner proportional to r^{-2} out to the range r_2 which is generally around 2 km depending on the local terrain and cell tower heights. As the aircraft antenna height increases, r_1 approaches r_2. Once these break points get within a few hundred meters of each other, r_2 is set equal to r_1 and the second path loss segment is eliminated. This is the case at aircraft heights approaching 535 meters as in the final approach fix waypoint scenario (see Section 3.2).

- From r_2 to the point r_3 where line of sight blockage becomes significant as determined for the specific site, median path loss is proportional to $r^{-\Gamma}$. The point r_3 varies proportionally with aircraft antenna height out to a maximum of 20 km at an aircraft antenna height of 535 meters. The parameter Γ is selected to provide continuity in path loss. At aircraft antenna heights slightly beyond 535 meters, the exponent Γ approaches 2 and the entire path loss model becomes deterministic (free space path loss). The remaining "extended Suzuki" parameters are set to values that reflect this change ($\psi_o(r) = 0$, $\rho^2(r) = 1$, $\sigma(r) = 0$).
- Beyond r_3 the Hata-Okumura suburban median path loss model is used.

Once these break points are known, the remaining "extended Suzuki" parameters, $\psi_o(r), \rho^2(r)$, and $\sigma(r)$, can be determined. For the shorter ranges, $0 \le r < r_2$, the line-of-sight parameter $\rho^2(r)$ will be unity while the Rayleigh parameter $k\psi_o(r)$ will conservatively be 10 dB lower [3-4]. At r_3 and beyond, there will be increasingly heavy blockage of the line-of-sight component with all of the power resulting from scattering (Rayleigh component). In between these two break points it is reasonable to assume both parameters $k\psi_o(r)$ and $\rho^2(r)$ change linearly with distance. Thus we have,

$$k\psi_o(r) = \left\{ \begin{array}{ll} .1, & 0 \le r < r_2 \\ .1 + ((1. - .1)/(r_3 - r_2))(r - r_2), & r_2 \le r < r_3 \\ 1., & r_3 \le r \end{array} \right\} \tag{5}$$

and

$$\rho^2(r) = \left\{ \begin{array}{ll} 1., & 0 \le r < r_2 \\ 1. - (1./(r_3 - r_2))(r - r_2), & r_2 \le r < r_3 \\ 0, & r_3 \le r \end{array} \right\} . \tag{6}$$

Some guidance regarding the standard deviation of the log-normal component can be found in [3-4] Figures 8.2 and 8.3. There, a standard deviation for "light shadowing" is given as 0.5 dB which is in agreement with Loo's result [3-5]. For "medium shadowing", the standard deviation suggested is 2 dB while for medium to heavy shadowing 3.5 dB is suggested. This has been adapted to the above break points and combined with the fact that for the Hata-Okumura model the standard deviation is set to 6.4 dB [3-2] as,

$$\sigma(r) = \left\{ \begin{array}{ll} 0.5dB, & 0 \le r < r_2 \\ 2dB, & r_2 \le r < (r_2 + r_3)/2 \\ 3.5dB, & (r_2 + r_3)/2 \le r < r_3 \\ 6.4dB, & r_3 \le r \end{array} \right\} . \tag{7}$$

Since standard deviation is more realistically expected to change in a continuous manner with range, the above formulation is approximated by a fifth order polynomial for this Report. Thus we replace the preceding equation with,

$$\sigma(r)=\begin{Bmatrix} Poly(r), & 0 \le r < r_4 \\ 6.4dB, & r_4 \le r \end{Bmatrix} \tag{8}$$

where

$$Poly(r)=a_0+a_1r+a_2r^2+a_3r^3+a_4r^4+a_5r^5 \tag{9}$$

and r_4 denotes the range at which the polynomial intersects the 6.4 dB standard deviation associated with the Hata-Okumura model.

Similar to the previous RTCA study (RTCA DO-327) [3-1], this Report uses a path loss formulation broken generally into segments by LightSquared tower to aircraft antenna lateral separation – short range two-ray, short range free space, medium and long lateral separation range. The segments are concatenated to be continuous across the boundaries and the segment formulations account for the changing nature of the propagation as separation range increases.

Greater detail may be found in Appendix B.

3.1.3 Aggregate Interference Assessment

Using any of the path loss models, the received interference at the aircraft is determined as the sum of the received signals from all towers within the radio horizon. Each sector transmits an independent signal (three sectors per tower, each with different orientation). Based on information from LightSquared, the signals transmitted with horizontal polarization are independent of the vertically-polarized signals, and they are transmitted with equal power. In addition, the propagation channel has a fast-fading component with coherence bandwidth on the order of 2 MHz (coherence time ~ 0.5 microseconds). Thus the propagation channel is equivalent to a tapped delay line structure with 5 taps spaced 0.5 µsec apart, each tap having an identically distributed, independent random variable weighting function. In the simulations, this fast-fading component was modeled as a 10 degree-of-freedom non-central Chi-Squared random variable (range-dependent combination of Rician and Rayleigh statistics, see Sec. 3.1.2.2). Therefore, the aggregate interference evaluations consider 30 signals for each tower: 3 sectors, 2 polarizations, and 5 independent flat-fading signal components. Based on information provided by LightSquared, each of these is assumed to have equal power at the transmitter.

For the propagation channel fast fading component, the use of 5 independent flat-fading signals has an overall effect of reducing the likelihood of interference at the aircraft. Although the current channel model assumptions are a reasonable initial estimate, some degree of model validation should be a part of further work. Additionally, since the analysis interference threshold was determined by assuming equivalent RFI effect on the *receiver of a 1531 MHz CW RFI signal and a broadband RFI signal centered at 1531 MHz with equal total power, the RFI effect of a revised channel model should be checked to assure consistency with the receiver threshold in order to finalize the assessment (see Section 1.3).*

3.2 LAKIE Scenario Description, Analysis, and Results

3.2.1 LAKIE Scenario Selection and Description

An initial screening for interfering power “hotspots” was performed using the deployment scenario consisting of LightSquared ATCt base stations collocated with Sprint equipment at 31446 towers across the continental United States broadcasting the lower 10 MHz channel (1526 – 1536 MHz) only. The relevant assumptions for these computations were effective isotropic radiated power (EIRP) of 62 dBm/sector; ATC base station antenna gain patterns as provided by LightSquared; and each ATCt tower with three sectors spaced 120 degrees in azimuth with the first sector pointing true North, and with free-space propagation modeling.

Based upon this initial screening determined with free-space propagation, a representative final approach fix (LAKIE waypoint) was identified for further analysis using higher fidelity propagation models. LAKIE is the Final Approach Fix (FAF) waypoint west of Manhattan for an area navigation (RNAV) GPS (LPV-250) approach to Runway 13 at LaGuardia. At this waypoint, the aircraft is at 1800’ altitude and at 40.828464^{o} North Latitude and 73.975269^{o} West Longitude.

The estimated radio horizon between the aircraft antenna height (1800’) and the LightSquared emitter height is approximately 125 km (4/3 Earth radius approximation [3-1]). That value is driven in part by the tall LightSquared towers heights located at about that radius. Locations of the 2383 visible ATC towers relative to the aircraft are shown in Figure 3-6.

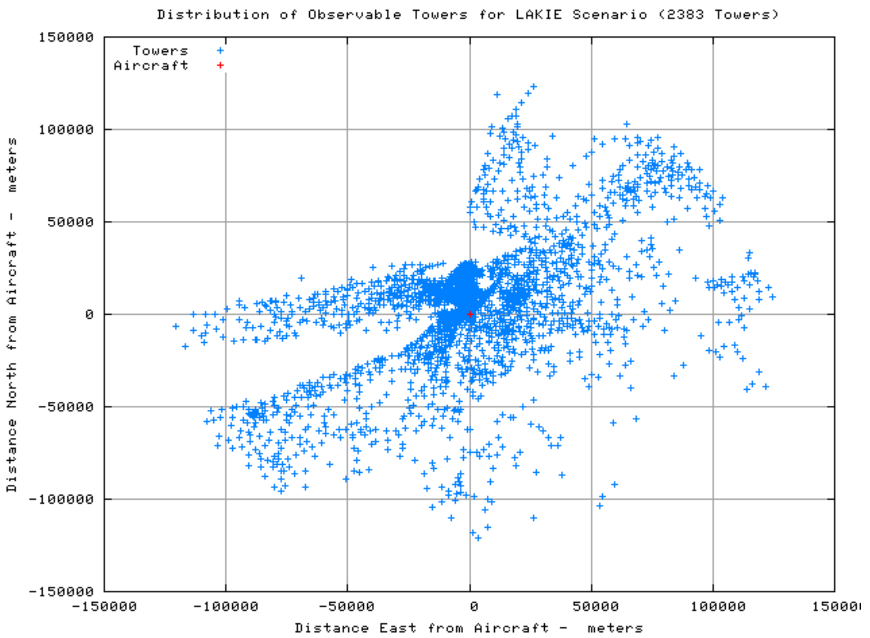

Figure 3-6. Distribution of 2383 Observable Towers Relative to Aircraft Location, LAKIE Scenario

3.2.2 LAKIE Scenario-Specific Path Loss Model Parameters

As earlier described (Sec. 3.1.2.2), the "Extended Suzuki" fast fading components are given as,

$$10\psi_o(r) = \begin{cases} .1, & 0 \le r < 1.6\,km \\ .1 + ((1.-.1)/(20-1.6))(r(km)-1.6), & 1.6\,km \le r < 20km \\ 1., & 20\,km \le r \end{cases}$$

and

$$\rho^2(r) = \begin{cases} 1., & 0 \le r < 1.6km \\ 1.-(1./(20.-1.6))(r(km)-1.6), & 1.6km \le r < 20km \\ 0, & 20\,km \le r \end{cases}.$$

The log normal standard deviation is given by:

$$\sigma(r) = \begin{cases} Poly(r), & 0 \le r < 38000m \\ 6.4dB, & 38000m \le r \end{cases}$$

where,

$$Poly(r) = 0.501416 + 0.000299604\,r - 4.65527 * 10^{-9}\,r^2 + 2.24671 * 10^{-14}\,r^3$$

Driven by the 1800 foot (548.6 m) aircraft antenna for the LAKIE scenario, there are 3 radial breakpoints in the isotropic median path loss model. The outer radius for the 2-Ray segment is 1597 meters. The logarithmic blend segment extends to 20.0 km at a slope of 2.089 and the Hata suburban model segment extends from 20 km to the radio horizon (~125 km). Figure 3-7 illustrates the modeled median path loss associated with the visible towers as a function of distance from the aircraft.

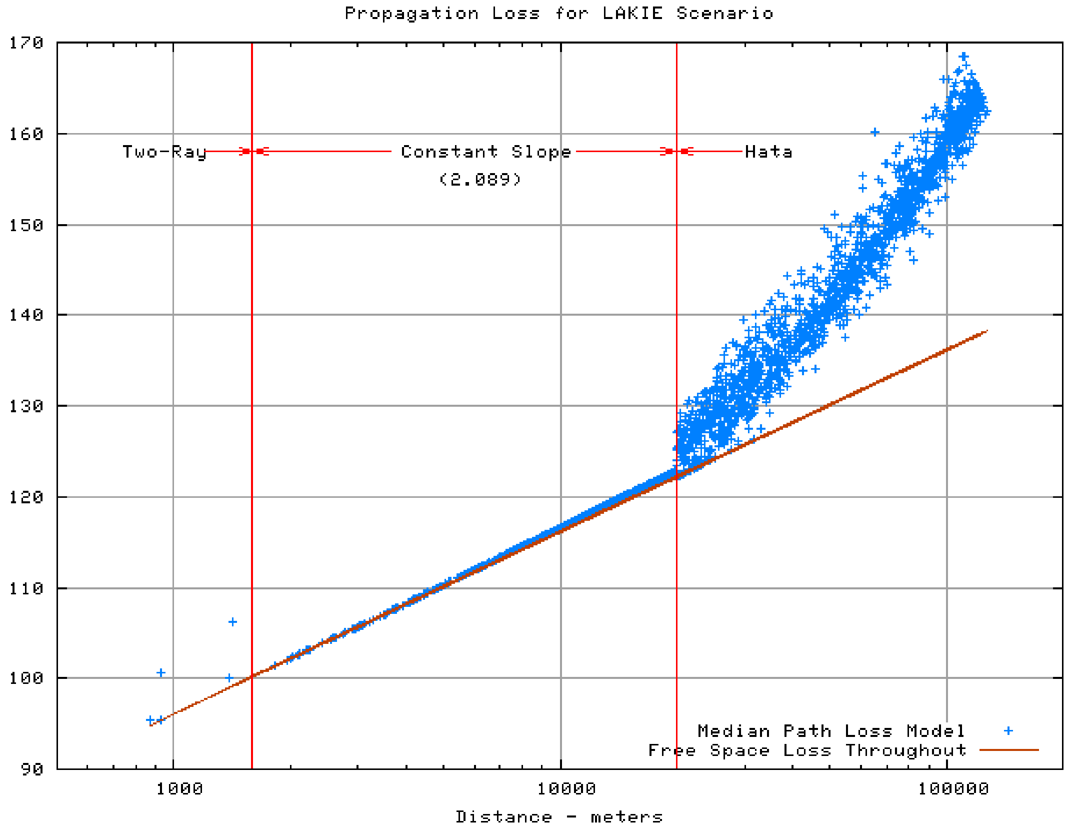

Figure 3-7. Isotropic Median Propagation Path Loss for LAKIE Scenario

3.2.3 LAKIE Scenario Aggregate Interference Analysis and Results

A detailed analysis of the LAKIE scenario was conducted using updated LightSquared tower/sector deployment data (see Section 2.2), Argus antenna data (see Section 2.1), and path loss models (see Section 3.1). The individual discrete tower received power contributions at the aircraft (both vertical and horizontal polarization components) were computed and summed. A Monte Carlo method generating 10 million statistical samples was used to determine the mean aggregate power and the cumulative distribution function for the scenario.

The following methodology is applied to determine the cumulative distribution function (CDF) of received power at the aircraft:

- The median received power, P_i, from each base station sector is determined using the model characteristics from Section 2 and 3.1. The median is computed by first separately determining the median vertical and horizontal polarization received power components (in milliWatts) and then adding these two components.
- For each operational scenario evaluated, Monte Carlo simulations are run to generate 10 million samples of a set of N random variables where N is the number of base station sectors visible to the aircraft. The random variates will have the statistical properties described earlier in Section 3. Visibility is determined using a 4/3 Earth model (see Appendix B of RTCA DO-327 [3-1]).
- For each Monte Carlo iteration, the N received power random variates is summed to produce a set of N aggregate received power values.
- The CDF of the aggregate received power is then determined by the standard method.

The fast fading parameters used for the LAKIE scenario, which are functions of distance between the aircraft and a particular site, are shown in Figure 3-8. The ‘constant power component’ represents the value of the constant component of the non-central Chi-squared process and the ‘average variable power component’ represents the expected value of the non-central Chi-squared minus its constant component. Note that the expected value of the modeled non-central Chi-squared is the sum of these two component terms and from Figure 3-8 assumes a value between 1.0 and 1.1 dependent upon the site/aircraft distance.

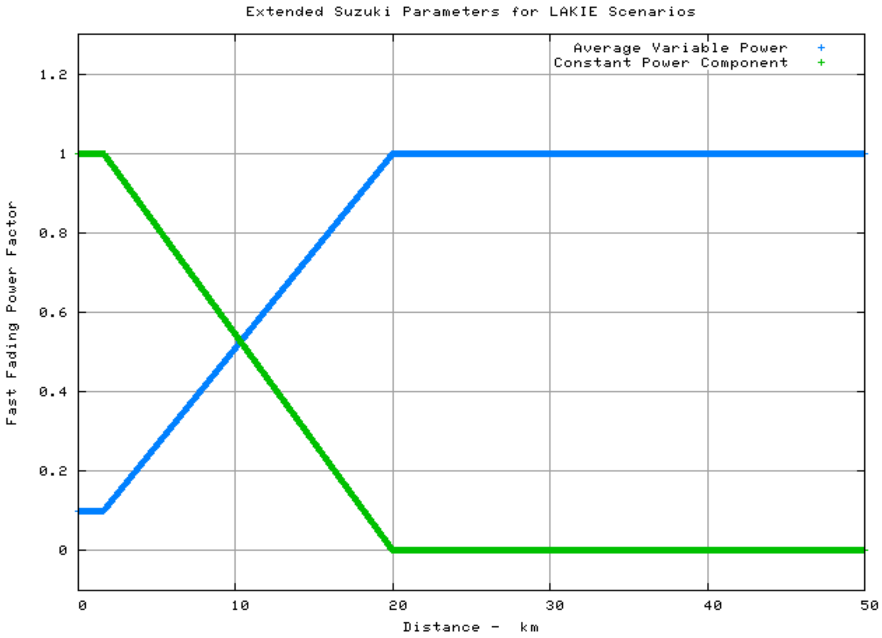

Figure 3-8. Extended Suzuki Parameters for LAKIE Scenario

The slow fading process is modeled as a log-normal distributed process with median value given by the received median power (i.e., function of the transmitter gain, receiver gain, and median path loss) and standard deviation in dB given by the parameter 'sigma-dB'. A plot of the sigma-dB distribution for LAKIE (from Section 3.2.2) as a function of distance is provided in Figure 3-9.

Using the models discussed above, cumulative distribution functions (CDFs) of received interfering power at the aircraft antenna output were calculated via Monte Carlo simulations both for no banking and for an aircraft bank angle of 25 degrees. Results are provided in Figure 3-10 which satisfy the mean power level requirement of -34.1 dBm, and the acquisition power level requirement of -34.1 dBm at a probability of 10^{-3}.

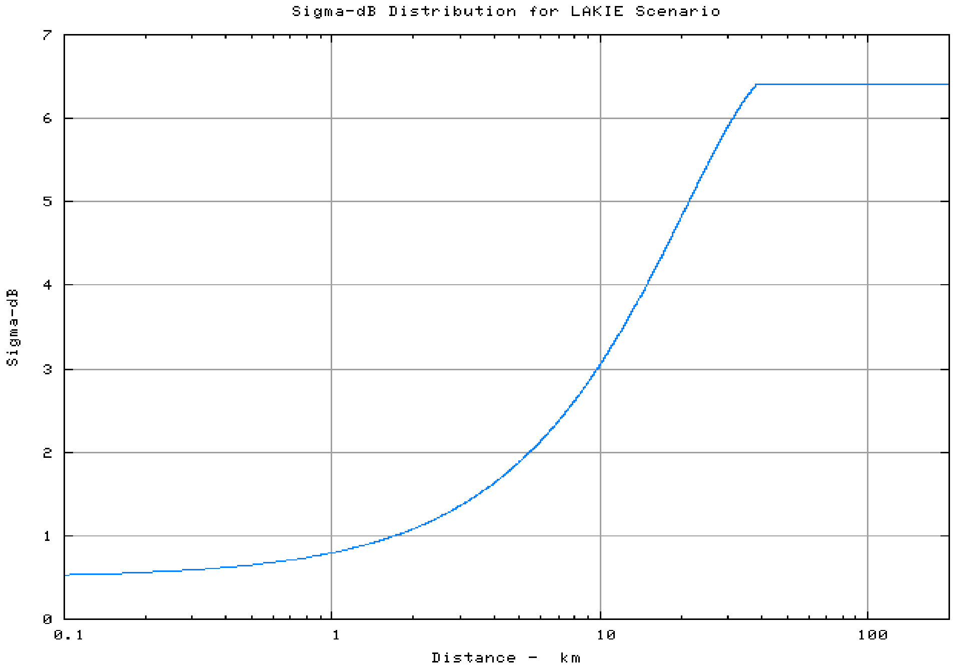

Figure 3-9. Sigma-dB Distribution for LAKIE scenario

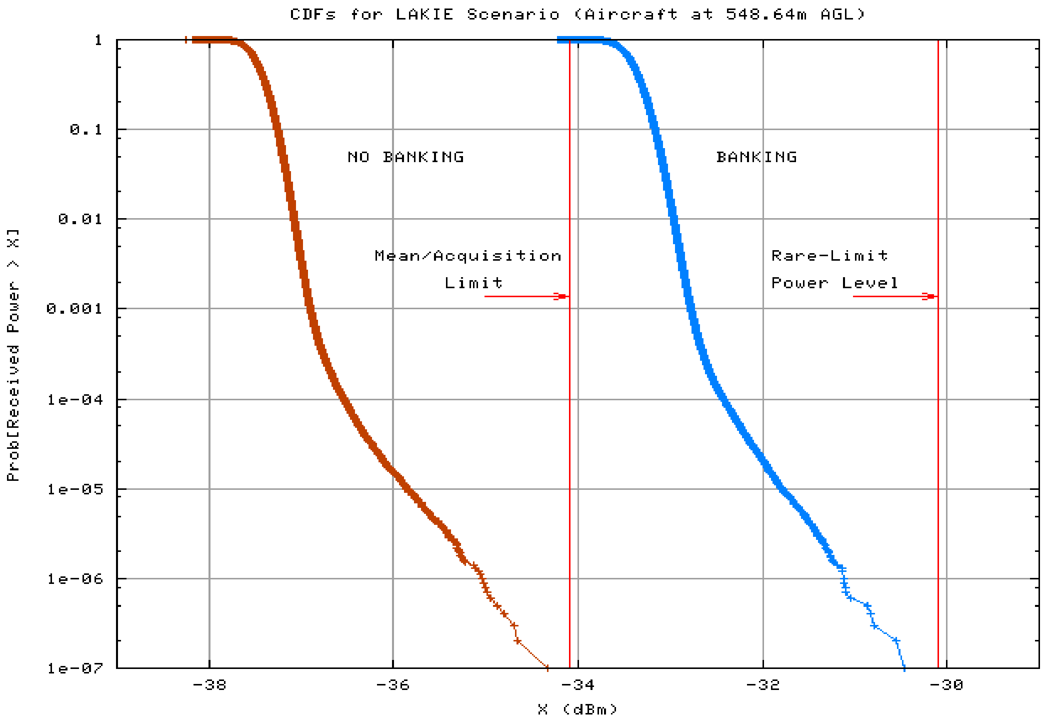

Figure 3-10. CDFs for LAKIE Scenario (10,000,000 statistical samples)

It should be noted that the rare-limit power level depicted in Figure 3-10 is calculated as a per-event probability, while the requirement represents the probability of the interference level exceeding -30.1 dBm being < 10^{-6} in any hour of flight, for an aircraft at any bank angle up to 25 degrees. Thus, in order to apply this probability to a point-in-space CDF path loss analysis, the probability per hour must be translated to a probability per independent event. This effect will vary with altitude and geometry (type of environment).

For example, if there are 100 statistically independent samples of interference in an hour and the per event probability of exceeding the power level requirement is 10^{-8}, then the corresponding per hour probability of at least one sample exceeding the threshold would be approximately 10^{-6}. So for this example the true power level to be compared to the threshold would be that achievable at a probability of 10^{-8}. However, the number of statistical Monte Carlo samples required for a reasonable estimate of the 10^{-8} probability value is approximately 10^9 × 2883 sites × 3 sectors/site, a value that significantly exceeds the currently available processing resources. Therefore, though the power level achieved at a 10^{-6} per event probability for the LAKIE scenario is less than -30.1 dBm, that calculated value does *under bound* the corresponding power level achieved at a 10^{-6} per hour probability, perhaps significantly.

3.3 DCA Approach Scenarios Description, Analysis, and Results

Interfering power statistics were calculated for two scenarios involving a fixed wing aircraft approach to DCA Runway 19, along the Potomac River just downstream from Key Bridge. Aircraft altitudes[11] were 312' MSL (denoted herein as Scenario DCA-1) and 400' MSL (denoted as DCA-2). For both cases the aircraft was assumed to be at 38.8976 N latitude and 77.0615 W longitude. The approach type is an RNP AR (0.11 NM).

These scenarios do not consider all of the coverage requirements of Section 1.4 but were selected to better understand the effects to aircraft on final approach.

3.3.1 DCA Runway 19 Approach Scenario Description

The aircraft location for these cases is approximately 0.22 nm left of the nominal approach course line (edge of permitted cross-track error). The 400 foot height corresponds approximately to the obstacle clearance surface at this location. The 312 foot case is used to check for sensitivity of mean aggregate received power to the aircraft antenna height parameter. It should be noted that helicopters are not allowed to fly over 200' MSL in this area and so both of these scenario cases apply strictly to fixed wing aircraft.

Figure 3-11, Figure 3-12, and Figure 3-13 illustrate several aspects of the site-specific propagation model for this scenario. In Figure 3-11, an example is shown of an aircraft whose nadir location is illustrated by the red thumbtack. LightSquared has identified tower locations in the vicinity.

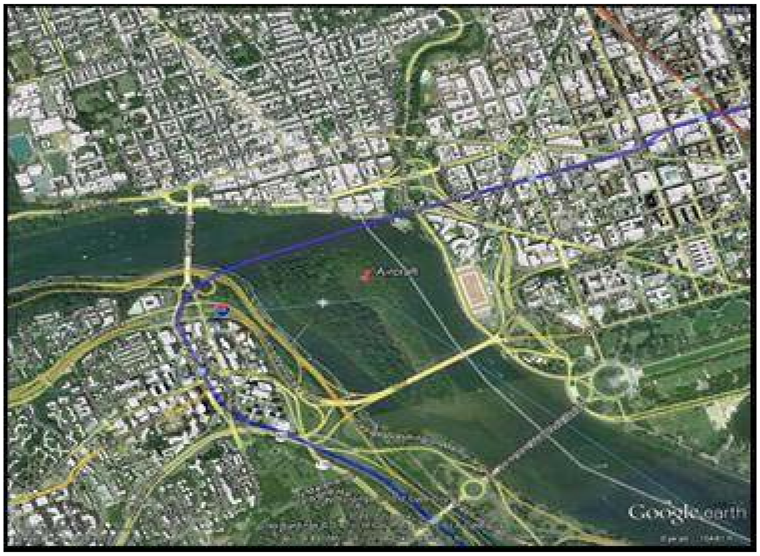

Figure 3-11. ATCt Tower Locations near Aircraft Over Roosevelt Island, Washington, DC ***[Redacted]***

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[11] These MSL altitudes correspond to aircraft heights of 76 and 102.8 meters, respectively, above average ground height under the 6 closest adjacent towers

Figure 3-12 plots the effective height of LightSquared towers as a function of distance out to 5.6 km from aircraft. The effective height of a given tower is the tower height above the ground at its base (from deployment data) added to a correction term. That term is difference between the actual ground height (MSL) at the tower base and the average ground height under the 6 towers closest to the aircraft nadir position (= 62.67 feet MSL). When taken together with the aircraft antenna height adjusted for the same average ground height, this correction term helps properly account for the effect the terrain variation on the path loss which otherwise assumed a "flat earth." The wide variation in tower heights precludes the use of a generic propagation model and instead forces the use of a site-specific model. This need is further illustrated in Figure 3-13 which shows the site-specific variation in cell tower concentration and average effective antenna height as a function of radial distance from aircraft nadir. Note also that six towers are within about 1 km of the aircraft location and a total of 13 towers are within 2.2 km (approximately 3 times the tower concentration used in the more general RTCA analysis [3-1]).

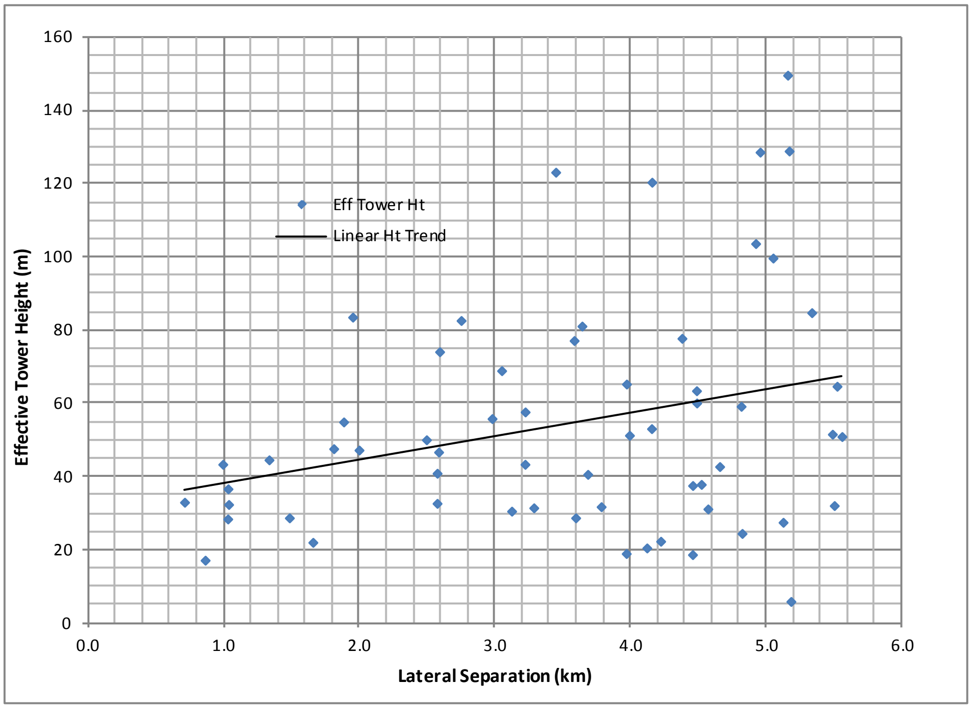

Figure 3-12. Cell Tower Effective Height Distribution (Relative to the Ave. Ground Height (62.67') below 5 Closest Towers

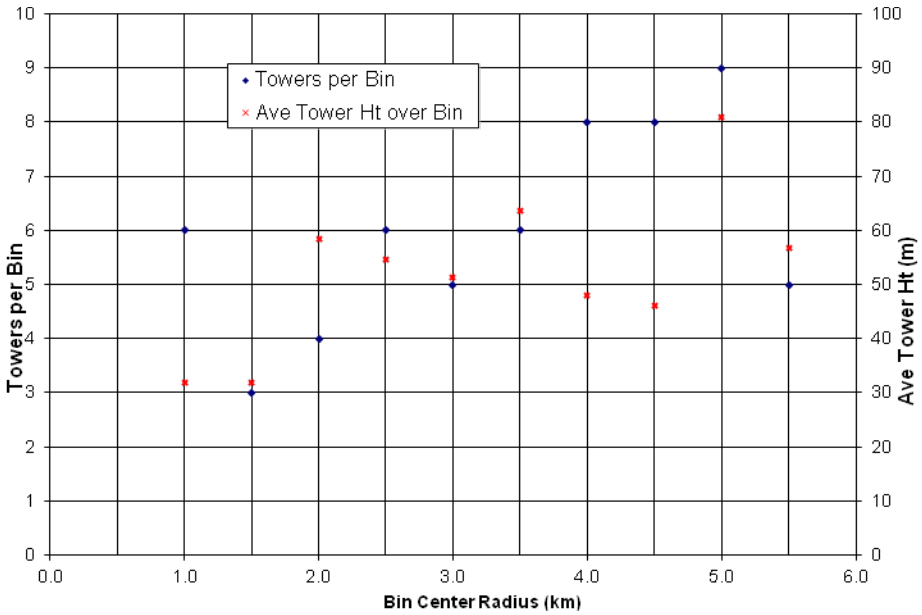

Figure 3-13. Tower Concentration and Average Effective Height
(0.5 km radial bins)

3.3.2 DCA Scenario Site-Specific Path Loss Model Parameters

For the 312 foot MSL aircraft height case (DCA-1) in this scenario, the lateral separation range outer breakpoints for the median isotropic path loss model are: 306.26 m (2-Ray), 2.500 km (free-space segment, slope = 2.0), and 5.2286 km (log fit segment, slope depends on tower height). The equivalent points for the 400 foot MSL case (DCA-2) are 395 086 m, 2.500 km (same as for DCA-1), and 5.38191 km

At the shorter ranges, $0 \le r < 2.5km$, the line-of-sight parameter $\rho^2(r)$ will be unity while the Rayleigh parameter $k\psi_o(r)$ will conservatively be 10 dB lower [3-4]. For the DCA-2 case at 5.38191 km and beyond (or 5.2286 km for DCA-1), there will be significant probability of blockage of the line-of-sight component with all of the power resulting from scattering (Rayleigh component). Thus we have for DCA-2,

$$k\psi_o(r) = \left\{ \begin{array}{ll} .1, & 0 \le r < 2.5\,km \\ .1 + ((1. - .1)/(5.38191 - 2.5))(r(km) - 2.5), & 2.5\,km \le r < 5.38191km \\ 1., & 5.38191km \le r \end{array} \right\}$$

$$\rho^2(r) = \left\{ \begin{array}{ll} 1., & 0 \le r < 2.5km \\ 1. - (1./(5.38191 - 2.5))(r(km) - 2.5), & 2.5km \le r < 5.38191km \\ 0, & 5.38191km \le r \end{array} \right\}.$$

and

$$\sigma(r) = \left\{ \begin{array}{ll} Poly(r), & 0 \le r < 6.16864km \\ 6.4dB, & 6.16864\,km \le r \end{array} \right\}$$

where,

$$Poly(r) = .470967 - .00004974r + 1.29711 * 10^{-7} r^{2} + 9.62438 * 10^{-12} r^{3} - 7.15798 * 10^{-16} r^{4} + 8.66748 * 10^{-21} r^{5}.$$

The comparable functions for ρ^2 and $k\psi$ in the DCA-1 use the 5.2286 km breakpoint instead of 5.3819 km. The sigma-dB function for DCA-1 is given by:

$$\sigma(r) = \left\{ \begin{array}{ll} Poly(r), & 0 \le r < 5.9695km \\ 6.4dB, & 5.9695\,km \le r \end{array} \right\}$$

where,

$$Poly(r) = .486064 - .000086428r + 1.38149 * 10^{-7} r^{2} + 1.17035 * 10^{-11} r^{3} - 8.33652 * 10^{-16} r^{4} + 1.00179 * 10^{-20} r^{5}.$$

3.3.3 DCA Scenario Aggregate Interference Analysis and Results

Detailed analyses of these DCA scenarios were conducted using the updated LightSquared tower/sector deployment data (see Section 2.2), Argus antenna data (see Section 2.1), and path loss models (see Section 3.1). The estimated radio horizons between the aircraft antenna height and the LightSquared emitter heights are 72 and 77 km, respectively for DCA-1 and -2 (4/3 Earth radius approximation). As in the LAKIE scenario, these values are driven by tower heights near these radii. Locations of the 917 visible towers for DCA-1 and the 983 visible towers for DCA-2 relative to the aircraft are shown in Figure 3-14. For these analyses, the AGL tower heights for the 60 towers closest to the aircraft location were corrected to effective tower heights by the procedure in Sec. 3.3.1 to properly determine the individual discrete source median path loss in the Monte Carlo analysis.

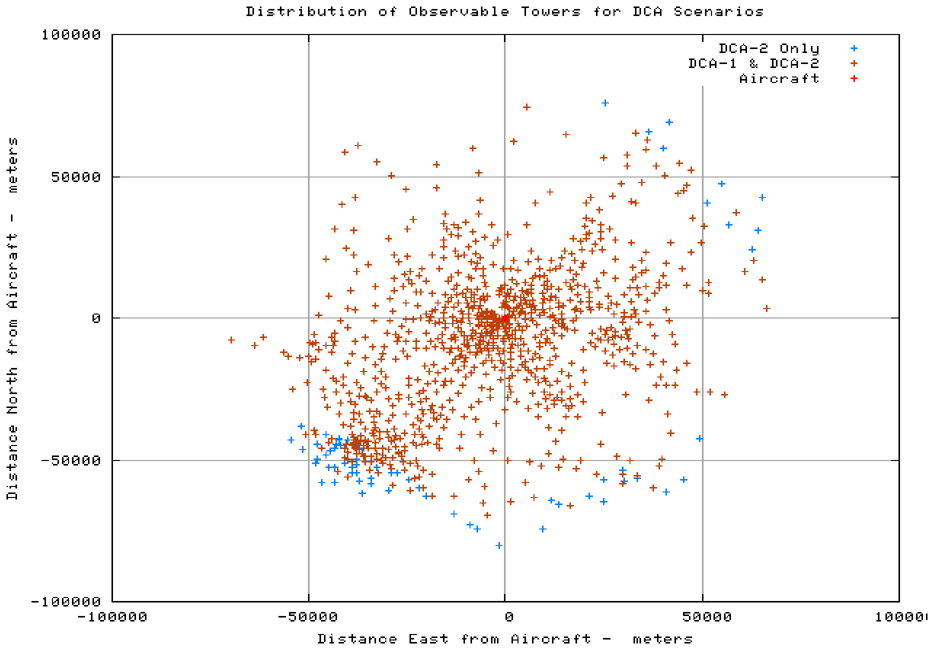

Figure 3-14. Distribution of Observable Towers Relative to Aircraft Location for DCA Scenarios

Figure 3-15 and Figure 3-16 illustrate the modeled median path loss associated with the visible towers as a function of distance from the aircraft for DCA-1 and DCA-2, respectively.

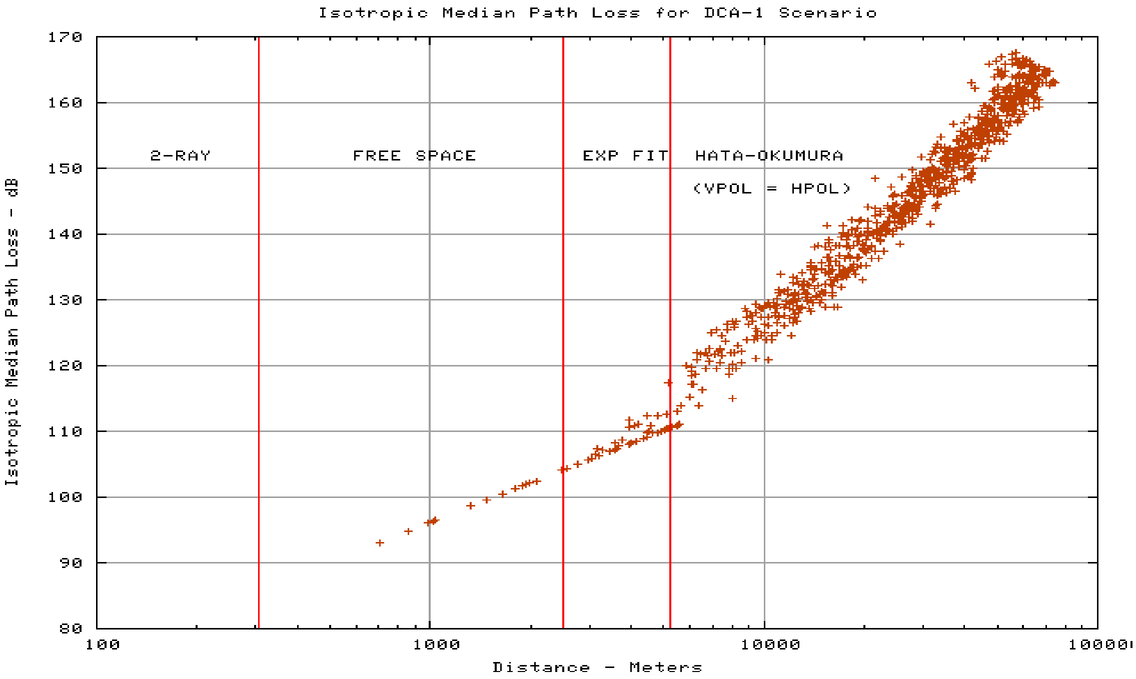

Figure 3-15. Isotropic Median Path Loss vs. Distance for DCA-1 Scenario

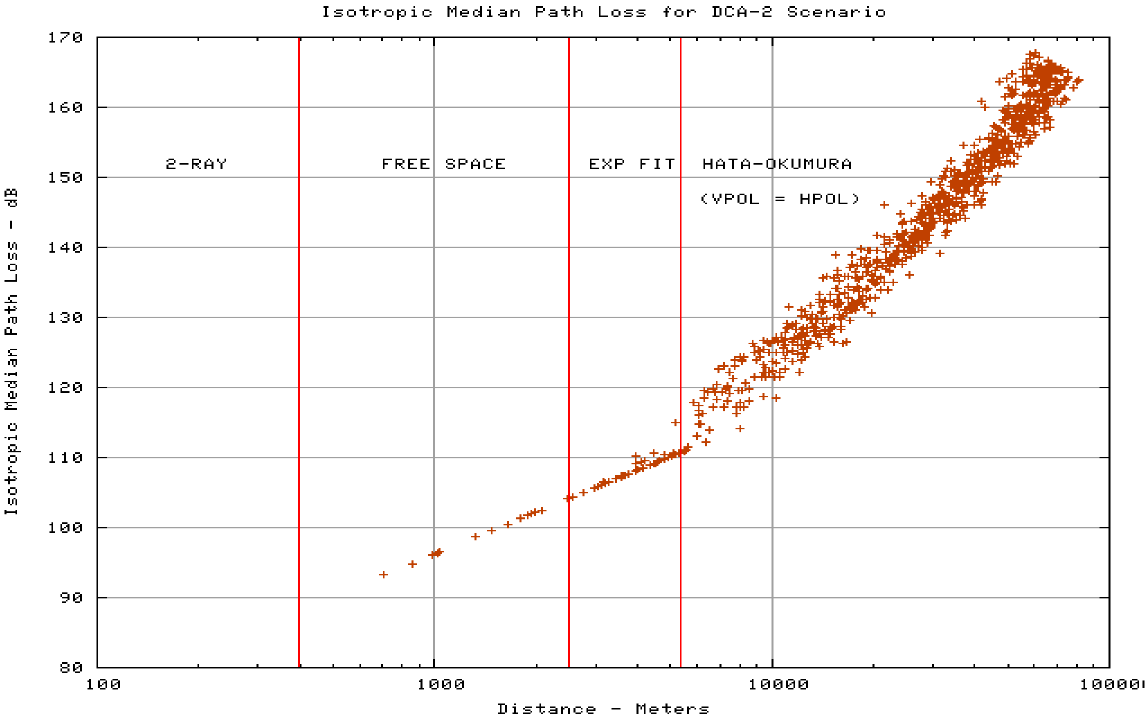

Figure 3-16. Isotropic Median Path Loss vs. Distance for DCA-2 Scenario

Figure 3-17 and Figure 3-18 illustrate the modeled total path loss for DCA-2, including LightSquared transmitter and aircraft receiver antenna gains, associated with the visible tower sectors as a function of distance from the aircraft for VPOL and HPOL, respectively. Sectors 1, 2, and 3 in these figures correspond to the sector numbering in the LightSquared-provided site deployment details, in which each base station sector was assigned a specific antenna azimuthal pointing direction.

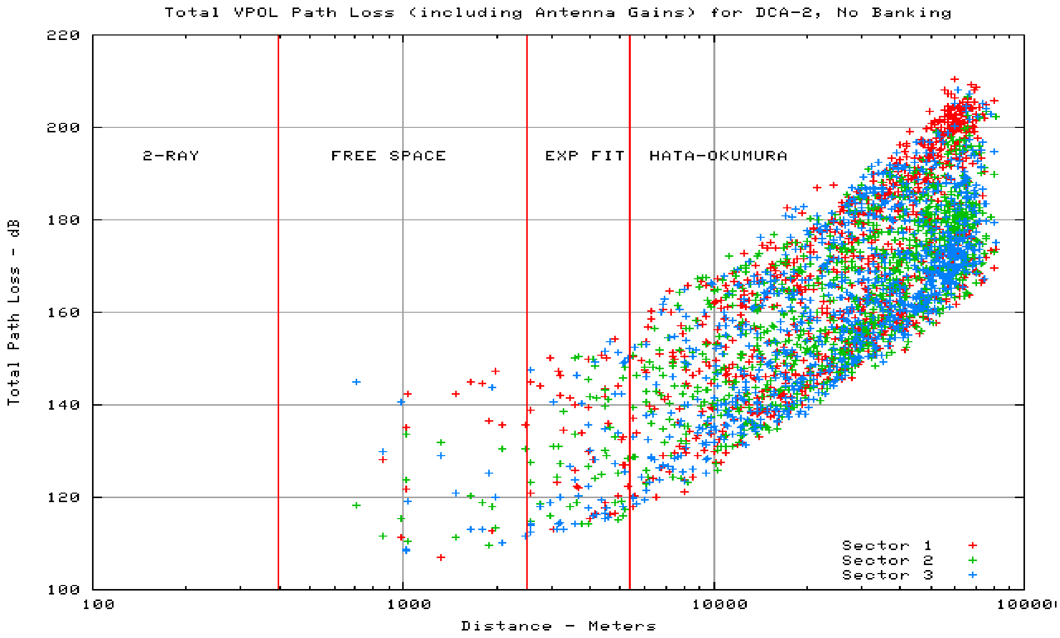

Figure 3-17. VPOL Total Path Loss for DCA-2, No Banking

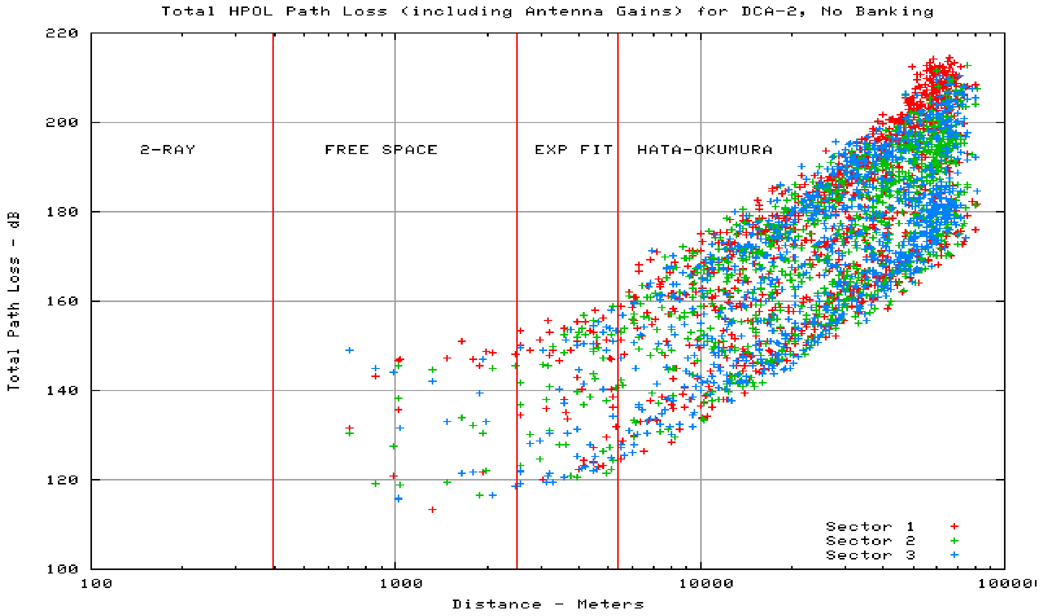

Figure 3-18. HPOL Total Path Loss for DCA-2, No Banking

The fast fading parameters and the sigma-dB distribution for the DCA scenarios as a function of distance are provided in Figure 3-19 and Figure 3-20.

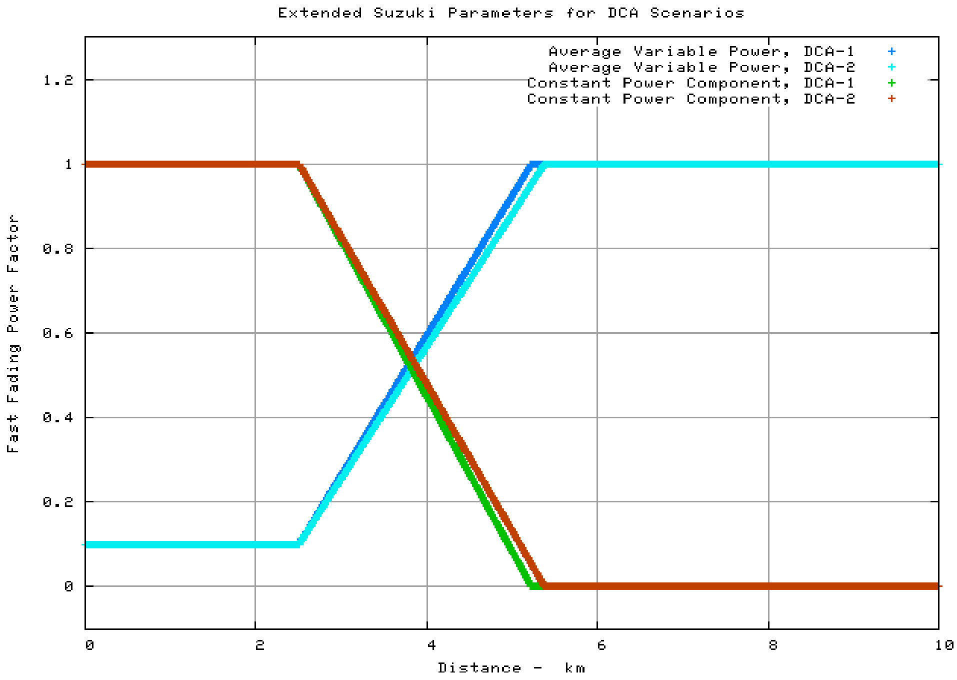

Figure 3-19. Extended Suzuki Parameters for DCA Scenarios

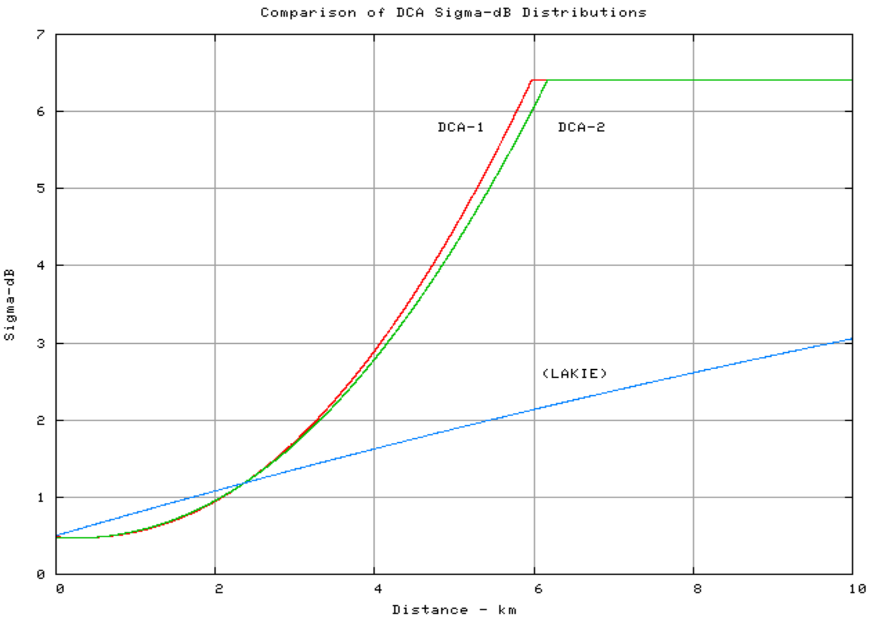

Figure 3-20. Sigma-dB Distributions for DCA Scenarios
(LAKIE Case shown for comparison)

Using the models discussed above, cumulative distribution functions (CDFs) of received interfering power at the aircraft antenna output were calculated via Monte Carlo simulations both for no banking and for an aircraft bank angle of 25 degrees. As an analysis of the sensitivity of the resultant CDFs to specific statistical model parameters, the Monte Carlo simulations were performed under the following three conditions: (a) limitation of the output of the associated random number generator to four standard deviations; (b) limitation of the output of the random number generator to five standard deviations; and (c) no limit to the number of standard deviations. The case of four standard deviations, which produces the smallest interfering power CDF tail extensions, corresponds to Figure 4 in Reference [3-6]. Here the CDF of the deviation of path loss exponent for field data is fit very well by a Gaussian over four standard deviations, indicating that shadow fading is log-normal over this region.

As summarized in Table 3-1, the calculated interfering power levels meet the mean power level requirement of -34.1 dBm for DCA-2 but do *not* meet this mean power level requirement for DCA-1. Moreover, these interfering power levels do *not* meet the acquisition power level requirement of -34.1 dBm at a probability of 10^{-3} or the rare-limit power level requirement of -30.1 dBm (with banking) at a probability of 10^{-6} , even for the most favorable case of a 4-sigma cap. Associated CDF results are provided in Figure 3-21 for DCA-1 and in Figure 3-22 for DCA-2.

Table 3-1. Comparison of DCA Interfering Power Statistics to FAA Requirements

Metric	Requirement	Calculated (DCA-1)	Shortfall with respect to Threshold (DCA-1)	Calculated (DCA-2)	Shortfall with respect to Threshold (DCA-2)
Mean Power Level	-34.1 dBm	-33.6 dBm	0.5 dB	-34.4 dBm	-0.3 dB*
Acquisition Power Level	-34.1 dBm at 10^{-3}	-32.3 dBm	1.8 dB	-32 7 dBm	1.4 dB
Rare-limit Power Level	-30.1 dBm at 10^{-6} with Banking	-26.9 dBm (best case, 4 sigma cap)	3.2 dB	-26.7 dBm (best case, 4 sigma cap)	3.4 dB

* Meets Mean Power Level Requirement (0.3 dB margin)

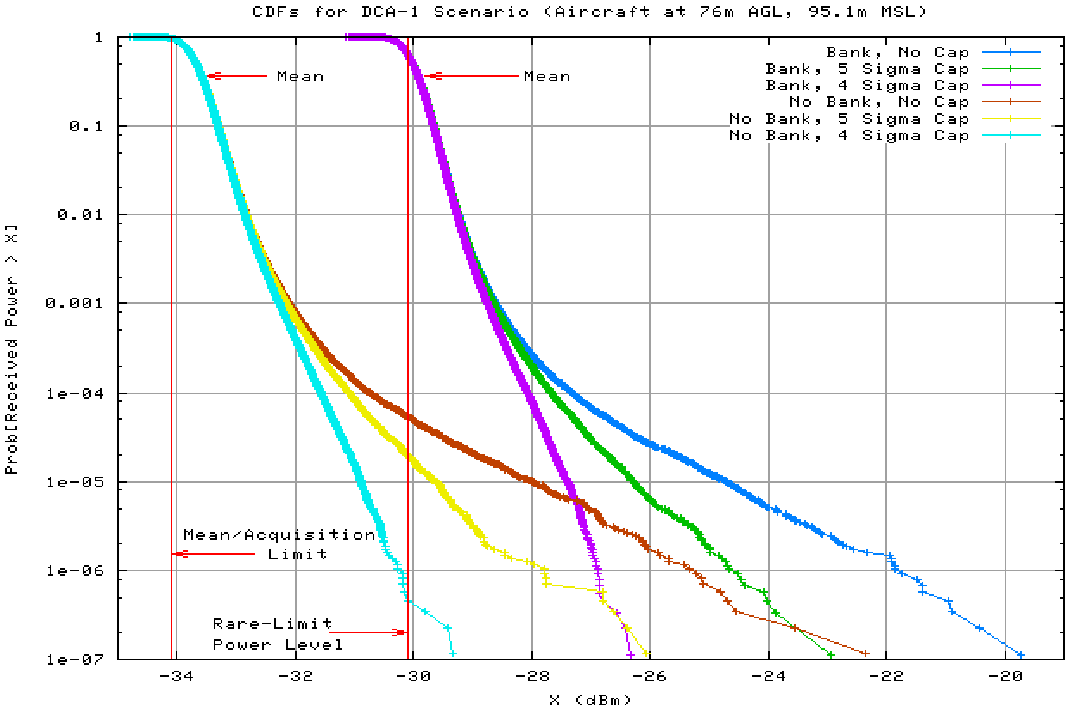

Figure 3-21. CDFs for DCA-1 Scenario

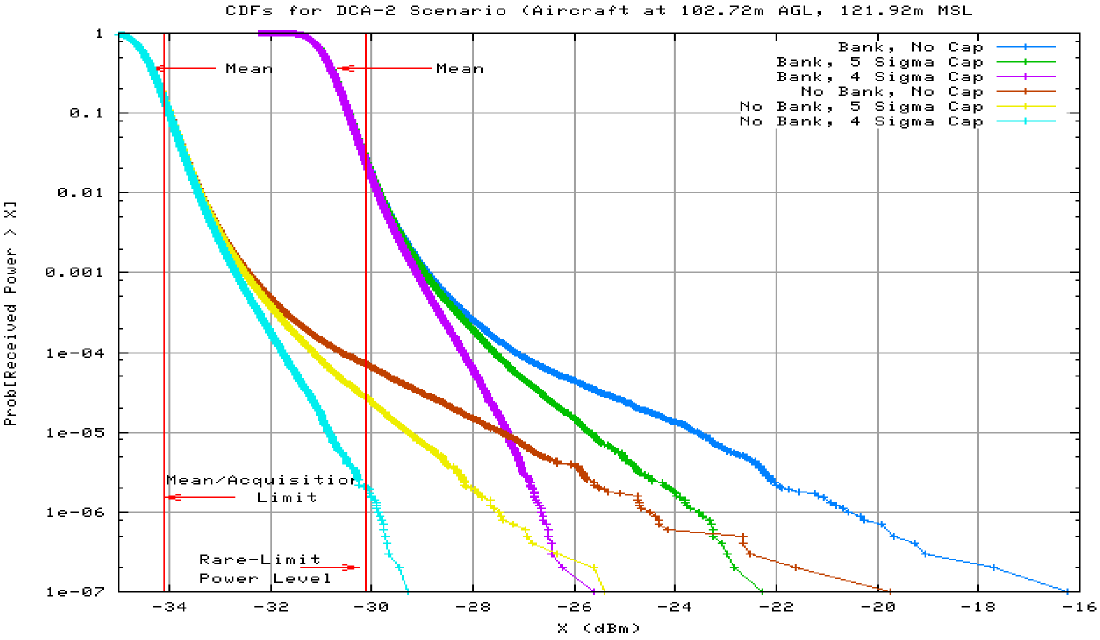

Figure 3-22. CDFs for DCA-2 Scenario

3.3.4 Sensitivity of Monte Carlo Results to Model Parameters

This section briefly addresses the sensitivity of the Monte Carlo simulation results to the following model parameters: sigma-dB, extended Suzuki line-of-sight parameter, and the number of statistical samples.

Figure 3-23 illustrates the original FAA model (step sequence) for the LAKIE sigma-dB distribution as well as the corresponding cubic fit distribution that was eventually used in the corresponding Monte Carlo simulations. CDFs corresponding to use of both the step and continuous models are shown in Figure 3-24. Note that the FAA 'Rare Limit Power Level' of -30.1 dBm was *not* met with banking for the step-sigma distribution though this requirement was met with the continuous distribution (also see Figure 3-10). Furthermore, use of the latter distribution resulted in approximately 3.5 dB less calculated interference power at the aircraft at the 10^{-6} CDF level.

The CDF tails (e.g., 10^{-6} region) results are quite sensitive to the modeled sigma-dB values. In view of this sensitivity, a modeling change to the continuous distribution was made after it was observed that the large CDF tails were being driven in part by the step-sigma value of 6.4 in the region slightly above 20 km. The associated abrupt step change was judged not to be physically reasonable.

With respect to incorporation of fast fading models, the CDF results in Figure 3-25 illustrate that there is very little difference in calculated interference power resulting from use of the following models: slow fading only, slow and fast fading (standard Suzuki), and 'extended Suzuki' (see Section 3.3.2).

With respect to sensitivity of results to the number of Monte Carlo iterations, five CDFs are plotted in Figure 3-26 resulting from Monte Carlo runs for DCA-2, with banking, using five distinct random number sequences. In general, 10^7 iterations were used for each Monte Carlo run in order to determine a reasonable estimate of the associated 10^{-6} CDF value. Note that the five CDF values at 10^{-6} are tightly clustered for capping at the 4 and 5 sigma levels and that the 10^{-6} CDF values with no capping are spread over approximately 1.5 dB. In summary, for the DCA scenarios the number of Monte Carlo iterations (10^7) was more than adequate for determining compliance/non-compliance with the FAA Rare-Limit-Power-Level requirement.

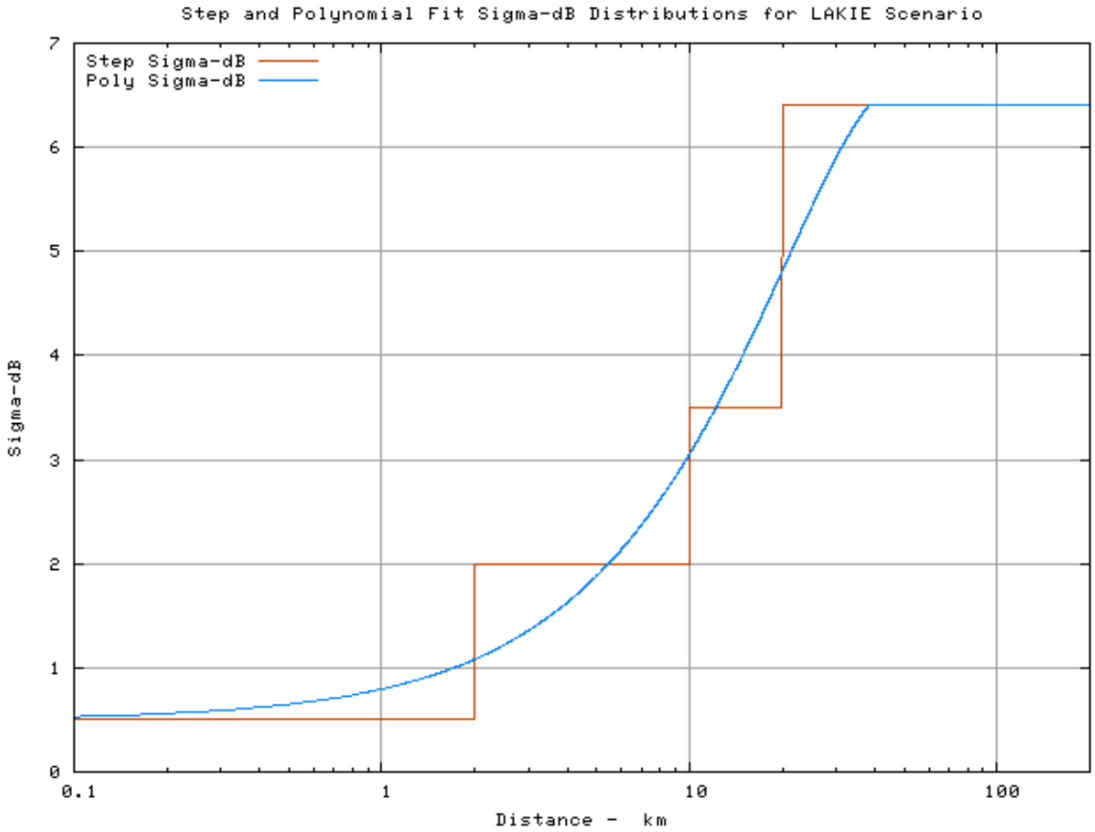

Figure 3-23. Step and Polynomial Fit Sigma-dB Distributions for LAKIE Scenario

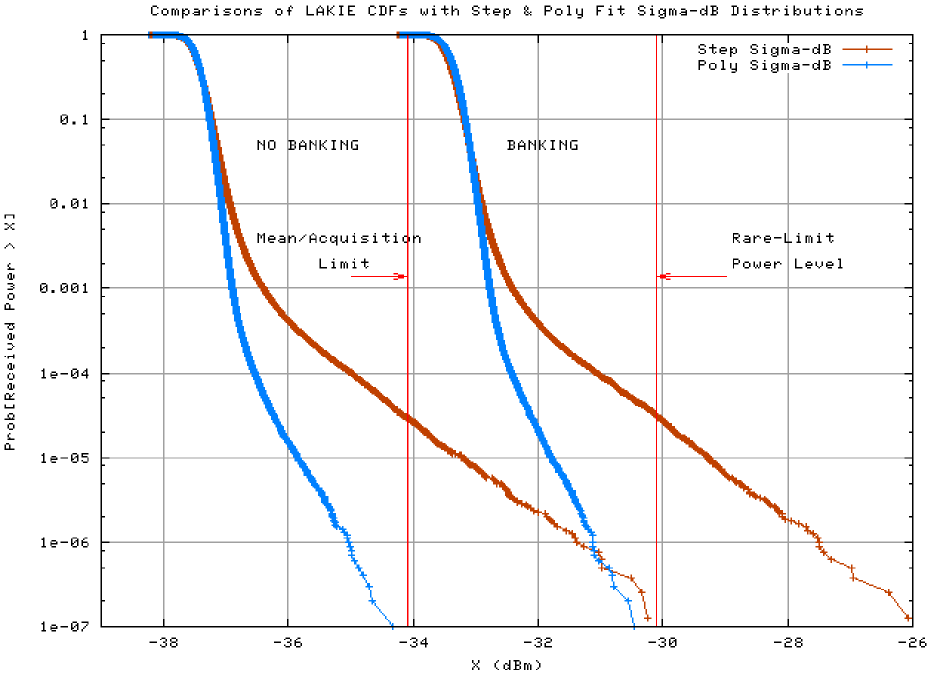

Figure 3-24. Comparisons of LAKIE CDFs with Step and Poly Fit Sigma-dB Distributions

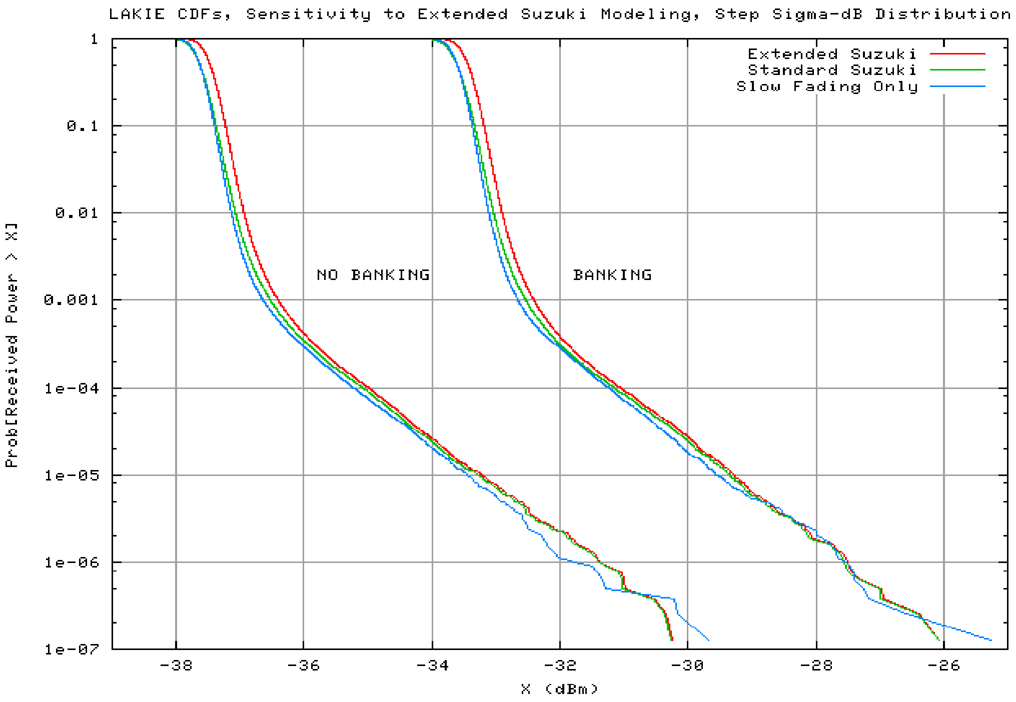

Figure 3-25. LAKIE CDFs, Sensitivity to Fast Fading Models

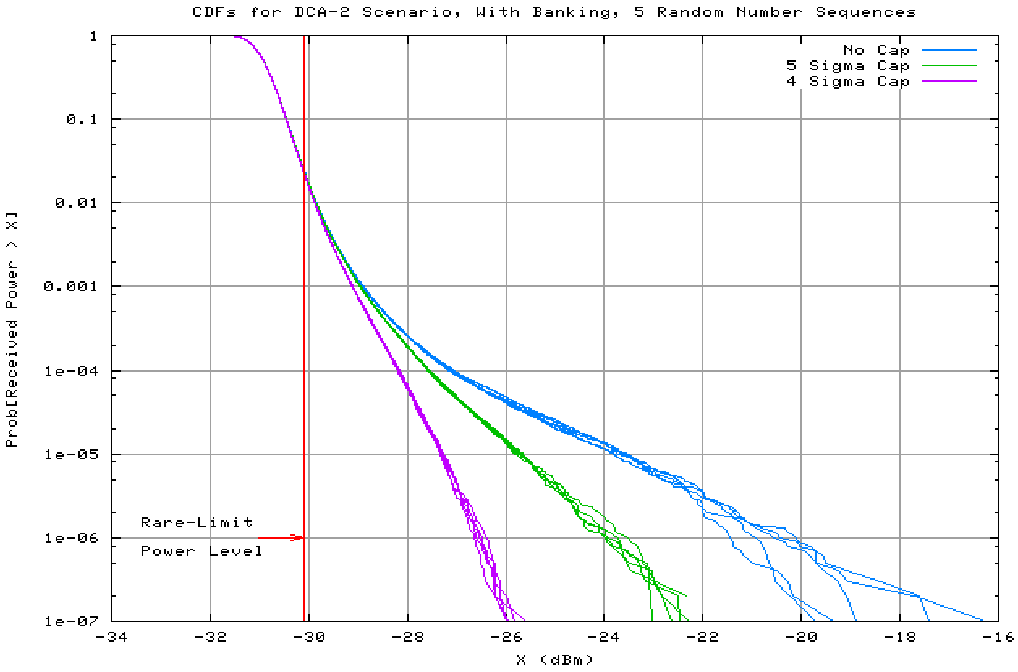

Figure 3-26. CDFs for DCA-2 Resulting from Five Distinct Monte Carlo Random Number Sequences, with Banking

3.4 Other Approach Scenarios and Landing/Surface Operations

This Section provides examples of LightSquared base station sites that result in received power levels for an aircraft on approach, landing or on the airport surface that exceed the thresholds described in Section 1.3. It is important to note that although there are some restrictions on LightSquared base station power levels near airports, these restrictions are *not* adequate to protect all near-airport operations since:

- The agreement only applies to FAA Primary Airports and to those airports that are either governmental or military. FAA Primary Airports are defined to be those airports with over 10,000 passenger enplanements per year. There are only about 400 Primary Airports, whereas there are nearly 20,000 airports and heliports in total within the United States.
- The restrictions codified in the March 2010 FCC SkyTerra Order and Authorization only affects power levels for base stations within 500 meters of the airport (using the 62 dBm maximum EIRP assumption for all base stations noted earlier in this report) and does not protect aircraft on approach and departure routes from base stations located beyond 500 meters of the airport.

It also should be noted that these examples were found through a manual screening of only a very small number of airports and helipads of the 20,000 in the United States, and as such do not necessarily represent the worst case.

3.4.1 United Medical Center, Washington, DC

Figure 3-27 is a Google Earth image of the United Medical Center in South East Washington, D. C. (North is approximately “up”). On the roof of the building (yellow/black dot) is a proposed LightSquared base station (Site 8504) with three sector antennas at 32.9 m AGL height pointing to the compass directions [15, 135, 255] degrees. In front of the building is a medevac helipad. Figure 3-28 shows the received power seen by a helicopter above the helipad (38.835086N, 76.984910W) using both the free-space path loss model and the two-ray path loss model. No aircraft pitch or bank was modeled. Note that both models predict a mean received power level of up to -16 dBm, which is significantly above the -34.1 dBm threshold for tracking. The results would be far worse if normal levels of helicopter pitch were modeled, and this pitch was towards the building. In addition, it must be emphasized that no accounting was made of additional interference power at the aircraft due to transmissions from other LightSquared towers.

Figure 3-27. United Medical Center, South East Washington, D. C

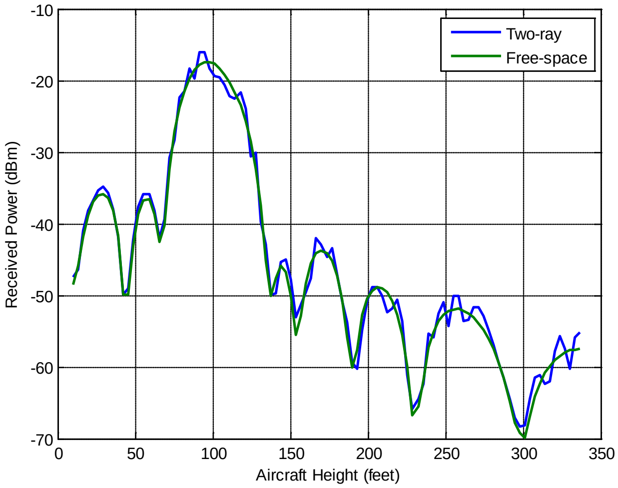

Figure 3-28. Received Power from a single LightSquared tower for Helicopter (Zero Pitch) above United Medical Center Helipad (38.835086N, 76.984910W)

3.4.2 LaGuardia Airport

Figure 3-29 shows the vicinity of LaGuardia airport in New York City.

Figure 3-29. Vicinity of LaGuardia Airport ***[Redacted]***

Figure 3-30 shows the received power seen by an aircraft in level flight descending down the nominal 3 degree glide path to the runway threshold, using both the free-space path loss model and the two-ray path loss model. Only Site 19817 was considered (i.e., the interference contribution from all other nearby sites was ignored). The threshold crossing height for the nominal approach is 52 feet AGL (left-hand end of plotted values) and the aircraft height is ~220 feet AGL at 3.2 km from the threshold (right-end of plotted values). The mean received power for the two-ray model peaks at -32.7 dBm, slightly exceeding the -34.1 dBm threshold.

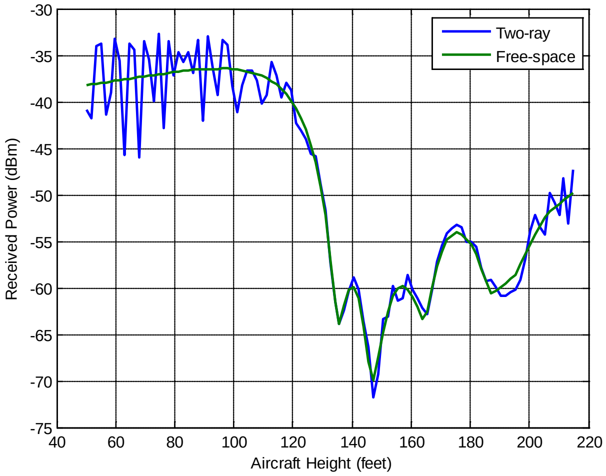

Figure 3-30. Received Power from a single LightSquared tower for Level Aircraft Descending to RWY4 on Nominal 3-degree Glide Path

As described in Section 1.4, however, it is not sufficient to solely evaluate the interference impact for aircraft in level flight on the nominal approach path. Aircraft routinely fly low due to barometric error, winds and other errors, and also experience non-zero roll and pitch angles. Figure 3-31 shows the received power for the same RWY4 approach when the aircraft is on the nominal 3-degree glide path but with 6-degree nose-up. Figure 3-32 shows the received power for a level aircraft that is descending below the nominal 3-degree glide path. For this result, the aircraft is assumed to be flying with its wheels just clearing the 34:1 obstacle clearance surface (see Appendix A), and the wheels are assumed to be 16 feet below the GPS antenna. For this "flying low" scenario, note that both the free-space and two-ray models predict a mean power level that is significantly above the -34.1 dBm threshold.

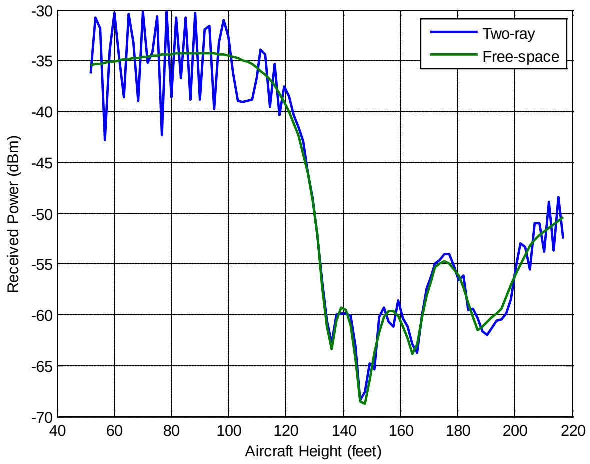

Figure 3-31. Received Power from a single LightSquared tower for Aircraft with 6-degree Nose-Up Descending to RWY4 on Nominal 3-degree Glide Path

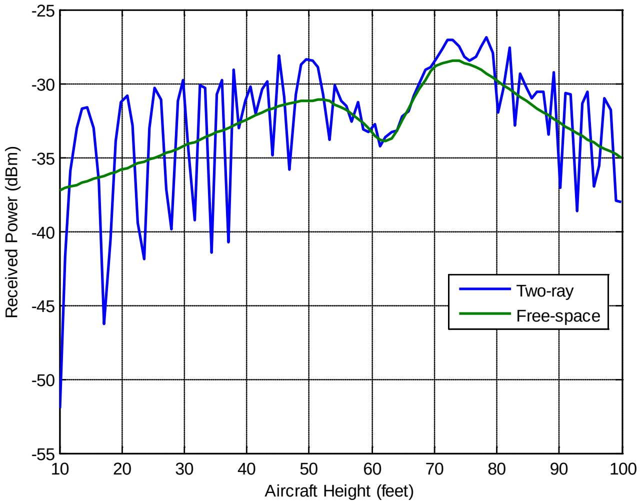

Figure 3-32. Received Power from a single LightSquared tower for Level Aircraft Descending to RWY4 Below the Nominal 3-degree Glide Path

3.4.3 Teterboro Airport

Teterboro is a general and business aviation airport in New Jersey. Located only 12 miles from Manhattan, it is extremely popular for private and corporate aircraft and has averaged around 500 operations/day in recent years. However, it is NOT an FAA Primary Airport and thus LightSquared base stations are not restricted in power by the LightSquared-Inmarsat agreement. A 17 m tower is approximately 1400’ from RWY6/24 and within about 1000’ of aircraft parking areas. From the plots in Section 3.1.1, it is clear that the proximity of this tower to the airport will result in received power levels in excess of the -34.1 dBm tracking threshold solely from that single LightSquared tower.

Figure 3-33. Teterboro Airport in New Jersey ***[Redacted]***

3.5 TAWS, HTAWS and Low Altitude Operations

As summarized in Section 1, in order to support TAWS for fixed-wing aircraft GPS must be available at and above 100 feet AGL within 7.5 NM of an airport. To support HTAWS, GPS must be available at and above 100 feet AGL everywhere. An exclusion zone that is 500’ laterally and 100’ above a base station is permissible, per Section 1, only if the base station is above 200’ AGL and thus likely to be in the airborne database and the exclusion does not infringe on any instrumented approach obstacle clearance surface. This incompatibility is primarily focused at lower altitude aviation operations, including (but not limited to) impacts to many helicopter operations. Aircraft navigation and ADS-B surveillance, and fixed-wing aircraft and helicopter Terrain Awareness Warning Systems (TAWS).

Figure 3-34 shows the locations of obstacles around LaGuardia airport (red triangles) contained within one widely used TAWS database. This particular TAWS obstacle database includes nearly 500,000 obstacles for the United States. Although some proposed LightSquared base station sites are on buildings or towers that are contained within the database, a large percentage of the base stations is not contained in this database. Most of the base stations are at heights of 20 – 30m AGL. The power that would be seen by an aircraft at 100 feet AGL could exceed -34.1 for thousands of feet laterally around each base station even neglecting aggregation and indirect signal effects that could be considerable in some areas. From a cursory nationwide scan of the TAWS obstacle data and proposed LightSquared tower sites, a similar low level of correlation is observed. As a result, TAWS, HTAWS and low altitude aircraft operations (especially helicopter operations) are *not* expected to be available within the vicinity of many of the planned LightSquared towers.

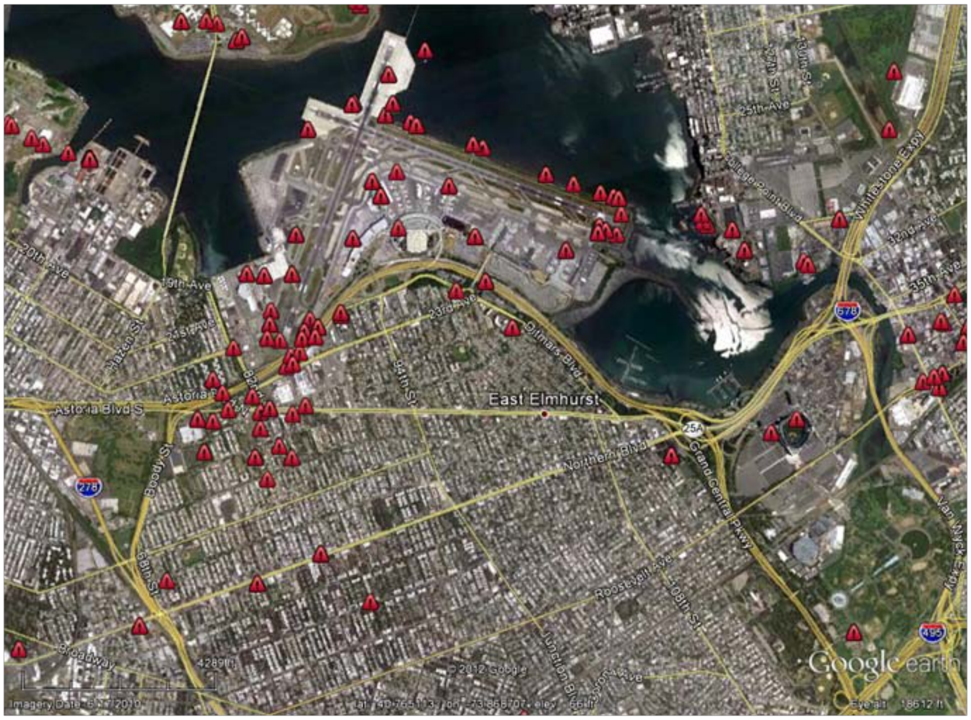

Figure 3-34. Location of Proposed LightSquared Base Stations and Obstacles in a Common TAWS Database Near LaGuardia Airport ***[Redacted]***

3.6 LightSquared Proposed Propagation Model

As noted above, no single propagation model was considered appropriate by either the FAA or LightSquared for all scenarios, but both oranizations agree that the propagation models for higher altitude and low altitude scenarios should be different.

In November 2011 LightSquared proposed the following approach – based on mobile satellite service studies -- to address high altitude scenarios:

- For aircraft-to-tower distance of 0 to 2 km, use 2-ray model.

- For the other distances, each base station is randomly declared as ‘Blocked’ or ‘Unblocked’ with a probability given by a site-specific blockage study and dependent on that tower’s distance from the aircraft.
- Each base station is then considered to have characteristic A or B, as far as mean gain and standard deviation is concerned, depending on whether it has been declared as ‘Blocked’ or ‘Unblocked’.
- A (unblocked): mean gain = 0.5 dB and standard deviation of 0.5 dB (this is basically the Rician case)
- B (blocked): mean gain = -10 dB and standard deviation of 3.5 dB.
- The mean path loss is calculated using the free space formula in all cases, with an excess loss given by the mean gain in characteristic A or B.
- The actual power is assumed to be log normal distributed about the mean value with a standard deviation given by A or B, depending on the state of the base station (‘Blocked’ or ‘Unblocked’).

For lower altitudes (below 53m), the LightSquared proposal was to use:

- Free Space for elevation angles (positive of negative) greater than 6^0
- A loss model with a slope of 2.9 for elevation angles less than 6^0.

3.7 References

[3-1] SC-159, "Assessment of LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS Airborne Receiver Operations", RTCA Document No., RTCA/DO-327, June 3, 2011.

[3-2] D. Parsons, The Mobile Radio Propagation Channel, Chichester, England: John Wiley & Sons, 1996.

[3-3] M. Patzold, Mobile Fading Channels, Chichester, England: John Wiley & Sons, 2002, pp. 172-173.

[3-4] J. Goldhirsh and W.J. Vogel, Propagation Handbook for Land-Mobile-Satellite Systems, Report SIR-91U-012, Johns Hopkins University Applied Physics Laboratory, April 1991.

[3-5] C. Loo, "A Statistical Model for a Land Mobile Satellite Link," IEEE Trans.on Vehicular Technology, vol. VT-34, no 3, August 1985.

[3-6] V. Erceg et al., "An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments", IEEE Journal on Selected Areas in Communications, Vol. 17, No. 7, July 1999.

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4. LightSquared Proposed Alternative to Resolve Incompatibilities

In attempting to address the identified performance compatibility issues using FAA's propagation model, LightSquared has proposed several mitigation measures. At this time the FAA has not expanded the compatibility analyses to encompass these LightSquared proposed mitigation measures.

On 13 December, 2011 LightSquared proposed that:

- LightSquared modify their ATCt transmit power to address these issues in certain areas-to preserve the navigation capabilities for NextGen- (the proposal provided a 'guaranteed' limit on ATCt 'power-in-the-air') based on propagation models which would have to be developed and agreed by the FAA.
- The FAA accept some reduced capability for fixed-wing aircraft using TAWS, and a reduced capability for GPS as an aid to navigation in visual conditions.
- The FAA revise the avionics specifications for helicopters (navigation and TAWS), and require a transition for existing installations.
- LightSquared might fund the testing, and replacement if necessary, of existing equipment in helicopters to this 'modified' standard that would need to be defined and accepted by both the aviation industry and the FAA. Fixed wing aircraft who wish to retain GPS capability at low altitudes could upgrade to the revised standard as well, however LightSquared has not offered to fund any equipment transition for fixed-wing aircraft.

After the FAA informed LightSquared that helicopter safety and operations must be assured, on 18 December, 2011 LightSquared provided another proposal to more closely align their 'power-in-air' commitment to the coverage defined in this Report[12]. Outside of these exclusion zones LightSquared's aggregate ATCt signal would never exceed -34.1 dBm. In addition, LightSquared committed to work with the FAA to develop a methodology acceptable to the FAA and FCC, including ongoing audits by independent third parties at LightSquared's expense, to ensure that the limits are met.

While this approach has not been extensively studied, certain concerns are immediately evident:

- As noted by LightSquared in their proposal, this exclusion zone does *not* match current FAA operations. This proposal introduces a significant number of exclusion areas (e.g. see Section 3.5) and correspondingly would cause greater operational impacts and compromise safety. To ensure aviation operators are aware of the exclusion zones where they should expect to lose GPS function, all LightSquared antennas would need to be tracked in aircraft databases. Equipment constraints preclude the addition of LightSquared location data in some fielded

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[12] LightSquared's proposal assumed that the FAA's definition of exclusion zones applied to towers of all heights, but was subsequently informed by the FAA that these zones only applied to towers which are 100 feet or greater in height AGL.

units. For those units where such inclusion could be physically accommodated however, database updates would be required every time any change is made to the LightSquared network.

- Since the FAA and LightSquared have not identified a general propagation model suitable for all facets of the necessary analysis, it is then not possible to agree on the aggregate LightSquared signal interference levels. LightSquared's proposed use of Free Space Path Loss is not acceptable for the envisioned scenarios and, as a result, the postulated LightSquared power levels (e.g., 51.5 dBm EIRP) are likely to significantly exceed the FAA required RFI protection criteria.
- Implementation of the most recent LightSquared proposal would still require an extensive site-by-site analysis, taking into account local topology, building/obstruction morphology, aircraft operations, and LightSquared ATCt deployment. Any future changes, e.g., new runway or area navigation approach or new LightSquared tower, would then require revisiting the analysis and potentially require changes to LightSquared's operating parameters for the ATCt sites in the area of impacted aviation operations. These activities would inherently become an open-ended compliance process issue with no definable end-date.
- LightSquared proposed that compliance with the power restrictions be monitored by an "independent third party" at LightSquared's expense. Further information on details associated with this approach – including implementation of necessary FAA authority to certify and oversee/audit the third parties processes and compliance with those processes – is required before any determination can be made with respect to its acceptability.

5. LightSquared Perspective

As noted above, this Report represents the FAA views on the progress and outcome of the joint analysis. In the interest of transparency, LightSquared was provided with draft copies of the Report and asked for their reaction. Due the length of their response it is incorporated, in its entirety and unedited (aside from some re-numbering to account for its new placement) comments. While LightSquared objected to the FAA suspension of further analyses of its proposal in order to prepare this Report, LightSquared has provided detailed comments. The details of LightSquared's analyses, including a critique of the FAA propagation models, proposals for alternative models, and simulation results using such models, are in Appendix C. It must be stressed that the views in that Appendix are those of LightSquared and its contractors, and are not necessarily shared by the FAA.

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6. Summary and Conclusions

The FAA and LightSquared cooperatively evaluated the compatibility of the planned LightSquared ancillary terrestrial component (ATCt) network with a signal broadcast limited to the 1526-1536 MHz band, with certified aviation receivers, based on the specified requirements for aviation. The FAA and LightSquared did not agree on the conclusions of the study.

The analysis concluded that the stated LightSquared ATCt deployment per LightSquared inputs, modeled based upon inputs provided by LightSquared through early December 2011 (62 dBm EIRP, Sprint tower locations, 2 degree antenna down tilt, etc), and the FAA-specified requirements are *not* compatible.

Given this result, there are few alternatives. Either LightSquared must significantly change their operating conditions (e.g., transmit power, antenna deployment, antenna down tilt, etc) or the FAA must change the avionics specifications and all GPS-equipped aircraft re-equip, or both.

It must be emphasized that the full extent of the LightSquared incompatibility with aviation safety-critical operations and systems (either in terms of interference power or area of impact) has not been determined due to a number of remaining issues in the analysis methodology, including the lack of an agreed upon propagation model to determine aggregate interference levels from the LightSquared network, the need for site-by-site analysis, and the lack of a feasible and affordable means to implement FAA aviation regulatory management/enforcement mechanisms. When using even the most optimistic propagation models, the safety of low-altitude operations (below 300’ above ground level, or AGL) in the vicinity of LightSquared ATCt transmitters *cannot* be assured. Comprehensive modeling shows that interference could occur at or below 1800’ AGL or higher, including on terminal area approach operations. The compatibility situation improves as the aircraft altitude increases so that at higher altitudes the interference is expected to be acceptable using any of the propagation models discussed.

The exact characterization of the LightSquared interference is not currently available due to the complexity of the propagation environment and several remaining open issues concerning how to complete the analysis. These open issues include:

- Coming to agreement on a set of propagation models suitable for analysis of the various aeronautical scenarios including addressing:
    - Lack of available data to address the propagation issues for aircraft, including the extent of signals which have direct line-of-sight, the effects of topography and building structures in generating signal reflections, and translating that into a likelihood of experiencing a given aggregate interference level.
    - Development of a model that enables assessment at all altitudes. For most operations of interest the path loss model must be tailored to the propagation environment requiring site-by-site engineering (e. g. , some sites have clear line of sight while others have many reflecting surfaces)

  - Further review and validation of the propagation channel fading model

- Determining whether the aeronautical CW interference mask is an adequate bound to the RFI effect of the agreed propagation channel characterization for the 10 MHz LightSquared signal as multiple independent flat-fading signals;
- Decomposition of the 10^{-6} per hour requirement into a per-event probability;
- Further revision of the TAWS and HTAWS evaluation surfaces in coordination with aviation industry;
- Site-by-site evaluation of areas of aircraft operations and the effect of LightSquared interference on those local operations; and
- Addressing impacts of LightSquared handset use on the aggregate interference environment, and perhaps the inadvertent operation of LightSquared handsets onboard aircraft.

As noted in Section 4, LightSquared has made several proposals on how it could modify the LightSquared system, or how the FAA could change receiver requirements and accept some operational impacts that LightSquared perceives to be minor. These proposals cannot be completely evaluated until the open issues for the modeling are addressed. Certain aspects of the proposals, such as accepting operational impacts or changing receiver requirements, are not supported by the FAA due to the operational, cost and schedule implications. Importantly, pending further study, it is clear that the TAWS/HTAWS issue cannot be resolved without reducing current levels of safety or requiring fleet-wide re-equipage prior to LightSquared network operation.

Given the expected high resource requirements which would accrue if the above issues were pursued further, the FAA seeks guidance from NTIA and the FCC prior to initiation of any further study activities. It is inappropriate to consider a reduction in safety-critical GPS based functionality including fixed-wing TAWS and aids to visual navigation and decreased helicopter TAWS functionality. Additionally, the FAA does not consider the LightSquared ‘power-in-air’ proposals as viable from the perspective of regulatory oversight and continued maintenance. A change to receiver standards – though untested – could be feasible for all aviation receivers, but would take more than 10 years to design, standardize, implement and field, and would result in significant cost to the United States Government and to current GPS aviation users.

Appendix A. Areas of GPS Aviation Operations

A.1 Purpose

This Appendix identifies areas where the continuity of GPS and GPS / WAAS services are essential to safe and efficient national airspace system (NAS) operations for both fixed wing airplane and rotorcraft (helicopter) aircraft[13] operations. This Appendix is not intended to address non-certified aircraft GPS device use nor high-precision and GPS timing use within the NAS infrastructure. Additionally, this Appendix does not consider the use of GPS in unmanned aircraft systems (UAS), many of which are dependent upon GPS for both navigation and the accomplishment of mission functions. Many UAS operations occur below 500' AGL to avoid interaction with airplane traffic above that altitude.

A.2 Overview

Certified GPS receivers support three main functions: navigation, surveillance (ADS-B) and terrain awareness and warning systems (TAWS).

A.3 Fixed Wing and Helicopter Navigation

A.3.1 General Navigation

The navigation function must be provided in all normal aircraft operation areas. 14 CFR 91.119 provides the general framework and minimum altitudes for each operating area. The lowest altitudes are those associated with takeoff and departure, or approach, missed approach and landing operations to any airport, heliport or seaport. Outside of the terminal area surrounding an airport, aircraft operate at or above the altitudes shown in Table A-1.

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[13] If a power unit fails, a pilot must be able to execute an emergency landing without undue hazard to persons or property on the surface. In addition, pilots must comply with any altitudes specifically prescribed for helicopters (generally the maximum altitude is prescribed).

Table A-1. Allowable Minimum Altitudes (Reference Part 91.119)

Type Aircraft	Over Water or Sparsely Populated	Other than Congested	Congested Area
Fixed wing	Surface, but no closer than 500' to any person, vessel, vehicle, or structure	500' above the Surface	1000' above highest obstacle within horizontal radius of 2,000'
Helicopter	Surface, operate without hazard and clear of clouds*	Surface, operate without hazard and clear of clouds*	Surface, operate without hazard and clear of clouds*

Fixed wing aircraft must maintain height and lateral clearance consistent with the area designation and CFR 91.119. There is no official FAA definition of “sparsely populated”, “other than congested,” or “congested.” A pilot is required to be able to make an emergency landing without injury or damage to persons or property. This means that in sparsely populated areas, or over water, it is legal to fly as low as you want so long as you can make a safe landing. Fixed wing pilots are also required to maintain 500' from any person, vessel, vehicle, or structure. However, helicopter pilots do not have any lateral object displacement requirement and in practice are only limited by pilot judgment and established noise abatement procedures or techniques.

Fixed wing aircraft operating IFR maintain wings level on departure until 400' AGL, but use 30 degrees bank for circling maneuvers. At higher altitudes, fixed wing bank angles are normally up to 25 degrees (~standard rate) except when small corrections are needed, and then 15 degrees is typically the maximum. General aviation VFR bank angles are typically up to 30 degrees. Crosswind landing/takeoff requirements and techniques vary by aircraft and operator, but a pitch up of 6 degrees and bank of up to 15 degrees is typical for maximum crosswind conditions.

A.3.2 Airspace Classifications and Helicopter Weather Minimums

Figure A-1 depicts the various categories of airspace in the U. S. NAS and the accompanying text identifies aircraft operations at minimum altitudes.

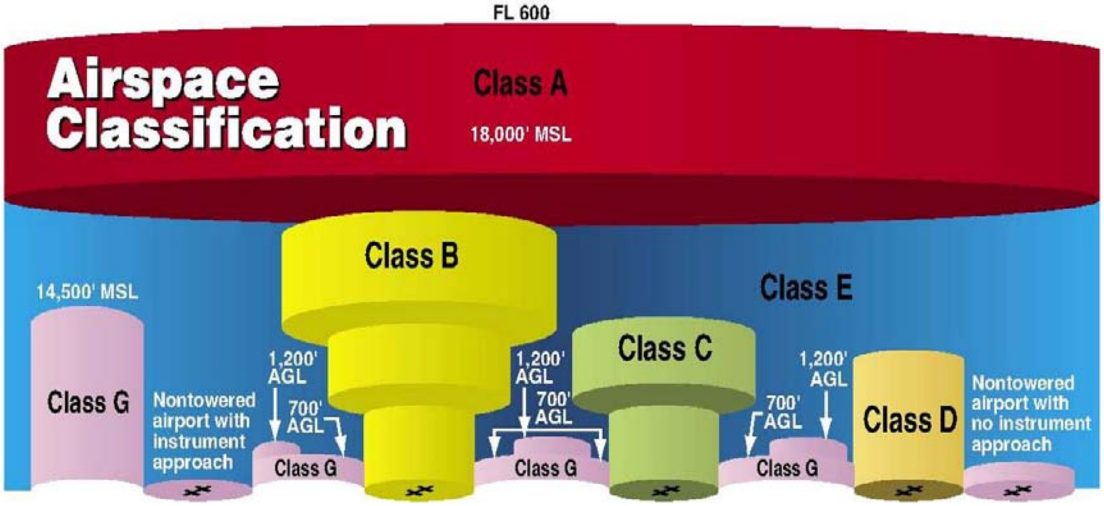


Figure A-1. Airspace Classifications

Class G Operations: Aircraft (especially helicopter) VFR operations are often conducted in Class G (uncontrolled) airspace as well as Class B, C, D, and E surface area controlled airspace. Class G airspace generally exists everywhere there is not a towered airport, Class E or restricted airspace. There are no entry or clearance requirements for Class G airspace, even for IFR operations. ATC has no authority or responsibility to control air traffic in Class G airspace. Class G uncontrolled airspace operations are conducted at either 1200' and below (to the surface), 700' and below, or as charted and at lower maximum altitudes when required by ATC.

Class B, C, and D Operations: Aircraft can operate in Class B, C or D airspace under visual flight rules (VFR) or special VFR (SVFR). Aircraft cleared by ATC to operate under SVFR are required to maintain specified at or below altitudes. ATC-prescribed maximum operating altitudes can be as low as 100' AGL. For example, the Carney heliport (near Teterboro International Airport) must be accessed below 300' MSL (~100' AGL) to avoid Teterboro traffic.

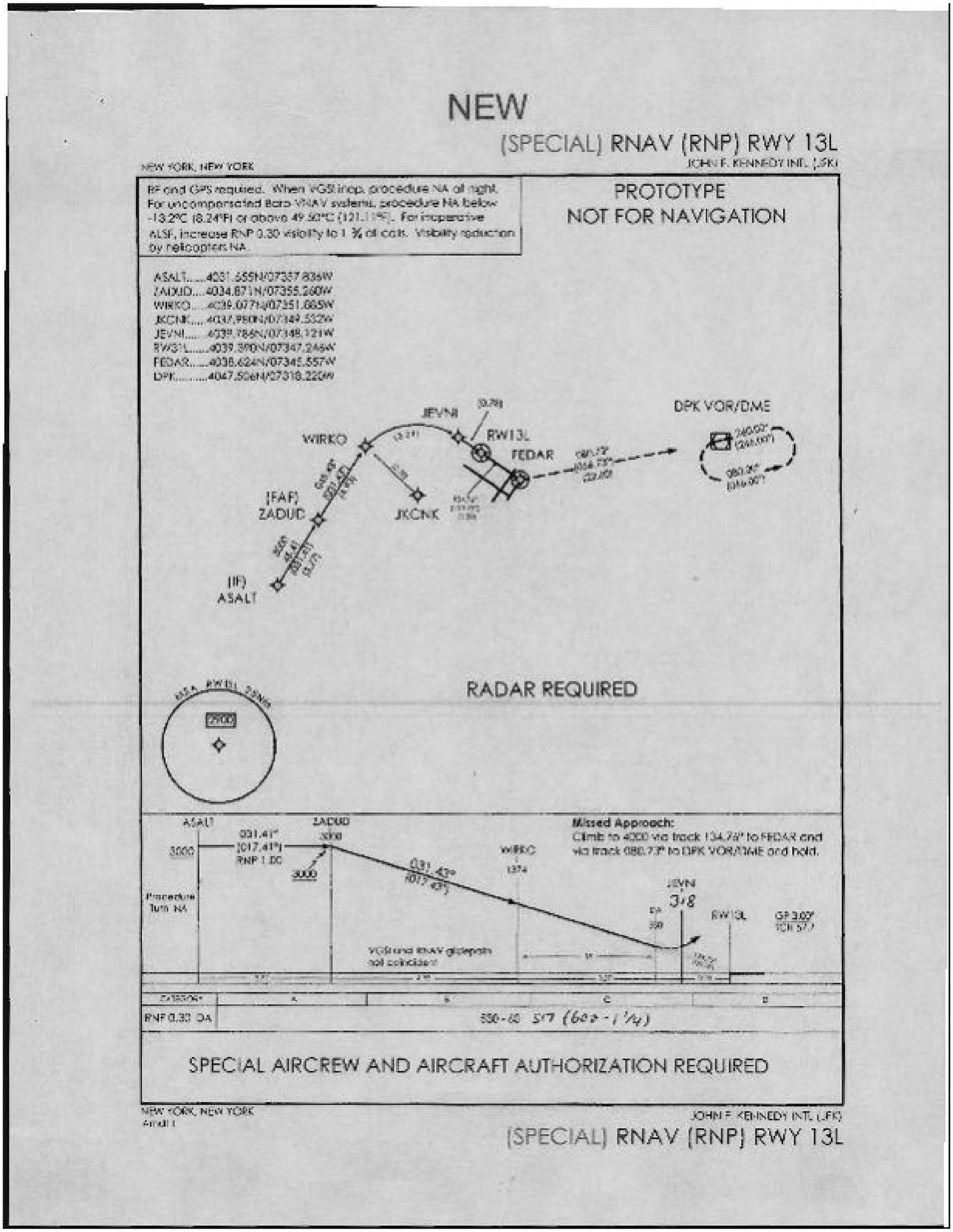
Class E Operations: The lowest tier layer of Class B and C airspace is often lower than the upper ceiling of Class G airspace (e. g. 500' AGL). Operations in Class E airspace under Class B and C layered controlled airspace are forced to lower and lower altitudes to maintain clearance from controlled airspace and IFR traffic (e.g., below 500' surrounding Newark Liberty International and below 900’ and 1500' in Manhattan). Aircraft operate VFR or SVFR below the terminal area IFR traffic.

A.3.3 Fixed-wing (and Helicopter) IFR and VFR Terminal Aircraft Operations

GPS is required throughout the terminal area for standard instrument procedures including arrival and departure procedures, non-precision approach, precision approach, and missed approach and helicopter PinS operations. IFR terminal area maneuvering not associated with a standard instrument procedure is normally conducted at or above 1000' AGL. Obstacle clearance surfaces (OSC), with slopes of 20:1, 34:1 and 40:1 and points of origin at, or near, the runway threshold or fictitious threshold point (FTP), are used to determine appropriate minimum altitudes for various phases of flight. A 40:1 surface (without obstacles) supports the lowest maneuvering altitudes. The 40:1 surface extends from all runway ends to 10,000' laterally (20:1 surface to 5,000' for heliports). Circling operations are conducted as low as 350' (with 300' obstacle clearance height) within 1.3 nautical miles from all runway ends to 550' within 4.5 nautical miles from all runway ends depending upon the approach speed category of the aircraft.

GPS-based Performance-Based Navigation (PBN) procedures include both area navigation procedures (i.e., RNAV (GPS)) and required navigation performance RNAV (RNP) procedures.

For the purposes of this study, the aircraft position should be assumed to be anywhere within the obstacle clearance surfaces defined for each type of procedure. These surfaces are defined in various FAA Orders, such as Order 8260.54 (for RNAV (GPS)) and Order 8260.52 (for RNAV (RNP)). As examples, Figure A-2 and Figure A-3 depict the RNAV (RNP) Runway 13 Left approach procedure and aircraft containment for John F. Kennedy International Airport, and Figure A-4 and depict the RNAV (RNP) Runway 19 approach at Ronald Reagan National Airport.



NEW

(SPECIAL) RNAV (RNP) RWY 13L

NEW YORK, NEW YORK

JOHN F. KENNEDY INTL (JFK)

RF and GPS required. When VGSI inop, procedure NA at night. For uncompensated Baro-VNAV systems, procedure NA below -13.2°C (8.24°F) or above 49.50°C (121.1°F). For inoperative ALSF, increase RNP 0.30 visibility to 1 ¾ all cats. Visibility reduction by helicopters NA.

PROTOTYPE
NOT FOR NAVIGATION

ASALT	4031.655N/07357.836W
ZADUD	4034.871N/07355.260W
WIRKO	4039.077N/07351.665W
JKCNK	4037.950N/07349.532W
JEVNI	4039.786N/07348.121W
RW31L	4039.390N/07347.246W
FEDAR	4038.624N/07345.557W
DPK	4047.506N/07318.220W

RADAR REQUIRED

Missed Approach:
Climb to 4000 via track 134.78° to FEDAR and via track 080.73° to DPK VOR/DME and hold.

CATEGORY	A	B	C	D
RNP 0.30 DA	550-60 517 (600-1 ¼)			

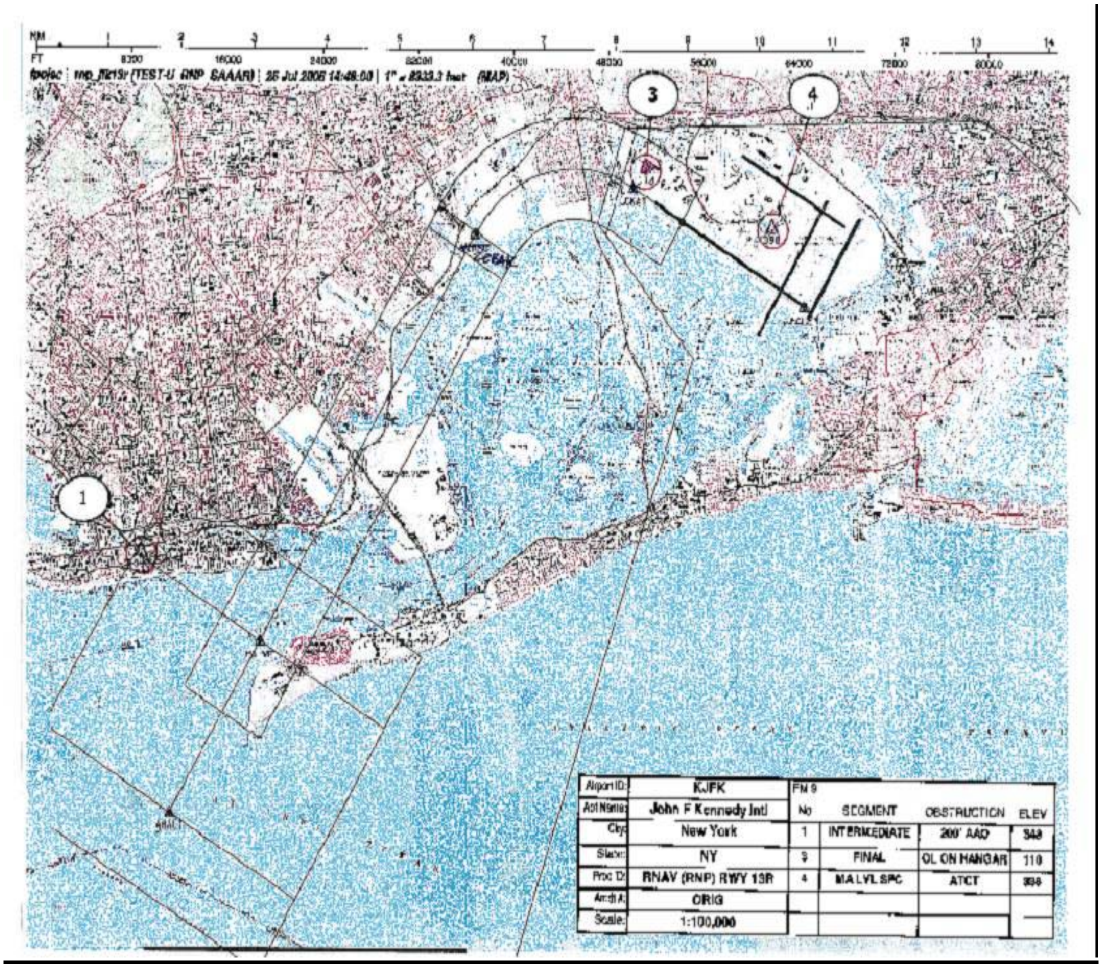
SPECIAL AIRCREW AND AIRCRAFT AUTHORIZATION REQUIRED

NEW YORK, NEW YORK

JOHN F. KENNEDY INTL (JFK)

(SPECIAL) RNAV (RNP) RWY 13L

Figure A-2. RNAV (RNP) RWY 13L John F. Kennedy International Airport



Airport ID:	KJFK	FM 9			
Arpt Name:	John F Kennedy Intl	No	SEGMENT	OBSTRUCTION	ELEV
City:	New York	1	INTERMEDIATE	200' AAO	348
State:	NY	3	FINAL	OL ON HANGAR	110
Proc ID:	RNAV (RNP) RWY 13R	4	MA LVL SPC	ATCT	334
Amdt #:	ORIG				
Scale:	1:100,000				

Figure A-3. RNAV (RNP) RWY 13L John F. Kennedy International Airport

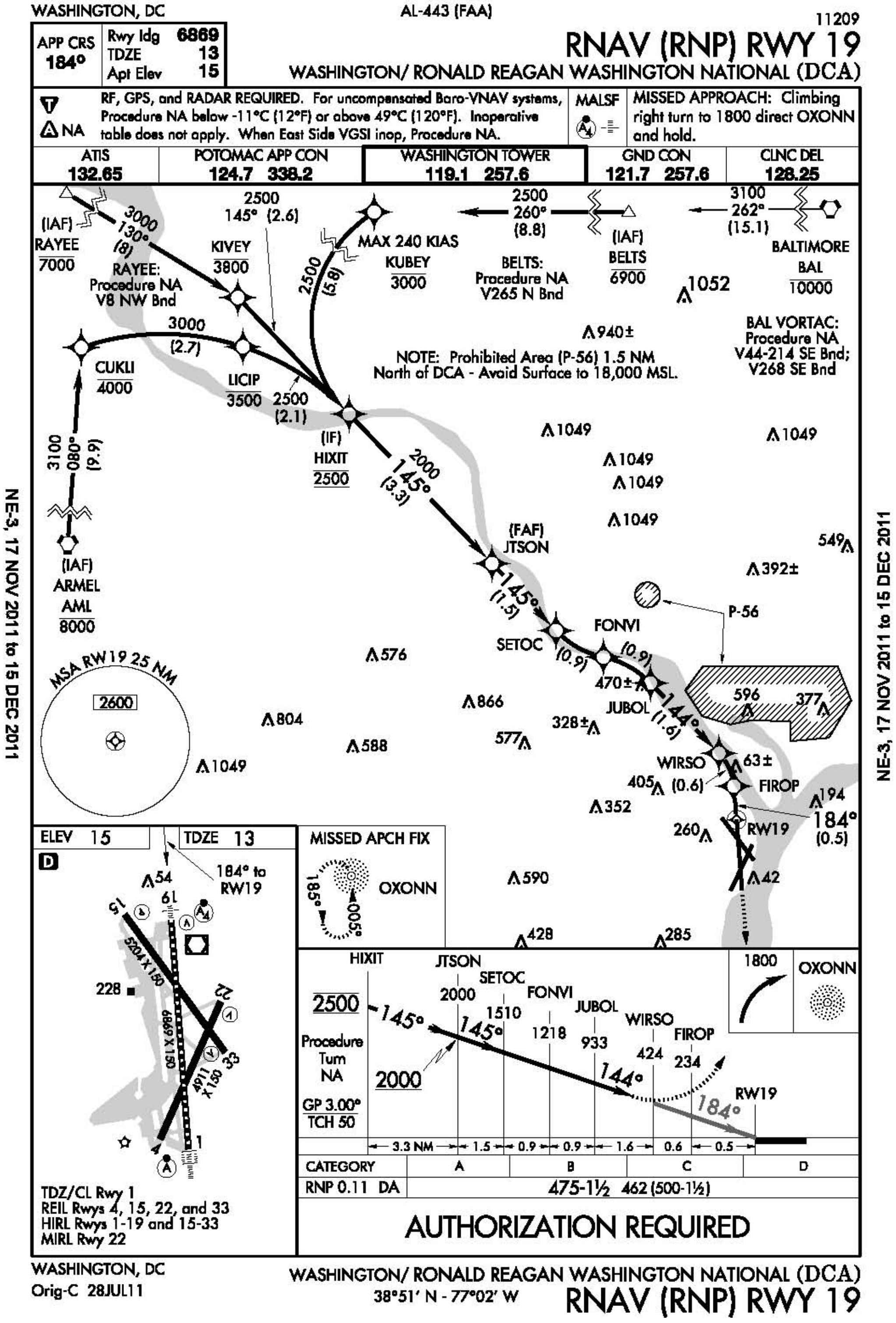


Figure A-4. RNAV (RNP) RWY 19 Ronald Reagan Washington National Airport

Figure A-5. RNAV (RNP) RWY 19 Ronald Reagan Washington National Airport

Aircraft can be expected to descend to lower altitudes than vertically guided approach procedures. For example, non-precision approach procedures allow the aircraft operator to descend to the minimum descent altitude (MDA) immediately after the Final Approach Fix (FAF). The MDA can be as low as 250' AGL in the final approach segment, which can extend up to 10 miles from the airfield. Arrival and departure procedures can include extended flight at lower altitudes for traffic de-confliction with other airfields and due to restricted or prohibited airspace requirements.

A.3.4 Helicopter-Specific Operations

Helicopters operate in widely diverse environments, often with a significant low-altitude en route phase of flight. Helicopters routinely operate below the top of adjacent man-made and natural objects (buildings, towers, trees, etc.) or terrain (hills, ridgelines etc.) While they generally operate above 100' AGL, they can and do operate at lower altitudes. Low level operations are routinely conducted in dense urban areas. A representative RF Interference analysis exemption area is shown in the Figure A-6 *GPS Exclusion Area for LightSquared ATCt Emissions* for representative helicopter operations. For example, in the New York City area there are an estimated 60,000 operations below 900' en route to 3 Manhattan heliports, 1 Seaport, 37 registered heliports and numerous unregistered heliports in the general area, in addition to EMS and other on-scene operations at unimproved and unplanned landing zones.[14] New York is unique in that the EMS facilities on Manhattan Island do not have heliports. However, patients are routinely flown from the city to EMS facilities with heliports in the areas surrounding Manhattan Island.

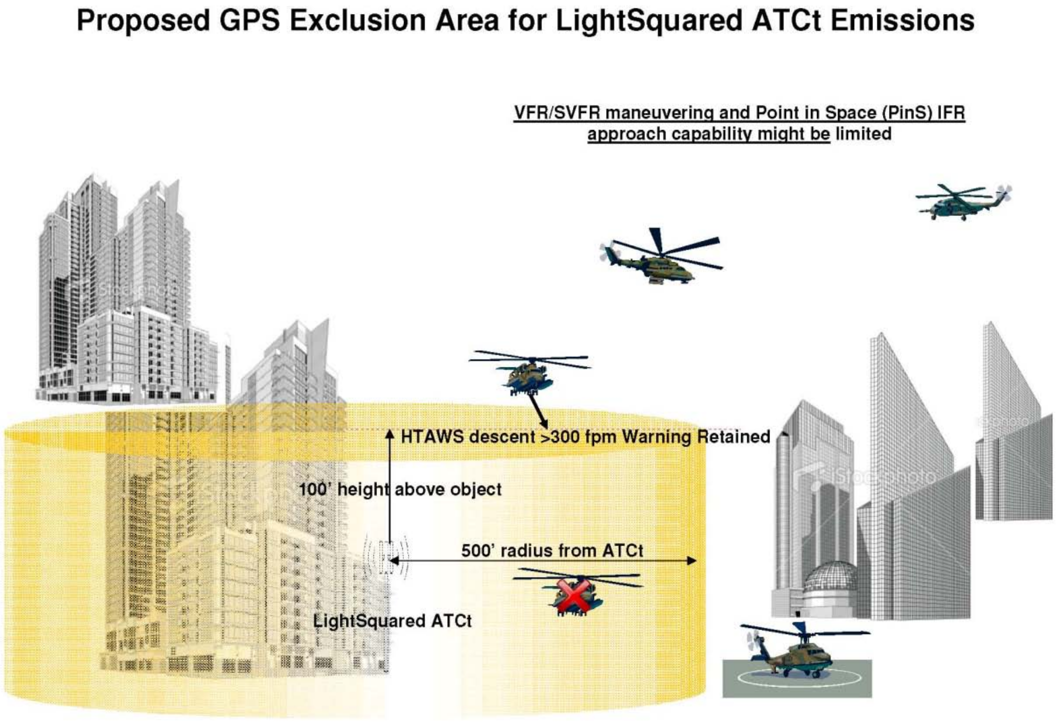


Figure A-6. GPS Exclusion Area for LightSquared ATCt Emissions

A.3.4.1 Point-in-Space (PinS) Approaches

PinS approaches are designed specifically for helicopter use. These approaches are conducted under IFR to VFR heliports. These approaches can be public procedures to a point in space or “Special” procedures to a specific VFR heliport that requires pilot training due to its unique characteristics. These approaches are predicated upon RNAV using GPS and wide area augmentation system (WAAS). RNAV using the WAAS provides the lowest possible approach minimums and narrower obstacle clearance widths. A majority of the special procedures to a specific VFR heliport are developed in support of HEMS operators and include a “Proceed Visually” segment between the MAP and the heliport.

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[14] Estimate provided by Eastern Region Helicopter Council http://www.erhc.org/

The approach scenario for a PinS Localizer Performance with Vertical Guidance (LPV) approach incorporates a vertically-guided instrument approach to a point in space with a decision altitude (DA) as low as 200', then the pilot proceeds visually at 200' (or lower) to the heliport. The “Proceed Visually” segment is designed to start at any azimuth and an optimum length of 0.65 nautical miles from the heliport to support the lowest and most effective access to the heliport. An example of a PinS LPV procedure is depicted in Figure A-7. This procedure has a decision altitude corresponding to 273' above the heliport and a visibility requirement of ¾ statute miles. The availability of these procedures significantly enhances safety.

The MAP can also be greater than 1 nautical mile from the heliport; however, for that procedure, the pilot must proceed under VFR to the heliport. For example, Figure A-8 shows an RNAV non precision approach GPS PinS procedure from John F. Kennedy International airport with descent to 500' after “WERIN” final approach fix (FAF) followed by extended VFR segments at 500' (up to 11. 8 NM from “HELOG” MAP to each of the 3 Manhattan heliports.

There are currently hundreds of PinS approaches. Now that WAAS and HTAWS have been certified and recently become standard equipage for HEMS and other applications, the expectation is that PinS approaches will provide access to many emergency facilities with RNAV route structures connecting outlying facilities. With up to 7,000 registered heliports and estimates of up to 2,000 unregistered heliports in use, the total number of PinS instrument approach procedures could reasonably end up in the thousands[15]. The vast majority of PinS procedures today are designed using private funding.

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[15] Estimate provided by Eastern Region Helicopter Council http://www.erhc.org/

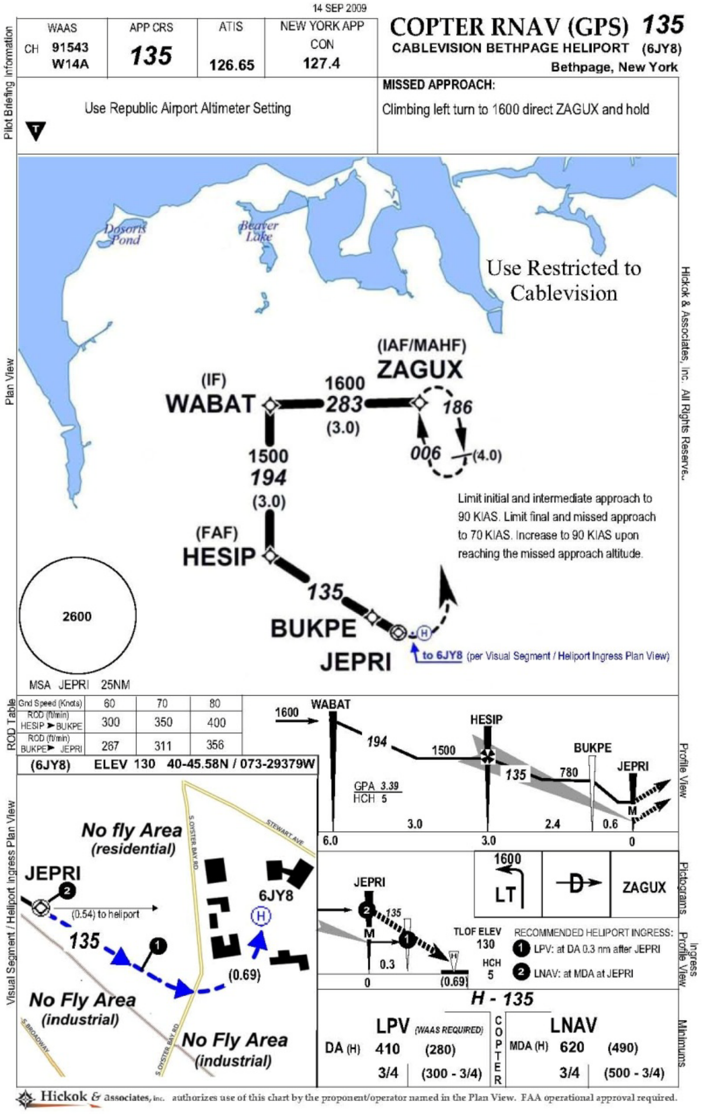

Figure A-7. WAAS PinS LPV Approach[16]

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[16] Approach Plate provided as an PinS example courtesy of Cablevision Systems Corporation

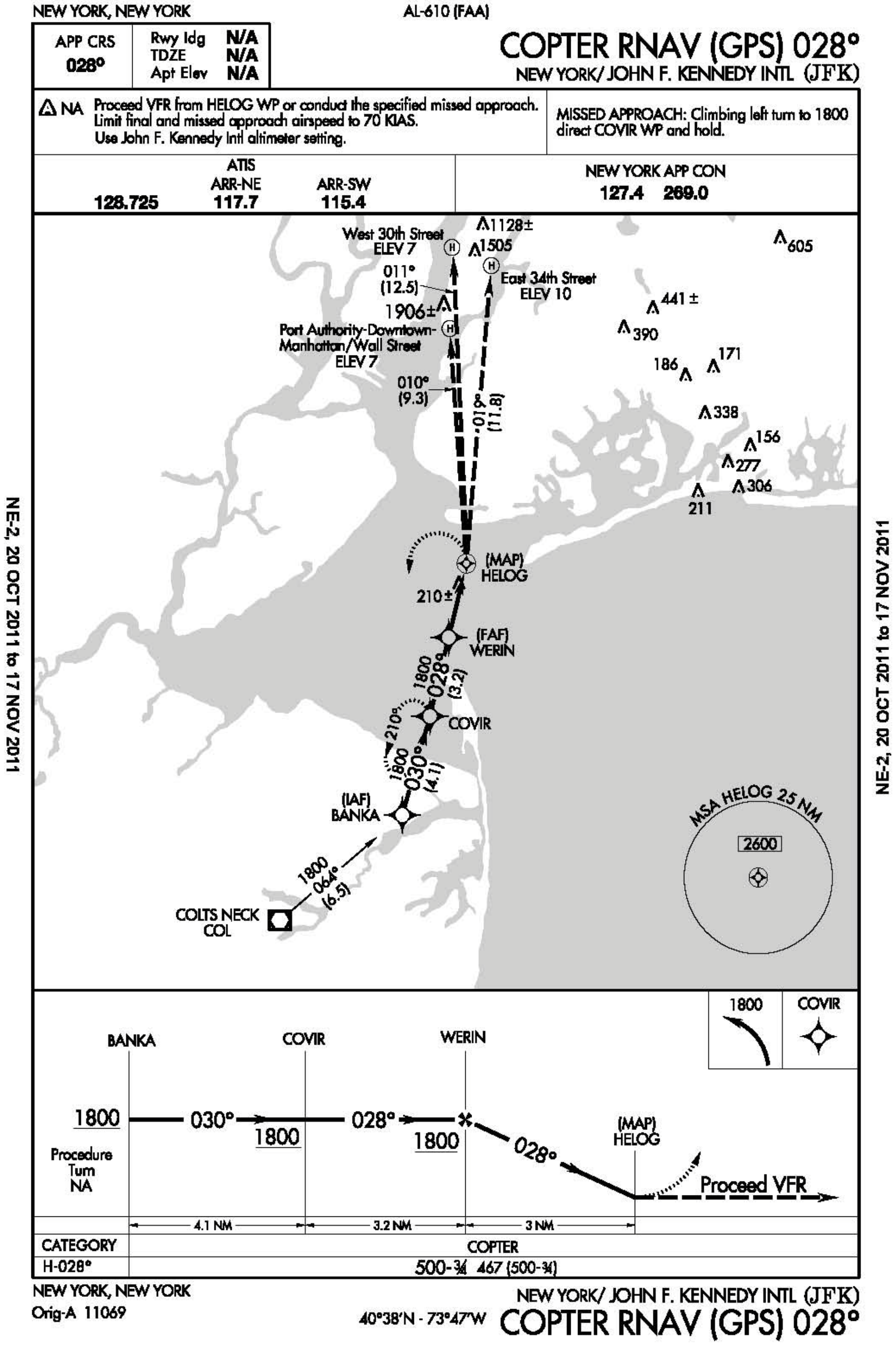

Figure A-8. Copter RNAV (GPS) 028 Non-Precision Approach to JFK

A.3.4.2 Helicopter VFR Charts

Ten NAS areas include helicopter specific VFR charts. An example is presented in Figure A-9. These helicopter VFR charts include helicopter routes (flyways and corridors) both in controlled and uncontrolled airspace. These routes are intended to facilitate transitions around, under and through complex areas such as Class B airspace to help pilots operating under VFR avoid major controlled traffic flows. These routes are not intended to discourage pilot requests to ATC for operations off of the published VFR routes (e. g. point-to-point direct, other than through restricted airspace).

VFR flyway routes do not have a minimum altitude. For example, Washington, DC VFR Route 1 () Figure A-9 is restricted to operations at or below 200' MSL from the Memorial Bridge to Hains Point to the 11th Street Bridge, as does the route to the heliport at the Navy Annex / Pentagon. The normal flight path altitude is lower than the surrounding terrain, buildings and towers along the Potomac River and parkland. VFR “corridors” unlike VFR Flyways provide a "hole" through Class B airspace with lateral bounds and both minimum and maximum altitudes.

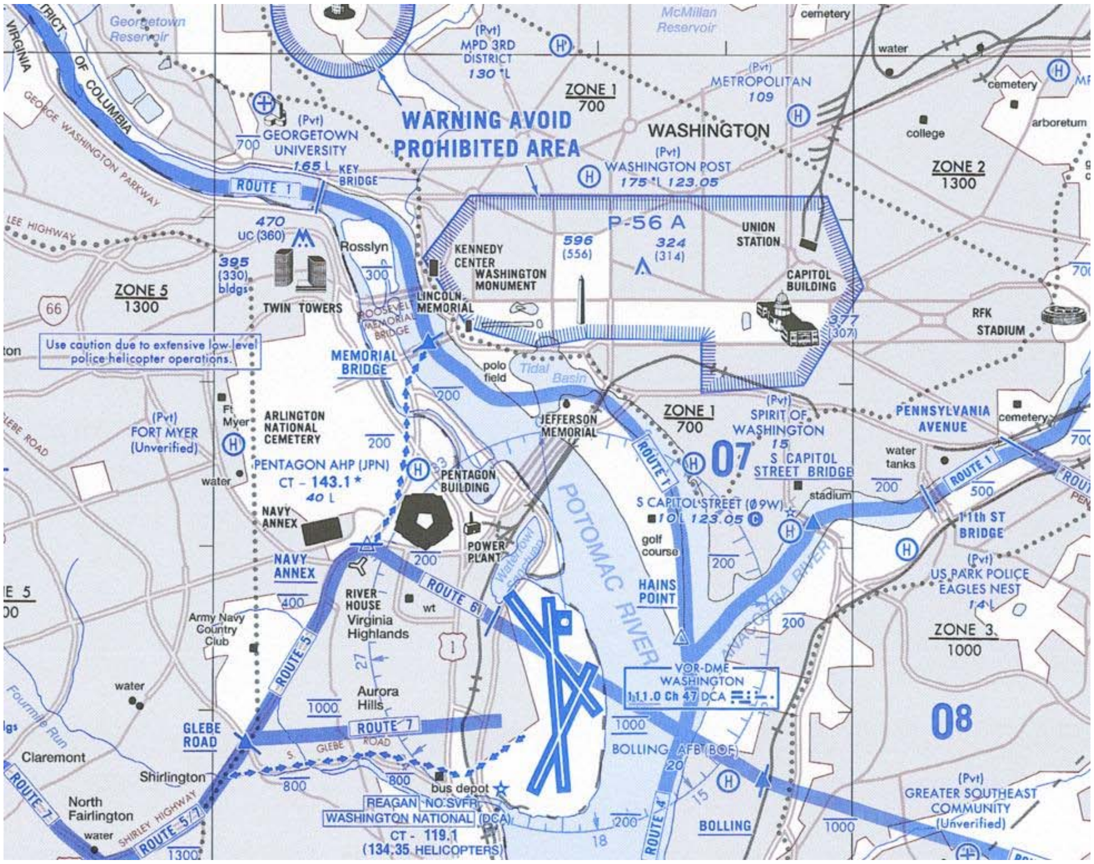

Figure A-9. Washington, DC VFR Helicopter

A.3.4.3 Helicopter Emergency Medical Services (HEMS) / Air Ambulance operations

HEMS operations are conducted in a demanding environment. They provide an invaluable service to the public by providing crucial, safe, and efficient transportation of critically ill and injured patients to medical care facilities. Helicopter air ambulance operations are unique due to the urgent nature of the flight. The FAA, operators, and the medical community all play a vital role in promoting a safety culture that ensures the safety of passengers, flight crews, and medical professionals in the execution of these critical operations. Since the mid 1990s, the helicopter air ambulance industry has grown by nearly 300 percent (54 percent between 2003 and 2008). In the United States, there are currently 74 certificated entities conducting helicopter air ambulance operations using approximately 929 helicopters from 764 base locations.[17]

HEMS / helicopter air ambulances are typically used for the transport of patients from the scene of an injury or accident directly to a hospital, and for flights between smaller hospitals and trauma centers or specialty hospitals (e. g., burn or cardiac centers). The National Transportation Safety Board (NTSB) estimates that 400,000 patients and transplant organs are transported by helicopter each year. If GPS continuity is not assured some of these low-altitude helicopter operations scenarios would need to revert to VFR-only, map-in-hand operations and the hub and spoke operations could be delayed or cancelled without the benefit of GPS.

Figure A-10 shows example facilities in Pittsburg with surrounding terrain (See References [3-4, 3-1]). Figure A-11 shows the U. S. population centers served by HEMS.

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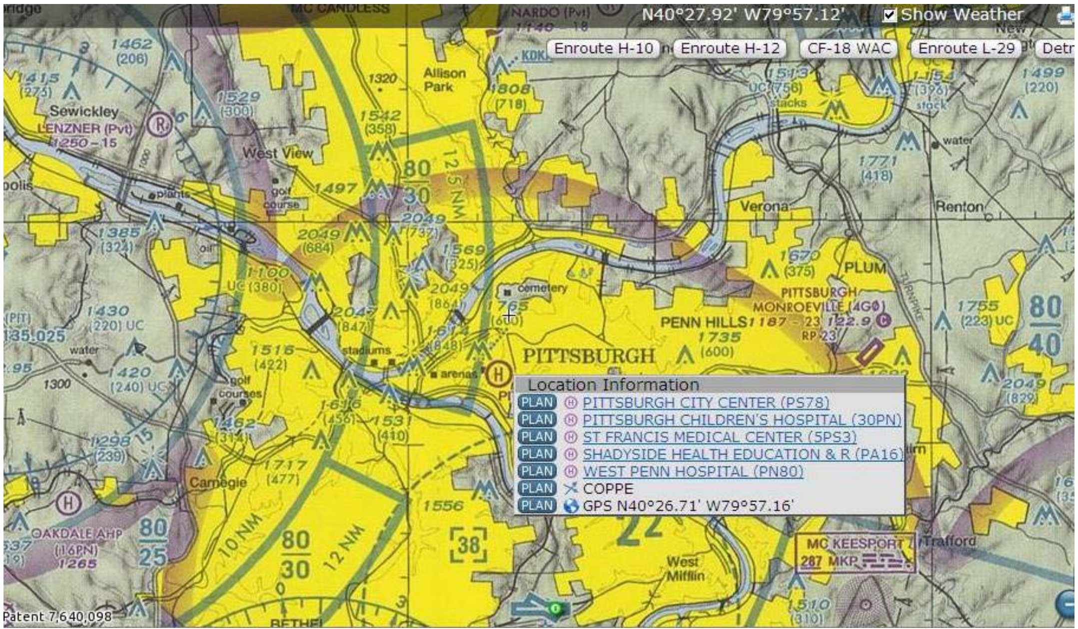
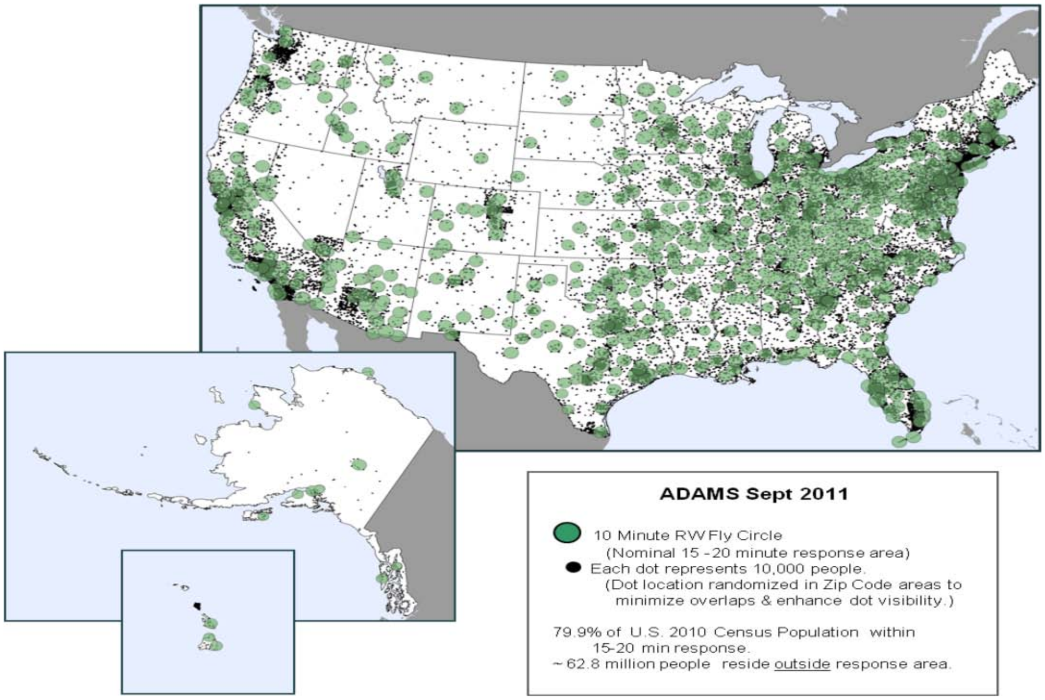
[17] Atlas & database of air medical services (ADAMS),. Available at: http://www.adamsairmed.org/. Accessed November 15, 2011.



Location Information
PLAN PITTSBURGH CITY CENTER (PS78)
PLAN PITTSBURGH CHILDREN'S HOSPITAL (30PN)
PLAN ST FRANCIS MEDICAL CENTER (5PS3)
PLAN SHADYSIDE HEALTH EDUCATION & R (PA16)
PLAN WEST PENN HOSPITAL (PN80)
PLAN COPPE
PLAN GPS N40°26.71' W79°57.16'

Figure A-10. Pittsburg Children’s Hospital and other HEMS facilities[18]



ADAMS Sept 2011

● 10 Minute RW Fly Circle
(Nominal 15 - 20 minute response area)
● Each dot represents 10,000 people.
(Dot location randomized in Zip Code areas to minimize overlaps & enhance dot visibility.)

79.9% of U.S. 2010 Census Population within 15-20 min response.
~ 62.8 million people reside outside response area.

Figure A-11 Population Density Map with 10 Min. Fly Circles around Rotor Wing Base Locations[19]

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[18] Graphic used with permission of Skyvector ® copyright © 2012, www.skyvector.com

[19] Graphic used with permission of Center for Transportation Injury Research, CUBRC ®http://www.adamsairmed.org/."

Public aircraft operation (e.g., law enforcement, forestry, military, etc.) are not required to comply with commercial operational requirements and can operate under Part 91 rules.

For expediency, HEMS flights are planned and conducted as direct operations from departure to destination based upon dispatch-provided E911[20] or other latitude and longitude coordinates. Commercial HEMS operations are more restrictive than Part 91 and must comply with FAA Part 135 HEMS Commercial Operations Specifications A021, dated 11/14/2008. Prior to each flight, the pilot in command must identify and document the highest obstacle along the planned route of flight. The flight can be broken into segments to achieve required weather minimums where terrain and obstacles permit. To determine the VFR minimum safe altitudes as specified in A021 paragraph i(2) along the direct flight path the pilot must ensure that all terrain and obstacles along the route of flight, except for takeoff and landing, are cleared vertically by no less than 300' for day and 500' for night operations. AO21 is available at: http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs200/branches/afs250/media/OpSpecA021. pdf .

CFR 135.203 VFR: Minimum altitudes, paragraph b, is less limiting and only requires on-demand, commercial helicopter operators (other than HEMS) to maintain 300' above the surface over a congested area.

Many helicopter air ambulance operators use night vision goggles (NVGs) / Night Vision Imagining System (NVIS) and HTAWS to enhance safety and permit HEMS operations with reduced required weather minimums.

A.3.4.4 Law Enforcement and Military Training

Police departments have improved their ability to fight crime and maintain public safety through advancements in helicopter and onboard equipment capabilities. Helicopters assist police activities by providing a presence in the air. From this unique vantage point, helicopter pilots (or observers) can monitor criminal and emergency activities. Helicopters allow law enforcement to remain in close proximity to suspects while tracking their location and direction of movement without being noticed, officers in trouble can be supported with a necessary show of force, and persons in distress can be rapidly located, monitored, assisted and if necessary evacuated. The versatility, range, and vantage point of the helicopter allows ground officers to conduct pursuits more successfully, decreasing the use of high-speed pursuits and increasing apprehension rates. Similar to HEMS/air ambulance, law enforcement operations can routinely require on-scene operations at unimproved and unplanned landing zones.

In military training applications, scout helicopters fly at low level at nap of the earth altitudes to locate enemy locations and map out approaches and ambush positions to be used by attack helicopters. Attack helicopters also maintain low level for defensive

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[20] Note that many E911 locations are determined by general location GPS devices. The performance provided by these devices are outside the scope of this Report.

tactics and only rise from cover briefly to attack the opposing forces and then return to concealed low-level positions.

Law enforcement, emergency responders, military and many other helicopter often perform abrupt maneuvers including steep turns (30 to 45 degrees) and high pitch angles (up to 30 degrees) for both departure and arrival operations in rapid response situations.

A.3.4.5 Diversity of Helicopter Example Low Altitude Helicopter Operational Requirements (Other than HEMS, Law Enforcement, and Military Training)

Helicopters are used extensively in a large number of applications requiring low level flight (other than HEMS/air ambulance, law enforcement and military training) including: agriculture; logging: news reporting; pipeline, power line (and other utilities) surveillance and maintenance; traffic control, VIP transport; etc. The full scope of helicopter operations is highlighted in a video clip at the footnoted reference.[21]

In response to Federal, state and local concerns about traffic-related surveyor injuries and the continuing need for high-quality survey information for our roadways, commercial operators now provide low-altitude (helicopter) photogrammetric mapping to the various Department of Transportation and contractor communities for roadway design projects, including road widening, resurfacing and concrete rehabilitation. Helicopter mapping eliminates the need to close busy travel lanes or place ground survey consultants in the middle of congested, high traffic corridors. The helicopters fly as low as 300' above the highest obstacle in the direct flight path. Using slow speeds and low altitude provide greater detail and more accurate measurements of height and distance. Photogrammetric measurements are routinely field-verified to plus or minus 0.03' to 0.05' for hard surfaces. Similar operations are performed for maintenance of power lines, pipeline surveillance and an increasing number of other applications made practical through helicopters and GPS. At some future point in time, it is envisioned that UAS might replace helicopters for many of these operations.

Helicopter pilots routinely use steeper bank angles (e. g. 25 degrees at 25' and 45 degrees at 200 to 500'). As an example, the helicopter traffic pattern at Falcon airfield (FFZ) in Mesa, AZ is inside the fixed wing traffic pattern and requires approximately 45 degree bank turns to maintain clearance from fixed wing aircraft.

A.3.4.6 Weather Minimums and Importance of GPS for Low Altitude Situational Awareness

In Class G airspace, Part 91 helicopter VFR operations do not have any specified minimum visibility requirements. The VFR (SVFR in Class B airspace) requirement is to remain clear of clouds and operate at a speed that is slow enough to give the pilot an adequate opportunity to see other aircraft or an obstruction in time to avoid a collision.

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[21] Applications Video: http://rotor.com/Default.aspx?TabID=279 .
Link supplied courtesy of Helicopter Association International

In controlled airspace, helicopter pilots can request clearance to operate under IFR or SVFR. A pilot operating under Part 91 IFR may not have any departure visibility requirements other than the basic requirement to attain required minimum speed (V_{mini}) before entering instrument meteorological conditions (IMC). For most helicopters, this requires approximately 1/2 mile and an altitude of 100'. Operations under SVFR also do not have a specified visibility requirement. The pilot is only required to remain “clear of clouds” and operate at a speed that is slow enough to give the pilot an adequate opportunity to see other aircraft or an obstruction in time to avoid a collision. A weather front or radiation fog that may linger all day can create metrological conditions requiring deliberate flight below clouds approaching near ground level. Some pilots refer to these operations as “scud running.” “Scud running” in uncontrolled airspace and SFVR operations in controlled airspace entails operation in minimum flight visibilities. Reduced visibility in these situations presents pilots with four areas of difficulty: aircraft attitude control, navigation, avoiding impact with terrain, and avoiding collision with other aircraft.

The limited geometric perspective of low level flight reduces contrast for night-time operations, and even the visibility constraints and limitation of night vision systems can make it difficult to maintain essential situational awareness and orientation for VFR / SVFR flight.

SAE International is preparing technical standards for enhanced synthetic vision systems (ESVS) for helicopters. These systems are dependent on GPS information (typically from the aircraft navigation system) to provide visual reference cues for helicopter pilots in white out, brown out and other degraded visual environments.

Helicopter pilots depend upon GPS area navigation enabling moving map and 3D synthetic vision displays for VFR operations. When flying at low altitudes, situational awareness to know where you are and where you are going is much more difficult than with higher altitude operations. The perspective is very different and objects and terrain appear to flow by much faster. Additionally, when slant range visibility is limited, visual contrast, movement perception and perception of distances, may be inhibited. Positional disorientation greatly increases the stress of flying. Any increase in stress focuses the pilot’s attention on the problem and decreases the flying capability of the pilot. Pilots do not react as well to visibility limitations, presence of turbulence, or aircraft malfunctions when compounded by the stress of being disoriented. GPS/WAAS provides significant benefits by limiting disorientation and loss of situational awareness, thus aiding pilots in low altitude situations, especially when there are compounding environmental factors.

A.3.4.7 Operations at Prepared Airfields/Heliports

Included in the FAA database are 19,795 "FAA Registered" currently operational facilities. Registration is a voluntary process and many, many VFR heliports have not registered with the FAA.[22] These unregistered heliports include private facilities, but also

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[22] Estimate provided by Eastern Region Helicopter Council http://www.erhc.org/

State and Local facilities that are not receiving Federal grant funds. By some organizations' estimates, as many as one-third of the heliports in some areas are not registered with the FAA. [23]

Airport data is publically assessable at: http://www.faa.gov/airports/airport_safety/airportdata_5010/ (Select data downloads, Airport Facility Data).

Other data available includes limited operations data; however, this data is gathered during irregular inspections and generally is not available for most private facilities. Definitions and other data is available in the NFDC Data dictionary: http://www.faa.gov/airports/airport_safety/airportdata_5010/nfdcfacilitiesdictionary. cfm

A.3.5 Low-level Training Routes/Areas

Congress has charged the Federal Aviation Administration (FAA) to administer and manage the national airspace in the public interest to ensure the safety of all aircraft and the efficient utilization of airspace. Airspace users, rights, rules and responsibilities are complex. Included among these users are military operators that in addition to operating in special use airspace (prohibited areas, restricted areas, military operations areas, etc.) also operate at low-level altitudes on military training routes (MTR) and in low altitude tactical navigation areas (LATN) that within Class E and G national airspace.

National security depends largely on the deterrent effect of our airborne military forces. To be proficient, the military services must train in a wide range of airborne tactics. One phase of this training involves "low level" combat tactics. The required maneuvers and high speeds are such that they may occasionally make the see-and-avoid aspect of VFR flight more difficult without increased vigilance in areas containing such operations. In an effort to ensure the greatest practical level of safety for all flight operations, the Military Training Route (MTR) program was conceived. The MTR program is a joint venture by the FAA and the Department of Defense (DoD). MTRs are mutually developed for use by the military for the purpose of conducting low-altitude, high-speed training[24].

MTRs are low-altitude corridors designed to support realistic training at speeds of more than 250 knots and at altitudes that range from ground level (surface) to 1,500 feet above ground level or higher. There are more than 500 routes, roughly divided in half for VFR and IFR operations (reference Figure A-12). Course widths vary between three NM to 20 NM either side of the reference line as depicted on the sectional and the routes are often 70 to 100 miles long. MTRs often cross highways and even populated areas especially where legacy routes were encroached as cities expanded. Navigation is extremely

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[23] Estimate provided by Eastern Region Helicopter Council http://www.erhc.org/

[24] FAA Airman's Information Manual, Chapter 3: http://www.faa.gov/air_traffic/publications/atpubs/aim/Chap3/aim0305. html

difficult on high-speed low-altitude flights and GPS provides an essential aid to navigation ground collision avoidance[25].

Low Altitude Tactical Navigation Areas (LATN) are large, clearly defined geographical areas wherein the Air Force practices random tactical navigation that typically ranges from surface to 1,500 feet AGL. These areas are not charted. Current information concerning LATNs is available from local Air Force facilities[26].

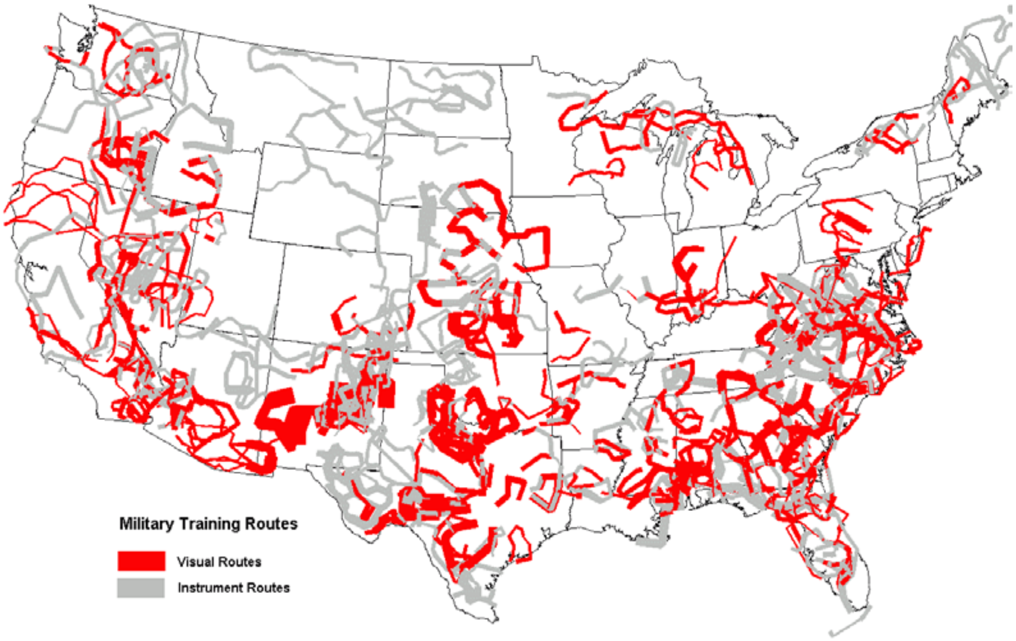

Figure A-12. Military Training Routes[27]

A.4. Surveillance (ADS-B)

The surveillance function must be provided wherever ATC separation services are applied. The ADS-B program requirement is to provide ADS-B surveillance in the areas where current secondary radars provide coverage. At many locations, ADS-B ground stations are providing surveillance coverage at lower altitudes than radar provides with significant benefit for general aviation and in the near future. The FAA expects to offer ADS-B separation services at reduced altitudes for these locations. The FAA is evaluating additional cost-effective expansions of ADS-B surveillance to lower altitudes and other areas without radar coverage. The ability of ADS-B to provide surveillance at

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[25] Interagency Airspace Coordination Guide, Chapter 3: http://www.airspacecoordination.org/guide/

[26] Interagency Airspace Coordination Guide, Chapter 3: http://www.airspacecoordination.org/guide/

[27] Interagency Airspace Coordination Guide, Chapter 3: http://www.airspacecoordination.org/guide/

lower altitudes is a primary benefit of the ADS-B program to the general aviation community. Due to the nature of these requirements, the ADS-B coverage altitudes vary significantly across the country. After 2020, when the FAA removes approximately one-half of the secondary surveillance terminal radars, radar coverage at lower altitudes will be decreased and lower altitude “ADS-B Only” airspace will increase. ADS-B is also being deployed in non-radar areas, such as Alaska, off the Gulf of Mexico coast and to smaller airports. However, wherever surveillance is needed, navigation is also required and therefore surveillance does not drive additional areas of coverage beyond navigation needs.

A.5 Use of GPS for Terrain Awareness and Warning Systems

A.5.1 TAWS (Fixed wing aircraft)

The TAWS function provides a key safety enhancement, designed to alert the flight crew of an operation outside of the normal envelope of safe operations. The FAA mandates this system for many airplane operators following the Cali, Columbia accident (e. g., 14 CFR 121.354). Most TAWS aircraft installations use the aircraft’s approved GPS navigation receiver for the positioning input. TAWS includes a GPS-based function to look forward along the projected flight path and identify hazardous terrain. The alerting that would occur depends on the aircraft trajectory, the terrain, the proximity to the airport, and details of the alerting algorithms implemented by each equipment supplier.

The standards for TAWS are defined in TSO-C151b and include three classes of equipment. In commercial aircraft, TAWS also has an alerting capability based on radio altitude that is independent of the GPS function. For the two classes of equipment applicable to general aviation aircraft, the alerting capability is wholly dependent on GPS. This analysis is based on preserving the full capability of the GPS-based safety alerts and does not consider the radio altitude alerting in air carrier aircraft.

The standards for TAWS GPS-based alerting terrain clearance are shown in Table A-2 (see Table 3.1 of TSO-C151b, Appendix A).

Table A-2. TAWS Airplane Alerting

TAWS REQUIRED TERRAIN CLEARANCE (RTC) BY PHASE OF FLIGHT	TAWS (RTC) Level Flight	TAWS (RTC) Descending
En route	700'	500'
Terminal (Intermediate Segment)	350'	300'
Approach	150'	100'
Departure (See Note 1)	100'	100'

The alerting thresholds are related to the obstacle clearance requirements of TERPS. The areas for these phases of flight are defined in Appendix A, Section 10 and in general, equate to:

Approach: within 5 NM of airport

Terminal: within 15 NM of airport

En Route: More than 15 NM from an airport

Departure: within 7. 5 NM[28] of an airport

TAWS includes look-ahead logic that typically evaluates a trapezoidal projection starting approximately 100' either side of the aircraft and projecting forward and outward approximately 1 degree to the left and right of the aircraft flight path vector. Typically manufacturers support flight approximately 125' (0. 02 NM + GPS Horizontal Figure of Merit (HFOM)) laterally adjacent to a hazard without a warning alert.

A.5.2 Helicopter TAWS (HTAWS)

An FAA review of 10 year period (1994 - 2004) accident data indicated that controlled flight into terrain (CFIT) was a major contributor to helicopter accidents, especially those resulting in fatalities. The data suggests that CFIT incidents can happen during day or night, under both visual and instrument meteorological conditions (VMC / IMC). Most

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[28] Approximation, based on standard climb gradient of 200 feet per NM, and TSO requirement of 1500 feet.

CFIT accidents are the result of lack of situational awareness. Limited visibility is often a contributing factor.

There were a total of 83 HEMS accidents from 1998 through mid-2004. The main causes were controlled flight into terrain, inadvertent operation into instrument meteorological conditions and pilot spatial disorientation / lack of situational awareness in night operations. Over 75% of the accidents that might have been prevented by HTAWS during this time period occurred at night in VFR flight. The year 2008 was the deadliest year on record for the HEMS industry, prompting the NTSB to place HEMS safety on the top of its “Most Wanted list of Transportation Safety Improvements” in Oct 2008. Eight of 13 accidents that year resulted in 29 fatalities, including a Maryland public service medevac accident.

The FAA has proposed mandating TAWS technology, adapted to rotorcraft[29]. The FAA is currently evaluating the comments received on the proposed rule, and considers HTAWS an important safety technology for helicopter operators as explained in the notice of proposed rulemaking (NPRM).

HTAWS was developed after helicopter operators installed standard TAWS systems and found that the system needed optimization for helicopter operations. Initial HTAWS installations started in 2002. The total number of HTAWS installations has not been determined; however, there are over 1,000 of a single manufacturer’s systems currently installed. Major manufacturers include, but are not limited to: Honeywell[30], Sandel[31], Cobham Chelton Flight Systems[32] and Garmin[33].

Most HTAWS installations use the helicopter’s approved GPS navigation receiver for the positioning input. Some HTAWS equipment may use an integral GPS sensor that may not be fully compliant with the GPS minimum operational performance standards.

The requirements for Helicopter TAWS (HTAWS) are defined in TSO-C194, which references RTCA/DO-309 for the technical criteria. Table 2-3 defines alerting criteria for

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[29] See Docket number FAA–2010–0982; Notice No. 10–13, Federal Register Vol 75, No. 196. http://www.gpo.gov/fdsys/pkg/FR-2010-10-12/pdf/2010-24862.pdf

[30] Product specifications for the Honeywell MK XXII HTAWS: http://www51.honeywell.com/aero/common/documents/Mk_XXII_EGPWS,P-N_965-1595-XXX.pdf . Link provided by Honeywell Aerospace Advanced Technology.

[31] Pilot Guide for the Sandel ST3400H HeliTAWS: http://www.sandel.com/pdf.php/82046-PG-C1_ST3400H_Pilots_Guide. pdf

[32] Cobham Chelton Flight Systems display - Graphic used with permission of Cobham plc. copyright © 2009.

[33] Garmin ® Optional Display Pilot's Guide Addendum http://www8.garmin.com/manuals/2887_GarminOptionalDisplayPilotsGuideAddendum.pdf. Link provided by Garmin Ltd.

descent operations, (varies by descent rate) to support a level off 100' above the terrain or obstacle.

HTAWS provides a “look-ahead” function to detect terrain or obstacle conflicts by comparing the helicopter flight path (as determined from position information provided by a GPS receiver) to a terrain and obstacle database (see example in Figure A-13). Caution and warning alerts are generated if terrain or obstacles conflict with the flight path of the aircraft and corrective actions are not taken. Caution alerts are advisory and Warning alerts require pilot corrective actions.

Figure A-13. Example Cobham EFIS Synthetic Vision System with HTAWS[34]

The FAA Aeronav Services Digital Obstacle File is a common denominator among the various manufacturers for commercial HTAWS databases. The commercial vendors add additional obstructions consistent with their product capabilities and needs. The FAA

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[34] Cobham Chelton Flight Systems display

Digital Obstruction File contains data for significant U. S. Federal Aviation Regulation Part 77 obstacles which affect domestic aeronautical charting products. The FAA does not purport to indicate the presence of all obstructions which may be encountered. The file is assessable at:

http://aeronav.faa.gov/index. asp?xml=aeronav/applications/digital/dof

TSO-C194 and DO-309 do not specify the height of obstacles that must be included in the database. Some systems display all known obstacles taller than 50' AGL, while others display only obstacles taller than 100' AGL. The terrain grid size is not specified. Some manufacturers currently provide a 0.1 nautical mile grid (6 arc seconds or 600' by 600') while others provide a 300' x 300' grid resolution to provide higher resolution and support operations closer to terrain and obstacles.

HTAWS manufacturers' equipment typically includes a "Normal" mode and one (or more) "Low Altitude" or "Obstacle" modes. The look-ahead logic for Normal mode operations typically evaluates a trapezoidal projection starting approximately 100' either side of the aircraft and projecting forward and outward approximately 1 degree to the left and right of the aircraft flight path vector. Typically manufacturers support flight approximately 125' (0.02 NM + GPS HFOM)) laterally adjacent to a hazard without a warning alert in "Normal" mode.

The Low Altitude mode is intended for low level operations generally below 700' and / or operations in high density metropolitan environments to reduce nuisance alerts due to buildings. The warning alerts are modified to support flight closer to terrain and obstacles without warnings. Manufacturers support flight as close as 40' (0.005 NM + GPS HFOM) to an object, building or tower in "Low Altitude" mode. In Low Altitude mode the look-ahead logic only considers a ribbon-like corridor that facilitates flight closer to objects without nuisance alerts.

TSO-C194 and DO-309 do not specify the minimum height a helicopter can fly above terrain or obstacles without an alert warning except when the helicopter is descending at 300 feet per minute or greater. Some systems only provide alerts when the flight path is predicted to be at or below the obstacle height.

One industry report stated that over 85% of wire strikes occurred in VFR while within 100' AGL and the majority occurred in cruise flight within 40' AGL. Figure A-14 shows an aerial marker being attached to a power line from a helicopter to make the power lines more visually prominent to aircraft pilots. Avionics developers have incorporated power line obstacle data into HTAWS with an expectation that power line display and warning will reduce the number of wire strikes.

Figure A-14. Aerial marker being attached to a power line from a helicopter

A.6 Residual Operational Risks

The coverage requirements identified for this analysis are intended to provide a reasonable bound for GPS reception. Prior to the LightSquared evaluation, the FAA has expected GPS to be available down to the surface throughout the country (as specified in GPS SPS Performance Specification and the GPS WAAS Performance Specification). Reducing the coverage from the current practice to the conditions outlined in this report does not ensure GPS availability for all operations. The following operations could be impacted:

- Normal VFR / SVFR helicopter and some VFR, general aviation fixed-wing and other operations below or inside the minimum coverage requirements identified above. These include fixed wing and helicopter low altitude flight (below 100') and flight within 500' and 100' above obstacles or buildings and towers that are over 100' with LightSquared antenna installations as well as flight below 100’ at distances potentially up to 1 km from a LightSquared transmitter. For those operations, GPS tracking would not be assured, moving map displays could blank out, caution and warning systems would alert, ADS-B positioning requirements would not be met and TAWS / Helicopter TAWS (HTAWS) safety systems would be rendered inoperative until GPS is reacquired. If GPS tracking is lost, reacquisition may not occur until the affected helicopter leaves the area and enters an area where the reacquisition threshold can be satisfied by exiting the general area or ascending. IFR clearance may be essential to maneuvering out of the affected area; however, the pilot may be inhibited or unable to perform IFR flight due to the loss of GPS navigation and ATC may be unable to provide surveillance.
- Helicopter Terrain Warning and Alerting Systems alerting would be compromised for systems that support operations below 100' AGL and within

500' of LightSquared antenna installations on obstacles or buildings and towers over 100'. This is particularly relevant for on-scene operations in emergency response situations. HTAWS provides a valuable “see and avoid” asset even in excellent visibility conditions. The benefits provided by HTAWS, in these areas, should not be compromised. The Airline Owners and Pilot Association provides an A video for the prevention of wire flights strikes that shows typical low level helicopter flight operations[35].

- Operations at some private unregistered or unlicensed heliports would be impacted.

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[35] Surviving the Wires video: http://www.aopa.org/aopalive/?watch=V1Mmk4MTpXN7h00NgfJFO8NhsnhULsvw. Link provided by AOPA. Video courtesy of Southern California Edison, HAI, and AEGIS Insurance Services, Inc. (Executive Producers: Charles Basham and Joan Cash from Southern California Edison. Video Production: Modern Industry Pictures).

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Appendix B. Determination of Median Isotropic Path Loss Segment Break Points

The general methodology for setting the median path loss break points has been discussed in Section 3.1.2.2. In this appendix, further clarification of the selection of these break points is provided incorporating where needed the applicable equations. Throughout a flat earth model is assumed out to the radio horizon R_o. To facilitate the discussion some background material on the two-ray and Hata-Okumura median path loss models are given below.

B.1 Two-Ray Isotropic Path Loss Model

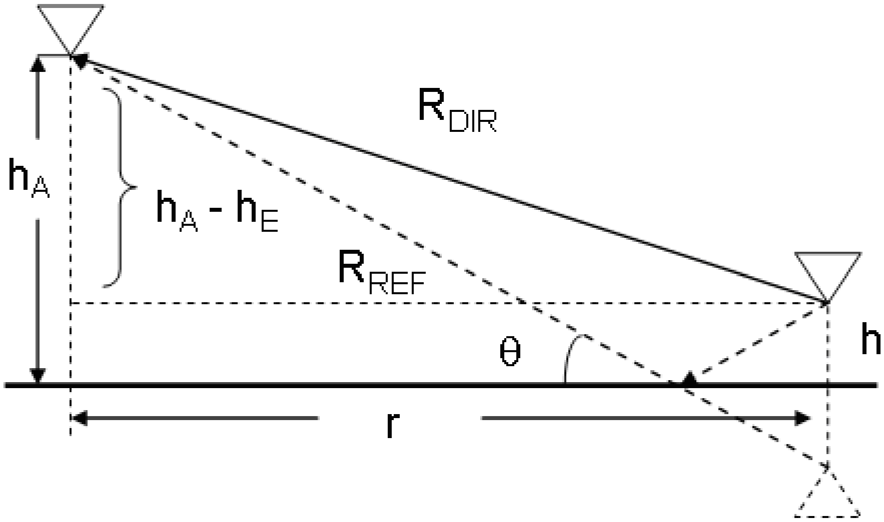

Figure B-1. Two-Ray Path Loss Model Geometry (Profile View)

From the 2-Ray model geometry, depicted in Figure B-1, the isotropic path loss can be derived in the following way. Define the direct ray path length, R_{DIR}, and reflect ray length, R_{REF}, as $R_{DIR}(r) = \sqrt{r^2 + (h_A - h_E)^2}$ and $R_{REF}(r) = \sqrt{r^2 + (h_A + h_E)^2}$; where h_A and h_E are the aircraft and RFI source antenna heights, respectively. Then by simple trigonometry, the ground reflection angle, θ(r), is given as: $\theta(r) = \sin^{-1}\left(\frac{h_A + h_E}{R_{REF}}\right)$.

For radio waves the ground reflection surface can be characterized by its electrical constituent parameters, ε_r, (relative dielectric constant), and σ_c (electrical conductivity). For vertically polarized waves, assumed to be emitted by the RFI sources in this evaluation, the complex wave reflection coefficient, $\rho_v(f_c, r)$, is determined by:

$$\rho_v(f_c,r)=\frac{(\varepsilon_r-ix)\sin(\theta(r))-\sqrt{(\varepsilon_r-ix)-\cos^2(\theta(r))}}{(\varepsilon_r-ix)\sin(\theta(r))+\sqrt{(\varepsilon_r-ix)-\cos^2(\theta(r))}}$$

; where the electrical dissipation ratio parameter, x, at the RFI source center frequency, f_c,, is defined as $x=\frac{\sigma_c}{2\pi f_c\varepsilon_0}$, ε_0 is the free-space permittivity, and i, the imaginary constant $=\sqrt{-1}$.

Similarly for the horizontally polarized RFI emission from the sources, the complex wave reflection coefficient is given as

$$\rho_h(f_c,r)=\frac{\sin(\theta(r))-\sqrt{(\varepsilon_r-ix)-\cos^2(\theta(r))}}{\sin(\theta(r))+\sqrt{(\varepsilon_r-ix)-\cos^2(\theta(r))}}$$

The longer reflected ray path length compared to the direct ray results in a relative phase delay, $\phi(r)=\frac{2\pi}{\lambda_c}\left(R_{REF}(r)-R_{DIR}(r)\right)$; where λ_c is the wavelength at the RFI source center frequency. The interaction between direct and reflected rays at the aircraft receive antenna is given by the complex field factors for each polarization, $P_v(r)=1+\rho_v(r)\cdot(R_{DIR}(r)/R_{REF}(r))\cdot e^{-i\phi(r)}$ and $P_h(r)=1+\rho_h(r)\cdot(R_{DIR}(r)/R_{REF}(r))\cdot e^{-i\phi(r)}$. Combining the relations for each polarization reflection coefficient, relative phase delay, and multi-path field factor results in the 2-Ray model isotropic path loss equations (in dB):

$$\text{dB}\,PL_{2Rv}(r)=20\log\left(\frac{4\pi}{\lambda_c}\cdot\frac{R_{DIR}(r)}{|P_v(r)|}\right) \qquad \text{(B-1)}$$

and

$$\text{dB}\,PL_{2Rh}(r)=20\log\left(\frac{4\pi}{\lambda_c}\cdot\frac{R_{DIR}(r)}{|P_h(r)|}\right) \qquad \text{(B-2)}$$

The reflection surface chosen for this report is concrete ($\varepsilon_r = 7$, $\sigma_c = 0.15$).

B.2 Hata-Okumura Median Isotropic Path Loss Model

For propagation from RFI sources at distances beyond about 1 km from the aircraft antenna, we use the well-known Hata-Okumura path loss model [3-2]. It was originally developed for predicting UHF cellular mobile telephone propagation at distances beyond 1 km from the base station for various types of terrain. In this report the suburban terrain parameters are used to represent the environment around a large metropolitan airport.

Define the factor α (lengths in meters, frequency in MHz) as

$$\alpha=(Ln(10)/10)(69.12+26.16\cdot\log(f_c)-2\cdot\log^2\left(\frac{f_c}{28}\right)-AF(h_A,h_E));$$

here the antenna factor, $AF(\,)$, is given by

$$AF(h_A,h_E)=13.82\cdot\log(Max(h_A,h_E))+3.2\cdot\log^2(11.75Min(h_A,h_E))$$

Note that h_A and h_E denote the aircraft and interfering emitter antenna heights respectively.

Also define β(r) as $\beta(r) = \left(4.49 - .655\log(Max(h_A, h_E)\right) F(r, h_A, h_E)$. For $r \leq 20$ km, $F(r,h_A,h_E))$ = 1; otherwise it is given by

$$F(r, h_A, h_E) = 1 + \left(0.014 + 1.87 \cdot 10^{-4} f_{c,MHz} + \frac{1.87 \cdot 10^{-3} Max(h_A, h_E)}{1 + 7 \cdot 10^{-6} (Max(h_A, h_E))^2}\right) \log\left(\frac{r}{20000}\right)^{0.8}.$$

The path loss model above incorporates the ITU-R extension to the conventional Hata model for lateral separations more than 20 km.

The Hata-Okumura median isotropic path loss can then be expressed as,

$$PL_{Hata}(r) = Exp(-\alpha)(r/1000)^{-\beta(r)} \qquad \text{(B-3).}$$

B.3 Break Point Determination

B.3.1 Determination of First Break Point r_1

The first break point is set to occur near the lateral range at which the magnitude of the vertical polarization reflection coefficient ρ_v is a minimum. Thus if $r_{\min} = \{r \in [0, 20\,km] \,|\, |\rho_v(r)| = \min\}$, then we compute r_1 as

$$r_1 = \{r \in [r_{\min} - \Delta, r_{\min} + \Delta] \,|\, PL_{2Rv}(r) = PL_{2Rh}(r)\}.$$

In other words, r_1 is the radial point close to r_{min} at which the 2-Ray horizontal and vertical polarization path losses are equal. The quantity Δ is typically on the order of about 2 meters. It should be noted that the r_1 breakpoint is a function of aircraft and RFI emitter antenna heights as well as the reflection surface properties. As such has to be re-computed for each of the individual cell towers in the Monte-Carlo simulation.

As an example, if h_A = 76 m, h_E = 41 m, and a concrete reflecting surface is assumed, then $r_{\min}$ = 313. 475 m and r_1 = 313. 92 m. The median isotropic path loss for this first segment of the model is either given by $10^{-(dBPL_{2Rv}(r)/10)}$ or $10^{-(dBPL_{2Rh}(r)/10)}$ depending upon the polarization component being considered.

B.3.2 Determination of Second Break Point r_2

The second segment of the median path loss model may entail the path loss increasing proportional to r^2 if a substantial clear line of sight dominates or this segment may be eliminated as in the case of the FAF Waypoint scenario. For the lower aircraft altitudes this segment is typically present and r_2 must be determined. This determination is unique to each site and has to be done by evaluating whether or not cell towers out to the radius r_2 are essentially within clear line of sight of the aircraft antenna. This may be done by on-site inspection or by using whatever other tools may be available. As an example for the two Washington DC scenarios, DCA1 and DCA2, this distance was determined using available software tools to be 2.5 km. The corresponding median path loss for this segment is then given by $PL_{segment2}(r) = PL_{2Rv}(r_1)(r/r_1)^{-2}$ where r is in meters. Note that in this segment, as well as all following segments, the path loss is identical for both polarizations.

As noted in Section 3.1.2.2, if the value of r_1 is fairly large, r_2 is set equal to r_1 and this segment is eliminated. This is the case for the FAF Waypoint scenario at LAKIE where r_1 is approximately 1.6 km and the path loss exponent for the following segment (r_2 to r_3) is computed to be very near 2.

B.3.3 Determination of Third Break Point r_3

The determination of the third break point is more complex than previous break points and begins with a site specific evaluation of the distance at which a majority of cell towers appear to be obscured from an aircraft antenna assumed to be at a height of 30 meters (approximately 100 ft). As with the preceding break point, this evaluation may be done by onsite inspection or using available software tools. Whatever method is used let this minimum value for r_3 be denoted by $r_{3\min}$. As an example, for the two Washington DC scenarios this minimum distance was determined to be about 5 km.

Having determined this minimum distance, we proceed by defining the function y(x) as

$$y(x) = -Ln[Exp(-\alpha)(x/1000)^{-\beta(x)}/(PL_{2Rv}(r_1)(r_2/r_1)^{-2})]/Ln(x/r_2)$$

and compute the derivative $\dot{y}(r_{3\min})$. We also define $\Gamma_1 = \underset{r_{3\min} \le x \le 20\,km}{Max}[y(x)]$, $\Gamma_2 = \underset{r_{3\min} \le x \le 20\,km}{Min}[y(x)]$,

$\gamma = \begin{cases} 0, & \{\Gamma_1 < 2\} \\ 1, & otherwise \end{cases}$, and

$$\Gamma_s = \left\{ \begin{array}{ll} \Gamma_1 U[-\dot{y}(r_{3\min}) + \Gamma_2 U[\dot{y}(r_{3\min})] + Sgn[\dot{y}(r_{3\min})]((\Gamma_1 - \Gamma_2)/(535.2-30))(h_A - 30), & 30 \le h_A \le 535.2m \\ \Gamma_1 U[-\dot{y}(r_{3\min}) + \Gamma_2 U[\dot{y}(r_{3\min})], & elsewhere \end{array} \right\}.$$

Then the path loss exponent Γ for this segment is given by $\Gamma = \left\{ \begin{array}{ll} \Gamma_s, & \gamma = 1 \\ 2, & otherwise \end{array} \right\}$.

If γ=0, the path loss is free space for all ranges r and there is no probabilistic path loss model, i.e., the extended Suzuki parameters are given by $\psi_o(r) = 0$, $\rho^2(r) = 1$, $\sigma(r) = 0$.

Assuming that γ=1, we set $\psi_2(r_2) = PL_{2Rv}(r_1)(r_2/r_1)^{-2}$ and compute the break point r_3 as

$$r_3 = \left\{ \begin{array}{ll} r_{3\min}, & 0 \le h_A < 30\,m \\ \{r \in [r_{3\min}, 20\,km] \mid \psi_2(r_2)(r/r_2)^{-\Gamma} = Exp[-\alpha](r/1000)^{-\beta(r)}\}, & 30 \le h_A \le 535.2\,m \end{array} \right\}.$$

As an example, for an aircraft antenna height h_A of 76 meters, a cell tower height of 45 meters, and $r_{3\min}$ = 5 km, the computed value for r_3 is 5.229 km. The path loss exponent Γ for this example is 5. 76 while the associated median path loss for the segment from r_2 to r_3 is given by $PL(r) = \psi_2(r_2)(r/r_2)^{-\Gamma}$.

The median path loss for ranges greater than r_3 and out to R_o and is given by $PL_{Hata}(r) = Exp[-\alpha](r/1000)^{-\beta(r)}$.

If the aircraft antenna height h_A is outside the range indicated in the equation defining r_3, the path loss is deterministic free space path loss and there are no segments.

B.3.4 Determination of Fourth Break Point r_4

The break point r_4 has nothing to do with defining path loss segments but rather is needed in the definition of the standard deviation σ_{dB} associated with the log-normal component of the fading channel. To determine r_4 we first define the standard deviation as a sequence of step functions as done in Section 3.1.2.2 and repeated here for convenience.

$$\sigma_{dB}(r) = \begin{Bmatrix} 0.5dB, & 0 \le r < r_2 \\ 2dB, & r_2 \le r < (r_2 + r_3)/2 \\ 3.5dB, & (r_2 + r_3)/2 \le r < r_3 \\ 6.4dB, & r_3 \le r \end{Bmatrix}.$$

This function is typically approximated by a fifth order polynomial although for the LAKIE scenario a polynomial of order 3 was used because of the large value of r_3. The coefficients of the polynomial are determined so as to minimize the mean square error between the polynomial and the step function definition of $\sigma_{dB}(r)$. Any number of commercially available numerical software packages can be used to compute the coefficients. Once the coefficients are computed, the polynomial is then defined as

$Poly(r) = a_0 + a_1 r + a_2 r^2 + a_3 r^3 + a_4 r^4 + a_5 r^5$; where we have assumed the use of a fifth order polynomial. The point r_4 is then found by $r_4 = \{r \in [r_{3\min}, R_o] \mid Poly(r) = 6.4\}$.

As an example, for the DCA1 scenario,

$$\sigma_{dB}(r) = \begin{Bmatrix} 0.5dB, & 0 \le r < 2.5km \\ 2dB, & 2.5km \le r < 3.941km \\ 3.5dB, & 3.941km \le r < 5.3819km \\ 6.4dB, & 5.3819km \le r \end{Bmatrix}$$

and the approximating polynomial is given by,

$$Poly(r) = .470967 - .00004974r + 1.29711 * 10^{-7} r^2 + 9.62438 * 10^{-12} r^3 - 7.15798 * 10^{-16} r^4 + 8.66748 * 10^{-21} r^5 .$$

The value for r_4 then becomes 6.1686 km.

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Appendix C. LightSquared Perspective

LightSquared appreciates the opportunity to comment on FAA's report,[36] and expresses its appreciation to DOT and FAA management and staff for their considerable time, effort, and professionalism in analyzing potential GPS interference issues associated with LightSquared's use of its FCC licensed spectrum.

LightSquared strongly disagrees, however, with the DOT/FAA's refusal to continue to analyze LightSquared's proposals, and respectfully submits that this report is fundamentally flawed, scientifically invalid, and procedurally deficient:

- As the report admits, the technical analysis is incomplete and key elements have not been adequately supported and submitted to technical review, making it inappropriate to reach any conclusions. Most of the joint work was on the higher altitude cases, where the parties are relatively close to agreement on favorable results, with only a short time devoted to low altitude cases, which the FAA now appears to be using to stop work.
- The report gives inadequate consideration to LightSquared's current proposals to modify its network to eliminate any risk of interference. When the report does consider LightSquared's proposals, it mischaracterizes them[37] and focuses on outdated proposals that are no longer relevant.
- The report continues a pattern of the FAA's inability to clearly and consistently identify its requirements for GPS. FAA initially did not identify terrain-avoidance warning systems ("TAWS") as a unique requirement to be analyzed.[38] When it did identify TAWS as a unique requirement, the FAA provided ambiguous information as to whether a minimal exclusion zone for terrain avoidance systems is acceptable.[39]

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[36] LightSquared is responding to the FAA's December 23, 2011 Draft Status Report: Assessment of Compatibility of Planned LightSquared Ancillary Terrestrial Component Transmissions in the 1526-1536 MHz Band With Certified Aviation GPS Receivers ("FAA Report"). While LightSquared was also provided an updated draft of the Report on January 13, 2012, it did not have sufficient time to review additions to that draft in detail. However, a preliminary review indicates that the FAA continues to lack empirical support for its selection of breakponts and parameter values for its propagation model.

[37] For instance, FAA states that free space propagation, as proposed by LightSquared is not acceptable to it, referring to the way the received power is calculated in the low altitude case for elevation angles less than 60. It is assumed that the FAA would prefer to use the 2-ray model in this case. Yet, in the FAA's own standards document (DO-327), it is explicitly stated that 2-ray model should be used for elevation angles greater than 60 and that lower elevation angles there is too much scattering to justify its use. This subject is discussed further in Appendix C. The report also focuses on the supposed management issues of insuring LightSquared's compliance. While such concerns are reasonable, it is far too premature for them to be the basis for any conclusions. Moreover, it is a blatant mischaracterization of LightSquared's proposal to say that it seeks no FAA role in oversight of LightSquared's compliance. (*See* Executive Summary "In addition, the FAA cannot hand over surveillance of LightSquared signal characteristics to a third party and does not have the resources to do that job.")

[38] RTCA Report 3.1.2.

[39] The report describes what it appears to consider to be an acceptable exclusion zone in Section 1 but then criticizes LightSquared's proposal for failing to "match current FAA operations."

- Based on the opinions of leading experts on wireless propagation and terrain avoidance warning systems, key aspects of the report's analysis are simply wrong.

In addition, the report does not even acknowledge the FAA's significant participation, through NTIA, in the original FCC rulemaking process in which the rules allowing for LightSquared's terrestrial deployment were first considered and ultimately approved.[40] At no time prior to late 2010 did FAA raise any issue regarding the compatibility of LightSquared's operation with its own existing standards for certified aviation GPS receivers or with its NextGen initiative. FAA raised these issues only long after the rules governing LightSquared's terrestrial operation had been finalized and LightSquared's terrestrial authorization had been granted.

Having raised these belated objections outside of the original rulemaking process, the FAA now refuses to spend the limited resources to complete a thorough and scientific analysis of potential solutions, let alone acknowledge its responsibility and commit to remedying its flawed standards and requirements. In that regard, the report's contention that a transition to new standards would take ten years is without support and ignores both the equities of the situation and the fact that testing of certified aeronautical GPS receivers, albeit small in number, by independent laboratories has demonstrated sufficient additional more resilience to transform the technical analysis.

Given the FAA's responsibility for creating this situation, it is only fair that FAA remain fully engaged and committed to finding a constructive solution that protects public safety and provides the benefits of greater spectrum use. As outlined further below, LightSquared is convinced that its proposals to accept modifications to its system to accommodate FAA requirements provide a first step in that direction and that, with FAA's help, a reasonable solution can be found. An objective examination of the record shows that the joint work that has been completed, along with LightSquared's most recent proposals, will provide compatibility between LightSquared's operations and FAA GPS requirements – even assuming the most conservative definitions of those requirements. However, should the FAA choose not to remain engaged with LightSquared in order to work in good faith to identify mutually acceptable solutions, LightSquared believes it is the FAA's obligation to immediately update the relevant GPS receiver standards, and require the immediate replacement of all non-conforming equipment, so that there is no conflict with LightSquared's authorized operations.

LightSquared has made a commitment to bring world-class wireless broadband connectivity to 260 million Americans by 2015 – and to do so by investing $14 billion of private funds in our nation's broadband infrastructure. LightSquared has plans to deploy an open wireless broadband network using a technology called Long Term Evolution (LTE), the most widely adopted 4G standard in the world. Its LTE network will be combined with one of the largest commercial satellites ever launched, and when combined with LightSquared's estimated 40,000 terrestrial-based wireless network of base stations, will bring high-speed, wireless broadband coverage to millions of Americans – many without any broadband access today. It will immediately create thousands of needed jobs, with more than 15,000 direct and indirect private sector jobs estimated

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[40] Despite that participation, the FAA failed to account for those developments in its standards, as the RTCA recently recognized. *See* RTCA Report, Section 1.1.1. ("RTCA Special Committee-159 (SC-159) took note of some of the ATCt regulatory developments and unwanted out-of-band-emissions (OOBE) limits but did not study fundamental emission overload effects in RTCA/DO-235B. *Id* at 1-1).

each year through 2015. As a wholesale provider, LightSquared will bring welcome competition in the provision of wireless services, promising to lower the price and increase the quality of broadband services for all Americans.

Even before they took office, then President-elect Obama and Vice President-elect Biden committed to work “towards true broadband in every community in America through a combination of reform of the Universal Service Fund, better use of the nation's wireless spectrum, promotion of next-generation facilities, technologies and applications, and new tax and loan incentives. [41] The President’s emphasis on this goal – reachable with LightSquared’s support – is consistent with the “National Broadband Plan,” which was announced on March 16, 2010. The goals of the plan include having the United States “lead the world in mobile innovation, with the fastest and most extensive wireless networks of any nation,” with “[e]very American community” having affordable broadband wireless access, which would help schools, hospitals, government buildings first responders, and a clean energy economy. [42]

In his 2011 State of the Union address, President Obama set forth a goal of enabling businesses to provide high-speed wireless services to at least 98 percent of all Americans within five years. As the President stated, the rollout of the next generation of high-speed wireless – the very 4G technology under development by LightSquared:

> “Promises considerable benefits to our economy and society. More than 10 times faster than current high speed wireless services, this technology promises to benefit all Americans, bolster public safety, and spur innovation in wireless services, equipment, and applications. By catalyzing private investment and innovation and reducing the deficit by $9. 6 billion, this initiative will help the United States win the future and compete in the 21st century economy. ” [43]

The Administration set a goal of nearly doubling wireless spectrum available for mobile broadband, with a goal of freeing up 500 MHz of spectrum for use, among others, on “wireless broadband connectivity for laptops to new forms of machine-to-machine communication within a decade.” [44] Yet, the U.S. remains lagging in broadband rollout, adoption, and pricing when compared to other developed nations. [45] And, it will continue to lag behind in the application of the technology it invented if it does not quickly find answers to accommodate the use of LightSquared’s more limited spectrum. Tens of thousands of jobs will go unfilled if the

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[41] See http://change.gov/agenda/technology_agenda/.

[42] See http://www.news-record.com/content/2010/03/15/article/fcc_set_to_unveil_sweeping_national_broadband_plan.

[43] Press Release, The White House, Office of the Press Secretary (Feb. 10, 2011), *available at* http://www. whitehouse. gov/the-press-office/2011/02/10/president-obama-details-plan-win-future-through-expanded-wireless-access

[44] *Id.* President Obama called for “the need to address high-speed connectivity in “every corner of our nation. It means expanding broadband lines across America, so that a small business in a rural town can connect and compete with their counterparts anywhere in the world. ”

[45] According to the latest OECD data from June 2011, the United States ranked 15th out of 30 countries measured in broadband penetration per 100 citizens; the Netherlands, Switzerland, Denmark, Korea, Norway, France, Iceland, the United Kingdom, Germany, Sweden, Luxembourg, Belgium, Canada, and Finland are all above the U. S. and the OECD average *See* http://www.oecd.org/document/54/0,3746,en_2649_34225_38690102_1_1_1_1,00.html.

government continues to attempt to block LightSquared's plans. None of the many benefits of ubiquitous wireless broadband will be realized unless the DOT and FAA continue their technical analyses with a view toward finding solutions, not impediments – toward applying mitigation based on sound science, not suspension of all further evaluation efforts based on unspecified "operational, cost, and schedule implications."

For its part, LightSquared is prepared to work exhaustively to resolve any remaining concerns to address again a problem that is not of their own making. LightSquared continues to believe that LightSquared and GPS can safely and efficiently co-exist. LightSquared is prepared to continue to work with the federal government on a solution that will allow it to begin investing $14 billion in private money into the infrastructure of America to create jobs, competition, and increased access to broadband wireless technology to the entire nation.

With so much at stake, and with this historic backdrop, LightSquared has taken extraordinary measures, at extraordinary expense, to solve a problem that is not of its own making. Extensive governmental testing, from RTCA and under NTIA auspices, has confirmed one salient fact. The so-called LightSquared GPS interference issues are not caused by LightSquared's spectrum, but by GPS manufacturers that have designed faulty devices that intentionally look into spectrum that is licensed to LightSquared. Other manufacturers have employed appropriate designs and will not be subject to interference. Yet, nowhere is this central point even recognized in FAA's report.

Recent government testing confirmed that 300 million GPS-enabled cell phones are fully compatible with LightSquared's network. In addition, several top-tier GPS device manufacturers, including Javad GNSS, PCTel and Hemisphere, have successfully developed and tested filters and antennas that are fully compatible with LightSquared's use of its licensed spectrum. Unfortunately, other GPS manufacturers, led by Trimble and Garmin, have chosen not to re-design their devices or develop effective filters and antennas, but instead, have spent millions of dollars lobbying the DOT, FAA, DOD, NTIA, NASA, and the Congress in an effort to preserve their faulty devices and interfere with LightSquared's use of its licensed spectrum. In the meantime, several government and non-governmental organizations are recognizing the vulnerabilities of the GPS system and recommending that urgent efforts be undertaken to create a robust research and development programs "focused on antenna and receiver improvements that would enhance the resilience of systems dependent on GNSS."[46]

From LightSquared's perspective, it is not an option for another agency within the Federal government to abruptly withdraw all support and cease all work on this matter because of unknown, unanalyzed, and unquantified "operational, cost and schedule implications." LightSquared is legally entitled to own and operate its FCC licensed spectrum, but out of abundance of concern and pursuant to FCC direction, LightSquared has worked diligently and in good faith with the FAA to ascertain the extent and nature of any interference, and what options exist to allay these concerns to create a win-win solution. LightSquared has invested significant

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[46] As the U.K.'s Royal Academy of Engineering recently pointed out: "Deliberate or unintentional interference with this signal can easily defeat the signal recovery overload the receiver circuitry. " Global Navigation Space Systems: reliance and vulnerabilities The Royal Academy of Engineering, at p. 5-6 (March 2011), recently viewed at http://www. raeng. org. uk/news/publications/list/reports/RAoE_Global_Navigation_Systems_Report. pdf. *Id*. at 30. *See also* Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities, GAO-09-670T (May 7, 2009), recently viewed at http://www.gao.gov/products/GAO-09-670T.

time and money to alter its business plan and find mechanisms to allow both technologies to peacefully and safely coexist. LightSquared's solution fosters both the preservation of the navigation and surveillance benefits of GPS with providing first-ever benefits of ubiquitous access of 4G wireless networks to all Americans.

For its part, LightSquared has made multiple and significant concessions – at a huge cost – by agreeing among other things not to use until further permitted by the Federal government half its spectrum and powering back significantly the signal at its base terrestrial stations. So far, the GPS manufacturers, which have created the problem, have offered nothing, other than putting together a "Coalition to Save Our GPS" that simply opposes LightSquared's plans, while taking no responsibility to fix the problem of their own creation. To date, the FAA itself has not offered any mitigation on its own in the form of new standards, procedures, or regulatory/compliance mechanisms. At this point, given the DOT/FAA's decision to arbitrarily suspend all further technical analyses, the NTIA, FCC, and Administration should provide the request or direction the FAA is seeking – complete the job so the President's promise and the goals of the Administration's National Broadband Plan can be fulfilled while maintaining the safety and efficiency of the national airspace system.

Indeed, given the flaws in aviation GPS receiver design standards and the inherent weakness of the GPS signal to interference, jamming, and spoofing now revealed to the entire GPS user community – along with the prevalence of other GNSS satellites, overlays, augmentation systems, and devices that can cause either out-of-band interference or overload – regardless of LightSquared operations, the Federal government should be urgently upgrading GPS design standards and taking immediate steps to enhance the resilience of the GPS signal, especially given increased reliance on GPS under NextGen.

To be clear, LightSquared is confident that as its network system is further evaluated objectively and professionally, it will be proven fully compatible with current FAA GPS receiver standards under MOPS. Still, it is surprising that the FAA report evidences extraordinary reluctance to even look at enhanced resilience in receiver design, saying how difficult it will be and repeating estimates of ten years or more to do so. Yet, in the wake of previous operational imperatives the FAA and other agencies have proven themselves highly capable of moving at great speed – in some cases less than three years – to completely revamp necessary procedures and standards. Because of the FAA's significant reliance on GPS for operational and safety procedures, it would seem only prudent for the FAA to urgently address obvious vulnerabilities in GPS and, at the same time, consider upgrading GPS receiver design standards to look only at the GNSS band signal and filter out other signals from different bands.

LightSquared has now spent over $20 million to assist in government-industry efforts to analyze any potential interference issues. As noted, several months ago, LightSquared extraordinarily agreed not to use half of its allocated spectrum, including all of the 10 MHz immediately adjacent to the L1 GPS band, unless and until fully approved by NTIA. In response to the challenging issues that remain relating to low-altitude aviation applications, specifically terrain awareness and warning systems ("TAWS"), LightSquared went the extra mile to fully ensure protection of existing FAA standards and requirements (including a substantial safety margin) for all cases, including low altitude TAWS and navigation – for both fixed wing aircraft and rotorcraft.

This includes significantly powering back its base stations by:

- Restricting the density and power levels of LightSquared base stations in urban areas to ensure that the aggregate emissions at the worst-case altitude over the largest cities does not exceed the interference threshold established in FAA certification standards for GPS aviation receivers and TAWS systems;
- At low altitudes, LightSquared agreed to limits on the power levels of nearby base stations so as to protect terrain avoidance systems everywhere beyond 500 feet laterally and 100 feet vertically of a building or two on which the base station operates, as previously described by FAA staff as acceptable; and
- Agreeing that at low altitudes, further limiting the power levels of nearby base stations so as to protect navigation during takeoffs and landings.

In addition, LightSquared committed to work with the FAA to develop a methodology acceptable to the FAA and FCC, including ongoing audits by independent third parties at LightSquared's expense, to ensure that the limits are met. LightSquared detailed appropriate compliance and enforcement mechanisms.

Unfortunately, the DOT and FAA refused to even consider these concessions and suggestions and announced, almost immediately upon receiving LightSquared's proposals that they were simply suspending all further technical analyses on LightSquared's proposals. They announced that all further efforts would be directed at writing this report, refusing to do any other work unless requested or directed to do so by NTIA, FCC, or the Administration.

We respectfully submit that DOT/FAA's artificial "stand down" on LightSquared's good faith concessions and mitigation proposals is arbitrary and capricious, not in the public interest, and flatly inconsistent with the Administration's Broadband Access policy. In addition, in giving LightSquared fewer than 14 business days over the holidays to provide comments to its incomplete, then 78-page single spaced draft report, introducing new material not discussed in the joint working group, the DOT and FAA are acting in a highly prejudicial and discriminatory manner toward LightSquared, and are basing their sweeping and inaccurate conclusions in this report on unscientific assumptions and modeling that reveal a lack of substantial evidence.

LightSquared disagrees strongly with any conclusion, based on the analysis that has been conducted to date, that the LightSquared terrestrial network is not compatible with FAA GPS requirements. As discussed further below, the analysis shows great progress in beginning to (i) clearly define FAA requirements for GPS; (ii) create a technical framework for analyzing the potential for interference; and (iii) consider potential modifications to the LightSquared network or to FAA requirements without compromising aviation safety. Each of these three steps is critical and, to the extent sufficient time has been permitted, the results have been positive. LightSquared believes that with additional joint effort the remaining issues can be fully resolved and full compatibility between LightSquared's terrestrial network and FAA GPS requirement can be achieved.

The greatest progress has been made on the aggregate impact of LightSquared's base stations on aviation at higher altitudes (above 300 feet) – the area where the vast majority of all analyses was devoted until only very recently. Throughout the RTCA process in early 2011 through until

October 2011, the higher altitude requirements were the primary focus of the process. As a result of that effort, it is clear that LightSquared's network is compatible with FAA requirements for higher altitude operations – a fact only begrudgingly acknowledged in FAA report. LightSquared and its experts disagree with certain aspects of the FAA's technical model for the higher altitude cases; if the LightSquared perspective were to prevail in even one of these regards, then no modifications to LightSquared's network would be needed to demonstrate compatibility, but even if all the FAA positions were to prevail, it is likely that LightSquared would be able to operate its network within those requirements.

Only recently, starting in October, did the analytical process turn to cases involving lower altitude aviation applications, including those unrelated to navigation, specifically, TAWS and HTAWS. In those areas, the process is still at the stage of describing the FAA requirements, and has had insufficient time to reach any professional conclusion regarding the technical model for analyzing impact, or to consider modifications that could reasonably accommodate both aviation safety and LightSquared.

Again, in December, LightSquared made a proposal for accommodating the newly described FAA requirements, but as the FAA report acknowledges, FAA has not yet reached any conclusions regarding the technical feasibility of the proposals. Its only expressed concern is with the potential logistical difficulties of implementing the proposals. LightSquared is confident, however, that, with a few months of concentrated effort, FAA and LightSquared would be able to complete their work establishing compatibility for the low altitude cases.

The remaining significant issues to address through continued joint work are:

1. Low altitude cases
    a. Finalize definition of FAA requirements
    b. Determine appropriate propagation model
    c. Consider rules to insure that LightSquared network complies with agreed limits
2. Higher altitude cases
    a. Resolve views on the relationship of standard deviation and path loss
    b. Run models with backed off base station EIRP
    c. Resolve the appropriate value for polarization mismatch

The greatest priority in future work would be given to the low altitude cases, since it is already clear that LightSquared likely can make any necessary modifications to its network to operate compatibly with FAA requirements regardless of further work on the higher altitude cases. LightSquared would like to see the additional work on the higher altitude cases because it believes its view of the science is correct and the additional margin that would be provided would reduce the cost of its network and increase its capacity for service. A declaration from one of the foremost international experts on radio propagation supports LightSquared's technical perspective on these issues, and is attached as Attachment 1.

Definition of FAA Requirements

As mentioned above, most of the effort to date has been on the impact of LightSquared's network on aviation use of GPS for navigation at higher altitudes. The May 2011 RTCA Report, for example, characterized the worst-case as involving aggregate interference at altitudes above 525 meters[47] and did not analyze terrain avoidance systems. [48] The FAA only recently shifted the attention of the working group to requirements at lower altitudes, for both navigation and terrain avoidance. [49]

The first indication that TAWS would be an issue came in an October draft position paper to the working group that contained additional operational requirements for low altitude navigation and terrain avoidance. Substantive discussions clarifying those newly identified requirements have been taking place as recently as this month.

In response, LightSquared has assembled experts on low-altitude navigation and terrain avoidance systems and is in the process of reviewing those requirements and its ability to modify its system to comply with those requirements. The preliminary assessment of the terrain avoidance system expert, John Howard Glover, which the FAA's requirements assessment is unreasonably conservative and goes beyond those requirements necessary to ensure an equivalent level of safety for TAWS and HTAWS, is attached as Attachment 2. Nonetheless, as mentioned above and described more fully below, LightSquared's view is that, even if the FAA's current definition of its requirements stands, it will be possible for LightSquared to adapt its network to those requirements to ensure compatibility.

Technical Framework for Analysis; Consideration of LightSquared Proposals

Progress to Date: Most of the technical effort to date has been directed at the complex issue of how to model potential interference from the LightSquared network to aviation GPS receivers that are minimally-compliant with FAA standards,[50] almost entirely focused on the higher altitude cases. Substantial progress has been made in reaching agreement on many aspects of the modeling that is required for those cases and on the results of running those models. FAA and LightSquared has performed substantial work during the joint working sessions that supports the

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[47] RTCA Report at Table 6-4 (showing that the received RFI power spectral density (PSD) is greatest for the FAF WP Case, when the aircraft is 535.2 m height. The value at this height is -73.55 dBm/MHz.)

[48] The RTCA Report evaluated five operational scenarios selected by the FAA, including Cat I, II, III approaches requiring GPS down to 100'. RTCA Report 3.1. The Report concluded that the lower altitude scenarios below 300' (Cat I, II, III) were compatible with LightSquared's proposed operations. The RTCA Report did not contain any specific requirements related to terrain avoidance. RTCA Report 3.1.2.

[49] The FAA Report also suggests the possibility of additional GPS requirement being defined for Visual Flight Rule and Unmanned Aircraft and other operations. For the purpose of this discussion, in light of the fact that FAA has not previously presented these as requirements, LightSquared is not attempting here to address its compatibility with these uses. LightSquared is also not addressing the FAA's indication for the first time in Section 6 of its Report (Summary and Conclusions) that additional work is needed to examine the potential impact of LightSquared handsets on certified GPS receivers. The Report makes no effort to justify this suggestion and ignores the facts that the May RTCA report concluded that ATCt base stations were the dominant concern.

[50] As noted in the RTCA Report, these standards were established without regard to the potential for overload interference as a result of the FCC's orders authorizing LightSquared operations. *See supra* note 8.

position that full convergence is possible and is within the scope of a few months of additional work. Significant areas of mutual progress are summarized below:

1. Agreement that a polarization mismatch existed between our base station signals and the response of the GPS antenna on the aircraft. Although LightSquared presented an analysis supporting a mismatch loss of 3-4 dB relative to DO-327, the FAA agreed to 2 dB.
2. Agreement that the standard deviation for Rayleigh fading was not 5.25 dB as claimed in DO-327, which assumed the fading characteristics of a narrowband signal, but 2 dB, which corresponded to a wideband (10 MHz bandwidth) signal with 2 MHz channel coherence bandwidth.
3. Agreement that the lognormal fading would not have a standard deviation of 6. 4 dB everywhere outside the 2-ray model region, as assumed in DO-327. Specifically, FAA accepted that the standard deviation is small (under 2 dB) close to the base station. However, FAA did not accept that the pathloss exponent should be tied to the standard deviation, which has been the greatest area of disagreement.
4. Tentative agreement that fast fading would not have a deleterious impact on a GPS receiver owing to the short time scale of fast fading compared to the 20 ms integration period of a GPS receiver.
5. Agreement that, in the presence of significant local scattering, the 2-ray model would not apply. Tentative agreement that the 2-ray model be used only when the magnitude of the elevation angle from the base station is greater than 6 degrees, as described in the RTCA Report.

Remaining Work

The remaining areas and current status, which are described in more detail below, are summarized below:

2. Low Altitude Navigation – Resolution of the appropriate propagation models and parameters for Navigation below 300 feet for individual base stations in line-of-sight[51] and LightSquared’s proposed high-level method of ensuring compatibility (control of “power in the air”). There have not been any substantive discussions in response to LightSquared’s proposal.
3. TAWS/HTAWS – In addition to resolution of the appropriate propagation models and parameters, resolution of the feasibility of LightSquared’s proposal for insuring

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[51] This is not to suggest that RFI from multiple base stations is irrelevant for the landing/departure use case but, owing to the short distance to the radio horizon and the low elevation angle, there is a significant probability of blockage to those base stations that are within the radio horizon. Therefore, typically, the dominant RFI contributions are found to come from a small number of base stations that are in line of sight of the aircraft and very close to the runway. The analysis methodology used by the FAA therefore consisted of examining the RFI from selected, individual base stations near runways. Clearly, if the RFI exceeds the -34. 1 dBm threshold from such cases, the aggregate-base-station RFI case is moot.

compatibility for TAWS and HTAWS. The technical discussions were terminated before the proposal could be discussed.

4. Higher Altitude Navigation – Further discussion of the propagation models/parameters for Navigation for aircraft altitudes ranging above 300 feet, involving all base stations in the radio horizon, with particular focus on the relationship between the pathloss model and the choice of standard deviation. The FAA should evaluate the DCA1 and 2 scenarios with base station EIRPs backed-off consistent with LightSquared's TAWS commitment.
5. Polarization – Further discussion of the appropriate value to assign to the polarization mismatch between LightSquared's linear cross-pol base station signal and the reference GPS antennas polarization response.
6. Service Probability – Discussion if needed of the FAA's proposed method of calculating service probability as the P^N, where P=1E-6 and N is an arbitrarily chosen number, indicative of the number of independent occurrences of LightSquared RadioFrequency Interference (RFI) in one hour, leading to the use of tails of assumed fading distributions at regions below 1E-9.

On items (1) and (2), the FAA's latest objections appear not to be fundamentally technical but related to the feasibility of compliance administration. LightSquared believes that further discussion on these subjects, which were raised late in the work, will lead to a mutually acceptable solution. To comply with the FAA's stated TAWS/HTAWS parameters, LightSquared has offered to accept reductions of base station EIRP as a function of base station antenna height that make disagreement on item (3) above potentially irrelevant.

As discussed in more detail below, LightSquared views item (4) as critical to determining the necessary base station EIRP backoffs in all scenarios, noting that each dB of backoff constitutes a financial burden on LightSquared's network. LightSquared believes, as stated in documents presented to the FAA in meetings during the study that, based on the example antenna pattern used in the first RTCA Report, which is based on DO-235B, Fig. G-13, a minimum discrimination of 11 dB is appropriate in the elevation angel range of 0 to -30 degrees.

On item (5), LightSquared understands that the RFI evaluation threshold, as currently used to define pass/fail criteria in the Report, does not extend below 1E-6 but that the FAA considers this an "open question." As discussed below, the importance of this point to the FAA is unclear at this time.

The following parts of this section discuss in more detail the important differences in the technical framework that LightSquared believes can be resolved. In some instances, those differences involve matters that have not been fully discussed; for instance, certain information regarding the basis for selecting specific parameters and values in the FAA model are being provided only in the draft of this very report and thus have not been subject to reviewed or comment by LightSquared. In other cases, the differences involve what LightSquared considers insufficient consideration of the underlying technical requirements.

Low Altitude Navigation and Terrain Avoidance

Technical Analysis

The FAA's newly stated low altitude GPS requirements assume the possibility of a base station near either an airport runway or an aircraft relying on GPS for terrain avoidance. LightSquared proposed that the propagation model to be used in these scenarios use the 2-ray model if the elevation angle magnitude exceeded 6^o and free space otherwise. [52] Exclusion of the +/- 6^o cone for 2-ray propagation has support both in the literature and in DO-327 as pointed out in [1]. LightSquared has based its proposals for compatible operations on the use of this propagation model. FAA has informally suggested that it would be in accord with such a model, but those discussions have not been finalized.

Proposals for Compatibility for Low Altitude Navigation

In the joint work, LightSquared accepted the possibility of incompatibility with a number of very proximate base stations. For such base stations, LightSquared offered to reduce the EIRP received by the aircraft by one of a number of RF engineering means, including base station transmit power reduction, re-orienting sectors, etc. LightSquared pointed out [1] that, if the surface of takeoff/descent could be defined, then a mathematical model could be constructed to determine the EIRP reduction required of all proximate base stations to ensure that the RFI limit of -34.1 dB is not exceeded. Some excerpts are provided below from [1].Figure C-1shows the scenario geometry whereas Figure C-2 shows contour maps of hypothetical base station locations, with each base at 32 dBW EIRP and its sector pointed at the aircraft. Plots show a plan view of an *x-y* grid around a glide path, with origin at the touchdown point. For any (*x,y*) coordinate in the grid, the contour lines show the *maximum* received power (dBm) at an aircraft located anywhere within the glide path cone from a transmitting base station located at the given coordinate. Therefore, the -34 dBm contour constitutes an exclusion zone around the flight path.

Such contour maps can be used to identify base stations that are primarily responsible for violating the -34.1 dBm requirement and determining the RF engineering steps that need to be taken to ensure compatibility. This was presented to the FAA in the last meeting before technical discussions were terminated. The FAA expressed doubts about the feasibility of administering compliance with such a model. LightSquared believes that site specific deployment rules could be codified, as was the case in the Inmarsat Cooperation Agreement that would meet the -34.1 dBm in the air requirement. Thus, with a manageable amount of additional effort going forward, LightSquared believes that a similar compliance mechanism can be developed with the FAA.

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[52] LightSquared originally proposed using a clutter model for the cone within +/- 6^o but is willing to use the free space model in this region.

Glide Path Cone Model

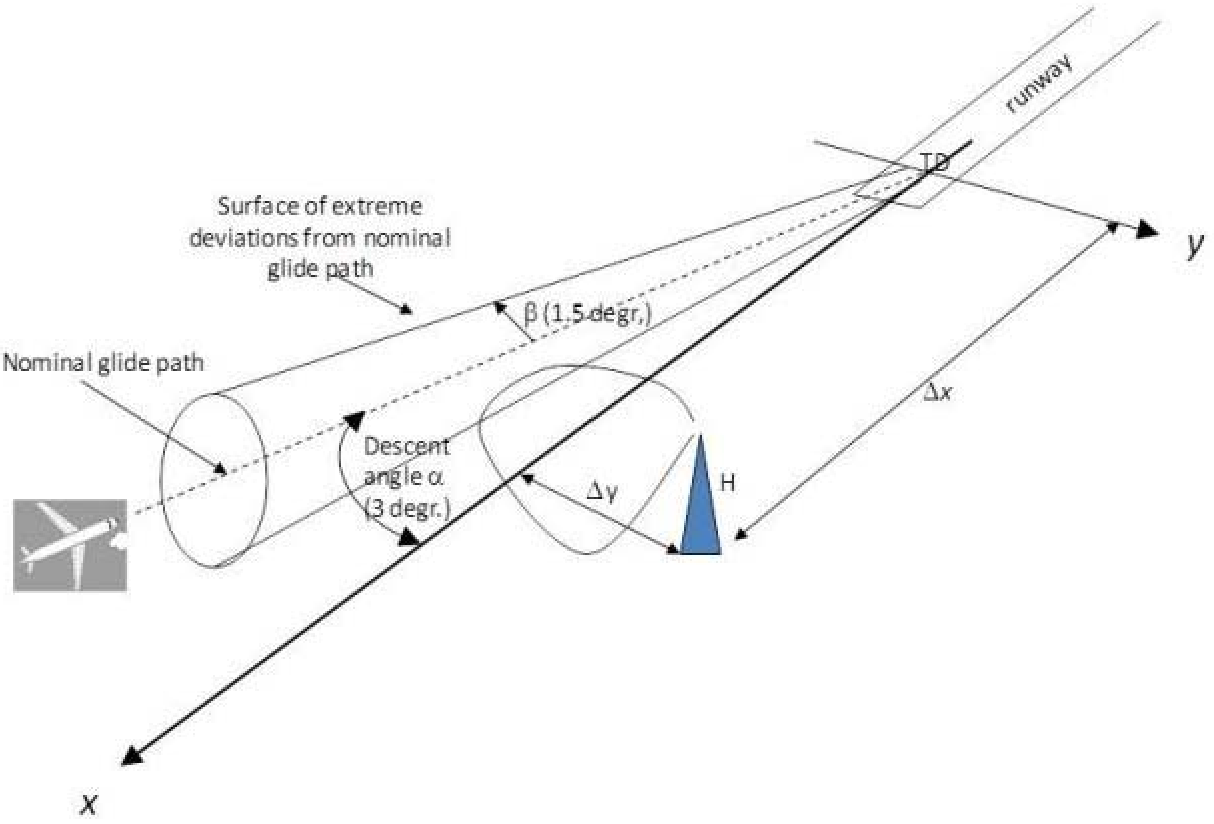

Figure C-1. Scenario Geometery for Aircraft in Final Stages of Descent or initial Stages of Takeoff

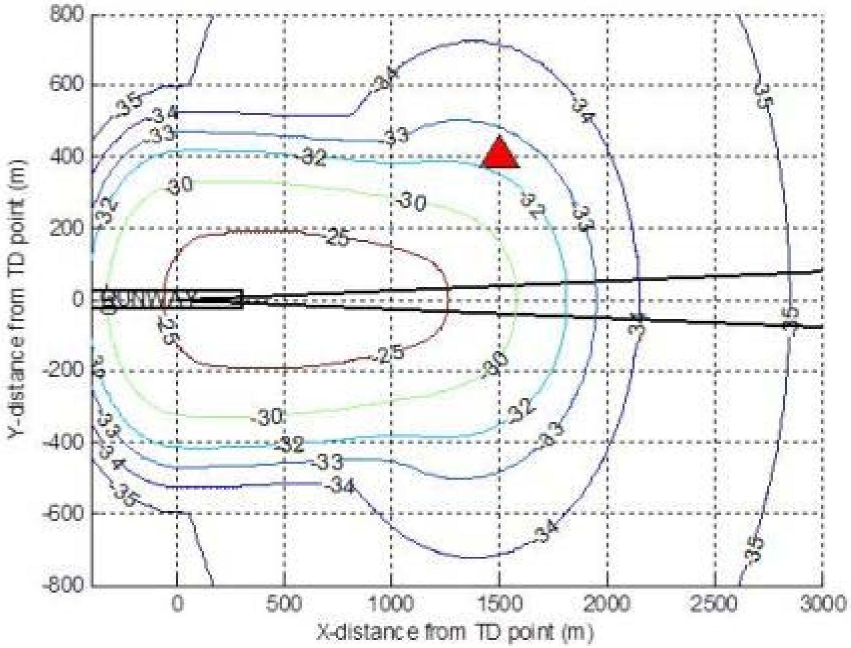

Figure C-2. Aggregate Power (dBm) from 2 Towers
Contours correspond to location of Tower #2 given that Tower #1 is fixed at x-y coordinates (1500,400)

Proposals for Compatibility for Terrain Avoidance Systems[53]

LightSquared has proposed a schedule of base station EIRP reduction with height to meet all the TAWS requirements stated in the FAA Report in Section [1. 4], including the "exclusion zones. " LightSquared understands that the FAA would accept that any exclusion zone that does penetrate a Part 77 notification surface set out in 14 C. F. R. § 77. 9(a), 77. 9(b), 77. 9 (c), 77. 9(d), or 77. 9(e) ("Part 77 Notification Surface") without regard to penetration of an OCS.

LightSquared understands that the FAA would work with it to identify applicable OCSs for instrument procedures and has attached its proposal for evaluating individual exclusion zones to take into account applicable OCS in Attachment 3. To the extent that such surfaces are found to encroach inside the 500'x100' exclusion zone, LightSquared will reduce its power accordingly.

LightSquared's proposal would ensure that, at all points in space outside the exclusion zone, the received RFI power would be less than -34.1 dBm. In essence it would comply fully with Figure 1-3 of this Report. The offer is explained below with respect to material presented in [2].

Figure C-3 shows the power received by an aircraft at 30.5 m altitude (the limiting height above ground where TAWS applies) at different lateral distances from the base station. The other scenario parameters are given below.

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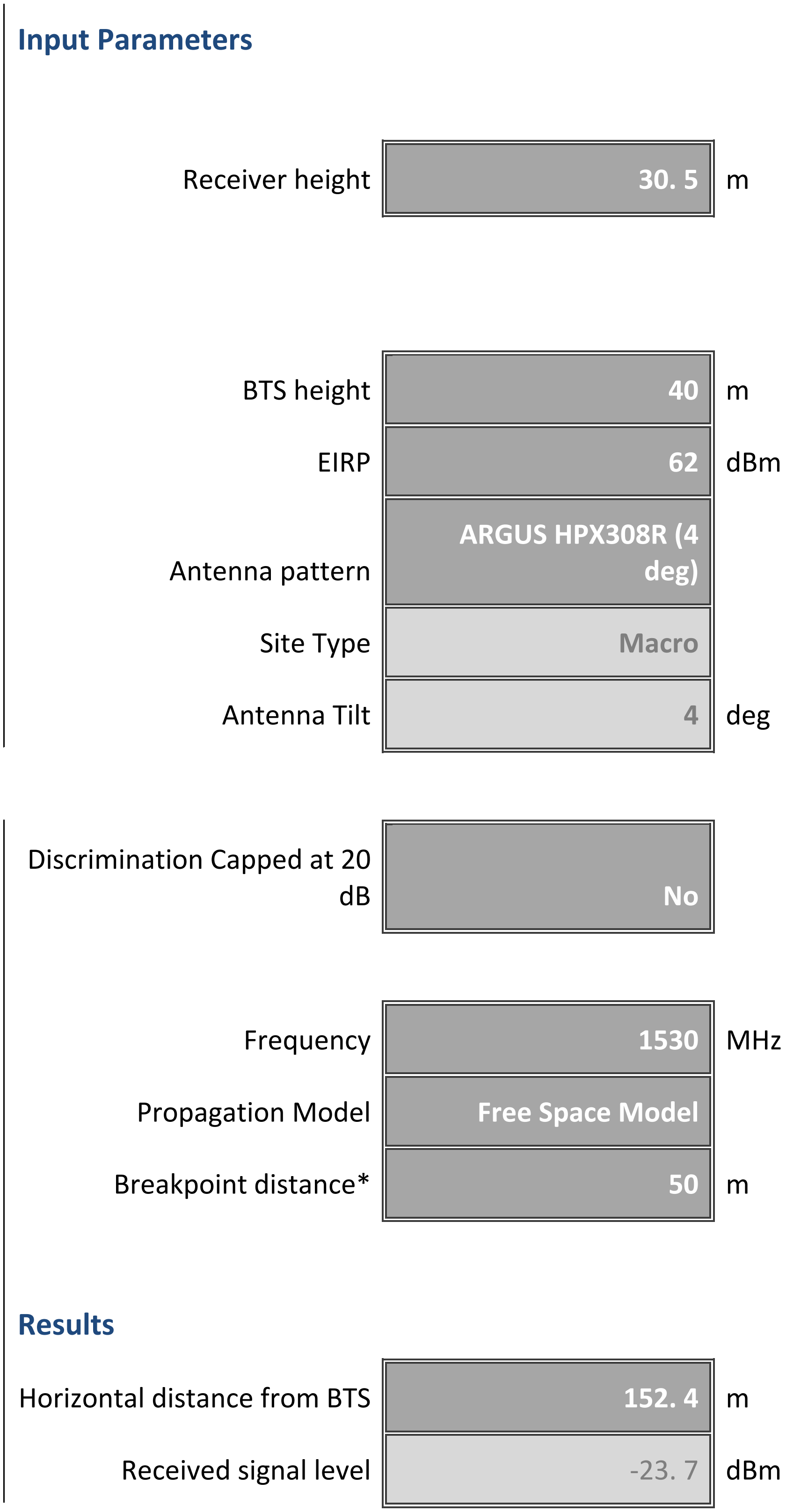
[53] LightSquared's proposal is intended to address both fixed wing TAWS and helicopter TAWS (HTAWS).



Input Parameters

Receiver height	30. 5	m
BTS height	40	m
EIRP	62	dBm
Antenna pattern	ARGUS HPX308R (4 deg)	
Site Type	Macro	
Antenna Tilt	4	deg
Discrimination Capped at 20 dB	No	
Frequency	1530	MHz
Propagation Model	Free Space Model	
Breakpoint distance*	50	m

Results

Horizontal distance from BTS	152. 4	m
Received signal level	-23. 7	dBm

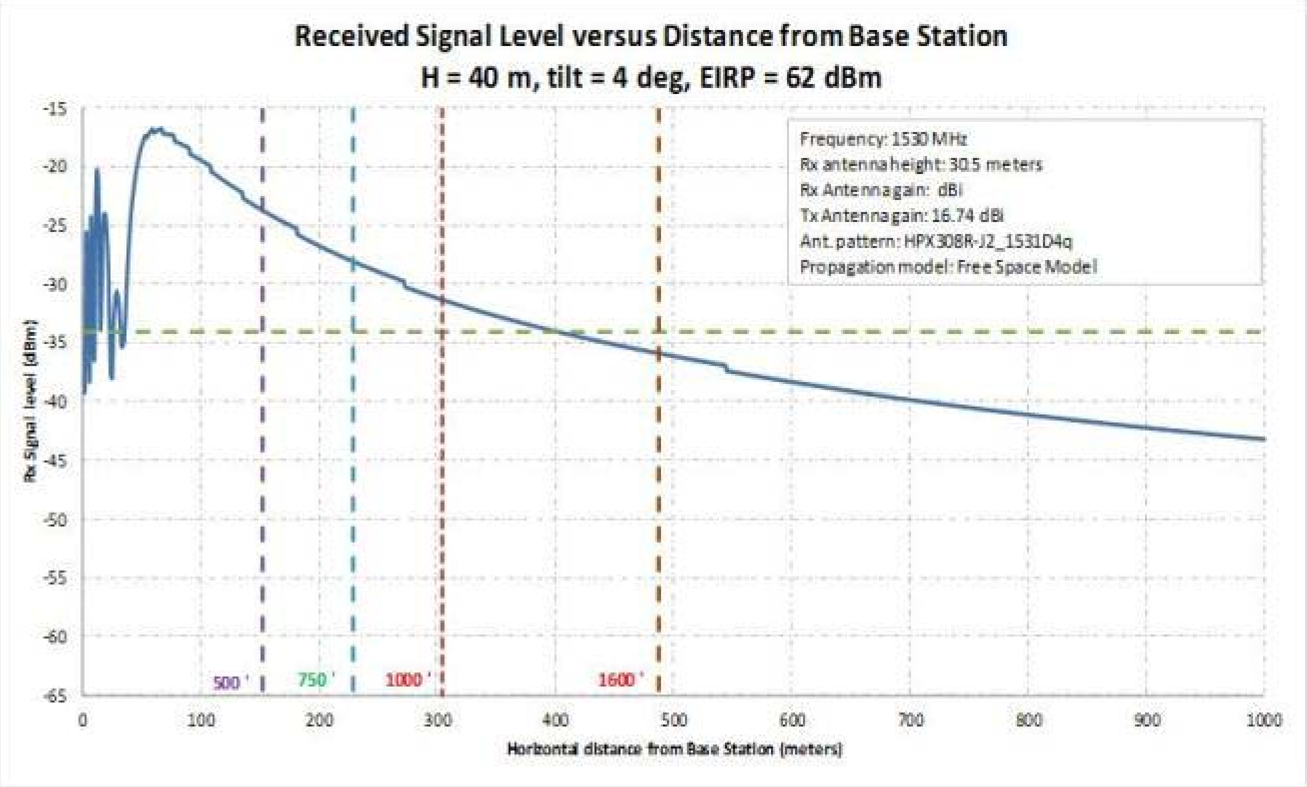


Figure C-3. Power Received by an Aircraft at 100 ft (30. 5m) as a Function of Lateral Separation from the Base Station

Although LightSquared understands that no existing criteria govern or address exclusion zones, the FAA has offered a lateral exclusion distance of 500 ft (152. 4 m) based on the likelihood that the obstacle on which the base station is mounted will be in the obstruction database used by TAWS/HTAWS. At this point on the x-axis, the received power is -23. 7 dBm. The assumed base station EIRP for this model was 62 dBm. To achieve compliance, the base station EIRP needs to be backed off by (-34.1 – (-23. 7) = 10. 4 dB

Using this method, the base station EIRPs (for the example of 4^{o} downtilt) were calculated for all base station heights relevant to the planned LightSquared network. The result is shown Figure C-4 as the red curve (for 500 ft lateral exclusion distance). It can be shown that, owing to the low pattern gain above the base station antenna, offering an exclusion distance to 100 ft of above the antenna, as offered by the FAA, is not the critical determinant of EIRP reduction.

In summary, LightSquared believes that the TAWS/HTAWS for both fixed wing and helicopters can be fully accommodated as per the requirements stated by the FAA.

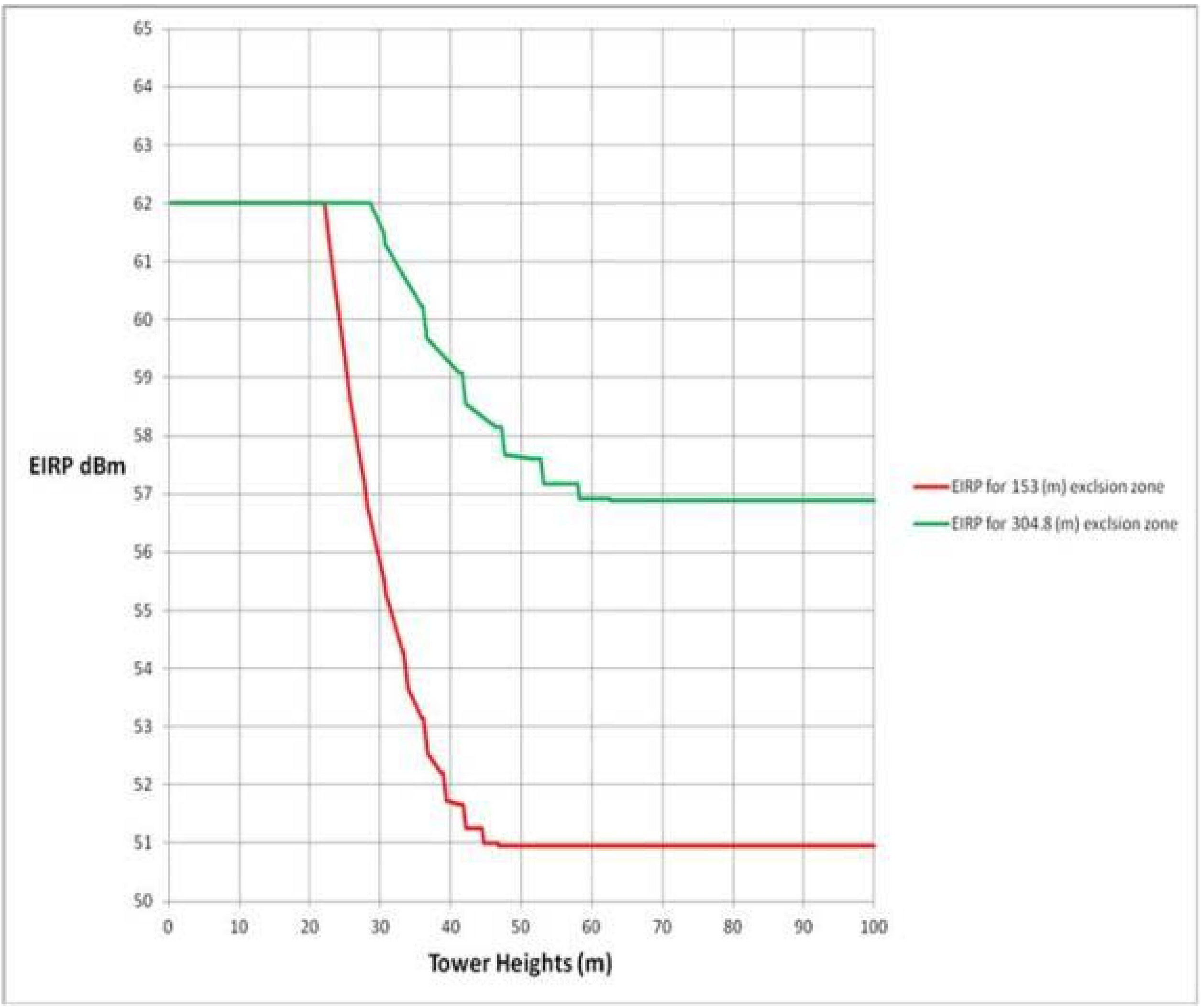


Figure C-4. Schedule of Base Station EIRP's versus Antenna Height required to achieve compliance with TAWS/HTAWS (4o antenna downtilt)

Higher Altitude Navigation

During the past several months, LightSquared and FAA have provided each other with suggested models and allowed the other to provide comments on such models in an effort to reach the most accurate scientific result. The Report's Navigation model, is based on the FAA's *interpretation* of the extended Suzuki model, and does not reflect LightSquared's input. While the FAA had, in fact, proposed the use of the extended Suzuki model based in [3], it cannot be said that it was accepted by LightSquared. The issue of "interpretation" is very important because the cited reference [3] provide no instruction on how to select parameters of the model, such as: $k, \psi_o(r), \rho^2(r), \sigma(r)$ relative to equation (4) of the present report.

The specific method of applying the above model to LightSquared scenarios (i.e. the interpretational aspect), which is now embodied in the report, were never discussed with LightSquared. Thus, it could be said that equations (3) – (9) are *new material* which was introduced by the FAA only after it informed LightSquared that it was suspending further analysis and focused solely on the writing of this report.

The introduction of a new segment in the path loss model, $r_1 – r_2$, is also new although it is acknowledged that it does not play an important part in the 535 m aircraft height scenario.

The FAA has also introduced the concept of a continuously variable standard deviation as a function of lateral range [equations (8) and (9)]. This is new material although, in discussions subsequent to the writing of this draft report, the FAA has pointed out that the particular curve of standard deviation versus range that it selected offered LightSquared a small benefit relative the previous step function.

The logic behind the choice of breakpoint distances, for arbitrary aircraft heights, is unclear. While it is understood that the first segment ($0 – r_1$) ends at the Brewster angle for vertically polarized signals, the logic for deciding r_3 is unclear to LightSquared. In the old FAA model, described below, the breakpoints were simulated as being fixed, i.e., independent of the height of the aircraft. LightSquared had presented many simulation results, for both 535 m and 33 m aircraft heights, with the above assumptions clearly stated and no stated disagreement from the FAA. If the FAA is proposing to make the breakpoints distance (from nadir point) dependent, this needs to be discussed. LightSquared had previously objected to the use of high standard deviation with low path loss exponent as it considers such scenarios to be physically unrepresentative (supported by Dr. Parsons [4]). This effect becomes much more severe in the DCA example [Section 3.3] where a standard deviation of 6.4 dB is attained at a lateral distance of 5.3 km because a large number of base stations emitting power with high standard deviation at short range are involved. LightSquared suspects (without having had the opportunity to replicate the simulation itself) that *this is the primary reason why negative margin is seen in **Table 3-1***. This is discussed further in the following sections.

Open Issues on Propagation Model Above 300 ft

Summary of Objections

The biggest unresolved issue relating to higher altitude propagation (use cases involving aggregate interference from multiple base stations) is the use of low path loss exponent, approaching values appropriate for free space propagation, i.e., 2.0, simultaneously with relatively high standard deviations (in excess of 2 dB).

During the joint work spanning September to December, 2011, the FAA seemed to be proposing a new model relative to DO-327[54] involving the following characteristics:

1. The 8.5 dB standard deviation from the first, lateral-distance breakpoint (where the 2-ray model ended) to the last breakpoint where the cellular channel based, Hata-Okumura model started, used in DO-327, was changed to a variable standard deviation ranging from 0.5 dB to 6.4 dB.
2. During the joint work, the variation of the standard deviation followed a step function with values of

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[54] The FAA model differs from the previous propagation model in the RTCA Report.

   a. 0.5 dB in the 0 - 1.6 km range, where the 2-ray model was applied
   b. 2 dB in the 1.6 – 10 km range, where the mean path loss exponent was 2. 09
   c. 3.5 dB in the 10 – 20 km range where the mean path loss exponent was 2. 09
   d. 6.4 dB for ranges greater than 20 km, where the Hata-Okumura model was applied to calculate mean path loss

3. The variations from the mean path loss were assumed to be caused by log normal distributed slow fading. It was recognized by both LightSquared and the FAA (as per discussions in the joint working sessions) that fast fading could be present but the time scales of such fading were too short compared to GPS receiver integration time of 20 ms to be of any consequence.
4. At the aircraft height of 535 m, which was previously (in DO-327) thought to be the height of greatest RFI, the first breakpoint was at approximately 1.2 km and the last breakpoint was at 20 km, as indicated above. These breakpoints were considered fixed. Although most of the joint work was focused on this aircraft height, LightSquared did present analyses of the FAA model at lower heights using the same propagation model and fixed breakpoints with no objection raised by the FAA [5], [6].

In the first draft of the Final Report made available to LightSquared, the FAA made following additional changes to the propagation model that had not been discussed in the joint work.

1. A new free-space segment was introduced between the end of 2-ray propagation and the onset of segments where the path loss exponent was 2.09. The rationale was unknown to LightSquared at the time of the first draft, although the FAA had subsequently promised to supply the rationale for all aspects of its propagation model in revised drafts.
2. The standard deviation was made continuously variable according to a polynomial, contrasted with the previous step function.
3. The propagation model was applied at an aircraft height of 300 ft with changes in the breakpoint distances. In particular, the last breakpoint distance, was moved to approximately 5.5 km. The rationale was far from clear in the first draft of the report although, as above, the FAA promised to provide clarifications in a subsequent draft.

LightSquared's objections to the above model, both in the version presented in the joint work and that presented subsequently in the first draft of the Final Report are the following.

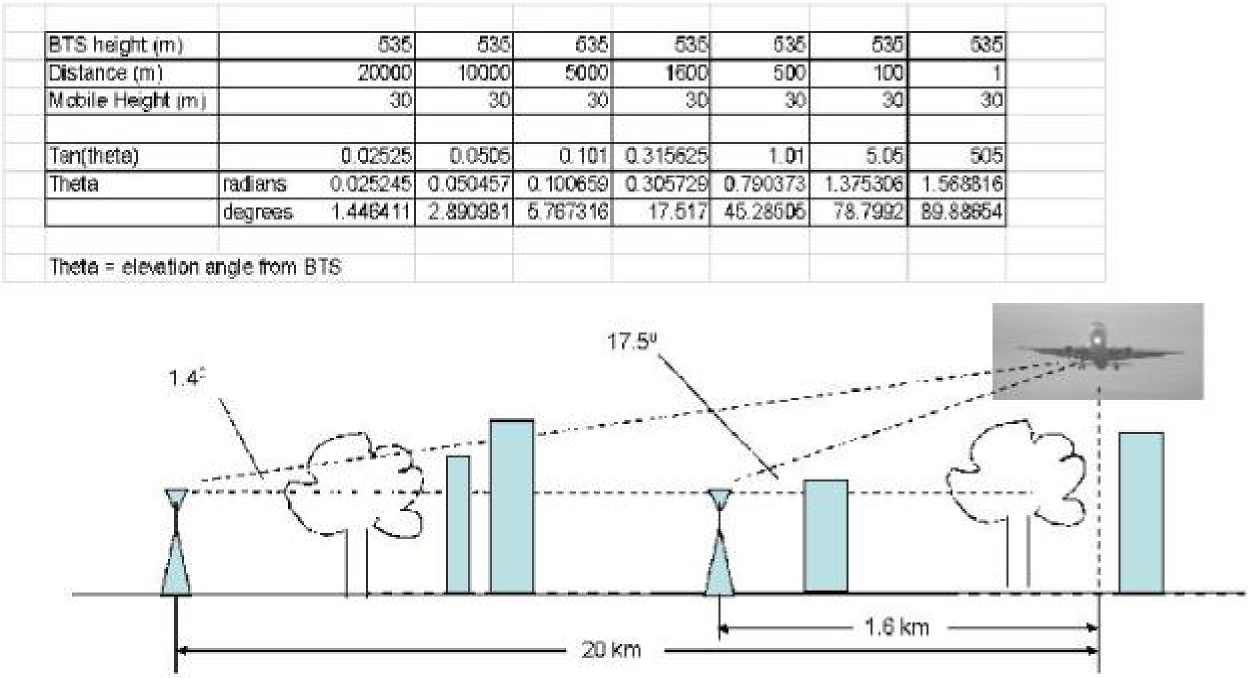
1. The biggest objection is the use of relatively high standard deviations (above 0.5 dB) with low path loss exponent (2.09) in the segments between the end of the first segment and the start of the last segment. The objections are discussed below in greater detail.
2. The re-introduction of fast fading in the Final Report when it had been considered inconsequential owing to its time scale relative to 20 ms. While LightSquared objects to this on both procedural and propagation-physics grounds, it acknowledges that this factor is not a major contributor to the RFI. Therefore it may not be fruitful to devote much additional time to this subject.

LightSquared has persistently pointed out that there is no support in the literature for a particular model of the variation of standard deviation with range. Assuming greater standard deviation is causally associated with greater likelihood of blockage, its blocked/unblocked analysis for LAKIE demonstrates that the blockage factor (S) can, depending on the morphology, actually decrease with range. However, in terms of RFI potential, LightSquared accepts that, at least for the LAKIE scenario, there is not much difference between the FAA proposed polynomial and the previously proposed step function.

It should be apparent from the above, that the main contention regarding the propagation model is the choice of the combination of path loss exponent and standard deviation. Whereas the FAA persists in using a path loss exponent of 2.09 (which is close to that of free space, where the path loss exponent is 2.0) *simultaneously* with a standard deviation in the 2.0 to 6.4 dB range, LightSquared has argued that there must be a monotonic relationship between path loss exponent and standard deviation (when one goes up, so must the other). This has been presented in documents such as [7] – [9].

The FAA states that it has used the MSS literature to guide its selection of propagation model and parameters. However, it has done so selectively, specifically using the standard deviations for blocked and unblocked cases but ignoring what the literature says about mean path loss of MSS signals in blocked cases. LightSquared agrees emphatically that the MSS literature can be used to guide the choice of a propagation model, especially at elevation angles above 5^o where propagation data is available.

Figure C-5 shows the similarity between MSS propagation and the LightSquared, base station to aircraft scenario (the path may be assumed to be reversed by reciprocity).



BTS height (m)		535	535	535	535	535	535	535
Distance (m)		20000	10000	5000	1600	500	100	1
Mobile Height (m)		30	30	30	30	30	30	30
Tan(theta)		0.02525	0.0505	0.101	0.315625	1.01	5.05	505
Theta	radians	0.025245	0.050457	0.100659	0.305729	0.790373	1.375306	1.568816
	degrees	1.446411	2.890981	5.767316	17.517	45.28506	78.7992	89.88654

Theta = elevation angle from BTS

Figure C-5. LightSquared Propagation Scenario (note similarity with MSS propagation)

Two problems with applying MSS propagation data directly to the LightSquared scenarios are (a) that the base station height is considerably above that of an MSS terminal (typically assumed to be 1. 5 m above ground), (b) the statistical data from field trials is often presented as the average over blocked and unblocked cases. However, if the data was identified in the trial as being blocked or unblocked, that data can be applied directly to the LightSquared scenario as the effect of terminal height then becomes less relevant. Fortunately many trials have reported the mean and standard deviations separately for blocked and unblocked cases. Examples are provided from [9], [10] and [11].

Figure C-6reproduces Table 1 from [10], which shows that when the link is rarely blocked, the typical values of standard deviation and mean path loss are 0.5 dB and 0.5 dB, respectively. The mean received power is slight above the free space, unfaded power level (indicated by a positive path loss). This is expected in a Rician channel. However when there frequency blockage, the corresponding values are 3.5 dB and -17 dB. FAA uses the 3.5 dB value but ignores the -17 dB.

Figure C-7 from [11] shows a time plot of signals recorded in MSS links in Europe. It is clear that the variations in the signal (standard deviation) are much greater when the signal is blocked than when it is unblocked.

Figure C-8 shows another time plot of an MSS signal recorded in Canada. It will be observed that, when there is a solid blockage such as a bridge, an additional loss of 15 dB is encountered. However, with tree shadowing, the excess loss varies between 13 dB and a few dBs.

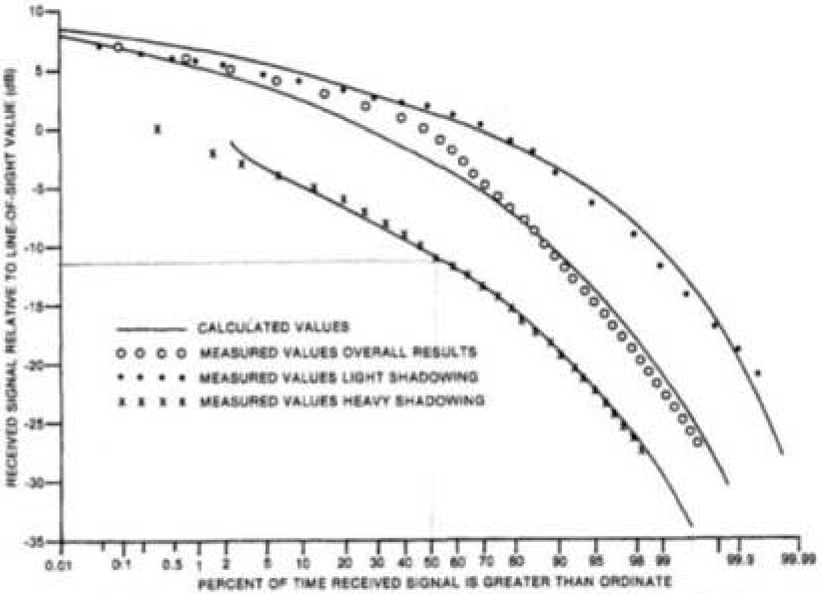


Fig. 1. A comparison of measured and calculated values of the probability distribution of signal.

TABLE I
MODEL PARAMETERS

Conditions	Standard Deviation $10\log_{10}(\sqrt{d_0})$	Mean $10\log_{10}(\mu)$	Multipath Power $10\log_{10}(b_0)$
Infrequent light shadowing	0.5	0.5	-8.
Frequent heavy shadowing	3.5	-17.0	-12.
Overall results	1.0	-3.0	-6

agreement with measured values throughout the fading range. For the combined results, the fit was poor about the median but reasonably good in the weak signal range which is most important for fade margin calculations. The model parameters were obtained by trial and error to fit measured values. These parameters are given in Table I.

Fig. 2 shows values for the LCR calculated using (6) and (25) for the case of infrequent light shadowing. The results show that the maximum LCR occurs when there is no correlation between the rate of change of the envelope due to multipath and that due to shadowing. Measured values [11] for this case are also shown. These results indicate that the model gives a good indication of the LCR, when high correlation, $\rho = 0.5$ to 0.9, between multipath and shadowing is assumed. The figure also indicates that there is a bound on the LCR when the signal is large. Fig. 3 shows a plot of the AFD calculated from the model and from measurements [11]. Application of the model results in a good approximation to the AFD anticipated on a mobile satellite link. For low signal

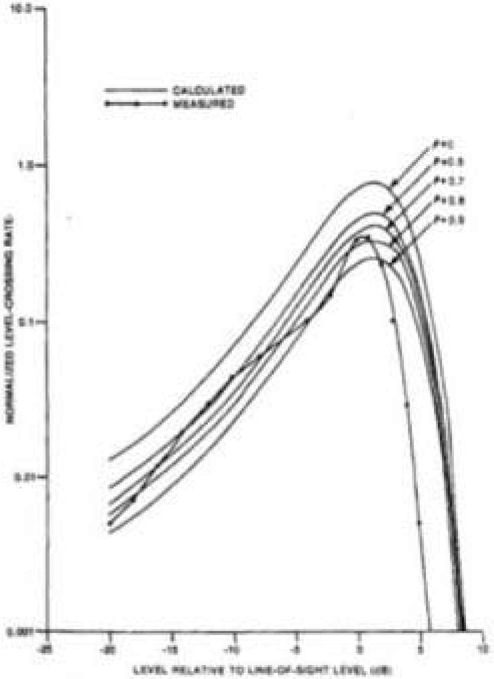


Fig. 2. Level crossing rate—infrequent light shadowing.

Figure C-6. MSS Mean Path Loss and Standard Deviations from Loo [10]
(c. f. Table 1)

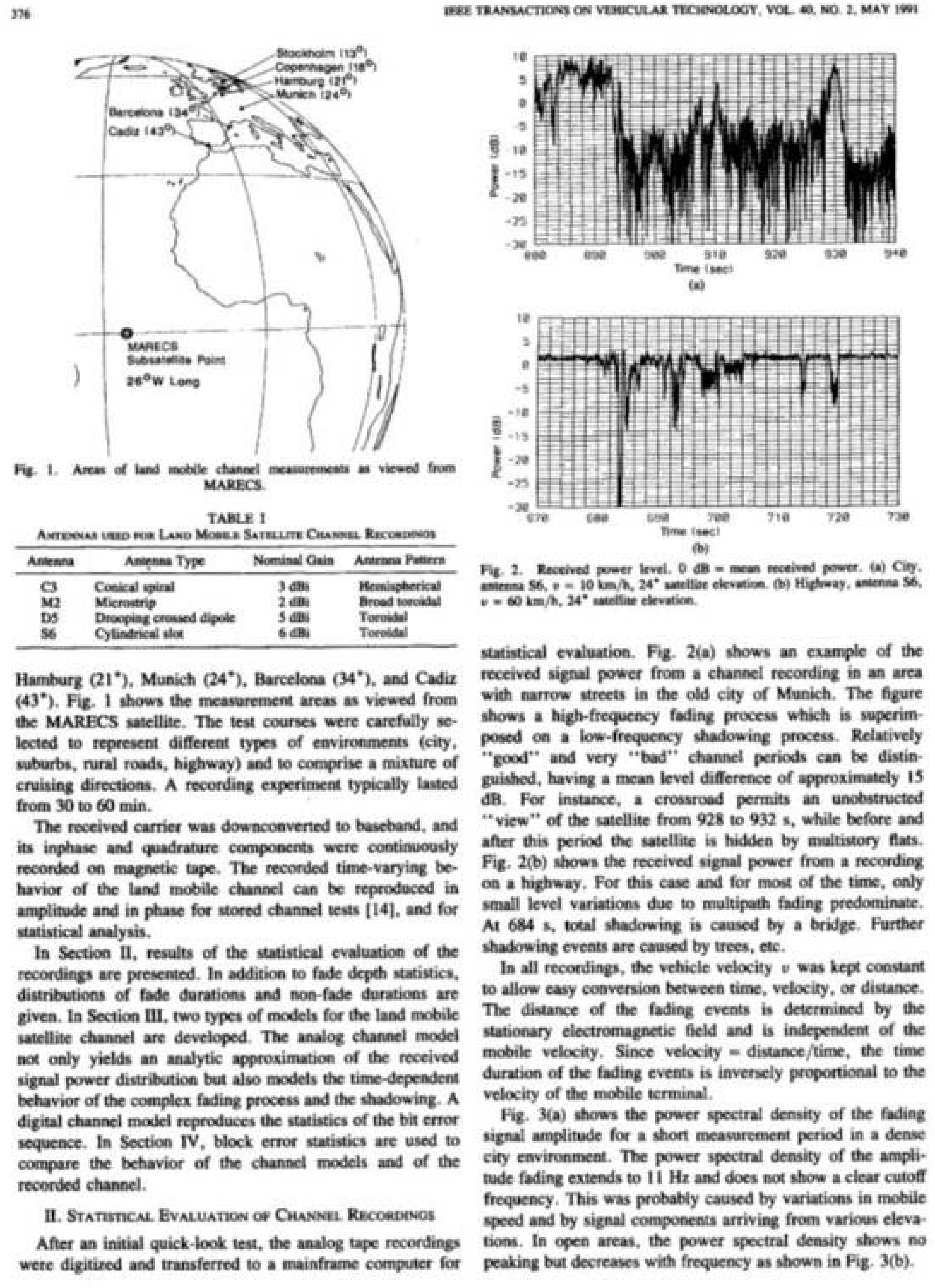


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Fig. 1. Areas of land mobile channel measurements as viewed from MARECS.

TABLE I
ANTENNAS USED FOR LAND MOBILE SATELLITE CHANNEL RECORDINGS

Antenna	Antenna Type	Nominal Gain	Antenna Pattern
C3	Conical spiral	3 dBi	Hemispherical
M2	Microstrip	2 dBi	Broad toroidal
D5	Drooping crossed dipole	5 dBi	Toroidal
S6	Cylindrical slot	6 dBi	Toroidal

Hamburg (21°), Munich (24°), Barcelona (34°), and Cadiz (43°). Fig. 1 shows the measurement areas as viewed from the MARECS satellite. The test courses were carefully selected to represent different types of environments (city, suburbs, rural roads, highway) and to comprise a mixture of cruising directions. A recording experiment typically lasted from 30 to 60 min.

The received carrier was downconverted to baseband, and its inphase and quadrature components were continuously recorded on magnetic tape. The recorded time-varying behavior of the land mobile channel can be reproduced in amplitude and in phase for stored channel tests [14], and for statistical analysis.

In Section II, results of the statistical evaluation of the recordings are presented. In addition to fade depth statistics, distributions of fade durations and non-fade durations are given. In Section III, two types of models for the land mobile satellite channel are developed. The analog channel model not only yields an analytic approximation of the received signal power distribution but also models the time-dependent behavior of the complex fading process and the shadowing. A digital channel model reproduces the statistics of the bit error sequence. In Section IV, block error statistics are used to compare the behavior of the channel models and of the recorded channel.

II. STATISTICAL EVALUATION OF CHANNEL RECORDINGS

After an initial quick-look test, the analog tape recordings were digitized and transferred to a mainframe computer for statistical evaluation. Fig. 2(a) shows an example of the received signal power from a channel recording in an area with narrow streets in the old city of Munich. The figure shows a high-frequency fading process which is superimposed on a low-frequency shadowing process. Relatively "good" and very "bad" channel periods can be distinguished, having a mean level difference of approximately 15 dB. For instance, a crossroad permits an unobstructed "view" of the satellite from 928 to 932 s, while before and after this period the satellite is hidden by multistory flats. Fig. 2(b) shows the received signal power from a recording on a highway. For this case and for most of the time, only small level variations due to multipath fading predominate. At 684 s, total shadowing is caused by a bridge. Further shadowing events are caused by trees, etc.

Fig. 2. Received power level. 0 dB = mean received power. (a) City, antenna S6, $v = 10$ km/h, 24° satellite elevation. (b) Highway, antenna S6, $v = 60$ km/h, 24° satellite elevation.

In all recordings, the vehicle velocity v was kept constant to allow easy conversion between time, velocity, or distance. The distance of the fading events is determined by the stationary electromagnetic field and is independent of the mobile velocity. Since velocity = distance/time, the time duration of the fading events is inversely proportional to the velocity of the mobile terminal.

Fig. 3(a) shows the power spectral density of the fading signal amplitude for a short measurement period in a dense city environment. The power spectral density of the amplitude fading extends to 11 Hz and does not show a clear cutoff frequency. This was probably caused by variations in mobile speed and by signal components arriving from various elevations. In open areas, the power spectral density shows no peaking but decreases with frequency as shown in Fig. 3(b).

Figure C-7. Excerpt from showing Time Plot of MSS Recording in Europe

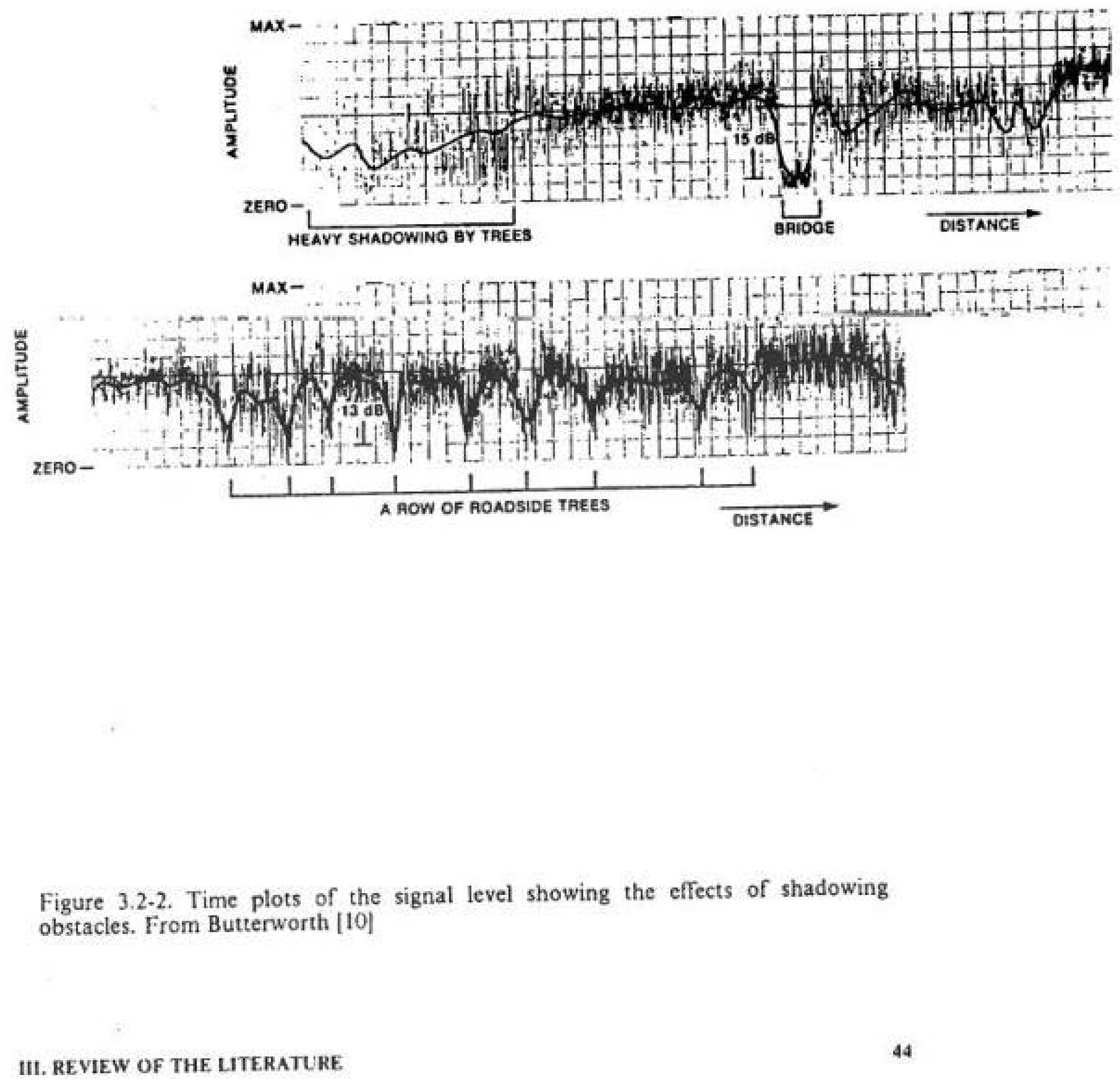


Figure 3.2-2. Time plots of the signal level showing the effects of shadowing obstacles. From Butterworth [10]

III. REVIEW OF THE LITERATURE 44

Figure C-8. MSS Recordings by CRC in Canada [9]

A more detailed review of the MSS literature and its applicability to the choice of propagation models and parameters for the LightSquared RFI scenario is given in [9]. *Sufficient evidence in the MSS literature supports that the mean path loss over free space should be 10 – 17 dB when the direct line of sight (LOS) is blocked*. In such cases, a choice of approximately 3.5 dB is appropriate for the standard deviation. In unblocked cases, it is appropriate to choose a mean path gain of 0.5 dB and a standard deviation of 0.5 dB.

LightSquared had presented an opinion from well-known and highly respected cellular propagation expert, Dr. David Parsons, which corroborated LightSquared’s position that it is unrealistic to simultaneously use low path loss exponent and high standard deviation [4]. To quote Dr. Parsons:

> “One cannot, at the same time, have a low path-loss exponent and a high standard deviation. A received signal that varies significantly, points to the existence of several propagation paths contributing to that signal. An exponent close to 2 indicates predominantly free space propagation. The two do not fit well together. ”

Application of Higher Altitude (Aggregate Base Station) Navigation Propagation Model to DCA Scenarios

The FAA models (before the changes in the draft Final Report) were:

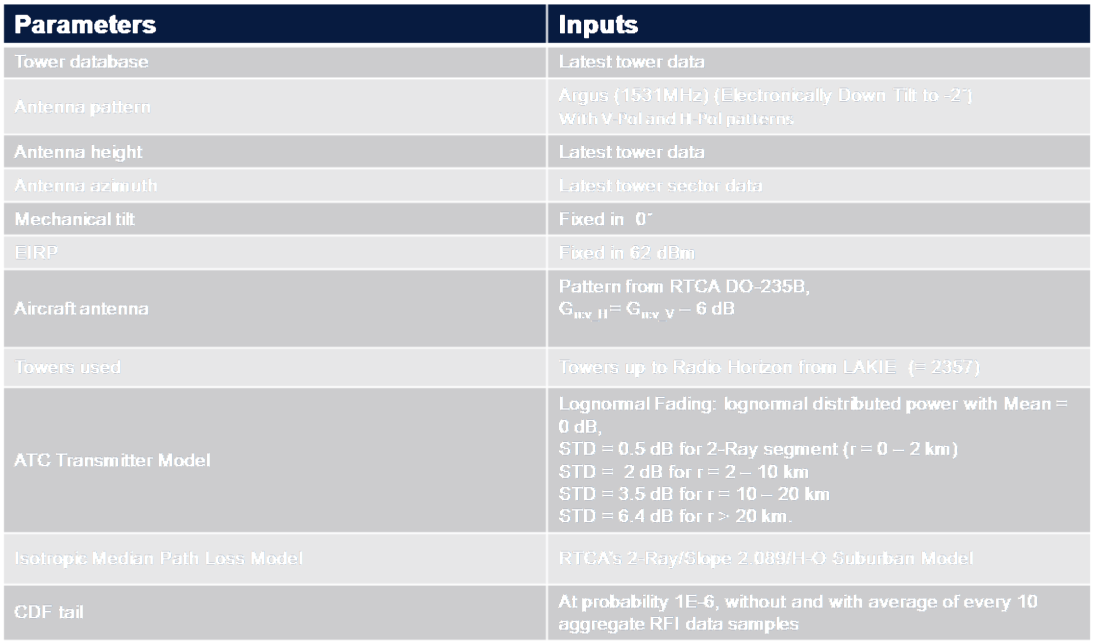
- 0 – 1.6 km: 2-ray model with 0.5 dB standard deviation
- 1.6 – 10 km: mean path loss exponent 2. 09 dB, slow lognormal fading with 2.0 dB standard deviation
- 10 – 20 km: mean path loss exponent 2. 09 dB, slow lognormal fading with 3.5 dB standard deviation
- 20 km: mean path loss exponent given by RTCA modified Hata-Okumura model, slow lognormal fading with 6.4 dB standard deviation

The results are shown below.

FAA Model:

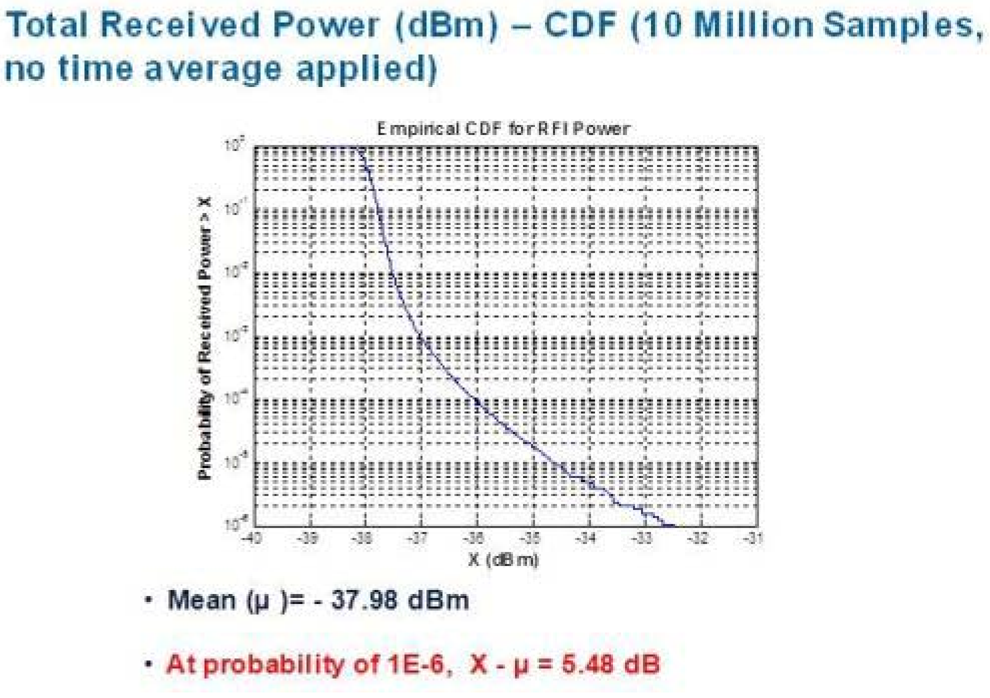
Mean RFI level:	-38 dBm
RFI level at CDF tail corresponding to P=1E-6:	-32.5 dBm

The results for the FAA model are shown in Figure C-9 (input parameters) and Figure C-10 (CDF result).



Parameters	Inputs
Tower database	Latest tower data
Antenna pattern	Argus (1531MHz) (Electronically Down Tilt to -2˚) With V-Pol and H-Pol patterns
Antenna height	Latest tower data
Antenna azimuth	Latest tower sector data
Mechanical tilt	Fixed in 0˚
EIRP	Fixed in 62 dBm
Aircraft antenna	Pattern from RTCA DO-235B, $G_{rcv\_H} = G_{rcv\_V} - 6$ dB
Towers used	Towers up to Radio Horizon from LAKIE (= 2357)
ATC Transmitter Model	Lognormal Fading: lognormal distributed power with Mean = 0 dB, STD = 0.5 dB for 2-Ray segment (r = 0 – 2 km) STD = 2 dB for r = 2 – 10 km STD = 3.5 dB for r = 10 – 20 km STD = 6.4 dB for r > 20 km.
Isotropic Median Path Loss Model	RTCA's 2-Ray/Slope 2.089/H-O Suburban Model
CDF tail	At probability 1E-6, without and with average of every 10 aggregate RFI data samples

Figure C-9. Input Parameters for FAA Model



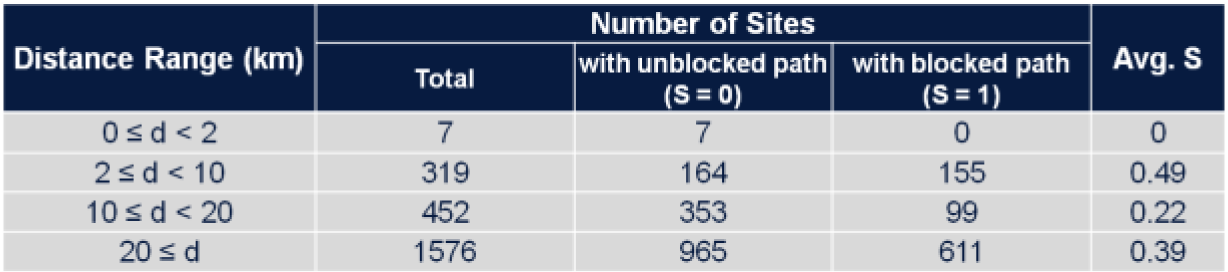
Total Received Power (dBm) – CDF (10 Million Samples, no time average applied)

- Mean (μ)= - 37.98 dBm
- At probability of 1E-6, X - μ = 5.48 dB

Figure C-10. Received RFI Power for LAKIE Scenario and old FAA Model

The RFI power levels at both the median (used interchangeably with mean) and P=1E-6 levels are critically dependent on assumptions about the path loss exponent and the standard deviation of the slow fading. To test LightSquared's hypothesis that the path loss exponent assumed by FAA for lateral distances in the 1.6 – 20 km range was too low, a "blocked/unblocked" propagation analysis was performed for the LAKIE control (nadir) point where the morphology database around the above control point was used in the following way.

Blockage data applicable to LAKIE was used to determine the probability of blockage (Avg. S) in each of the zones 2 – 4 [12]. This data is available in cellular planning tools like CelPlan. The results are shown below.



Distance Range (km)	Number of Sites			Avg. S
	Total	with unblocked path (S = 0)	with blocked path (S = 1)	
0 ≤ d < 2	7	7	0	0
2 ≤ d < 10	319	164	155	0.49
10 ≤ d < 20	452	353	99	0.22
20 ≤ d	1576	965	611	0.39

From the above it is evident that, in the critical 2 – 10 km range, where the majority of the RFI contribution originates, 49% of the base stations are blocked from clear LOS. Yet, the FAA model assumes that each will contribute *more free space power*[55] to the net RFI.

Based on the MSS literature teachings discussed above, in particular Loo [10], a Monte Carlo simulation model was built with the following attributes:

1. Base stations in each of the above zones were randomly declared as blocked and unblocked based on the S-factor for the zone. An exception was the 0 – 2 km zone, where the unmodified, 2-ray FAA model was used)
2. If the base station was unblocked, it was assumed to have a gain of 0.5 dB over the free space path loss and a slow fading component with a standard deviation of 0.5 dB
3. If the base station was blocked, it was assumed to have a loss of 10 dB[56] relative to free space path loss and a slow fading component with a standard deviation of 3.5 dB.

The resulting CDF distribution is shown in Figure C-11 below.

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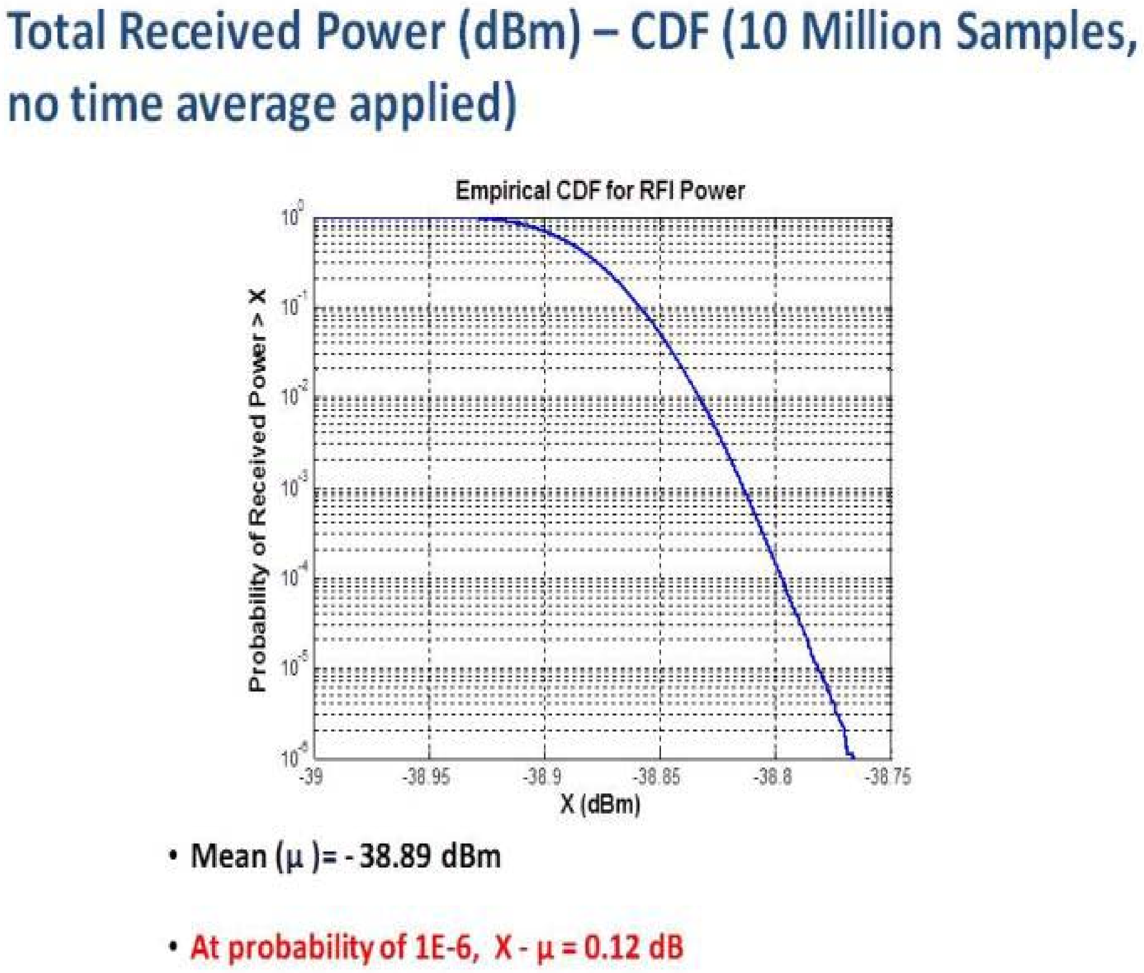
[55] The contribution is greater than free space owing to the assumed lognormal variation centered on the mean power.

[56] Loo suggested using a mean path loss of 17 dB. This was reduced to 10 dB to account for the fact that a blocked base station would have 3 sectors and therefore 3 times the power of a single sector, i. e., 7 dB greater power than the maximum value of 32 dBW. Power from all sectors would have the potential to contribute to the net RFI through reflections and diffraction.



Total Received Power (dBm) – CDF (10 Million Samples, no time average applied)

- Mean (μ)= - 38.89 dBm
- At probability of 1E-6, X - μ = 0.12 dB

Figure C-11. CDF Distribution of RFI Power for LAKIE (535 aircraft height) using Blocked/Unblocked Analysis

The following are the major conclusions from this result:

- At 1E-6, there is an approximately 5 dB positive margin (-34.1 – 38.77 = 4.7 dB) compared to a 1.5 dB negative margin with the old FAA model.
- *The CDF curve is extremely steep*. This is to be expected owing to the fact that most of the variation comes from base stations that have 10 dB blockage, the unblocked base stations contributions are very little as they have a standard deviation of 0.5 dB.

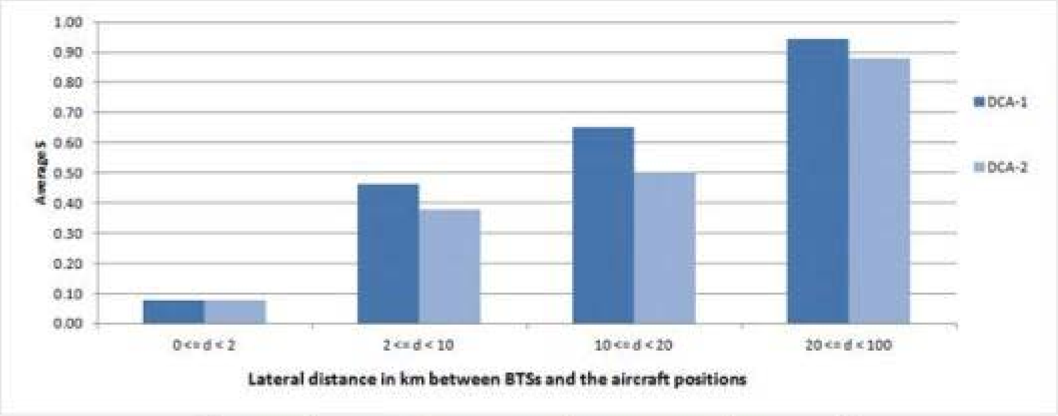
In summary, *the probabilistic element of the propagation model is largely redundant*.

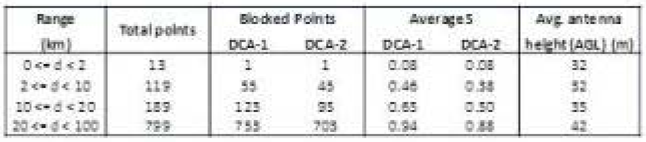
FAA questioned whether 10 dB loss was adequate to characterize a blocked base station, notwithstanding the evidence in the MSS literature, which showed losses in the 10 – 20 dB range. To provide further support for the 10 dB value, ray tracing was performed for a number of specific base stations near the LAKIE control point [13]. They showed that the blockage loss was well in excess of 10 dB. An analysis was also performed using the theory of radar cross sections, which supported the same conclusion [14].

Application of High Altitude Navigation Propagation Model to DCA Scenarios

In the Final Report (3.3.1 DCA Runway 19 Approach Scenario Description), the FAA has shown examples of applying its new, high altitude propagation model to two DCA scenarios at an aircraft height of 300 ft. The results show negative margins up to 6.9 dB and 8.0 dB for Tracking at P=1E-6 with banking. These results were revealed to LightSquared for the first time in the first draft of the Final Report. In the extremely short time available thereafter, LightSquared ran the blocked/unblocked analysis, as described above[57], for these two scenarios without banking. There was insufficient time to run the scenarios with banking. However, the FAA's results show that the impact of banking in both of these scenarios was 3 dB.

The results are shown below. More detail is provided in [15] and [16]. [58]





Range (km)	Total points	Blocked Points		Average S		Avg. antenna height (AGL) (m)
		DCA-1	DCA-2	DCA-1	DCA-2	
0 <= d < 2	13	1	1	0.08	0.08	32
2 <= d < 10	119	55	45	0.46	0.38	32
10 <= d < 20	189	125	95	0.65	0.50	35
20 <= d < 100	799	755	703	0.94	0.88	42

Figure C-12. Blockage (S) factors for DCA-1 and DCA-2

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[57] An improvement was made to the blocked/unblocked propagation model for these runs. Instead of randomly assigning a blocked or unblocked status to base stations in a given zone according to the S-factor for that zone, the actual blocked/unblocked status of the base station, determined from a cellular planning tool with a morphology database, was used. This makes the results more specific to the site being analyzed.

[58] The reports in [15] and [16] have not been shared or discussed with the FAA as they were prepared after technical discussions were suspended.

CDF Simulation Parameters

Parameters	Inputs
Tower database	Latest tower data
Antenna pattern	Argus (1531MHz) (Electronically Down Tilt to -2˚) With V-Pol and H-Pol patterns
Antenna height	Latest tower data
Antenna azimuth	Latest tower sector data
Mechanical tilt	Fixed in 0˚
EIRP	From latest tower data
Aircraft antenna	Pattern from RTCA DO-235B, $G_{rcv\_H} = G_{rcv\_V}$ for elevation at or above 45º G_{rcv_H} fall off relative to G_{rcv_V} up to a maximum difference of 6 dB for the horizon and below.
Towers used	Towers up to Radio Horizon (4/3 Earth radius approx.) for DCA-1 (1072 towers), DCA-2(1087 towers) (aircraft and towers heights in MSL are used for computations)
Lognormal Fading Model	Mean = 0 dB, STD = 0.5 dB for r = 0 – 0.306 km; Loo's lognormal fading model parameters with ***actual*** blockage (LOS/NLOS) analysis data for each specific tower for r > 0.306 km: • Mean = 0.5 dB, STD = 0.5 dB for LOS, • Mean = **-10 dB**, STD = 3.5 dB for NLOS.
Isotropic Median Path Loss Model	2-Ray (r = 0 – 0.306km)/Free-space (r > 0.306 km) Model
CDF tail	At probability 1E-3 At probability 1E-6

Figure C-13. Simulation Parameters for Blocked/Unblocked Analysis applied to DCA-1 and DCA-2

Total Received Power (dBm) – CDF for DCA-1 & DCA-2 (10 Million Samples, no time average applied)

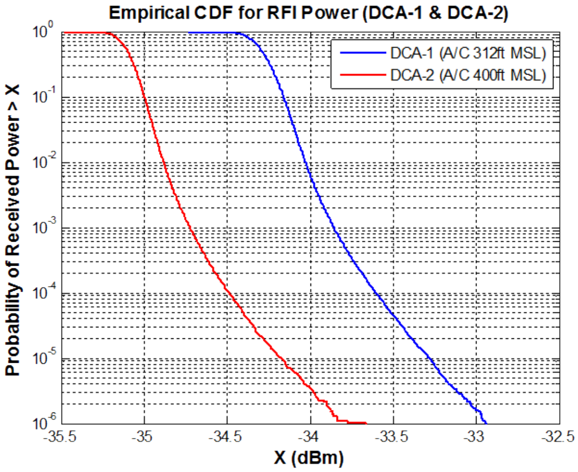

Figure C-14. Results of Blocked/Unblocked Analysis applied to DCA-1 and DCA-2 (All Base Stations at 32 dBW)

	DCA-1	DCA-2
Mean	-34.28 dBm	-35.10 dBm
At Probability 1E-3	-33.80 dBm	-34.75 dBm
At Probability 1E-6	-32.92 dBm	-33.65 dBm

The above results show the following:

- Mean Value: Both DCA-1 and DCA-2 satisfy the mean value threshold of -34.1 dBm (although DCA-1 has little additional margin).
- Acquisition at P=1E-3: DCA-1 has a negative margin of 0.3 dB and DCA-2 has a positive margin of 0.65 dB relative to the threshold of -34.1 dBm.
- Tracking with banking at P=1E-6 (assuming that the power will increase by 3 dB owing to banking): DCA-1 has a positive margin of 0.82 and DCA-2 has a positive margin of 1. 55 dB relative to the threshold of -30.1 dBm

In general, the pass/fail margins above are quite small (most are less than 1 dB). However, *if one accounts for the base station EIRP backoffs offered by LightSquared to accommodate the TAWS requirements, the margins become substantially positive (in excess of 6 dB), as shown in Figure C-15.* These results were produced with the same scenario as for Figure C-14 except that, whereas in the scenario of Figure C-14 all base stations had an EIRP of 32 dBW, in the scenario of Figure C-15, the base stations had an EIRP that was height dependent according to the red curve in Figure C-15.

In summary:

- The negative margins shown by the FAA model in the DCA-1 and DCA-2 cases are primarily the result of the assumption of low path loss exponent and high standard deviation, for which the FAA had provided no support at the time of writing LightSquared's section of this report. [59]
- When analyzed with a simple free space model for unblocked base stations out to the radio horizon and 10 dB additional loss for blocked base stations, with standard deviations support by the MSS literature (0.5 dB for LOS and 3.5 dB for NLOS cases) both DCA-1 and DCA-2 pass marginally in all cases and fail marginally (by 0.3 dB) for Acquisition, when all base stations are assumed to be at 32 dBW.

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[59] As noted above, LightSquared's response is limited to the materials in the FAA report as of December 23, 2011.

- When the above scenario is run with the base station EIRP backoffs offered by LightSquared to accommodate TAWS, the margin is greater than 6 dB in all cases.

It is quite possible that if the reduced base station EIRPs were used with the latest FAA model, all scenarios would also show positive margin. However, this needs to be verified in the follow on work proposed by LightSquared.

Total Received Power (dBm) – CDF for DCA-1 & DCA-2 (10 Million Samples, no time average applied)

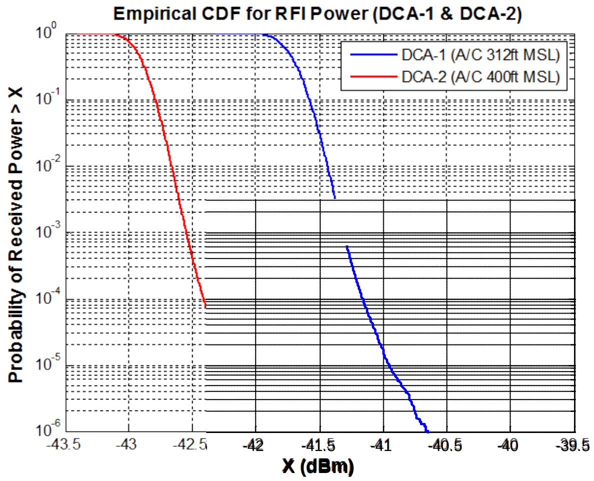


Figure C-15. Results of Blocked/Unblocked Analysis applied to DCA-1 and DCA-2 (Base Stations EIRPs backed off to accommodate TAWS according to 5-4)

	DCA-1	DCA-2
Mean	-41.73 dBm	-42.92 dBm
At Probability 1E-3	-41.30 dBm	-42.56 dBm
At Probability 1E-6	-40.64 dBm	-41.92 dBm

Additional Corrections

This section catalogs the instances where the main Report incorrectly represents LightSquared's analysis and conclusions. LightSquared offers the following clarifications and corrections to the FAA Report:

Report Section	Topic	LightSquared Position
1.2	Older Receivers	LightSquared notes that older receivers, certified to pre-DO-229 standards are far more likely to be compatible with LightSquared's system, and LightSquared believes that no increased risk exists.
1.3	Tracking & Acquisition	The Report states that "results from testing a limited number of certified receivers has indicated that tolerable interference levels are nearly equivalent for CW and a 10 MHz broadband noise signal centered at 1531 MHz. " The tolerance for a 10 MHz bandwidth LTE signal with a center frequency of 1531 MHz was found to be 0. 7 dB greater than for a CW signal at 1531 MHz, which adds margin for the RFI tolerance. With respect to the Note in Section 1. 3: When a receiver is in the Tracking mode, owing to the typically low (few Hz) tracking bandwidth of the receiver, a single, short duration (under 100 ms) RFI pulse is unlikely to cause loss of Tracking. Further, LightSquared does not agree that the assurance of continuity of service should be based on assessing the probability of RFI at values lower than 10^{-6}, especially where the above probability is calculated as P^N, where P is the probability of the RFI exceeding the RFI threshold and N is an arbitrarily chosen large number (assuming N independent occurrences of the RFI event). This opposition is based on two major factors. The first is that a single, short pulse of RFI is unlikely to cause loss of Tracking, as described in the previous footnote. The second is that the statistical models used in this analysis (Rayleigh, Rician, etc.) cease to accurately predict the actual distribution of RFI at very low probabilities, such as 10^{-6}, i.e. at the tails of the distribution. To assume that the method can be extended to even lower probabilities is unfounded.

1.4	Areas of Operation	- No consideration is given to non-GPS-dependent modes (radio altimeter). In fact, these modes provide a large proportion of the protection provide by TAWS, particularly for Class A equipment. - Not all rotorcraft operations require HTAWS. In these operations, loss of GPS data would not significantly affect safety of flight. - Figures 1-2 and 1-3: For fixed-wing operations, TAWS protection is actually higher than the figures imply.
2.1	Peak gain of Argus antenna	- The value of 16. 94 is incorrect. The correct value is 16. 74.
2.5	6 dB Difference	LightSquared does not agree to the 6 dB difference in the response of GPS receive antenna to vertical and horizontal linear polarization. LightSquared agreed to use it in calculations to determine (a) if its calculations matched those of the FAA, and (b) to determine if a positive margin would result even with the extreme conservatism embodied in the 6 dB difference. LightSquared believes, as stated in documents presented to the FAA in meetings during the study that, based on the example antenna pattern used in the first RTCA Report, which is based on DO-235B, Fig. G-13, a minimum discrimination of 11 dB is appropriate in the elevation angel range of 0 to -30 degrees. It is also noteworthy that the RTCA Report DO-235B states, “For horizontal polarized signals in the backlobe region, the data suggest a conservative polarization mismatch loss factor is 15 dB.” [p. G-14]
3.1.1	Deterministic Model	LightSquared’s views on the applicability of the 2-ray model, i.e. that it should be applied for elevation angles greater than 6^o, which is also supported by the previous RTCA report (DO-327) on the same subject, are not mentioned. In fact, the present report states a contrary view in Section 3.1.1, where it is opined that the 2-ray model should be used for “low-level operations, close to the ground”. Even the new FAA model uses the 2-ray model at aircraft heights up to 535 m for lateral ranges up to 1. 6 km. The characterization of the RTCA DO-327 recommendation appears to be different from what is stated in DO-327 (first RTCA report on the subject of LightSquared RFI). The latter specifies that the 2-ray model should be used for aircraft

		heights below 550 m and lateral distances of up to a few hundred meters [Section B. 3.1.1], not just for "low-level operations". In DO-327, the lateral distance up to which the 2-ray model is applied depends on the path geometry and in particular the elevation angle relative to the base station antenna. When the aircraft is at a height of 535 m, the 2-ray model is applied up to a lateral distance of 1. 6 km, at which point, the direct ray launch angle is 17. 6 degrees, which corresponds to the Brewster angle. In the case when the aircraft height is 53 m [Section B. 3.2.2], the 2-ray model is applied only up to 223 m, again using the Brewster angel as the cutoff point for the use of the 2-ray model. In [Section B. 3.1.1.1] the following is further stated about the applicability of the 2-ray model, "This model should be reasonably accurate out to a lateral radius where the direct ray launch angel toward the aircraft antenna is above about 6 degrees. For radii much beyond that point, more complex scattering, blockage, and shadowing effects become significant. " <u>LightSquared supports the view that the use of the 2-ray model be restricted to elevation angles greater than 6 degrees</u>, referenced to the base station antenna, owing to the high probability of side-scatter for low elevation angles. It is noteworthy that side-scatter from surrounding structures will typically involve much greater time dispersion than is the case in the 2-ray model; this will prevent the flat (frequency independent) fading that is inherent in the 2-ray model for a 10 MHz bandwidth LightSquared signal. It is the flat fading that causes the recurring, sinusoidal variation in interference power, reaching peak levels of up to 6 dB above the free space value.
3.1.1	Figures	While these figures represent scenarios that are *theoretically* possible, many of them violate the *6 degree elevation angle rule for the applicability of the 2-ray model*, which is discussed in the previous comment. It is noteworthy that at the higher elevation angles, where the 2-ray model might be applicable, two counteracting effects come into play – (i) the reflection coefficient becomes small for vertical polarization, approaching zero for the Brewster angle, which is around 10 – 20 degrees; (ii) as the elevation angle increases from grazing incidence, the phase of the reflected, vertically polarized signal changes rapidly from -180 degrees towards negative 10 to 20 degrees. Both of these effects reduce the peak rise of the LightSquared signal above the free space value.

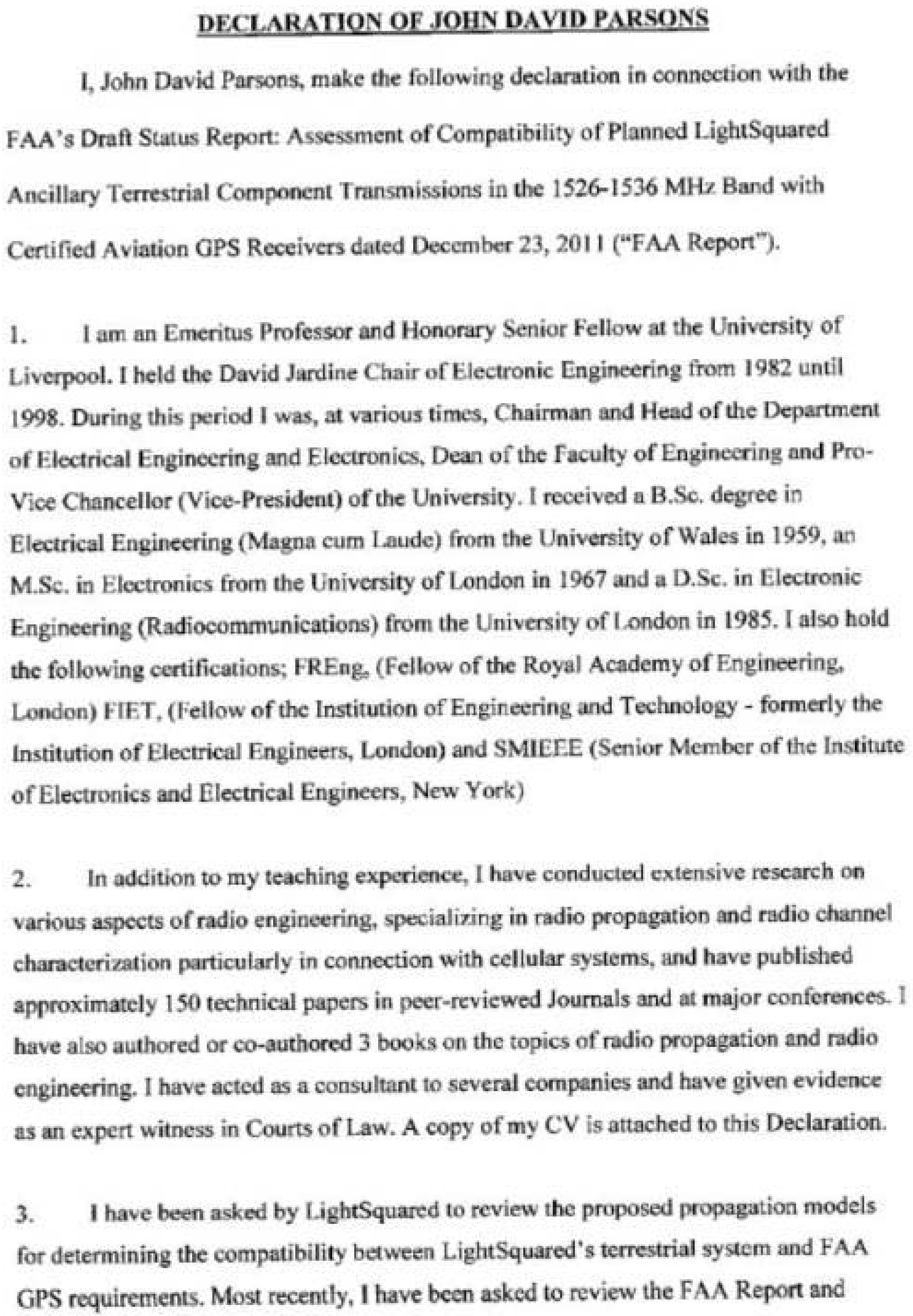
3.1.2	Probabilistic Model	As discussed above, this new model was not presented to LightSquared prior to this report. Re: “The parameter Γ is selected to provide continuity in path loss”. Both LightSquared and its consultant and industry expert, Dr. Parsons, have stated [4] that they consider this a totally artificial requirement, especially as it involves assuming an exponent close to 2 for considerable lateral distances while claiming that there is significant scattering (standard deviation much greater than 0. 5 dB) up to such distances. The only benefit of this assumption is mathematical convenience – it is unsupported by physical evidence and severely burdens the LightSquared network. Re: incorporation of fast fading in the Extended Suzuki Model, as represented by $\psi_o(r), \rho^2(r)$. It is appears that the FAA is now recommending the re-incorporation of fast fading in the propagation model. It had been agreed that that time scale of changes in the RFI power caused by fast fading were sufficiently short compared to the GPS receiver integration period of 20 ms that their effect would be averaged out. Therefore it was agreed between the FAA and LightSquared that all CDF analyses would be based on the slow fading component alone. Re: continuously variable standard deviation. This is new relative to the “FAA Model” discussed in LightSquared-FAA meetings. LightSquared has seen no support for this in the literature – MSS or Cellular. However, LightSquared does not have an incremental objection on this account relative to the previous FAA model as the particular polynomial chosen yields slight lower RFI for the LAKIE scenario than the step-function standard deviation.
3.2.2	LAKIE Scenario – Specific path loss parameters	The FAA model discussed previously had 4 segments separated by fixed break points: (0 -1. 6 km), (1. 6 – 10 km), (10 – 20 km) and (>20 km). This is a new FAA Model, which LightSquared has not had an opportunity to evaluate.
3.2.3	LAKIE Scenario – Aggregate	As discussed previously in comments to Section 1. 3, LightSquared does not believe this is a valid approach for assessing service continuity probability.
3.3.3	DCA – Site Specific – Table 3-1	LightSquared disagrees with the use of 6. 4 dB standard deviation at approximately 6 km with a path loss exponent of 2. 09. This is unrealistic and without support in the propagation literature to LightSquared’s knowledge.

		LightSquared believe that this may be the main reason why Table 3-1 shows negative margin for many cases. LightSquared considers the result too pessimistic, based on the unrealistic assumption of a path loss exponent of 2. 09 out to approximately 5 together with a standard deviation of 6. 4 dB in the range shown.
3.4.2	LGA Airport	LightSquared views the 2-ray model as inappropriate here due to the low elevation angle at launch and the significant likelihood of side-scatter. For the scenario used, it passes with approximately 2 dB margin for free space propagation.
3.5	TAWS/HTAWS	TAWS protection surfaces will potentially be revised following FAA and industry evaluation, and may relax the requirement for GPS data at low altitudes and close to runways.
3.6	Alternate Propagation Models	Section 3. 6 states that use of “these alternate propagation models would *not* materially change the overall conclusions presented in Sections 3.2-3.5 above. ” LightSquared believes this is incorrect. For the high altitude Navigation case, (aircraft at 535 m), the LightSquared model yields a 5 dB positive margin against interference even at the 1E-6 point of the CDF, tail relative to the threshold level of -34.1 dBm. Furthermore, recent analyses performed by LightSquared for DCA-1 and DCA-2, using the blocked/unblocked free space propagation model documented in Section B.2.3.3 above, show that all but one of the “failed” cases result in small positive margins and that all cases show substantial positive margins if the base station power backoff for TAWS is considered. In addition, the blockage probabilities are not “site-specific” as claimed by FAA in the sense that they apply to a specific nadir point. As the control point (nadir point) sensitivity analysis by LightSquared has shown, the same results would be obtained if the control point were moved laterally in any direction by 5 km. For low altitude Navigation and TAWS, LightSquared is willing to use the 2-ray model for elevation angles whose magnitude exceed 6^o and Free Space propagation where the magnitude of the elevation angle is less than 6^o. LightSquared did not have an opportunity to present this proposal this owing to the termination of technical discussions. For the high altitude Navigation case, (aircraft at 535 m), the LightSquared model yields a 5 dB positive margin against

		interference even at the 1E-6 point of the CDF, tail relative to the threshold level of -34. 1 dBm. The corresponding analysis in this report shows a negative margin of -6. 9 dB [Table 3-1].
4	Exclusion Zone	LightSquared is claimed to have accepted that “this exclusion zone does *not* match current FAA operations”. This is incorrect. LightSquared does not accept this and does not understand why its present proposal would not comply with the FAA’s *stated* requirements. If the FAA is implying that the requirements it gave LightSquared are inconsistent with current operations, then LightSquared cannot be held accountable – LightSquared assumes that this is an element of risk management that the FAA has accepted.
4	Power in the air	The Report states that LightSquared’s proposal regarding “power in the air” cannot be practically administered. LightSquared understands this is based on one meeting before LightSquared had the opportunity to present draft, codifiable rules similar to the Inmarsat rules for protecting airports and waterways.
Appendix-A	Page A-54: • In sparsely populate areas, while it is true that low flying is allowed by FAR Part 91, current TAWS systems will give alerts if the airplane descends below 700’ unless in final landing configuration. Page A-59: • There is no regulatory requirement to descend to MDA immediately after crossing the FAF. Flight Safety Foundation ALAR Briefing Note 7.2 recommends a “stabilized, constant angle approach profile. ” The airplane does not need to be down to MDA until close to the runway (*e. g.* within 1NM for a 250’ MDA). • Also, note that EGPWS would give an alert below 400’ unless the landing gear is down. Page A-68: • Attack helicopters in the very low-level tactical environment are operated by visual reference (or by NVG-reference) to the terrain and obstacles, and do not rely on TAWS for terrain avoidance. Page A-71: • In Table 2, the values of 100’ clearance in the right-hand column are not	

	representative of actual TAWS alerting limits: TAWS will generally give alerts at a higher altitude than this (see Figure 2 of Attachment 2, below).

Attachment 1: Declaration of Dr. John David Parsons



DECLARATION OF JOHN DAVID PARSONS

I, John David Parsons, make the following declaration in connection with the FAA's Draft Status Report: Assessment of Compatibility of Planned LightSquared Ancillary Terrestrial Component Transmissions in the 1526-1536 MHz Band with Certified Aviation GPS Receivers dated December 23, 2011 ("FAA Report").

1. I am an Emeritus Professor and Honorary Senior Fellow at the University of Liverpool. I held the David Jardine Chair of Electronic Engineering from 1982 until 1998. During this period I was, at various times, Chairman and Head of the Department of Electrical Engineering and Electronics, Dean of the Faculty of Engineering and Pro-Vice Chancellor (Vice-President) of the University. I received a B.Sc. degree in Electrical Engineering (Magna cum Laude) from the University of Wales in 1959, an M.Sc. in Electronics from the University of London in 1967 and a D.Sc. in Electronic Engineering (Radiocommunications) from the University of London in 1985. I also hold the following certifications; FREng, (Fellow of the Royal Academy of Engineering, London) FIET, (Fellow of the Institution of Engineering and Technology - formerly the Institution of Electrical Engineers, London) and SMIEEE (Senior Member of the Institute of Electronics and Electrical Engineers, New York)

2. In addition to my teaching experience, I have conducted extensive research on various aspects of radio engineering, specializing in radio propagation and radio channel characterization particularly in connection with cellular systems, and have published approximately 150 technical papers in peer-reviewed Journals and at major conferences. I have also authored or co-authored 3 books on the topics of radio propagation and radio engineering. I have acted as a consultant to several companies and have given evidence as an expert witness in Courts of Law. A copy of my CV is attached to this Declaration.

3. I have been asked by LightSquared to review the proposed propagation models for determining the compatibility between LightSquared's terrestrial system and FAA GPS requirements. Most recently, I have been asked to review the FAA Report and

provide my opinion on the validity of the FAA's most recent propagation model described therein.

4. In my professional opinion, LightSquared's proposed approach to modeling propagation is scientifically valid and supported by available scientific literature. The company has drawn on well-established physical and engineering principles and models that have stood the test of time, to characterize the propagation scenario in which its proposed system will operate. At all times it has applied these principles with appropriate scientific rigour.

5. On the other hand, in my professional opinion, the approach to modeling propagation being proposed by the FAA and its consultants is often not supported by similar scientific evidence; it contains significant inconsistencies, and in many ways could be characterized as arbitrary.

I declare that the foregoing Declaration it true and correct.

Executed on January 9, 2012.

John David Parsons

John David Parsons

Attachment 2: TAWS/HTAWS Considerations – Expert View of John Howard Glover[60]

TAWS Functionality Requirements

While fully acknowledging the important safety benefits of TAWS and HTAWS, temporary loss of GPS information to TAWS equipment in the very low altitude environment would not constitute a significant lowering of the level of flight operational safety. Most significantly, in the process of descending to an altitude low enough for the system to be exposed to interference-induced loss of GPS data, the airplane must pass through an environment where a TAWS alert will be given before that airplane enters the very low altitude zone. In this case it can be assumed that the flight crew will have taken action to avoid the terrain or obstacle threat before the loss of signal has occurred.

TAWS Use of GPS Data

By the requirements of TSO-C151b, all three classes of TAWS (A, B and C) may use GPS position data (latitude and longitude) to locate the airplane with respect to the terrain database and also with respect to a runway.

For Class A TAWS, the position data is obtained from a Navigation Computer that blends GPS data, Inertial Reference System data (and for some systems also Radio Navigation data) in order to calculate aircraft position. For these systems, the loss of GPS signal does not degrade the position data until Inertial Reference System drift errors become significant – typically only after several minutes. Consequently, Class A TAWS systems operating in an airport terminal airspace environment are relatively immune to loss of GPS data.

TSO-C151b requires that both Class A and Class B TAWS that have internal GPS receivers must have the capability of monitoring the validity and position error of the GPS system, and the TAWS must provide an indication to the pilot if the GPS error is excessive. For these systems the flight crew will be aware that the TAWS system is degraded if a loss of GPS signal occurs.

TAWS Modes not requiring GPS

Class A TAWS systems have several alerting functions that use Radio Altimeter signals for determining the height of the airplane above the terrain. These functions are independent of GPS position data. For example, the DO 161A Mode 4 “Too Low” alert mode provides an alert if the airplane descends below 500 feet with the landing gear up, and provides an alert if the airplane descends below 200 feet if the landing gear is down but landing flaps are not set. An advisory call is also required when the airplane descends below 500 feet, irrespective of configuration.

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[60] Mr. Glover’s CV is included at the end of this Attachment. Mr. Glover has worked for more than 35 years on the development, flight testing and certification of terrain awareness and alerting systems. His experience includes early Ground Proximity Warning systems for civil and military aircraft and also modern Terrain and Obstacle Awareness and Warning systems and displays. He was secretary of the EUROCAE working group which developed TAWS design standards for US and European certification. He is the holder of more than a dozen patents in the field of airborne alerting systems. He was an FAA Systems and Equipment Designated Engineering Representative for more than 20 years.

Loss of GPS Data during a TAWS Alert

If loss of GPS signal occurs while a TAWS alert in progress, it would be improbable that the pilot would assume that the terrain threat has ceased. The correct pilot response to a TAWS alert is to ensure adequate terrain clearance. The following is an excerpt from Pilot Guide/Flight Manual Supplement for systems provided by a TAWS manufacturer:

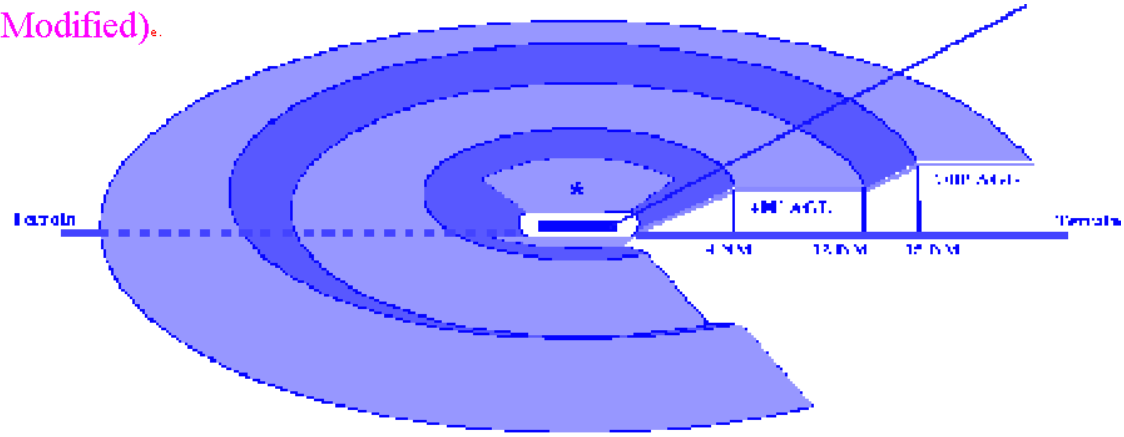
> Recommended response to EGPWS alerts are as follows:
>
> **Caution:**
>
> 1. Stop any descent and climb as necessary to eliminate the alert. Analyze all available instruments and information to determine best course of action.
>
> 2. Advise ATC of situation as necessary.
>
> **Warning:**
>
> 1. Aggressively position throttles for maximum rated thrust.
>
> Apply maximum available power as determined by emergency need. The pilot not flying (if applicable) should set power and ensure that TO/GA power and modes are set.
>
> 2. If engaged, disengage the autopilot and smoothly but aggressively increase pitch toward "stick shaker" or Pitch Limit Indicators (PLI) to obtain maximum climb performance.
>
> 3. Continue climbing until the warning is eliminated and safe flight is assured.
>
> 4. Advise ATC of situation.
>
> **NOTE:** Climbing is the only recommended response unless operating in visual conditions and/or pilot determines, based on all available information, that turning in addition to the climbing is the safest course of action. Follow established operating procedures.

TAWS Protection for Landing Approach

TSO C-151b requires that Class A and B systems provide Forward Looking Terrain Avoidance (FLTA) and Premature Descent Alert (PDA) functions.

A typical TAWS system (*e. g.* the Honeywell EGPWS) implements PDA function with a "Terrain Clearance Floor" function (see drawing below). The "floor" slopes upwards from the threshold of the nearest runway, reaching a height of 400 feet at 4 nautical miles from the threshold. It then remains at 400 feet until 12 nautical miles, when it again slopes up to 700 feet at 15 nautical miles. If an airplane descends below this floor an alert is provided, irrespective of landing gear position or flap setting. The floor begins at a distance from the runway threshold that varies with the quality of position data, but is typically ¼ nautical mile. Current systems provide further protection by holding the height of the floor at a minimum of 245 feet unless the airplane track is aligned with the runway within +/- 45 degrees, thus ensuring that an airplane that is not within the approach corridor will receive a terrain alert at a minimum height of 245 feet.

(Modified)



*245 foot curve expansion on runway sides only applicable to 200/210 and on.

Figure 2-1. Terrain Clearance Floor

Even when the airplane is above the clearance floor, if it is descending at an angle such that its flight path is predicted to intersect the ground before the runway, then the required Forward Looking Terrain Avoidance function will provide an alert.

This PDA function ensures that if an airplane is not aligned with the approach corridor to a runway, then a terrain alert will be given if the airplane descends below 245 feet.

If the airplane is within the approach corridor, then a descent below 200 feet will result in an alert unless the airplane is closer than 2¼ nautical miles to the runway threshold, and a descent below 100 feet will result in an alert unless the airplane is closer than 1¼ nautical miles to the runway threshold.

Consequently, if GPS signals are available when the airplane is above 200 feet, and are subsequently lost when the airplane continues to descend, there is a very small volume of unprotected airspace close to the runway. If an airplane is established on an approach path which is sufficiently stable to not generate a terrain alert above 200 feet, then it is considered to be very improbable that anything less than an extreme deviation from the stabilized path below this height would result in a terrain collision. Such an extreme maneuver is likely to result in an accident even if the TAWS function were fully operational.

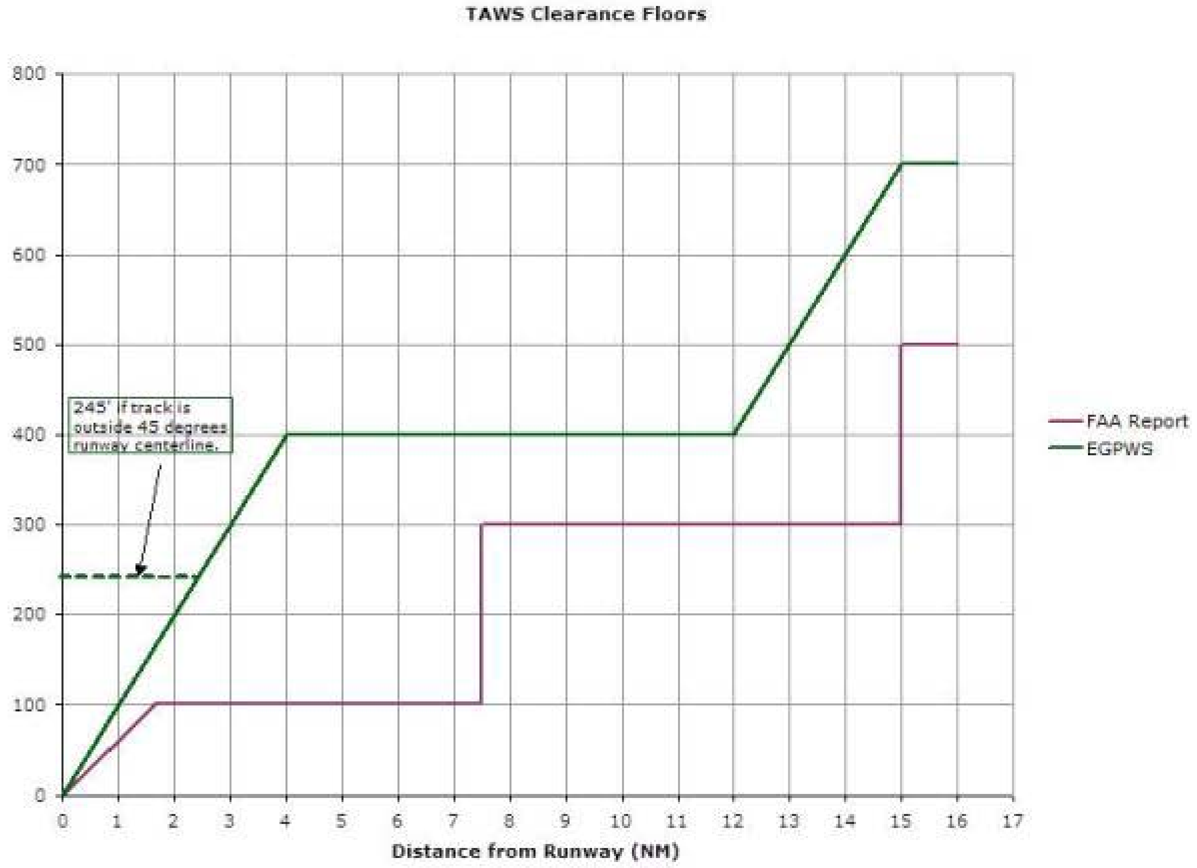


Figure 2-2. Terrain Clearance Floors: Typical Production Equipment vs. FAA Minimum Requirements.

John Howard Glover

Total years of experience in aviation industry: *49*

Areas of technical expertise:

- ***Aircraft Operations Analysis***
- ***Alerting Systems Design***
- ***Flight Deck Design***
- ***Systems Certification***

Education:

- ***B.Sc. (Honors): Aeronautical Engineering, Imperial College, London University, UK***
- ***Advanced degree: Associate of City and Guilds Institute (London University): Aeronautical Engineering.***

Experience:

- ***British Aircraft Corp., Bristol, UK (2 years): Research Engineer. Development of missile guidance systems.***
- ***British Royal Aircraft Establishment (2 years), Bedford, UK: Scientific Officer. Development and flight testing of tactical landing system for V/STOL aircraft.***
- ***The Boeing Co., Seattle, WA (9 years): Staff Engineer. Development of flight deck alerting systems, B747 airplane. Development and flight testing of fly-by-wire control system for proposed B707 patrol airplane. Development of advanced propulsion control systems.***
- ***Sundstrand Data Control/Allied Signal/Honeywell, Redmond, WA (36 years): Engineering Fellow. Development, marketing, flight testing and certification of flight safety products.***
- ***Member/officer on several aviation industry technical committees in the USA and Europe:***
    - ***Member of SAE S-7 committee (Transport Airplane Handling Qualities and Flight Deck Design Standards),***
    - ***Secretary of EUROCAE Working Group 44 (Terrain Awareness Warning System design standards),***
    - ***Member of RTCA committee SC-186 (Aircraft Surface Alerting standards).***

Professional Memberships: ***Fellow, Royal Aeronautical Society, UK***

Other Qualifications:

- ***FAA licensed multi-engine and instrument rated commercial pilot (airplane, helicopter and glider).***
- ***Author of several patents in the flight safety and control domains.***

- ***FAA Systems DER for more than 20 years***

Attachment 3: Proposed OCS Methodology

For purposes of determining the exclusion zone, LightSquared understands that the OCS carve out would not apply to any exclusion zone that does not penetrate a notification surface set out in 14 CFR.77. 9(a), 77. 9(b) or 77. 9(d) (“Part 77 Notification Surface”).

For those exclusion zones that penetrate a Part 77 Notification Surface, LightSquared will conduct an analysis of the exclusion zone to determine whether it penetrates an OCS.

- Because FAA Order 8260.19D, Appendix 3, “Obstacle Accuracy Standards, Codes, and Sources,” does not identify a specific code for exclusion zones, LightSquared would evaluate the 3D shapes of the instrument procedure at OCS elevations and to determine possible exclusion zone penetrations to the 8260 OCS.
- To the extent that the FAA wishes to include OCS for any “Special Procedures” for landing facilities requiring notice per 77.9(d) (4), those procedures must be provided so 3D surfaces can be evaluated.
- Future procedures will be accommodated on a case-by-case basis in coordination with the FAA.

Attachment 4: References

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[4] Fizzle Technologies, "Opinion on the Exponent of the Path Loss Equation and its Standard Deviation," document submitted to FAA during joint work (Sept. 18, 2011).

[5] CDF Simulation of FAA Model with Lognormal Fading - Aircraft Height 100 ft Approaching LAX Rwy. 24L Version 2.0, LightSquared report submitted to FAA during joint work (Oct. 26, 2011).

[6] CDF Simulation of FAA Model with Lognormal Fading - Aircraft Height 100 ft Approaching JFK Rwy. 13L Version 2.0, LightSquared report submitted to FAA during joint work (Oct. 26, 2011).

[7] Santanu Dutta, Ajay Parikh, Gary Churan, & Dunmin Zheng, "LightSquared's Understanding of FAA Position re: Choice of Propagation Model," LightSquared report submitted during joint work (Sept. 12, 2011).

[8] Proposed Revision to 1.6 to 20 km Segment of RTCA Propagation Model Version 0.1, LightSquared report submitted to FAA during joint work (Sept. 15, 2011).

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[10] Loo, C., "A Statistical Model for a Land Mobile Satellite Link," *IEEE Transactions on Vehicular Technology* Vol. 34, No. 3 (Aug. 1985). Copyright © 1985 IEEE. Reprinted, with permission, from IEEE Transactions on Vehicular Technology.

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[12] LOS/NLOS Analysis at Lakie Waypoint, LightSquared report submitted to FAA during joint work (Oct. 7, 2011).

[13] LightSquared Ray Tracing Analysis Lakie Point, NY/NJ, LightSquared report submitted to FAA during joint work (Nov. 2011).

[14] G. Churan, "Obstructed Path Loss Calculation Using Radar Cross Section of a Reflecting Surface," LightSquared report submitted to FAA during joint work (Nov. 11, 2011).

[15] Blockage Study near DCA, LightSquared report submitted to FAA during joint work (Oct. 7, 2011).

[16] CDF Simulation for DCA Scenarios with Blockage Data, LightSquared report submitted to FAA during joint work (Nov. 11, 2011).

[17] Parsons J. D., The Mobile Radio Propagation Channel (2ed), John Wiley and Sons, Chichester, UK, 2000.

[18] CDF Simulation for DCA-1 and -2 with Blockage Data & Scheduled EIRP, LightSquared work performed after joint work in order to respond to new FAA results contained in the first draft of the FAA Final Report (Jan. 8, 2012).