



**Cuestión 4 del
Orden del Día:**

Evaluación de los requisitos operacionales para determinar la implantación de mejoras de las capacidades de comunicaciones, navegación y vigilancia (CNS) para operaciones en ruta y área terminal

DATOS DE VIGILANCIA ADS-B SATELITAL Y SU DISTRIBUCIÓN A TRAVÉS DE LA REDDIG II

(Presentado por AIREON)

RESUMEN	
El objetivo de este documento de trabajo es presentar el progreso sobre el análisis realizado por Aireon acerca del posible uso de la red REDDIG para distribuir datos ADS-B satelital a los Estados SAM.	
REFERENCIA	
<ul style="list-style-type: none">• Informe de reunión SAM/IG/18• Informe de reunión RCC/20	
Objetivos estratégicos de la OACI:	<i>A – Seguridad operacional</i> <i>B – Capacidad y eficiencia de la navegación aérea</i>

1. Antecedentes

El programa Aireon

1.1. Aireon es el único proveedor de Vigilancia ATS que a partir del año 2018 ofrecerá cobertura mundial de datos ADS-B. La compañía ha sido creada por 4 ANSP (NavCanada, ENAV, IAA, Naviar) e Iridium como socio tecnológico, los cuales de forma conjunta han logrado ejecutar una idea bastante sencilla y eficiente: instalar en cada uno de los nuevos satélites Iridium NEXT, volando en altitud de órbita terrestre baja, una carga útil capaz de recibir mensajes ADS-B enviados en frecuencia 1090Mhz. La constelación estará compuesta de 66 satélites operativos, más 6 piezas de repuesto en órbita y 9 piezas de repuesto en tierra. En enero de 2017 se lanzaron los primeros 10 satélites, los cuales ya están recibiendo mensajes ADS-B, con excelentes resultados. Las primeras pruebas de vuelo realizadas por Nav Canada, FAA y Polaris también han tenido éxito. Los resultados se muestran en el Apéndice A de este documento de trabajo titulado "Análisis inicial de desempeño en órbita en el espacio ADS-B de Aireon". Muchos ANSP de todo el mundo ahora están planeando una actividad de V & V que demostrará la calidad de los datos de satélite ADS-B. Además, la Agencia Europea de Seguridad Aérea (AESA) está en proceso de certificar a Aireon como un proveedor de servicios de vigilancia paneuropea. Esto se hará sobre la base de los criterios de rendimiento EUROCAE/ RTCA ADS-B. El efecto de esta certificación será que el ADS-B basado en el espacio será comparable a un sistema de vigilancia de largo alcance de por lo menos de 5 millas en la ruta de separación.

1.2. A partir del año 2018, el espacio aéreo mundial contará con otra capa de vigilancia ATS, totalmente independiente de los sensores terrestres, lo cual tendrá como resultado que en las áreas oceánicas y remotas que actualmente no tiene cobertura con ningún tipo de tecnología de vigilancia ATS, los ATCO tendrán la ubicación de aeronaves en tiempo real, aumentando así, drásticamente, la seguridad y la posibilidad de adoptar servicios de tránsito aéreo optimizados y monitorear la ubicación remota y la separación mínima. Además, para el espacio aéreo continental, el cual ya cuenta con cobertura de tecnología de vigilancia ATS y DCPC (por ejemplo, VHF), la capacidad de tener otra capa de vigilancia puede desbloquear la optimización operativa adicional (como moverse a 5NM en ruta), así como tener una perfecta solución para contingencias en caso de fallas del radar o problemas en instalaciones terrestres.

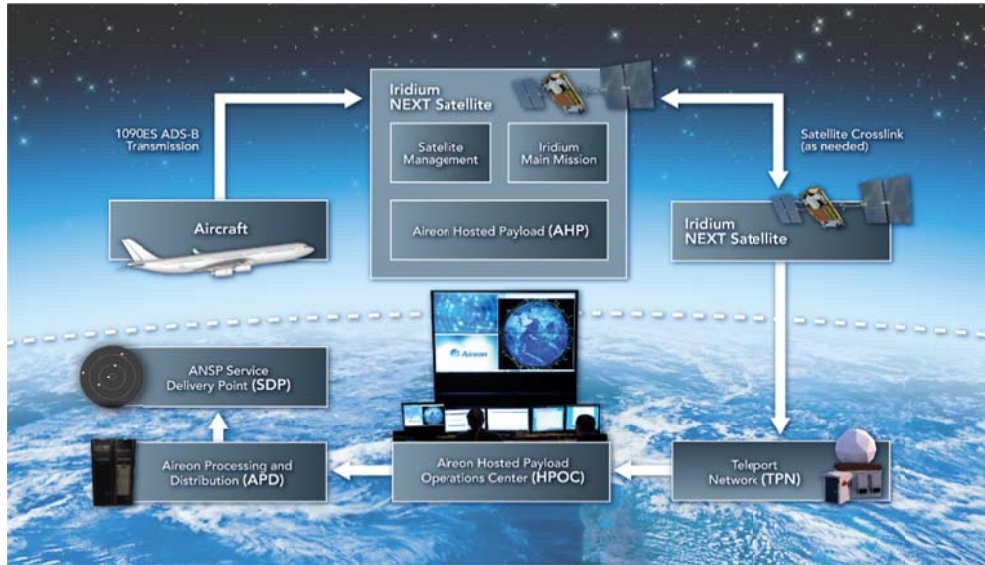


Figura 1 – El flujo de información Aireon

Distribución de datos Aireon

1.3. A partir de la Figura 1, la conexión entre el APD Aireon y el ANSP específico se realiza típicamente a través de una conexión MPLS dual, que conectará el APD con un Punto de Entrega de Servicios (SPD por sus siglas en inglés) instalado en el sitio del ANSP.

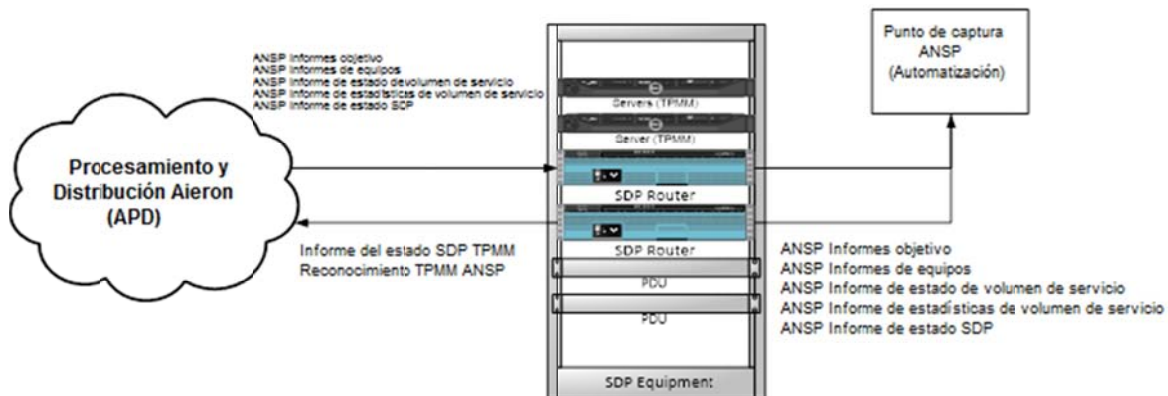


Figura 2 – Esquema del hardware del Punto de Entrega de Servicios (SDP)

1.4. El SDP (Figura 2) es el verdadero punto de demarcación entre el dominio Aireon y el dominio del ANSP: el resultado del SDP son los datos de vigilancia para el ANSP, listos para ser integrados en la plataforma de automatización ATC (rastreador - *tracker*).

1.5. Debido a que los mensajes ADS-B son pequeños en términos de bytes, el enlace entre Aireon y los ANSP no requiere mucho ancho de banda, sin embargo, es importante tener un enlace firme. Debido a que las conexiones MPLS en algunas regiones pueden ser costosas y a fin de optimizar las conexiones con el APD, Aireon analiza igualmente la posibilidad de utilizar redes regionales ya existentes en todo el mundo, tales como REDDIG, MEVA o PENS, para la distribución de los datos de vigilancia de Aireon en cada región.

2. Análisis

REDDIG como la Red Regional SAM

2.1. REDDIG es la distribución regional de datos que los ANSP están utilizando en Sudamérica. Es una combinación de conexiones VSAT y MPLS, proporcionando un enlace muy sólido al cual los 14 ANSP ya se encuentran interconectados con esta red.

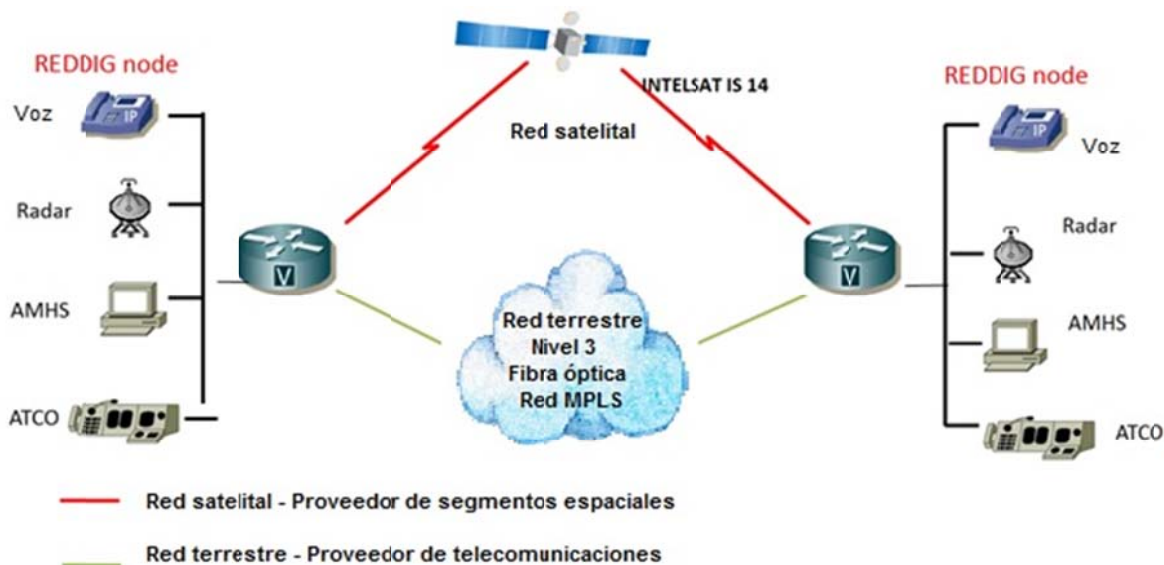


Figura 3 – Arquitectura REDDIG

2.2. La red es propiedad de los Estados y se gestiona bajo la supervisión de la oficina regional de la OACI para Sudamérica.

2.3. Al utilizar la red REDDIG para distribuir datos satelitales ADS-B, los costos de implementación y distribución podrían ser minimizados por aquellos Estados interesados en suscribirse al sistema.

Distribución de datos satelitales ADS-B a través de REDDIG

2.4. Con el uso de REDDIG, Aireon podrá conectar el APD localizado en Virginia (Estados Unidos de América) potencialmente a dos (2) o más Puntos de Entrega de Servicio (SDP) estratégicamente ubicados en la Región Sudamericana, a través de conexiones MPLS y así distribuir los datos a toda la región Vía REDDIG (Figura 4).

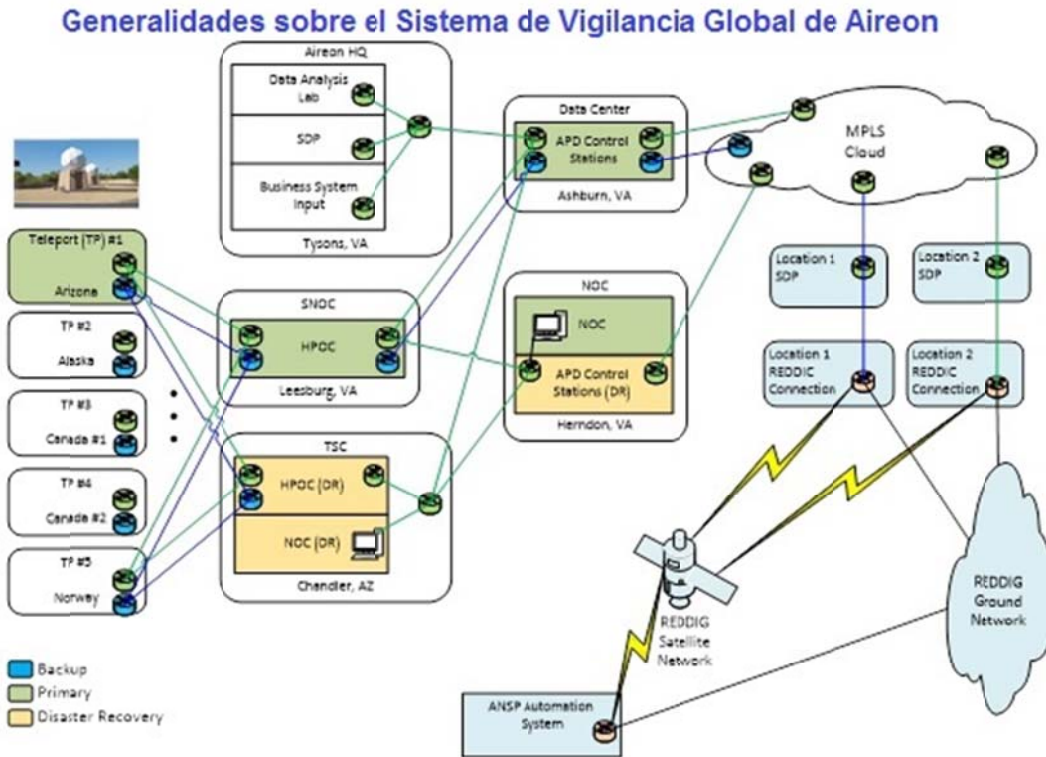


Figura 4 – Hardware del Puntos de Entrega de Servicio Regional (SDP)

2.5. Cada uno de los SDP podrá introducir, como VPN separadas, los datos satelitales ADS-B de cada ANSP que deseen obtener esos datos. El punto de demarcación de Aireon estará entonces a la entrada de la red REDDIG, tras lo cual el administrador de red REDDIG se ocupará de la distribución de datos. De esta manera, habrá sólo 2 conexiones MPLS sólidas entre el APD de Aireon y la red REDDIG, optimizando así, costos y rendimiento. Este enfoque también proporciona la diversidad geográfica de los SDP en caso de interrupción del servicio localizada.

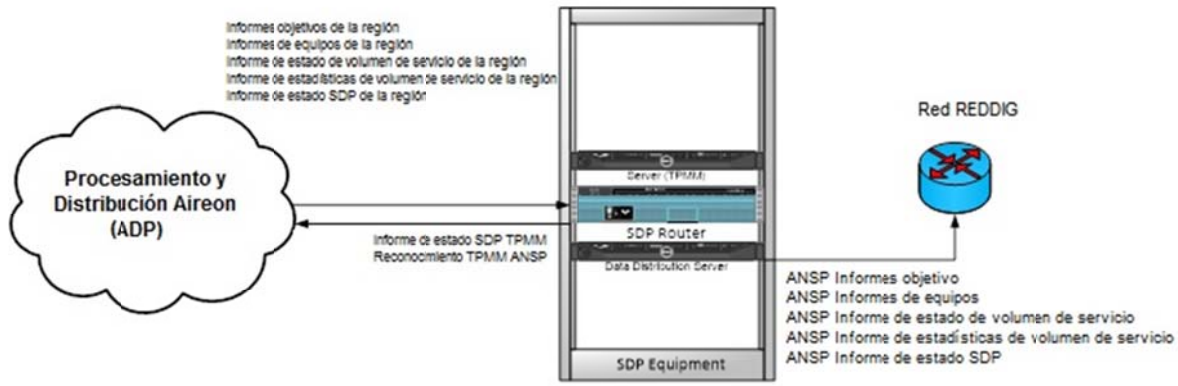
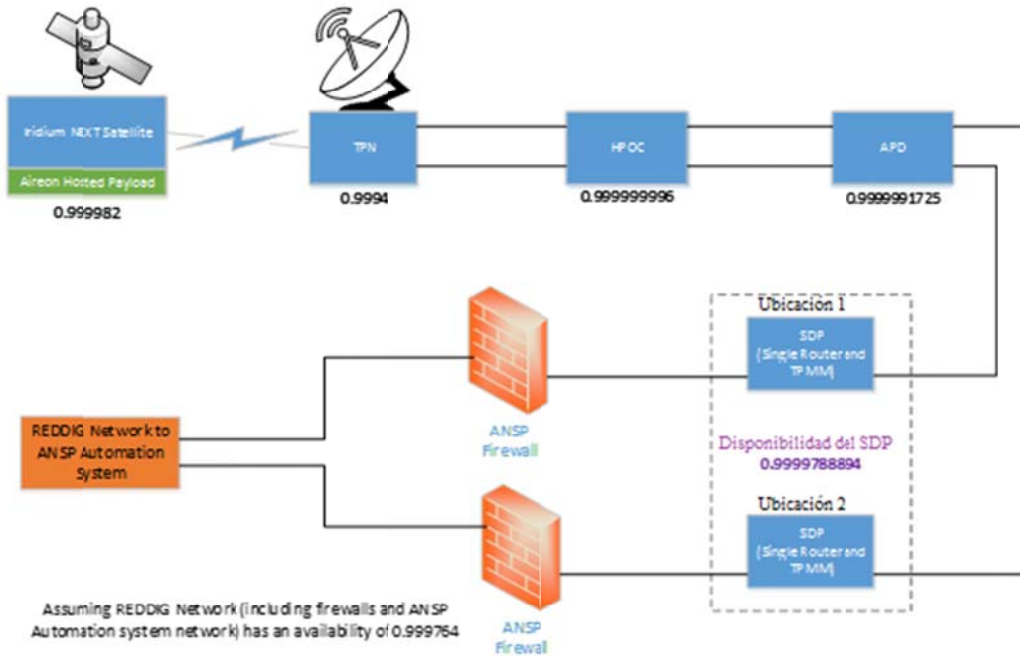


Figura 5 – Hardware del Punto de Entrega de Servicios (SDP) Regional

2.6. Con esta configuración, la disponibilidad de la red completa desde la recepción de datos en los satélites al sistema de automatización del ANSP será mayor a 0.999 suponiendo que la disponibilidad de la red REDDIG sea mayor que 0.9999 y que la conexión MPLS desde APD al SDP sea al menos 0.997.

Disponibilidad utilizando dos SDP de cadena única que alimentan un sistema de automatización único



La disponibilidad del sistema es de 0.99912

2.7. Requisitos de red REDDIG

- Disponibilidad del sistema > 0.999
- Acepta multidifusión de datos
- Entrega al Sistema de automatización en baja latencia
- Segregación de datos de vigilancia para cada uno de los ANSP conectados

2.8. Uso del ancho de banda de los datos satelitales ADS- B de Aireon

Según la solicitud de la reunión de RCC/20, Aireon ha estimado el ancho de banda total que será necesario en caso de que todos los Estados se suscribieran a los servicios de datos satelitales ADS-B, para su uso pleno tanto en el espacio aéreo como terrestre y oceánico, y el espacio aéreo superior e inferior. La Tabla 1 muestra el ancho de banda total potencial del uso total del sistema por todos los países, estimado en los niveles de tráfico aéreo para el año 2030, que suma un total de 2.061 kbps por un período de 24 horas.

País	FIR	CAT021		CAT025		CAT238		CAT253		Total	
		Medio (kbps)	Max (kbps)	Medio (kbps)	Max (kbps)	Medio (kbps)	Max (kbps)	Medio (kbps)	Max (kbps)	Medio (kbps)	Max (kbps)
Argentina	SACF	8	21	0	1	0	19	6	32	14	73
Argentina	SARR	3	11	0	1	0	17	6	32	9	61
Argentina	SAMF	9	14	0	1	0	17	6	32	15	64
Argentina	SAEF	15	29	0	1	0	39	6	32	21	101
Argentina	SAVF	6	14	0	1	0	85	6	32	12	132
Bolivia	SLLF	6	16	0	1	0	21	6	32	12	70
Brasil	SBAZ	24	48	0	1	0	43	6	32	30	124
Brasil	SBRE	23	43	0	1	0	30	6	32	29	106
Brasil	SBBS	53	93	0	1	0	27	6	32	59	153
Brasil	SBCW	29	50	0	1	0	23	6	32	35	106
Chile	SCFZ	8	18	0	1	0	30	6	32	14	81
Chile	SCEZ	10	23	0	1	0	26	6	32	16	82
Chile	SCTZ	9	10	0	1	0	23	6	32	15	66
Chile	SCCZ	9	9	0	1	0	39	6	32	15	81
Colombia	SKEC	10	28	0	1	0	17	6	32	16	78
Colombia	SKED	26	51	0	1	0	23	6	32	32	107
Ecuador	SEGU	6	18	0	1	0	20	6	32	12	71
Guyana	SYGC	9	13	0	1	0	16	6	32	15	62
Paraguay	SGFA	9	9	0	1	0	17	6	32	15	59
Perú	SPIM	19	34	0	1	0	36	6	32	25	103
Surinam	SMPM	9	11	0	1	0	16	6	32	15	60
Uruguay	SUEO	5	14	0	1	0	30	6	32	11	77
Venezuela	SVZM	10	24	0	1	0	22	6	32	16	79
Guyana Francesa	S000	9	9	0	1	0	23	6	32	15	65

Tabla 1. Total ancho de banda potencial por FIR para los servicios de datos satelitales ADS-B

Costos de implementación para la distribución de datos satelitales ADS-B

2.9. Para determinar el beneficio económico de los ANSP al obtener datos satelitales ADS-B a través de REDDIG, Aireon estimó los costos de implementación del diseño original (Figura 2) donde los ANSP recibirían los datos directamente del Centro de Procesamiento y Distribución Aireon, y lo comparó con la distribución de los datos a través de la red regional (Figuras 4 y 5). Los resultados se muestran en la Tabla 2.

Costos estimados utilizando REDDIG	US\$	Costos estimados por ANSP Conexión directa	US\$
a. Gastos de despliegue y prueba de SDP (2 SDP) - costo único	320,000	a. SDP en la ubicación del ANSP – costo único	300,000
b. Costos de telecomunicaciones en 2 ubicaciones (línea única en cada ubicación) / anual- costo recurrente	95,000	b. Costos de telecomunicaciones por ANSP (línea dual)/anual – Costo recurrente	95,000
c. Prueba de aceptación del servicio de instalación por parte del ANSP – costo único	112,000	c. Prueba de aceptación del servicio de instalación por parte del ANSP	112,000

Tabla 2. Comparación de costos de implementación de los datos satelitales ADS-B data a través de REDDIG y directamente con cada uno de los ANSP

Según la tabla anterior:

Gastos de despliegue y pruebas al SDP:

- I. Utilización de REDDIG: para la implementación en dos nodos REDDIG - Este es un costo único para desplegar un solo SDP en dos (2) puntos de conexión REDDIG. Esto permitirá acceder a los datos globales de Aireon ADS-B desde la red REDDIG mediante la suscripción por parte del ANSP. El costo incluye hardware para dos (2) SDP de cadena única (Figura 5), un solo circuito MPLS de 2MB Ethernet punto a punto para cada SDP; Software SDP y Prueba de Aceptación del Sitio (SAT) (una visita a cada ubicación), para verificar que el sitio está instalado y funcionando correctamente. Los ANSP tendrán que hacer la instalación de los SDP de acuerdo con las instrucciones proporcionadas por Aireon.
- II. Conexión directa del ANSP al APD: Para la implementación en un ANSP - Este es un costo único para desplegar un SDP redundante en una instalación del ANSP para conectarse a los datos globales ADS-B de Aireon. El costo incluye hardware para SDP redundantes (Figura 2), dos circuitos punto a punto MPLS de 2 MB Ethernet para el SDP de ANSP; Prueba de aceptación del sitio (SAT) y del software del SDP para verificar que el sitio está instalado y funcionando correctamente. Cada ANSP deberá hacer la instalación de los SDP de acuerdo con las instrucciones proporcionadas por Aireon.

2.10. Costo de telecomunicaciones: Se trata de un costo anual recurrente para dos (2) conexiones MPLS establecidas y probadas durante la instalación del SDP explicado anteriormente. El costo que se muestra en la tabla 2 es un costo estimado, que puede variar dependiendo de las ubicaciones seleccionadas para el SDP y la disponibilidad de conexiones MPLS en las regiones seleccionadas.

2.11. Costo de prueba de aceptación del servicio de instalación (ISAT): es un costo único para cada ANSP suscrito para recibir el servicio. ISAT es conducido por Aireon antes de la prueba y la evaluación por el ANSP y se realiza en un solo viaje a la ubicación ANSP y los datos de pruebas pertinentes para el ANSP. Los objetivos principales de esta prueba son:

- Verificar que los datos de destino y estado del servicio se entregan al ANSP en el formato adecuado y con la periodicidad requerida;
- Verificar que el servicio cumple con los requisitos críticos de rendimiento de ANSP;
- Verificar que la cobertura del servicio cumple con el volumen de cobertura requerido según lo determine el ANSP;
- Verificar que el servicio se encuentra listo para las pruebas que requiera el ANSP, la evaluación regulatoria respectiva y para uso.
- Entrenamiento basado en computadora (CBT)
- Gastos de viaje y estadía de los Ingenieros encargados de realizar las validaciones y pruebas durante su asignación, estimada en un periodo de 3 meses.

2.12. Las partidas de costo a y b descritas en la Tabla 1 serían compartidas entre los países que se suscribieran al sistema, utilizando REDDIG, mientras que las mismas tendrían que ser pagadas por cada uno, en el caso de que cada ANSP instalara el sistema directamente, con sus propios SDP y líneas de telecomunicaciones. Lo anterior nos demuestra un claro beneficio económico para todos los ANSP de la región SAM de utilizar REDDIG como medio para recibir datos satelitales ADS-B.

Costos del servicio de datos satelitales ADS-B.

2.13. Los cargos que Aireon realice por la entrega de datos de vigilancia ADS- B a los ANSP se basan en un costo fijo anual y se calculan sobre la siguiente base:

- Horas de vuelo sobre el espacio aéreo del ANSP/FIR correspondiente
- Densidad del tráfico que sobrevuela el espacio aéreo ANSP/FIR correspondiente
- Área de espacio aéreo: Oceánico o terrestre

2.14. Los costos varían entre los ANSP debido a que cada espacio aéreo tiene su propio volumen de tráfico por lo que los ANSP pueden suscribirse ya sea a porciones del espacio aéreo o la totalidad de su espacio aéreo controlado. Por lo tanto, estos costos no han sido incluidos como parte del alcance de este documento de trabajo.

2.15. Invitamos a los países que deseen suscribirse a los servicios de datos de vigilancia satelital ADS-B a que tomen en consideración todos los beneficios económicos de la distribución de los datos a través de REDDIG y los posibles beneficios económicos y operacionales de la implementación de dicho sistema en la región, lo que complementa las capacidades actuales de vigilancia en la región SAM y las aumenta, teniendo una cobertura de vigilancia completa en áreas oceánicas, remotas y de sólo radar, entre otras aplicaciones como ATFM y otros.

3. Acciones sugeridas

3.1 La reunión es invitada a:

- a) Tomar nota de la información facilitada en el documento;
- b) A requerimiento de los países presentes en la reunión RCC/20, continuar con el desarrollo del análisis de costos para distribuir datos satelitales ADS-B en los países que estén interesados en hacerlo a través de REDDIG.
- c) Los Estados que tomen consideración de la posible realización de un proyecto regional de la implementación de los servicios de ADS-B satelital.

AIREON'S INITIAL ON-ORBIT PERFORMANCE ANALYSIS OF SPACE-BASED ADS-B

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Abstract

On January 14th, 2017, the first SpaceX rocket launch of 10 of Iridium NEXT's satellites generated an exciting milestone towards the global coverage of Aireon's space-based Automatic Dependent Surveillance-Broadcast (ADS-B) system [1]. ADS-B is a cornerstone technology for the aviation industry that enables significant improvements in aircraft based travel efficiency and safety. Aireon's hosted payload ADS-B receivers have the potential to accelerate and extend the benefits of ADS-B to the entire Air Traffic Management (ATM) community by significantly expanding the boundaries of legacy infrastructure.

To evaluate the full extent of this potential, the Aireon team embarked on a series of functional and performance tests on the hosted payloads as well as integration with the operational system. About 2 weeks after the first launch, Aireon began to receive and analyze on orbit ADS-B data from equipped aircraft.

This paper describes the key test approaches, results, and analysis that were used to tune and verify Aireon's space-based ADS-B models to estimate the expected end-state ADS-B data service metrics when all 66 operational satellites have reached their mission orbit.

I. Introduction

In prior work, Aireon's methods for estimating performance and ensuring interoperability were described in detail [2] [3]. Once the satellites arrived in their respective mission orbit slots, the opportunity arrived to determine the accuracy of these performance estimates using measured data from the Space Based ADS-B receivers. Of the first 10 satellites launched, 8 went into the same orbital plane while 2 were commanded to drift to an adjacent plane. Iridium's satellite constellation has 6 polar orbiting planes with 11 satellites per plane [4].

During the initial on-orbit test campaign of the first Aireon payload, Aireon received ADS-B data from aircraft of opportunity (see Figure 1) and flight

tests were coordinated with NAV CANADA and the Federal Aviation Administration (FAA) to validate aircraft detection and tracking in an operational environment. Furthermore, a ground-based reference transmitter (GBRT) was activated for in-depth calibration of Aireon's system performance models. The results from these tests go a long way to addressing the question:

“How does the measured performance compare to the expected?”

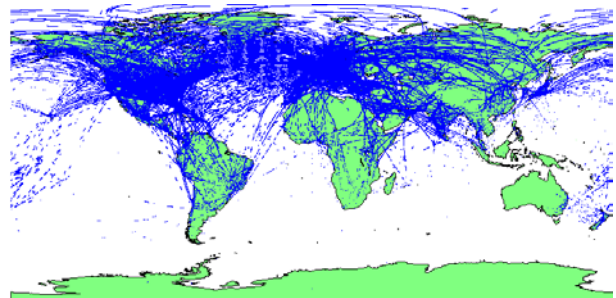


Figure 1: 62 Hours of Stitched Global Coverage

II. Clear Sky Environment

Background

ADS-B avionics are currently available in a wide variety of make, model, and transmitter power. In order to comply with most Air Traffic Control (ATC) airspace requirements, the minimum expected equipment for passenger-carrying aircraft is a class A1 transmitter which has an Equivalent Isotropically Radiated Power (EIRP) output of 125W (measured at the antenna connector) [5] [6] [7]. Furthermore, aircraft that exceed 5700 kg or plan to travel faster than 250 kt will need antenna diversity (top and bottom mounted antennas) [5]. Therefore, a class A1 diversity aircraft with 1090 MHz ADS-B is considered the minimally equipped aircraft that Aireon needs to support and became the “subject” of many test case scenarios.

Two challenges related to these low power aircraft tests became apparent early in the test planning phases:

- 1) Most ADS-B equipped aircraft transmit at a power $\geq 200\text{W}$. This makes it difficult to find true 125W subjects for testing that are naturally part of the airspace.
- 2) The airspace is a busy place. An area needed to be identified that could more closely match the “Clear Sky” conditions (i.e. low interference environment) described in the performance models [2].

Once the Clear Sky model is tuned and validated then the High Interference portion of the model can be layered on top to analyze the aggregate system model.

The first challenge was met by requesting and commissioning flight test aircraft from NAV CANADA and the FAA. Both Air Navigation Service Providers (ANSPs) have several aircraft that they use for specialized flight tests of equipment that supports their operations. Some examples of safety-critical equipment that ANSPs test with these aircraft are: ADS-B ground stations [8] [9], radars [10], multi-lateration systems [11], and navigation aids [12].

The use of controlled flight test aircraft allowed the uncertainties of the Clear Sky test to be significantly reduced. The FAA and NAV CANADA flight test crews are highly experienced in setting and calibrating the avionics and antennas as well as flying unique flight plans. This leads to resolving the second challenge. The NAV CANADA aircraft (a CRJ-200) was planned for a flight in the Northern Territories where the aircraft density is very low (Figure 2). The FAA aircraft (a Global 5000) planned a flight from the William J Hughes Technical Center (WJHTC) in Atlantic City, New Jersey (KACY) approximately 500 NM eastward into the New York Oceanic airspace (KZWY) and then returned (Figure 3).



Figure 2: NAV Flight Test Plan and Aircraft¹



Figure 3: FAA Flight Test Plan and Aircraft²

NAV CANADA Results

During the time of this NAV CANADA flight test, 3/7/2017, only one Aireon payload was providing ADS-B data due to the stepwise schedule in gradually implementing the new satellites into the constellation. With limited coverage, bandwidth, and time due to the $\sim 17,000$ mph satellite orbit speeds, the flight tests had to be executed within a narrow window. Only less than or equal to 11 minutes of coverage is expected for each “pass” of the satellite relative to a given point on the earth over a 100 minute orbital period. The orbital planes are approximately “fixed” while the earth rotates underneath the planes which leads to the satellite coverage migrating westward. Given the westbound flight with a ground speed at about 320-420 knots, the NAV aircraft stayed in view of the satellite vehicle for 4 passes (see Figure 4).

¹ Photo Credit: NAV CANADA

² Flight Plan Provided by FAA: Source John Kimpton

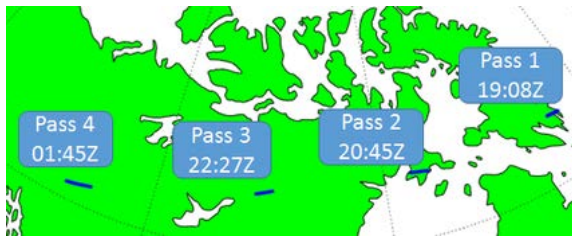


Figure 4: Overview of the Passes

6935 ADS-B messages were received from the NAV CANADA flight test aircraft during this event with about 1500 ASTERIX CAT021 reports, which are triggered by position messages and filtered for duplicate messages from overlapping receiver beams. The histogram of Update Interval (UI) measurements is shown in Figure 5, showing a mean value close to 1s. Some of the outliers in this histogram is due to channel fading from a single satellite (near the edges of coverage) and will be further improved when the full constellation of 66 new satellites is operational.

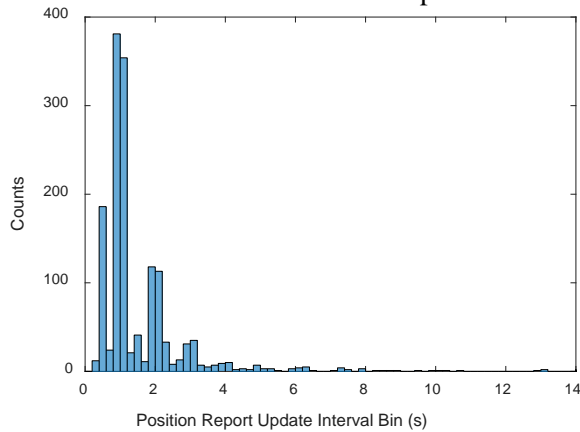


Figure 5: Measured UI for NAV Aircraft

The slant range histogram in Figure 6 shows excellent performance at long ranges and certainly exceeded expectations for a 125W aircraft. Over 13% of the measured elevation angles were less than the expected minimum of ~7 degrees. This is likely due to an overly conservative atmospheric attenuation model [13] and a receiver that surpasses its anticipated sensitivity (probability of detection versus signal strength). Table 1 summarizes expected versus measured performance for some key parameters.

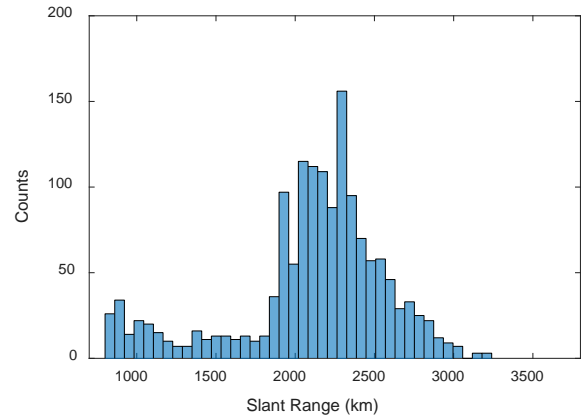


Figure 6: Measured Slant Range for NAV

Table 1: Summary of NAV Results for 125W

From 1 Payload	Best Expected	Best Measured
Aircraft Elevation (deg)	7.00	0.08
Slant Range (km)	2550	3229
95th % Update Int.(s)	8.00	4.09

FAA Results

The flight test for the FAA aircraft was on 3/30/2017 with a takeoff time from the FAA Tech Center airport at 17:40Z. During this flight test, three Aireon payloads were available to receive data, offering significantly more samples than if only one payload was in operation. Figure 7 shows the measured UI performance and the results look strikingly similar to terrestrial ADS-B coverage with the characteristic descending “harmonics” in the histogram at 1s intervals. Figure 8 reveals an impressive set of slant ranges, including a sizeable cluster near 3500 km. The differences in the slant range histograms from Figure 6 compared to Figure 8 are mainly due to variations in geometry from the payloads relative to the aircraft for a particular time period (as opposed to being an isolated measure of performance vs. slant range). Table 2 summarizes expected versus measured performance for some key parameters.

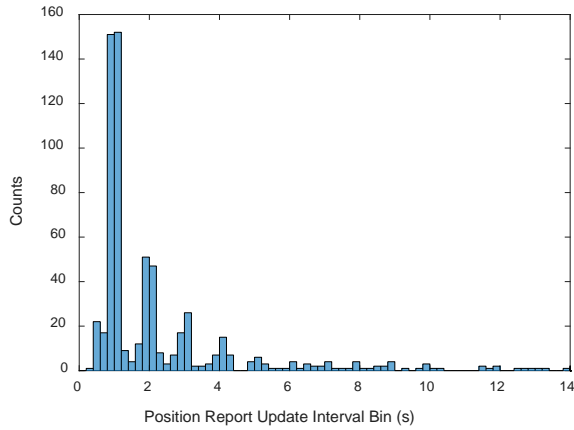


Figure 7: Measured UI for FAA Aircraft

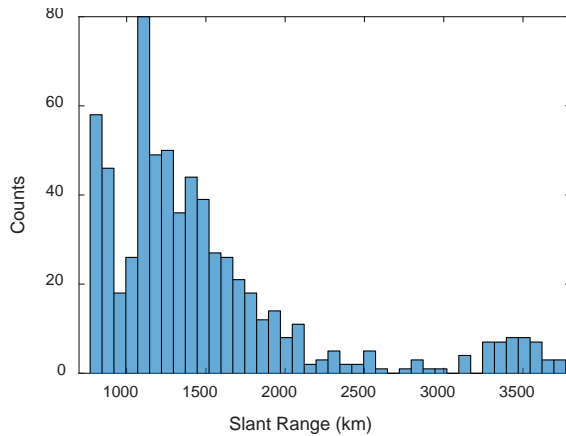


Figure 8: Measured Slant Range for FAA

Table 2: Summary of FAA Results for 125W

From 3 Payloads	Best Expected	Best Measured
Aircraft Elevation (deg)	7.00	-4.58
Slant Range (km)	2550	3768
95th % Update Int.(s)	15.00	10.02

One of the reasons why the UIs are distributed more towards higher values in Figure 7 than Figure 5 is that the NAV CANADA aircraft flew in significantly lower density airspace than the FAA aircraft. Even though the FAA aircraft was in an oceanic airspace, it is adjacent to one of the busiest airspaces in the world and the receiver beam footprints can cover over 1500 km in diameter. In order to more accurately portray this environment, the interference

environment must be measured and tuned in the model.

III. High Interference Environment

Background

The estimated impact of in-band and near-band interference on the reception of ADS-B messages from space was the primary topic of prior publications by Aireon [2] [3]. A few years later it is exciting to test the methods outlined in those studies and compare measurements to the expected results. The plan for the high interference environment test was to have a dedicated flight test from a General Aviation (GA) aircraft flying near the “middle” of terrestrial US airspace.

The flight plan (shown in Figure 9) involved flying a Beechcraft Bonanza from the Moore County Airport in Dumas, TX (KDUX) to Show Low (KSOW) in Show Low, AZ.



Figure 9: Polaris Flight Test Plan and Aircraft³

Although the local environment of KDUX is not particularly high density on its own (Figure 10) one aggregate satellite footprint can cover most of North America. Using FlightAware to depict the aircraft density, Figure 11 illustrates the approximate size of an 8 degree elevation angle satellite footprint directly over North America (light blue outline). Therefore, it was agreed amongst the stakeholders to conduct the primary high interference test case in this region.

³ Photo Credit: Polaris Flight Systems

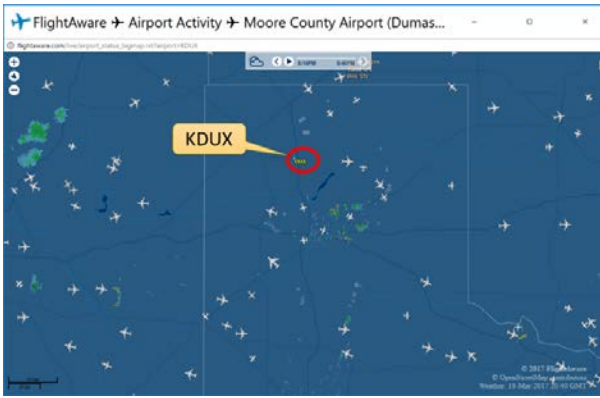


Figure 10: Example Aircraft Density near KDUX⁴

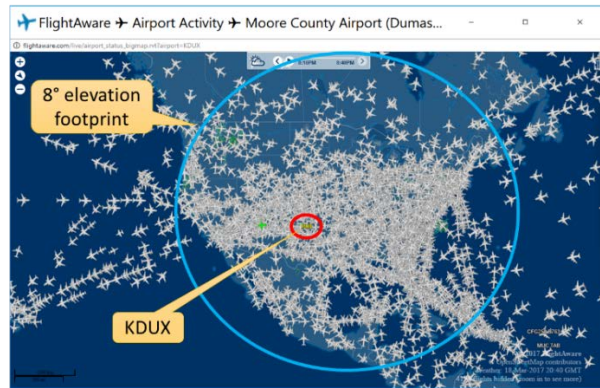


Figure 11: Aircraft Density over North America⁵

Polaris Results

The Polaris flight test took place on 3/20/2017 with three passes from two satellites collecting data for about 16 minutes each. Figure 12 and Figure 13 show the aircraft’s measured UI and slant range histogram, respectively. As indicated in Figure 13 and Table 3, the maximum slant range (and minimum elevation) has improved relative to NAV CANADA’s 125W clear sky test, which likely due to the higher power transmissions (200W) on the Polaris aircraft. Additionally, the UI performance is shifted due to the high density of aircraft with 1090 MHz transmissions (ADS-B, Mode S, and ATCRBS). However, the 95th percentile UI is about 10s which is an improvement on the performance of the expected value of 15s for two payloads. Better receiver range performance comes with the counter-acting Pd penalty of increased potential for overlapping message interference. A more detailed dissection of the measured impact of the

interference environment will be more applicable when several additional orbital planes filled in later in the constellation deployment sequence. Naturally, the UIs will improve significantly when more Aireon payloads are in their mission orbit since overlapping payload footprint coverage mitigates many of the challenges associated with high density aircraft airspaces.

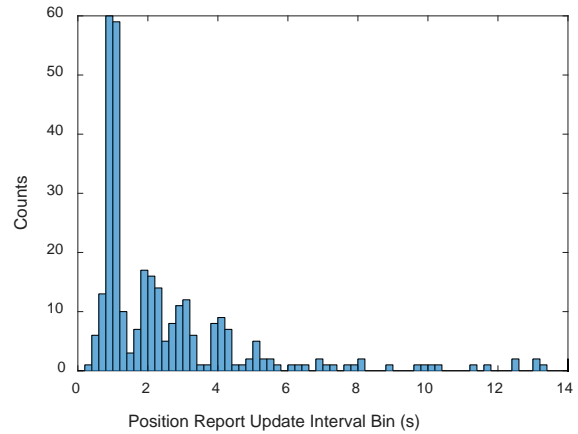


Figure 12: Measured UI for Polaris Aircraft

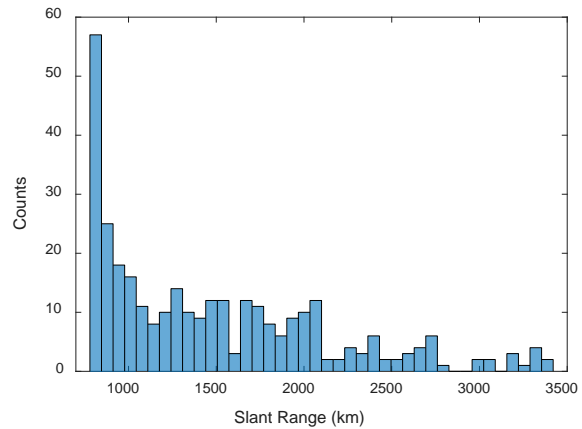


Figure 13: Measured Slant Range for Polaris

Table 3: Summary of Polaris Results for 200W

From 2 Payloads	Best Expected	Best Measured
Aircraft Elevation (deg)	4.00	-1.37
Slant Range (km)	2800	3392
95 th % Update Int. (s)	15.00	9.97

⁴ Figure Sourced from FlightAware

⁵ Figure Sourced from FlightAware

IV. Reference Transmitter Calibration

Background

Below is a list of some of the uncertainties that can make it challenging to evaluate the performance model:

1. Aircraft TX power
2. Aircraft antenna gain pattern, orientation, and source (top vs. bottom)
3. Link budget
4. Payload receiver spatial gain
5. Payload receiver MER curve
6. Interference environment

One of the methods employed by Aireon to reduce the uncertainty for items 1-5 on the above list was to provision a Ground Based Reference Transmitter (GBRT). The role of the GBRT is to transmit ADS-B messages from a fixed ground location to the satellites using a carefully calibrated transmitter and antenna system. Since the GBRT is a calibrated transmitter operating from a controlled environment, the received signal level at the satellite can be known with a much higher degree of certainty than by using targets of opportunity. The GBRT was designed to have four calibrated antennas (from Til-Tek) with approximately 15 degree half-beam widths (similar to a radar beam shape), each pointed in a different direction with site surveyed information. The GBRT is driven by a Selex 4 channel radio (Figure 14), which is also used in several of the FAA's Wide Area Multilateration (WAM) systems [14].

Transmit power and attenuation were carefully measured and controlled to each antenna (which addresses items 1 and 2). The link budget is assumed to have the least amount of uncertainty considering how well-established Free Space Path Loss (FSPL) is calculated in the telecommunications industry [15]. To control the interference environment (item 6), the GBRT was located in an area with very low aircraft density in Iqaluit, Canada on a site owned and operated by NAV CANADA (Figure 15). The high latitude also increases the number of passes per day by the satellites. Given the reduction in uncertainty the GBRT provided, it allowed for analysis with this test

asset to be focused on items 4 and 5.

The primary concept of operations for this GBRT was for it to be always on and transmitting 10 messages per second out of each antenna with approximately the same peak output power as the TLAT antenna model used in simulations at 25 degrees of elevation (51 dBm EIRP + 4 dBi TLAT antenna peak gain = 55 dBm) [16]. The gain roll-off from the GBRT boresight would be analogous to "walking down" an aircraft antenna's lower gain areas as the satellite passes over, capturing the near full range of the expected 125W aircraft output power profile.

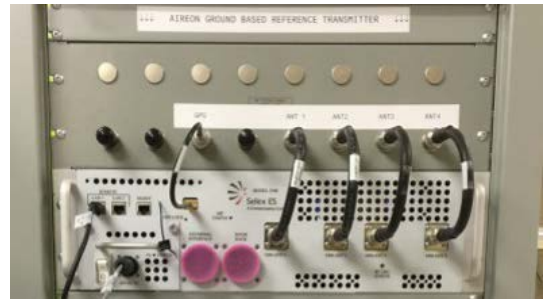


Figure 14: GBRT Selex ADS-B Radio Tx and Rx⁶



Figure 15: GBRT in Iqaluit w/ 4 Tx Antennas⁷

Results

Data from the GBRT was collected and analyzed from a single payload over a 6 day period. During this time period the satellite had many passes over the GBRT and collected 37,863 ADS-B messages. Figure 16 shows a spatial conformance plot from the GBRT perspective for a single antenna transmitter (i.e. a bird's eye view polar plot of conformance vs.

⁶ Photo Credit: NAV Canada

⁷ Photo Credit: NAV Canada

elevation and azimuth). The conformance values are calculated simply by dividing the measured samples by the expected samples (based on the model in ASIM) for each “pixel” where a pixel represents the counts at each respective elevation and azimuth angle observed. A histogram of the pixel conformance counts is in Figure 17 with a distribution centered at approximately 1 (where 1 is the ideal and values greater than 1 indicate expectation exceedance).

Table 4 summarizes the expected versus measured performance with the measured clearly outshining the expected values in each category. However, given the mean conformance is at 1 in these results as well as others collected, the spatial gain and MER curves were considered tuned well enough for initial on-orbit analysis and within an appropriate range of error.

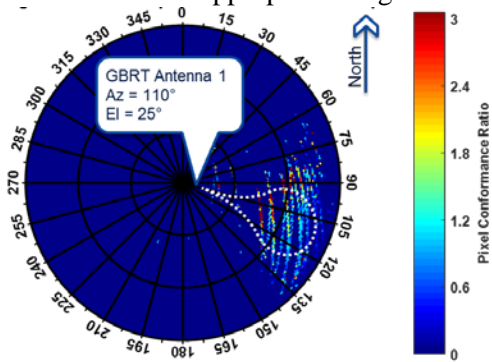


Figure 16: GBRT Spatial Conformance

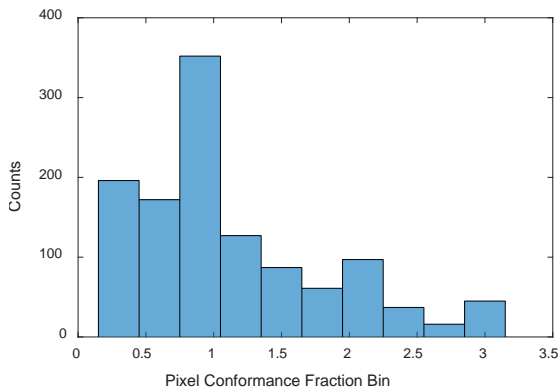


Figure 17: GBRT Pixel Conformance Histogram

Table 4: Summary of GBRT Results for 125W

From 1 Payload	Best Expected	Best Measured
Aircraft Elevation (deg)	7.00	0.70
Slant Range (km)	2550	3175
95th % Update Int. (s)	1.66	1.35
95th % Pixel Conform.	1.50	3.00

V. Summary

Each test discussed in this analysis consistently shows the measured performance of the Aireon payload going beyond expectations. With over one hundred thousand unique ADS-B aircraft and hundreds of millions of messages observed from a few payloads in just one month, this is clearly only the beginning of discovering the system’s full potential. More testing, analysis, and tuning will certainly be necessary for both the first set of payloads as well as the other payloads that are launched and placed into mission orbit. However, these initial results certainly increase confidence that, with a complete constellation, an 8s UI will be achievable by Aireon in the majority if not all airspaces.

These results would be difficult (if not highly unlikely) to be produced from prototype, experimental, novelty, or adoption-limited technologies for continuous ATC-grade surveillance and global flight tracking. For example, hundreds of small-sats/cubesats would be needed to generate global coverage without loss of continuity from a given aircraft. Geosynchronous satellites have a much higher latency and tougher link budget to overcome than low-earth orbiting constellations. As another example, although 15 minute updates can be provided by ADS-C, the platform does not readily support much higher update rates at the same aircraft capacity levels as an enterprise space-based ADS-B system.

ANSPs will likely continue to choose a variety of surveillance technologies (as opposed to only one or two) to support separation services in their airspaces. Indeed, most aircraft surveillance systems are not mutually exclusive with each having tradeoffs in performance, operability, and cost. An ANSP is typically motivated to implement an ecosystem of solutions to solve different problems. As evidenced by this paper, once fully deployed, Aireon’s Space-Based ADS-B system will be capable of meeting the same performance requirements as terrestrial systems

for en-route (8s) and, by extension, oceanic airspaces. This increase in choice and capability for an ANSP is anticipated to bring tangible benefits for the airlines and air traffic community at large.

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