uAvionix tailBeaconX Transponder Performance with Aireon Space-Based ADS-B

Revision: 1.0
Date: May 27, 2021

Revision Status/Description			
Upon revision, this document will be reprinted and reissued in its entirety. All pages will be at the same revision status.			
Revision	Description	Date	Approval(s)
1.0	Initial Release	2021-05-27	

1 Executive Summary

Capital Sciences, LLC, a company that has extensively worked with Aireon LLC on system design and performance analysis, performed an analysis on over a year's worth of Aireon data, comparing General Aviation (GA) aircraft equipped with uAvionix's tailBeaconX transponder and similar aircraft equipped with traditional diversity transponders. The analysis was conducted using Aireon data in Canadian airspace, calculating the Probability of Update Interval (PUI) and Probability of Long Gaps (PLG) using standards set forth in EUROCAE ED-129B. The calculations were run on over 4 million ADS-B messages dividing among a number of facets including known transponder type, airborne, and surface time.

Overall, uAvionix's tailBeaconX transponder performed similarly to GA aircraft equipped with diversity transponders, both meeting the requirements for PUI and PLG set forth in ED-129B. Both transponder types meet the threshold values of ED-129B.

It is the recommendation of this analysis that any ADS-B mandate which requires diversity transponders due to the use of space-based ADS-B should also consider tailBeaconX as an acceptable means of compliance in such mandate.

2 Introduction and Background

2.1 tailBeaconX

tailBeaconX[1] (Figure 1) is a Class1, Level 2 Mode S Extended Squitter (ES) transponder developed and manufactured by uAvionix Corporation. It received a Technical Standard Order (TSO) authorization from the Federal Aviation Administration (FAA) on January 26, 2021, inclusive of TSO-C112e, TSO-C166b, TSO-C145e, and TSO-C30c.

Figure 1: tailBeaconX

[1] https://uavionix.com/products/tailbeaconx/

The tailBeaconX is not certified as a “diversity” transponder, which would have two independent antennas for mounting on the top and the bottom of the aircraft. Instead, the tailBeaconX utilizes a unique design with a dipole antenna inclusive of an aircraft rear navigation light. This unique design, combined with its intended installation location on the rear extent of an aircraft is intended to provide spherical radio-frequency (RF) coverage above and below the aircraft comparable to the performance of a “traditional” diversity transponder.

The use of space-based ADS-B services from the Aireon satellite network is providing regulators and Air Navigation Service Providers (ANSPs) worldwide with an opportunity to leverage space-based ADS-B data for Air Traffic Services (ATS). However, in order to achieve acceptable performance in terms of update rates and surveillance coverage – these regulators must require diversity transponders in order to consistently receive the signal from the satellite network. This presents a problem for GA owners since a diversity transponder is not a typical installation on GA aircraft and have costs that exceed traditional transponders by 2-3X and installation costs which exceed traditional transponders by 2-3X.

uAvionix proposes that the tailBeaconX unique design and installation location achieves performance levels similar to diversity transponders on GA aircraft. uAvionix equipped a number of aircraft in Canada with pre-certified versions of tailBeaconX and in partnership with Aireon collected a full year worth of space-based ADS-B data for analysis.

2.2 Purpose

uAvionix desires to have a better understanding of the performance of their tailBeaconX transponders. It commissioned Capital Sciences, LLC with analyzing GA aircraft equipped with tailBeaconX transponders to determine the Probability of Update Interval of 8 seconds (PUI) and Probability of Long Gap (PLG) with n of 3 in comparison to known diversity GA aircraft along several types of flight operations and maneuvers.

2.3 Capital Sciences, LLC

Capital Sciences, LLC, is a Virginia based small business founded in 2009. It offers an extensive depth of knowledge in the fields of systems engineering and analysis within the aviation industry. It has worked closely with Aireon almost since the latter’s inception on the development, design, implementation, and analysis of its various systems.

3 Methodology

3.1 Benchmark

The EUROCAE ED-129B “Technical Specification for a 1090 MHz Extended Squitter ADS-B Ground System” document provides a basis for performance metrics. Probability of Update Interval (PUI) is the probability of receipt of an ADS-B message within a specified update interval. Probability of Long Gaps (PLG) is a probability that a gap in update occurs that is more than ‘n’ times the respective update interval.

PUI and PLG requirements differ for different types of airspace. Table 1: ED-129B PUI Requirements and Table 2: ED-129B PLG Requirements illustrate the ED-129B PUI and PLG thresholds for various Enroute (ER), terminal area (TMA), and airport (APT) airspaces.

Table 1: ED-129B PUI Requirements

ATC Sector Type	Update Interval (s)	Horizontal Position
Low-Density ER	8	96,0%
Medium-Density ER	8	97,5%
High-Density ER	8	98,5%
Low-Density TMA	5	96,5%
Medium-Density TMA	5	97,5%
High-Density TMA	5	98,5%
High-Density APP2.5	5	99,0%
High-Density APP2.0	5	99,0%
ADS-B APT (moving)	1	90,0%
ADS-B APT (stationary)	10	90,0%

Table 2: ED-129B PLG Requirements

ATC Sector Type	Update Interval (s)	n = 3
Low-Density ER	8	0.222%
Medium-Density ER	8	0.083%
High-Density ER	8	0.037%
Low-Density TMA	5	0.185%
Medium-Density TMA	5	0.074%
High-Density TMA	5	0.030%
High-Density APP2.5	5	0.015%
High-Density APP2.0	5	0.012%
ADS-B APT (moving)	1	N/A
ADS-B APT (stationary)	10	N/A

In practical use, Aireon surveillance will likely be combined with existing ground-based infrastructure in medium and high-density airspace. In low-density airspace, Aireon may be the only surveillance source available. For this reason, Low Density Enroute ED-129B values for PUI and PLG have been chosen as benchmark metrics for this analysis as follows:

PUI 8s = 96.0%
PLG 8s, n=3 = 0.222%

3.2 Calculations

Calculations were done in accordance with the standards set forth in ED-129B Appendix C, as follows:

For PUI:

PUI = 1-((Total miss period/Total flight time)

For PLG:

n = number of consecutive missed update intervals
UI = update interval
G = gap time

Pgi(n) = (G/UI -n) Where n*UI <= G < (n+1)*UI
+(n+2 – G/UI) Where (n+1) *UI <= G < (n+2)*UI

agi(n) = pgi(n) * n

PLG(n) = sum(agi(n))/Total flight time

3.3 Data Used

Aireon data collected during calendar year 2020 for certain Canadian airspace which data was throttled to a four second-update rate to allow for access via the cloud was used for the analysis. As a consequence of the four-second throttling, real-world results in an ANSP automation environment will show improvements over the values in this analysis due to the higher resolution of data being provided to the ANSP. Figure 2 and Figure 3 offer a comparison of throttled vs unthrottled data for the two operations of tailBeaconX target C0654A in September. These operations occurred close to Ottawa; the take off and landings for each occurred outside of the test area locations utilized for this analysis, as detailed in Section 3.5. The throttled operations have noticeably more gaps than the unthrottled. Table 3 gives a comparison of PUI and PLG for 4 targets during the month of September, 3 tailBeaconX and 1 standard GA diversity, using throttled and unthrottled data, and shows a clear improvement in metrics.

Figure 2: Throttled operations for target C0654A September 2020. Red portions are a failure of PUI of 8 seconds, yellow are failures of PLG n=3

Figure 3: Unthrottled operations for target C0654A in September 2020. Red portions are a failure of PUI of 8 seconds, yellow are failures of PLG n=3

Table 3: Comparison of four targets, throttled vs. unthrottled, during September of 2020

ICAO Address	Throttled PUI	Unthrottled PUI	Throttled PLG	Unthrottled PLG	Transponder
C079F7	97.20%	98.23%	0.0000%	0.0000%	tailBeaconX
C05EFF	97.74%	98.76%	0.0000%	0.0000%	tailBeaconX
C0654A	90.33%	91.49%	0.2975%	0.2681%	tailBeaconX
C076DE	95.27%	96.51%	0.0000%	0.0000%	GA Diversity

Figure 4 illustrates an overview of a superset of data collected during 2020.

Figure 4: Example Aireon Data Captured in North America

3.4 Challenges of GA Flight Profiles

As PUI and PLG statistics are percentages based on total flight time in the denominator, shorter flights with maneuvers and frequent touch and go's such as those conducted by GA aircraft are disadvantaged as compared to typically longer commercial and business jet flights given the performance characteristics of "flight time", versus "ground time". For this reason, a comparison of GA flights to commercial flights is not an adequate comparison.

Working with the Canadian Owners and Pilots Association (COPA), uAvionix was able to identify the ICAO addresses of a number of GA aircraft confirmed to have traditional diversity installations. A number of these aircraft were indeed flying commercial operations but were doing so with Cessna 208B

Caravan and DE Havilland DHC-6 Series 300. While these aircraft do typically fly at a higher altitude, and longer duration than a typical private GA pilot, this is a better comparison and as close as uAvionix was able to come to identifying comparable "GA" aircraft for comparison.

In addition to shorter flight times disadvantaging PUI and PLG statistics, GA aircraft often also perform maneuvering unique to GA operations such touch-and-go activities, stop and taxi-back or steep bank and pitch maneuvers, which can reduce PUI and PLG performance. The analysis intent was to try to identify these maneuvers and identify the PUI and PLG statistics accordingly.

Figure 5: Example of Touch and Go Maneuvers as Observed by Aireon. Red portions are a failure of PUI of 8 seconds

3.5 Test Location

Nav Canada previously conducted an analysis of all aircraft performance data as tracked by Aireon across Canadian airspace. Dividing this airspace in a grid of 1 degree of Latitude by 1 degree of Longitude, Nav Canada analyzed the performance within each grid segment to determine if Aireon data alone would meet the ED-129B performance and identified those grid cells with green shading.

Figure 6 illustrates grid cells in green where Aireon data alone generally meets ED-129B performance, and where flight data was used for the analysis.

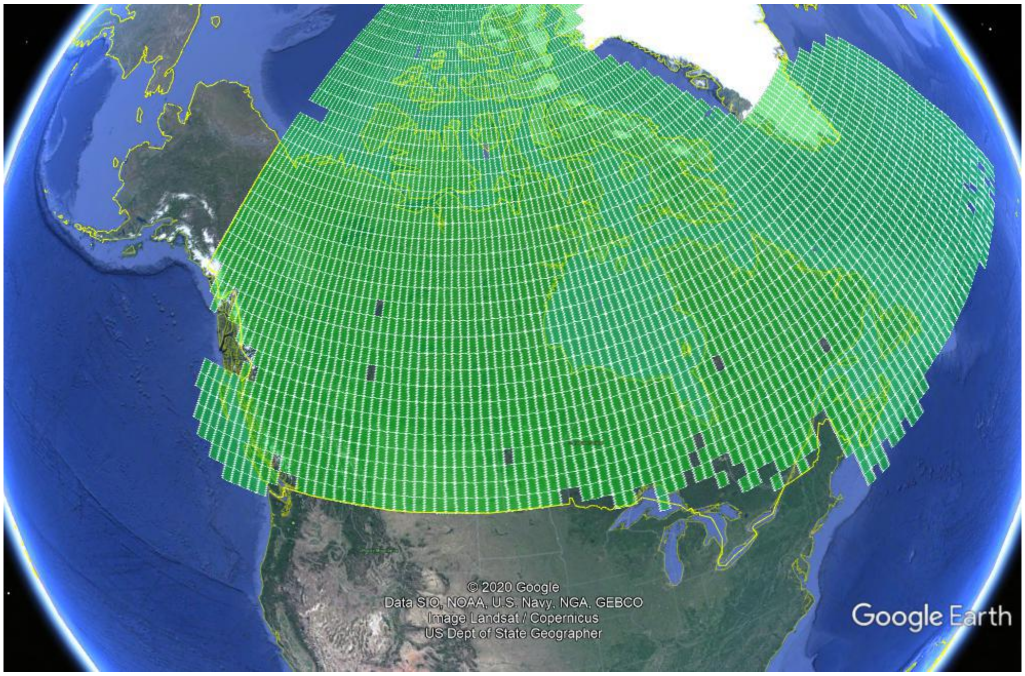

Figure 6: Test Area Locations (Green Cells)

3.6 Test Aircraft

A total of 48 aircraft were initially identified for analysis. Post filtering, the data used contained 38 unique targets, 20 tailBeaconX equipped, and 18 traditional diversity. There were significantly more operational hours for traditional diversity equipped aircraft (6647 hours) due to the nature of the commercial operations conducted compared with 453 hours for those that were equipped with tailBeaconX transponders. Overall, 4,845,352 messages were evaluated. The list of aircraft and equipment installed appears in Appendix A. Figure 7 illustrates some example installations of tailBeaconX.

Figure 7: Example tailBeaconX Installations

4 Analysis

4.1.1 Data Division

After processing, the throttled Aireon data was split by 24-bit ICAO address, so that each individual aircraft's data was separated from the others. In order to not disadvantage the statistics due to events such as refueling stops for GA aircraft, each aircraft's data was then broken up by identifying gaps of ten minutes or longer without messages to define an "operation."

Within each operation, there could be multiple sub operations, as defined by time when the target was on the surface versus when it was airborne, as detailed in Figure 8. This process was used to identify taxi-back events, pilot/ instructor swaps or touch-and-go activities where the aircraft was reported to be on the ground but did so for less than the ten-minute threshold.

This sub-operation analysis was done so by examining the Flight Level data field in the CAT021 message. When set to N/A, the target was assumed to be on the surface. An analysis was also run using the Ground Bit data item in the CAT021 message and found the results to be almost identical.

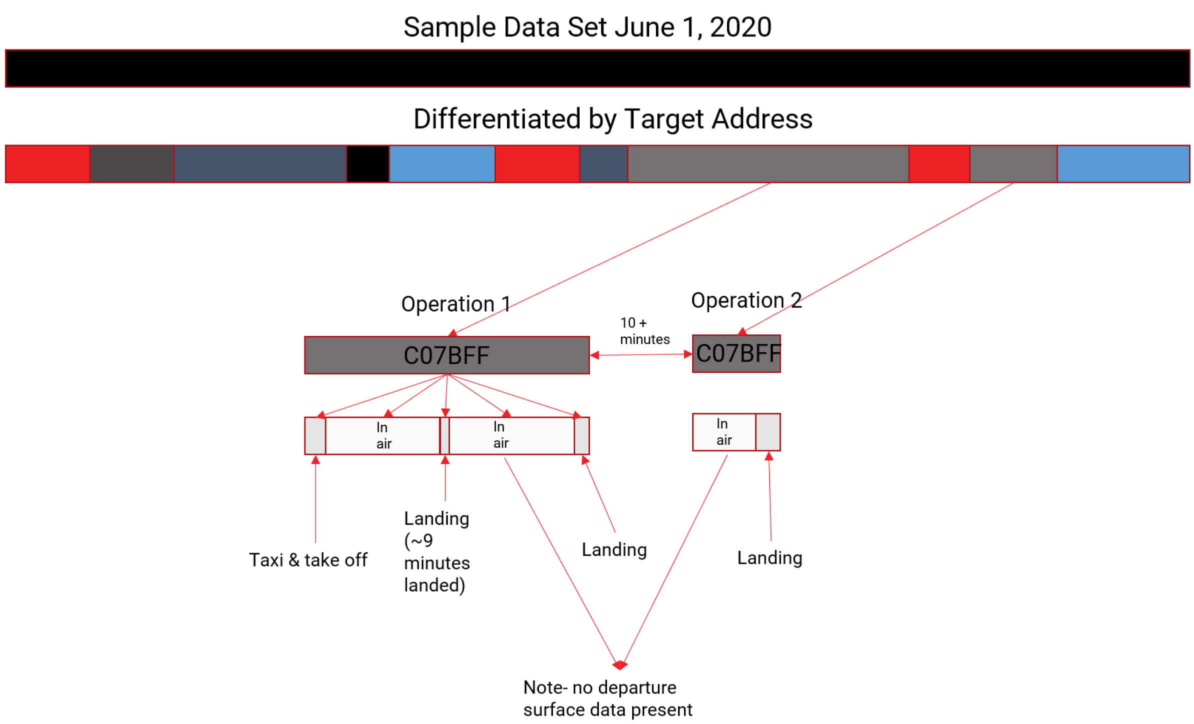

Figure 8: Data split by Target, operation, and suboperation

PUI and PLG were calculated by suboperation, operation, target, and by airborne and surface time, as detailed in Figure 9.

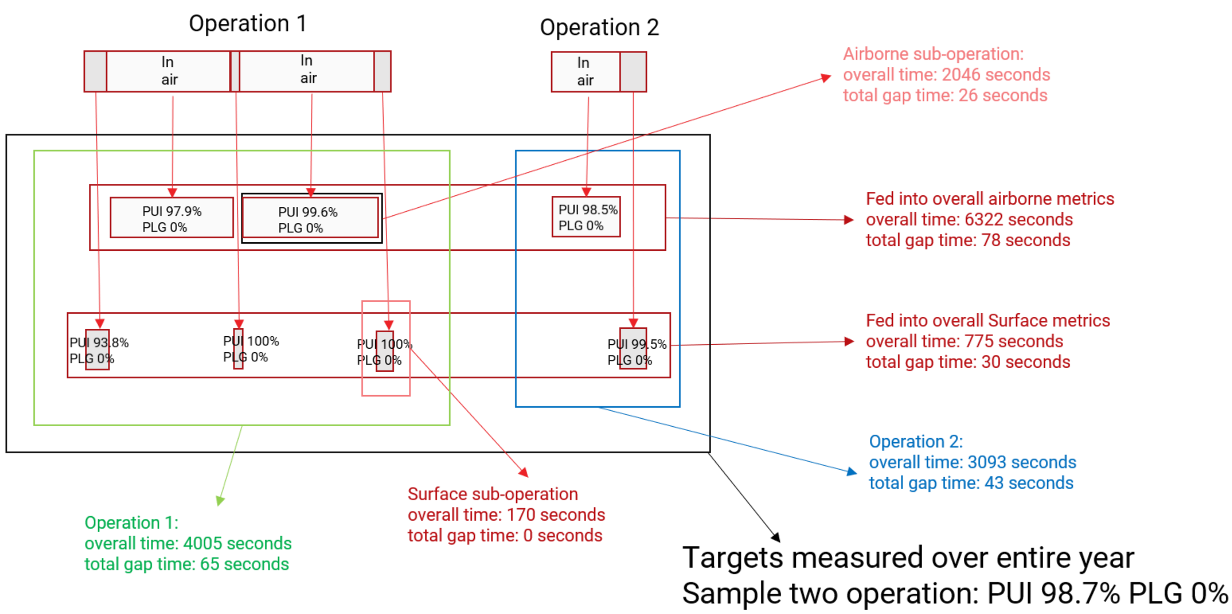

Figure 9: Calculations by Target, operation, and suboperation

5 Data Characteristics & Observations

5.1 Operations per Month

The number of operations per month tended to be higher in the latter part of the year. March, April, May, and June were particularly low likely because of the COVID-19 pandemic. See Figure 10. Temporal analysis of PUI/PLG statistics were not conducted.

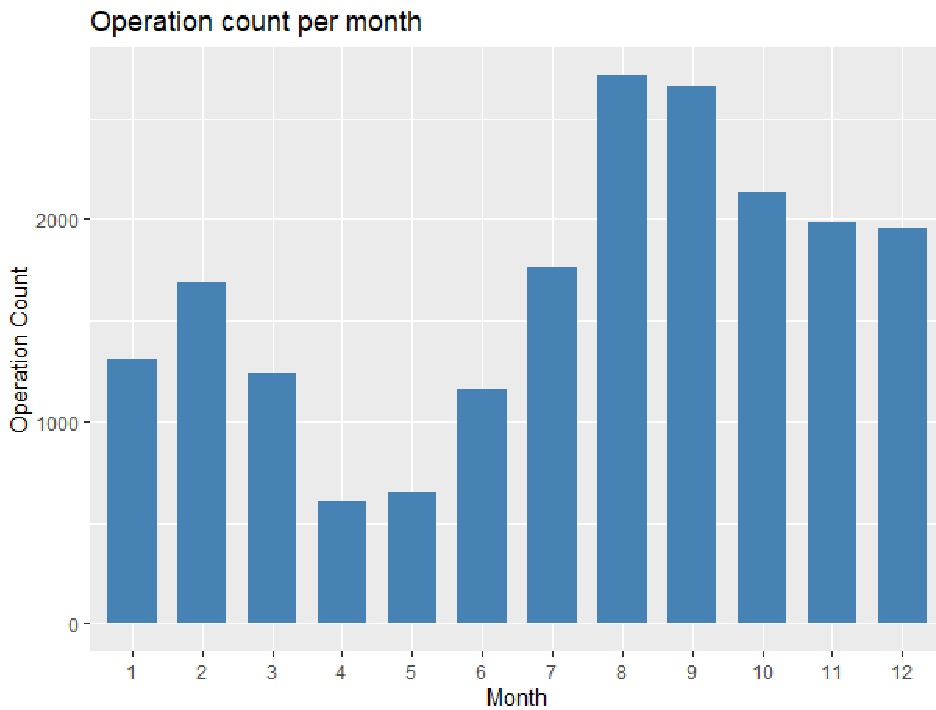

Figure 10: Observed Operations per Month

5.2 Operation Locations

The highest density of operations centered around the North Western part of Canada. This is the location of the commercial operator operating the Cessna 208B and DE Havilland DH6 aircraft. tailBeaconX operations were generally concentrated further south, closer to the border with the United States, both in the Western and Eastern parts of Canada. Figure 11 illustrates the heatmap of all analyzed operations, Figure 12 illustrates the heatmap of all tailBeaconX analyzed operations, and Figure 13 illustrates the heatmap of all traditional diversity installation analyzed operations.

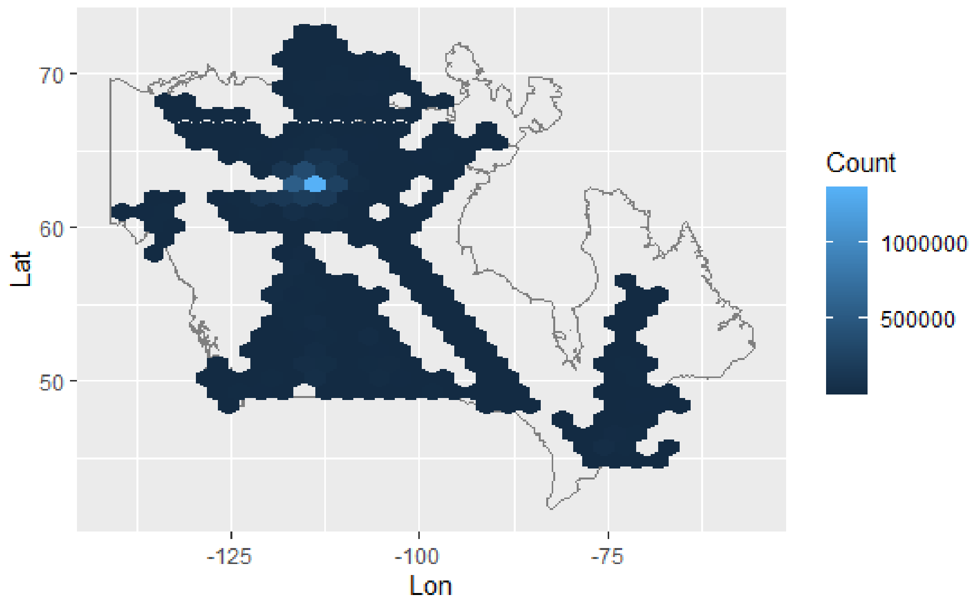

Figure 11: Heatmap of All Operations by Message Count

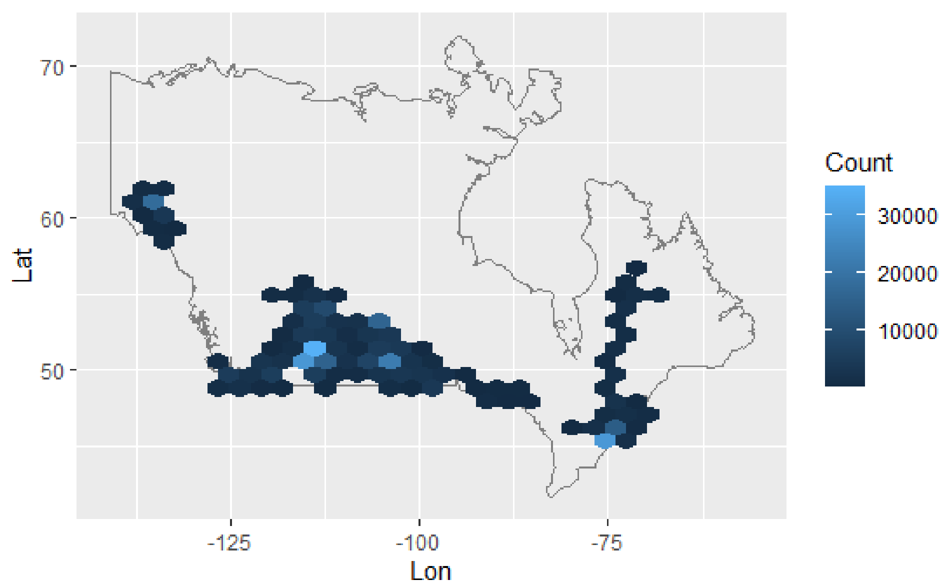

Figure 12: Heatmap of tailBeaconX Operations by Message Count

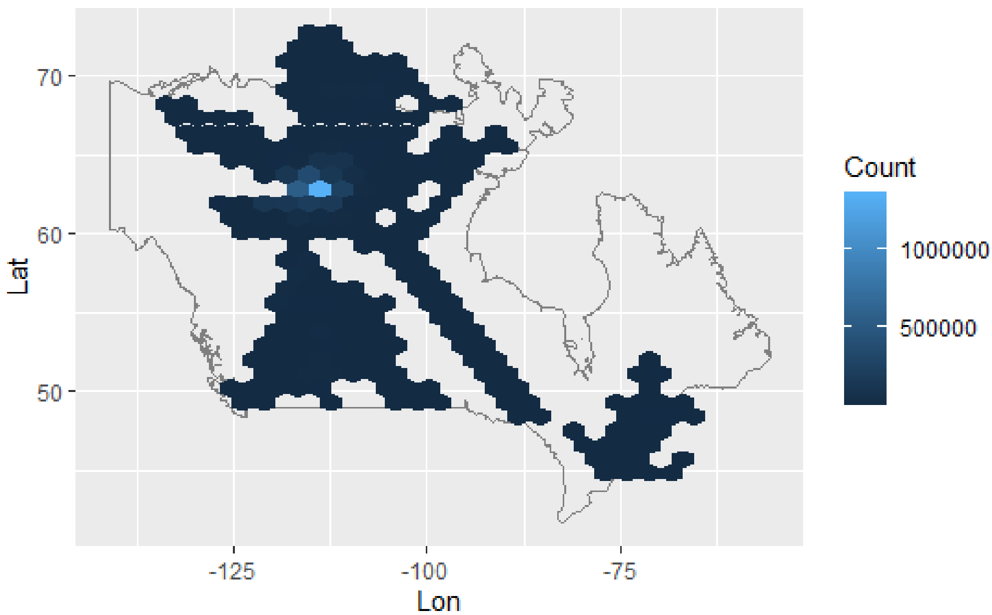

Figure 13: Heatmap of Traditional Diversity Transponder Operations by Message Count

5.3 Geographic PUI Performance

PUI performance was high over the Western, Mid and Northern part of Canada for both tailBeaconX and non-tailBeaconX transponder equipped aircraft and tended to be lower in the South-Eastern portion of the country. It was significantly lower in the area around Montreal. See Figure 14.

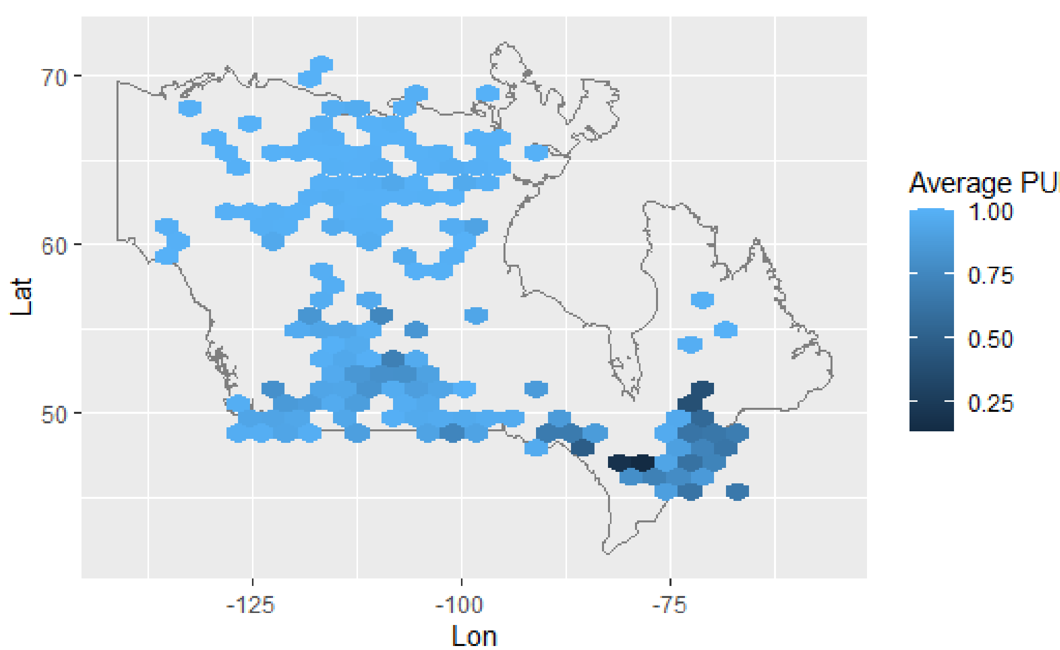

Figure 14: Average PUI Geographically

Figure 15 illustrates an aircraft which performed poorly in the area directly adjacent to the Nav Canada identified grid-squares in Montreal. Because of this, the analysis presents results both including and excluding the areas immediately surrounding Montreal to better reflect the actual performance in "normal" airspace without the interference.

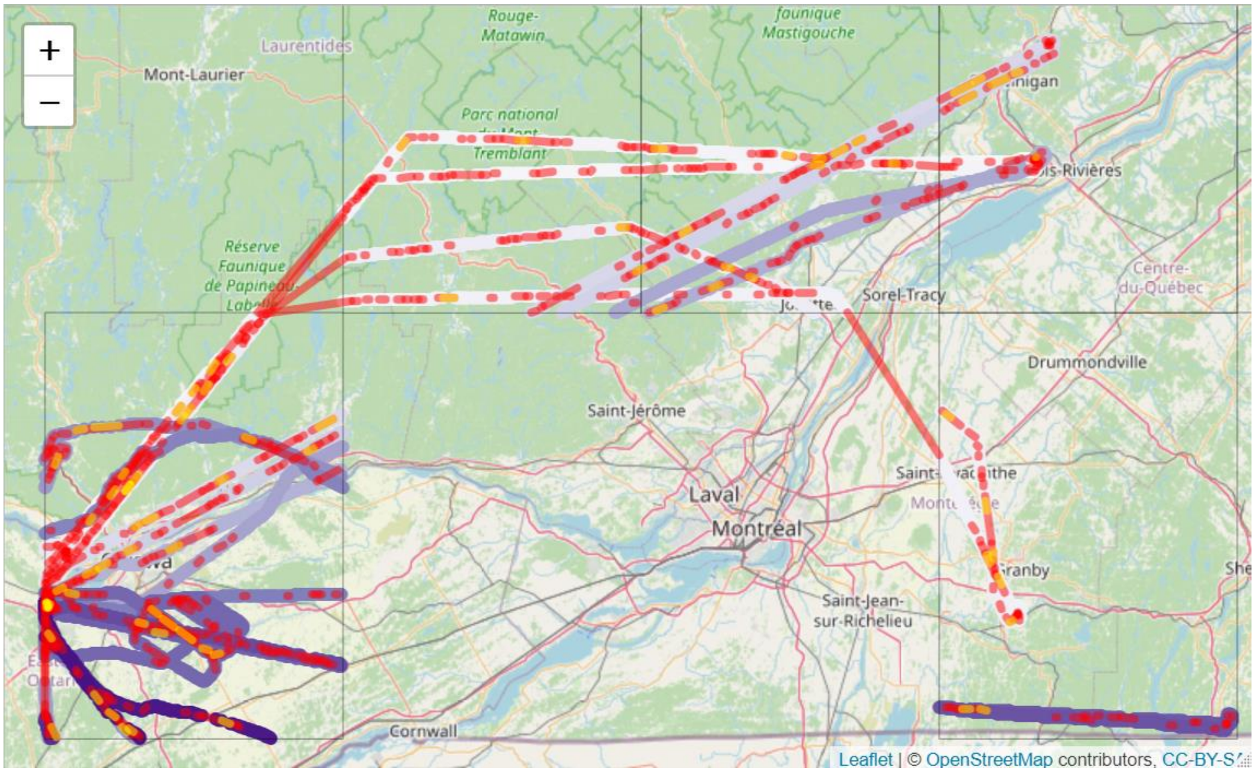

Figure 15: Poorly Performing Aircraft Flights Conducted Surrounding Montreal. Red portions are a failure of PUI of 8 seconds, yellow are failures of PLG n=3.

Figure 16 illustrates the resulting geographic PUI after excluding the filtered region.

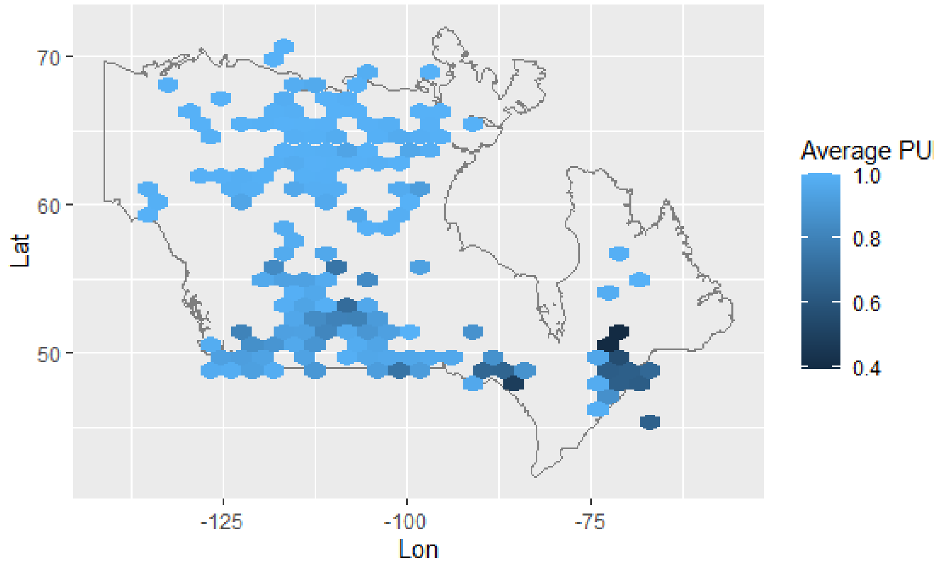

Figure 16: Average PUI Geographically excluding the area around Montreal

6 Results

Using the methods described herein, the analysis produced the following results for the full year of 2020. Table ***4*** illustrates the results when including the poorly performing region surrounding Montreal, and Table 5 illustrates the results when excluding this region.

Table** 4**: PUI and PLG Results Inclusive of Montreal Region

	Overall time (hours)	UI gap time (hours)	PUI 8s (ED-129B Threshold >96.0%)	LG time (hours)	PLG n=3 (ED-129B Threshold <0.222%)
All tailBeaconX	453	19	95.74%	0.22	0.0485%
tailBeaconX Airborne	391	14	96.33%	0.18	0.0460%
tailBeaconX Surface	62	5	92.03%	0.04	0.0642%
All Diversity GA	6647	258	96.13%	2.15	0.0324%
Diversity GA Airborne	6129	213	96.52%	1.96	0.0321%
Diversity GA Surface	518	44	91.42%	0.19	0.0358%

Excepting Montreal and surrounding area, tailBeaconX equipped aircraft performed better than diversity equipped GA aircraft overall, in the air, and on the ground for a PUI of 8 seconds. It is notable that if an aircraft is stationary on the ground, its squitter rate is reduced to once per 5 seconds per RTCA DO-260B. Therefore, a reduction in performance on the surface is expected on the surface.

Table 5: PUI and PLG Results Excluding Montreal Region

	Overall time (hours)	UI gap time (hours)	PUI 8s (ED-129B Threshold >96.0%)	LG time (hours)	PLG n=3 (ED-129B Threshold <0.222%)
All tailBeaconX	368	10	97.29%	.1	0.0323%
tailBeaconX Airborne	314	6	98.08%	.09	0.0299%
tailBeaconX Surface	53	4	92.66%	.02	0.0468%
All Diversity GA	6564	218	96.69%	1.8	0.0275%
Diversity GA Airborne	6053	175	97.11%	1.6	0.0271%
Diversity GA Surface	511	42	91.72%	0.2	0.0324%

7 Conclusion

In the data set inclusive of the Montreal region, tailBeaconX still met the PUI performance of ED-129B in Low-Density Enroute airspace while airborne, and PLG performance of Medium-Density Enroute airspace while airborne. Traditional diversity transponders also met Low-Density Enroute airspace performance while airborne and met the PLG performance of High-Density Enroute airspace.

Neither transponder type was able to meet the PUI threshold values while on the surface, where squitter rates are reduced per RTCA DO-260B. This lower performance combined with the comparatively longer time targets equipped with it spent on the surface pulled the tailBeaconX overall average down to just below the 96% threshold. Looking only at airborne data seems to be a more reasonable approach when comparing GA targets of opportunity to typical diversity antenna targets of opportunity.

tailBeaconX met the PUI performance of Medium-Density Enroute airspace and the PLG performance of High-Density Enroute airspace when airborne and met the Low-Density PUI and High-Density PLG requirements even while keeping surface operations in the analysis outside the Montreal area. Traditional diversity transponders met the PUI performance of Low-Density Enroute airspace and met the PLG performance of High-Density Enroute airspace using the same filtering when airborne.

All result for both transponder types are expected to improve above those calculated here due to 4 second throttling in the test data.

This analysis shows that tailBeaconX performs very similarly to traditional diversity transponders, sometimes outperforming and sometimes underperforming, both by very slim margins which may not be meaningful. Both transponder types meet the threshold values of ED-129B in airspaces where Aireon data is likely to be the only surveillance source available.

It is the recommendation of this analysis that any ADS-B mandate which requires diversity transponders due to the use of space-based ADS-B should also consider tailBeaconX as an acceptable means of compliance with such mandate.

Appendix A. List of Aircraft & Individual Average Performance

ICAO	Time in hours	PUI	PLG	tailBeaconX	TCAS
C07BFF	72.46189	98.73%	0.0781%	TRUE	FALSE
C040AA	54.46546	92.67%	0.2489%	TRUE	FALSE
C037E8	54.21998	96.30%	0.0000%	TRUE	FALSE
C00D67	49.85517	97.05%	0.0285%	TRUE	FALSE
C04D83	37.31476	94.87%	0.0225%	TRUE	FALSE
C05D4C	30.1712	98.72%	0.0525%	TRUE	FALSE
C01D59	28.05914	95.36%	0.0000%	TRUE	FALSE
C020D3	26.69724	92.81%	0.0087%	TRUE	FALSE
C06A2F	15.60844	76.67%	0.0209%	TRUE	FALSE
C07B02	15.35232	99.67%	0.0096%	TRUE	FALSE
C05EFF	14.1137	98.84%	0.0000%	TRUE	FALSE
C0654A	13.05927	97.51%	0.0000%	TRUE	FALSE
C04B77	9.768511	97.80%	0.0000%	TRUE	FALSE
C07872	8.863164	98.96%	0.0287%	TRUE	FALSE
C079F7	8.535569	93.77%	0.0653%	TRUE	FALSE
AAB653	4.477526	96.59%	0.1207%	TRUE	FALSE
A02C30	4.177431	99.38%	0.0000%	TRUE	FALSE
C02D0E	3.059681	98.33%	0.0000%	TRUE	FALSE
C06336	1.798559	95.22%	0.0000%	TRUE	FALSE
A7B674	0.673179	96.03%	0.0998%	TRUE	FALSE
C001FD	940.6633	98.90%	0.0069%	FALSE	FALSE
C06895	923.5377	99.04%	0.0002%	FALSE	FALSE
C0469E	905.6726	98.79%	0.0001%	FALSE	FALSE
C001FB	754.2243	98.73%	0.0071%	FALSE	FALSE
C00205	733.0147	99.34%	0.0010%	FALSE	FALSE
C0646B	681.3352	99.23%	0.0009%	FALSE	FALSE
C00089	547.8099	99.00%	0.0057%	FALSE	TRUE
C046AF	437.5478	98.49%	0.0398%	FALSE	FALSE
C04F70	304.4654	95.07%	0.3699%	FALSE	TRUE
C064C3	224.4263	41.64%	0.6830%	FALSE	TRUE
C01D46	65.94201	87.18%	0.1141%	FALSE	TRUE
C07692	51.15362	57.42%	0.3906%	FALSE	TRUE
C081C1	28.87772	78.83%	0.3095%	FALSE	TRUE
C03D12	28.19143	72.01%	0.1579%	FALSE	TRUE
C042DA	9.712687	64.13%	0.0022%	FALSE	FALSE
C03B63	9.132676	79.15%	0.4737%	FALSE	FALSE
C076DE	0.724954	97.04%	0.5779%	FALSE	FALSE
C04DBE	0.421645	88.42%	0.0000%	FALSE	FALSE

Aireon

4 June 2021

uAvionix Corporation
880 Harrison St., Suite 185
Leesburg, VA 20175

Ref: uAvionix tailBeaconX Transponder Performance with Aireon Space-Based ADS-B, Rev. 1 (the "**Report**")

Dear Mr. Ramsey:

This is to confirm that Aireon provided uAvionix with Aireon data collected during calendar year 2020 for certain Canadian airspace, which data was throttled to a four second update rate for use in the preparation of the Report. Aireon has reviewed the above referenced Report and supports the findings contained therein.

Should there be any questions regarding the information contained within the report related to Aireon data, please do not hesitate to reach out to Dr. Michael Garcia at +1 (703) 762-6673.

Sincerely,

Vincent Capezzuto

Vincent Capezzuto
Chief Technology Officer
Aireon LLC

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