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Research Article

Space-Based ADS-B Latency Evaluation in Jakarta and Makassar Flight Information Regions

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ABSTRACT

This study evaluates the latency performance of Space-Based Automatic Dependent Surveillance–Broadcast (ADS-B) within the Jakarta and Makassar Flight Information Regions (FIRs). A quantitative comparative analysis is conducted using secondary data obtained from Aireon's operational trials in Indonesia, processed through statistical filtering to assess end-to-end latency distributions. The results show a stable average latency ranging from 0.46 to 0.48 seconds, with 95th percentile values consistently remaining below 0.5 seconds, satisfying international aviation surveillance performance requirements. These findings confirm that Space-Based ADS-B is capable of supporting reliable real-time surveillance operations in Indonesian airspace. This study contributes a QoS-based latency assessment that highlights the need for harmonized, satellite-oriented surveillance performance standards beyond existing ground-based ADS-B regulations.

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1. INTRODUCTION

Automatic Dependent Surveillance–Broadcast (ADS-B) is an air traffic surveillance system that enables aircraft to automatically broadcast their position, velocity, and identification data through a 1090 MHz Extended Squitter (1090ES) signal [1]-[4]. ADS-B consists of four key components: Automatic, meaning that information is transmitted automatically (at least once per second); Dependent, because the transmission relies on the aircraft's onboard equipment to determine position and velocity [5]Surveillance, as the system allows continuous monitoring of aircraft information; and Broadcast, since the data are openly transmitted and can be received by other aircraft or ground stations equipped with ADS-B receivers [6][7]. Therefore, ADS-B can also be utilized to detect and localize GNSS interference by monitoring changes in parameters such as the Navigation Integrity Category (NIC) and Navigation Accuracy Category (NAC) [8][9]. Within this system, each aircraft is equipped with a GNSS receiver that obtains satellite navigation signals to accurately compute its position. ADS-B operates in two primary forms: ADS-B Out (Transmitter) and ADS-B In (Receiver) [10][11].

While Ground-Based ADS-B has been widely implemented, its coverage remains limited to terrestrial infrastructure, leaving vast oceanic and remote areas unmonitored [12][13]. This limitation reduces situational awareness and complicates search and rescue operations, as highlighted in several aircraft accidents occurring outside radar coverage. The operational impact of these surveillance gaps has also been demonstrated in real-world incidents. Ashton et al. [14] showed that the disappearance of Malaysia Airlines flight MH370 over remote oceanic airspace underscored the constraints of radar and Ground-Based ADS-B coverage, reinforcing the global need for continuous space-based surveillance.

To overcome these gaps, Space-Based ADS-B was developed, utilizing Low Earth Orbit (LEO) satellites such as the Iridium NEXT constellation to provide continuous global surveillance [15]-[17]. In addition to real-world operational cases, several simulation-based studies have demonstrated the technical challenges of receiving ADS-B signals from Low Earth Orbit [18]-[20]. Van der Pryt and Vincent [21] simulated LEO ADS-B reception and showed that message detectability is highly dependent on satellite altitude, antenna characteristics, and link geometry. Their follow-up analysis of signal collisions over the North Atlantic [22] highlighted the increased probability of packet overlap in high-density routes, stressing the importance of robust spaceborne signal processing. Further validation was provided through the CanX-7 nanosatellite mission, where

Vincent and Van der Pryt [23] demonstrated the feasibility of space-based ADS-B reception using small satellite payloads, while also noting that orbital dynamics influence latency, update rate, and message completeness.

This innovation represents a major step toward achieving seamless global air traffic monitoring, enabling near-real-time tracking even in previously unobservable regions [24]. One of the most critical performance factors of Space-Based ADS-B is latency, defined as the time difference between when aircraft data is generated and when it is displayed to Air Traffic Controllers (ATC) [25]. Latency directly affects the timeliness and accuracy of surveillance information, and excessive delays may compromise operational safety. Ground-Based ADS-B typically achieves latency between 1–2 seconds, while Space-Based ADS-B introduces more complex transmission paths, creating potential for higher delays [26].

Latency is measured by comparing the timestamp transmitted from the aircraft with the time at which the data is received by the Air Navigation Service Provider (ANSP) [27]. Overall, the average latency of Space-Based ADS-B is approximately ≤1.5 seconds [28], which is higher than that of Ground-Based ADS-B (≤0.5 seconds) due to the additional transmission stage from the satellite to the ground segment . However, to minimize latency, the Aireon system is designed using Inter-Satellite Link (ISL) technology, which allows data to be relayed from one satellite to another without waiting for a direct connection to a ground station. This architecture enables Aireon to transmit ADS-B data to end users in less than 400 milliseconds, with an update interval of under 8 seconds in 95% of cases, even in regions with high traffic density [29].

In the context of this research, QoS serves as a framework to assess how effectively the Space-Based ADS-B system provides real-time aircraft position data, which generally considers parameters such as latency (delay), jitter, packet loss, and throughput [30][31]. QoS measurement presented in this paper also refers to the standards established by the European Telecommunications Standards Institute (ETSI) and the International Telecommunication Union (ITU-T E.800), which classify latency as a primary indicator of end-to-end communication performance [32]. However, despite these challenges, Space-Based ADS-B offers an unprecedented opportunity to enhance global situational awareness and optimize airspace efficiency, making latency assessment an essential metric for ensuring the technology's operational readiness.

Several studies have explored various aspects of Space-Based ADS-B and latency performance. Baker [27] discussed the overall architecture, performance, and reliability of Space-Based ADS-B, including its latency characteristics, but did not assess QoS metrics in depth. Sirigu et al. [33] examined turbulence detection using Aireon's satellite-based ADS-B data, addressing latency analysis yet without linking it to QoS evaluation. Garcia et al. [25] presented a compilation of measured ADS-B performance characteristics from Aireon's on-orbit testing, focusing on latency behavior but similarly omitting QoS considerations. Mr. Taruna Jaya et al. [34][35] conducted a feasibility study of Space-Based ADS-B implementation in Indonesia, analyzing latency factors and operational readiness but not within a QoS framework. Meanwhile, Pedersen et al. [35] investigated latency as a QoS indicator in global cloud computing systems, providing theoretical grounding for latency-based QoS evaluation but outside the aviation domain. Overall, prior studies have provided valuable insights into latency performance and satellite-based surveillance reliability, yet none have comprehensively analyzed Space-Based ADS-B latency through a QoS perspective. Although Space-Based ADS-B technology has been implemented globally, a specific evaluation within the Jakarta and Makassar Flight Information Regions (FIRs) presents unique challenges due to Indonesia's archipelagic geographical characteristics and the high density of transcontinental traffic on the Australia-Asia route.

Therefore, this study aims to evaluate the latency performance of Space-Based ADS-B within the Jakarta and Makassar Flight Information Regions (FIRs) using a Quality of Service (QoS) perspective. This research represents the first latency-focused assessment of space-based ADS-B operations in Indonesian airspace that explicitly integrates international aviation surveillance standards (ICAO [36] , FAA [37], and EUROCAE [28]) with telecommunication-based QoS metrics and service-level agreement (SLA) criteria.

The novelty of this study lies in three main contributions. First, it presents the first latency-focused assessment of Space-Based ADS-B operations in Indonesian airspace. Second, it combines aviation surveillance standards (ICAO, FAA, and EUROCAE) with a QoS-based analytical framework. Third, it highlights regulatory and interpretative gaps between generic telecommunication-based QoS delay classifications and aviation-specific surveillance performance requirements for satellite-based ADS-B systems.

2. RESEARCH METHODS

2.1 Research Flow

The methodology employed in this study adopts a descriptive–analytical approach based on quantitative secondary data, with a focus on evaluating latency performance in Space-Based ADS-B systems. The research flow is organized into four main stages, as illustrated in Figure 1.

Figure 1. Research flow

a. Requirement Analysis.

Defining performance requirements by referring to international surveillance standards, including ICAO Doc 9924 [36], FAA 14 CFR §91.227 [37], and EUROCAE ED-129B [28]. Additional latency benchmark considerations were reviewed from global studies on satellite-based surveillance and LEO communication delay modelling.

b. Data Collection.

The study uses secondary data from Aireon consisting of feasibility trial results in Indonesia and technical presentations shared with Air Navigation Service Providers (ANSPs) [35]. Supporting documentation from Aireon's publicly available system descriptions and performance briefs was also consulted to confirm the consistency of latency characteristics across LEO-based ADS-B operations [26]. Since Aireon does not provide access to raw ADS-B message packets or timestamp-level data due to security and operational policy restrictions, the dataset utilized for this analysis consists solely of processed latency outputs obtained from publicly released technical documentation. Therefore, the analysis in this research is performed based on secondary, aggregated performance results, rather than raw message-level measurements.

c. Data Analysis.

Latency values were extracted from Aireon's latency charts, which represent the time difference between message reception at the Aireon Hosted Payload (AHP) and delivery to the Service Delivery Point (SDP). This approach aligns with standard latency-assessment practices in ADS-B system performance studies [27]. Furthermore, literature discussing LEO satellite detection behaviour—such as the influence of multi-beamforming, signal collision probability, and receiver sampling efficiency—was reviewed conceptually to contextualize factors that may contribute to message acquisition timing in space-based ADS-B systems [38].

d. Evaluation and Interpretation.

Latency results were evaluated against international benchmarks defined by ICAO Doc 9924 [36], FAA 14 CFR §91.227 [37], and EUROCAE ED-129B [28]. The interpretation also incorporates a QoS perspective focused on delay [32], referring to frameworks commonly used in communication network performance analysis [30][31]. In addition, evaluation criteria include Aireon's SLA, which sets limits for maximum allowable latency, update probability, and service availability.

2.2 Data Source

The evaluation presented in this study is based on secondary data derived from publicly released technical documents and publications provided by Aireon, the operator of a Low Earth Orbit (LEO) satellite–based ADS-B service [26]. These documents include technical presentations and trial reports delivered in seminars and shared with Air Navigation Service Providers (ANSPs), particularly regarding implementation trials conducted in the Jakarta and Makassar FIRs in 2021 [34]. In addition, peer-reviewed journal articles reporting or discussing these trials are used as supporting references. Collectively, these materials provide aggregated latency performance results that form the basis of the Space-Based ADS-B evaluation presented in this paper.

a. Aireon Documentation.

Publicly released technical presentations, feasibility study materials, and Service Delivery Point (SDP) performance reports contain aggregated results related to latency, update interval, and service availability for Space-Based ADS-B operations within the Jakarta and Makassar FIRs. The observation period referenced in these materials spans from April to December 2021, corresponding to the stable operational phase of the Indonesian feasibility trial.

All latency curves, update-interval histograms, and long-gap distributions analyzed in this research are digitally reconstructed from figures and charts contained in the published feasibility study materials. No raw packet-level measurements or timestamp-based calculations are performed by the authors, as Aireon does not provide access to raw ADS-B message packets or timestamp fields due to security and operational data policy restrictions. The reconstruction process is intended solely to enable comparative analysis against international performance benchmarks and does not alter the original reported latency distributions.

b. International Standards.

ICAO Doc 9924 (ADS-B Implementation and Operations Guidance) [36][39], FAA 14 CFR §91.227 (ADS-B Out Performance Requirements) [37], and EUROCAE ED-129B (Technical Specification for Mode S Extended Squitter ADS-B) [28] provide the regulatory thresholds that serve as the primary benchmarks for this analysis.

2.3 Analytical Framework

The analytical framework applied in this study is based on a QoS perspective [40], with latency (delay) serving as the primary performance parameter. Latency is generally defined as the time difference between the generation of aircraft position data and its reception by Air Traffic Controllers (ATC). However, within the scope of Space-Based ADS-B and the available dataset, latency is specifically defined as the interval between the reception of an ADS-B message by the satellite hosted payload and the delivery of the corresponding surveillance report to the Service Delivery Point (SDP) [25]. This definition reflects the operational latency segment that can be consistently evaluated using the aggregated performance indicators reported by Aireon.

In operational surveillance systems, latency is typically measured using message-level timestamps. Nevertheless, due to the unavailability of raw timestamp data under Aireon's data access policy, the present analysis evaluates latency based on aggregated latency distributions reported in the Feasibility Study and SDP Performance Reports [27]. These reported indicators provide a representative measure of end-to-end system delay from the satellite reception stage to service delivery.

To support a QoS-based interpretation, delay performance is classified using reference categories adapted from the European Telecommunications Standards Institute (ETSI) [41]. According to this framework, delay performance can be grouped into four qualitative categories: very satisfactory, satisfactory, unsatisfactory, and poor. The adopted delay classification ranges used for analytical interpretation in this study are summarized in Table 1 [42]. It should be noted that these categories are employed as an analytical reference to contextualize latency behavior and do not represent a formal compliance assessment against ETSI standards.

Table 1. QoS delay categories

Category	Delay Range	Index
Very Satisfactory	<150 ms	4
Satisfactory	150 – 300 ms	3
Unsatisfactory	300 – 450 ms	2
Poor	>450 ms	1

The deployment of Low Earth Orbit (LEO) satellite constellations, such as Iridium NEXT, significantly reduces signal propagation delay between aircraft, satellites, and ground infrastructure, thereby improving data timeliness in oceanic and remote airspace [43]. Nevertheless, overall latency is also affected by processing and transmission paths, which can influence the accuracy and timeliness of surveillance information.

Previous studies have shown that message acquisition timing in space-based ADS-B systems is also influenced by update-interval behavior and message reception probability. Similar principles are observed in other space-based surveillance applications, where detection probability is regarded as a key indicator of reception performance [44]. Variations in GNSS positioning performance and satellite reception dynamics may therefore indirectly affect the temporal characteristics of ADS-B message delivery [45]-[47]. While these factors are not explicitly isolated in the present analysis, they provide important contextual background for interpreting latency behavior in LEO-based ADS-B systems.

Optimization research on digital multi-beamforming demonstrated that the update interval can be minimized while maintaining a 95% update probability under full-coverage constraints, indicating that antenna-level signal processing plays an important role in ensuring consistent data delivery in LEO-based surveillance systems [48]. Beyond antenna-level optimization, satellite demonstration missions have also provided empirical insights into update-interval behaviour. In-orbit experiments such as the GOMX-3 mission reported variations in message update rates driven by orbital geometry, receiver sampling windows, and aircraft density, showing that latency and update probabilities are influenced not only by propagation factors but also by satellite motion and payload reception dynamics [49].

Observed latency values are then evaluated against international benchmarks—ICAO Doc 9924 [36], FAA 14 CFR §91.227 [37], and EUROCAE ED-129B [28]. To provide an additional regulatory benchmark, Aireon's SLA specifies three key performance metrics, as illustrated in Figure 2.

a. service availability ≥ 99.9%,
b. latency ≤ 2.0 s (99th percentile), and
c. update probability ≥ 96% within the required update interval.

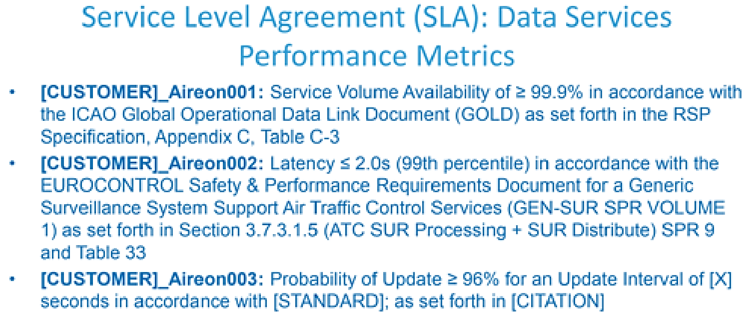

Figure 2. Aireon SLA performance metrics for data services

These SLA parameters are used as complementary references to international standards such as ICAO Doc 9924, FAA 14 CFR §91.227, and EUROCAE ED-129B by providing quantitative service-level thresholds for evaluating Space-Based ADS-B performance [31]. This analytical framework enables a structured evaluation of latency performance and supports comparison with both international regulatory requirements and contractual service-level expectations.

2.4 Limitations of the Study

It should be noted that the latency results presented in this study are derived from aggregated secondary data obtained from publicly available Aireon documentation. Due to data access restrictions, raw ADS-B message packets and timestamp-level measurements are not available for independent verification. Consequently, potential confounding factors such as aircraft avionics performance, onboard processing delay, ground ATC system latency, traffic density, and ionospheric conditions are not individually isolated in this analysis. These factors may influence end-to-end latency and are therefore acknowledged as limitations of the present study.

3. RESULTS AND DISCUSSION

3.1 Latency Performance Results

Based on publicly released technical documentation and performance presentations provided by Aireon, the global deployment of Space-Based Automatic Dependent Surveillance–Broadcast (ADS-B) demonstrates a consistently stable latency profile across multiple Flight Information Regions (FIRs). As the present study relies on secondary data sources, access to raw ADS-B message packets, message-level timestamps, and record counts is not available due to data policy restrictions. Consequently, the latency figures presented in this section are reconstructed from official Aireon performance charts contained in feasibility study materials and technical briefings.

Figure 3 illustrates the global latency distribution derived from the technical presentation *"Aireon Space-Based ADS-B Implementation and Operation"* delivered at the Bangkok Seminar on November 5, 2018 [31]. The distribution covers several FIRs, including Roma, Shanwick Oceanic Control Area (OCA), København, Shannon, and Edmonton. The reported results indicate a mean latency of 226 ms, with 95th and 99th percentile values of 312 ms and 345 ms, respectively. These figures imply that more than 99% of surveillance reports are delivered within 0.35 seconds, demonstrating highly time-consistent performance across geographically diverse regions. From an operational perspective, this global latency performance is significantly lower than the maximum latency limits specified in EUROCAE ED-129B for ADS-B surveillance applications. Although ED-129B was originally developed with ground-based ADS-B systems in mind and does not explicitly define requirements for space-based implementations, the observed latency margins suggest that Space-Based ADS-B comfortably satisfies real-time surveillance expectations under existing regulatory interpretations.

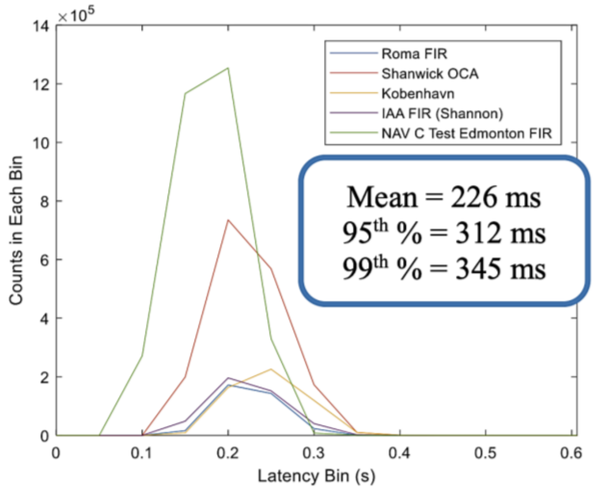

Figure 3. Global space-based ADS-B latency distribution across selected FIRs

Building upon this global benchmark, an evaluation was conducted to assess system performance within Indonesia's airspace, focusing on the Jakarta and Ujung Pandang (Makassar) FIRs. These evaluations are based on feasibility trials conducted in 2021 to assess system behavior under regional operational conditions characterized by dense traffic flows and extensive oceanic coverage. The data presented in Figures 4 and 5 represent aggregated monthly latency statistics reported by Aireon and AirNav Indonesia, covering the operational period from April to December 2021. Due to the proprietary nature of Aireon's processing algorithms, detailed message-level computations are not available for independent verification.

As shown in Figures 4 and 5 [34][50], the average latency in both FIRs remains consistently stable throughout the observation period, ranging between 0.46 and 0.48 seconds. These values represent the time interval between message reception at the Aireon Hosted Payload (AHP) and delivery to the Service Delivery Point (SDP). Notably, the absence of significant temporal fluctuation indicates that latency performance is resilient to variations in traffic density and seasonal operational conditions within the evaluated timeframe.

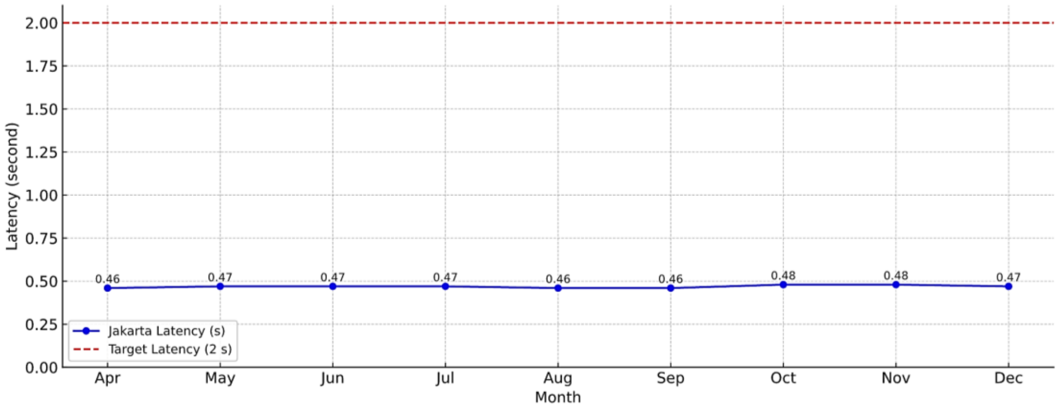

Figure 4. Space-Based ADS-B Latency in Jakarta FIR (Apr – Dec 2021)

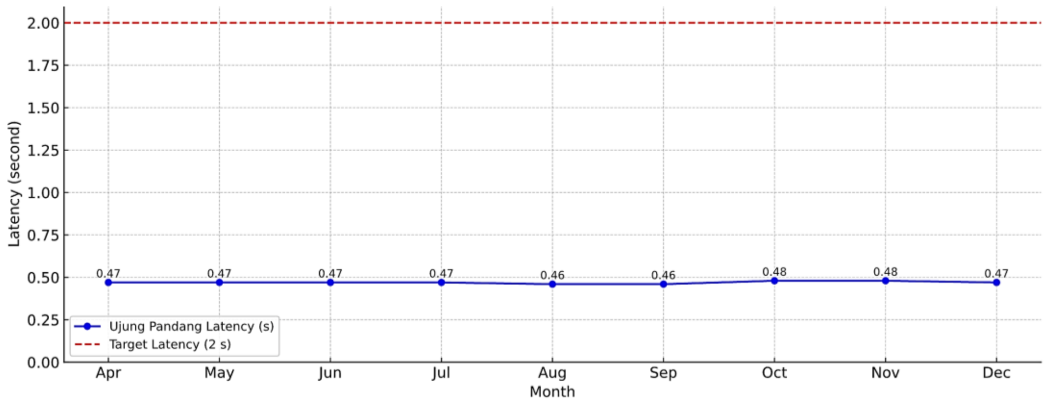

Figure 5. Space-Based ADS-B Latency in Ujung Pandang FIR (Apr – Dec 2021)

When compared with typical ground-based ADS-B latency values reported in the literature—commonly in the range of 1 to 2 seconds depending on ground infrastructure, network routing, and processing delays—the observed space-based latency in Indonesian FIRs demonstrates comparable or superior timeliness. This finding supports the suitability of Space-Based ADS-B as a complementary surveillance solution, particularly in remote and oceanic regions where ground-based sensor coverage is inherently limited.

Overall, the results confirm that Space-Based ADS-B delivers reliable and time-consistent surveillance data within Indonesian airspace, aligning both with global performance benchmarks and with the operational requirements defined by ICAO Doc 9924, FAA 14 CFR §91.227, and Aireon's Service Level Agreement (SLA). These findings reinforce the operational readiness of space-based surveillance to support real-time air traffic monitoring in geographically complex regions such as Indonesia.

3.2 Comparison with International Standards

The observed latency values were compared with international surveillance benchmarks, namely ICAO Doc 9924, FAA 14 CFR §91.227, and EUROCAE ED-129B. According to ICAO and FAA standards, ADS-B systems must transmit position data with a maximum allowable latency of ≤ 2.0 seconds at the 95th percentile. The measured latency of 0.46–0.48 seconds falls comfortably within this limit, confirming compliance with both ICAO and FAA requirements.

Within the framework of EUROCAE ED-129B, total latency is defined as the elapsed time from the generation of an ADS-B message onboard the aircraft to its availability at the Air Traffic Control (ATC) display system. While ED-129B provides detailed latency budgeting for ground-based ADS-B systems, it does not explicitly define performance criteria for space-based ADS-B implementations. Consequently, the observed end-to-end latency of approximately 460–480 milliseconds is interpreted in relation to the total latency budget commonly referenced in ED-129B, which allocates up to 2.0 seconds across airborne, ground, and distribution segments. Within this interpretative context, the measured latency values remain comfortably below the commonly adopted total latency envelope.

A summary comparison between the observed latency performance in the Jakarta and Makassar FIRs and major international standards is presented in Table 2. The results indicate consistent alignment with regulatory thresholds defined by ICAO, FAA, and EUROCAE, as well as with Aireon's contractual Service Level Agreement (SLA).

Table 2. Comparison of Observed Latency and International Standards

Reference Standard	Defined Latency Threshold	Observed Latency (Jakarta/Makassar FIRs)	Compliance Status	Remarks
ICAO Doc 9924	≤ 2.0 s (95th percentile)	460 – 480 ms	✓	Within recommended operational limit.
FAA 14 CFR §91.227	≤ 2.0 s (95th percentile)	460 – 480 ms	✓	Meets ADS-B Out latency performance requirement
EUROCAE ED-129B	≤ 700 ms (Total Latency)	460 – 480 ms	–	Within total latency requirement.
Aireon SLA	≤ 2.0 s (99th percentile)	460 – 480 ms	✓	Consistent with SLA performance metrics.

To provide broader regulatory context, Table 3 extends the comparison by incorporating latency requirements from additional international organizations, including EUROCONTROL, ICAO APAC, and Transport Canada. Despite variations in regulatory terminology and percentile definitions, these frameworks consistently adopt maximum allowable latency thresholds in the order of ≤ 2.0 seconds. Both regional latency results in Indonesia (0.46–0.48 s) and global latency performance reported by Aireon (mean 0.226 s; 99th percentile < 0.345 s) remain well below these limits.

Table 3. Summary of International Latency Standards and Aireon Performance Evaluation

Organization	Maximum Latency Standard	Evaluation of Aireon Data
EUROCONTROL GEN-SUR SPR Document (ICAO ADS-B Implementation Meeting, Mexico 2018)	≤ 2.0 s (99th percentile), adopted from GEN-SUR SPR and used in Aireon–ANSP SLA (Section 2.2.7, p.4) [50]	Indonesia's data: ~0.46–0.48 s (99%); Global 99th percentile 0.345 s. Meets GEN-SUR SPR requirement.
FAA 14 CFR §91.227 (Aeronautics and Space Regulation)	Aircraft must transmit geometric position within ≤ 2.0 s after measurement (Section E: ADS-B Latency Requirements, p.85) [37]	Aireon latency ~0.46–0.48 s (Indonesia), global average 0.226 s. Complies with FAA §91.227.
AC 500-029 (TCCA/FAA Guidance)	Total compensated latency must remain within ≤ 2.0 s (Section 4.0, Appendix C — Latency Analysis) [51]	Measured latency <0.48 s (Indonesia) and <0.345 s (global). Complies with AC 500-029**.**
ICAO APAC – Baseline ADS-B Service Performance Parameters (APANPIRG/18)	Network latency: 95% of ground-station outputs must be <2 s [52]	Latency in Jakarta and Ujung Pandang ~0.46–0.48 s; Global 95th percentile 0.312 s. Meets ICAO APAC baseline.
EUROCONTROL – ESASSP Volume 2	Airborne to ground receiver: ≤1.5 s (95%); Ground to ATC: ≤0.5 s (95%) (p.33) [53]	Aireon total latency ~0.46–0.48 s (Indonesia), global 99% <0.345 s. Within ESASSP combined limit (2.0 s).
EUROCAE ATS Surveillance Requirements	Latency ≤ 1.5 s to the ATM Automation Platform [28]	Aireon global and regional latency <0.48 s. Complies with ATS SR limit.
EUROCAE ED-129B, Technical Specification for a 1090 MHz Extended Squitter ADS-B Ground System	System latency budget ≤2.0 s (1.5 s to distribution edge + 0.5 s internal tracker network) [25]	Aireon latency <0.48 s (Indonesia), global 99% <0.345 s. Well below ED-129B limit.

Overall, the results indicate that Aireon's Space-Based ADS-B system demonstrates latency margins well below the thresholds defined by ICAO, FAA, EUROCONTROL, and EUROCAE standards. This strong alignment across both global and regional regulatory frameworks confirms that the system provides reliable, low-latency surveillance performance suitable for real-time air traffic monitoring, including in non-radar and oceanic regions.

The comparison with ground-based ADS-B latency presented in this study is based on values reported in existing literature and international standards and is intended to provide contextual reference rather than a direct empirical comparison derived from synchronized datasets within the same observation period.

3.3 QoS Categorization and SLA Compliance

When mapped to the telecommunication-based QoS delay categories presented in Table 1, the observed latency of approximately 0.46–0.48 seconds is positioned slightly above the 450 ms boundary, which corresponds to the *"Poor"* category in the ETSI delay classification. However, this categorization should be interpreted with caution, as the ETSI QoS framework was originally developed for generic data communication networks rather than safety-critical aviation surveillance systems.

In aviation surveillance contexts, latency performance must be evaluated against domain-specific operational and regulatory requirements. Under Aireon's Service Level Agreement (SLA), the key performance criteria specify that the 99th percentile latency shall not exceed 2.0 seconds, with an update probability of at least 96% and system availability of no less than 99.9%. The measured latency in both the Jakarta and Ujung Pandang (Makassar) FIRs remains well below the SLA latency threshold, thereby demonstrating full compliance with contractual service-level requirements.

Furthermore, the observed latency range of 0.46–0.48 seconds also satisfies the performance thresholds defined by ICAO Doc 9924, FAA 14 CFR §91.227, and EUROCAE ED-129B. A summary comparison between the telecommunication-based QoS categorization and aviation-specific performance benchmarks is provided in Table 4.

Table 4. Comparison of QoS Delay Category and Aireon SLA Compliance

Evaluation Framework	Defined Threshold	Observed Latency (Jakarta/Makassar FIRs)	Classification / Compliance	Remarks
QoS (ETSI) Delay Categorization	>450 ms = "Poor" (Index 1)	0.46–0.48 s	Categorized as Poor	Reference to telecommunication-based QoS framework.
Aireon SLA	≤ 2.0 s (99th percentile)	0.46–0.48 s	✓	Meets SLA performance standard.
ICAO / FAA / EUROCAE	≤ 2.0 s (95th percentile)	0.46–0.48 s	✓	Satisfies all aviation benchmarks.

The contrast between these two evaluation perspectives highlights that generic telecommunication-based QoS indices do not fully capture the operational reliability requirements of air traffic surveillance systems. While QoS metrics emphasize network transmission efficiency, aviation-specific standards and SLAs focus on end-to-end system performance, service continuity, and operational suitability for Air Traffic Control (ATC). Consequently, despite its lower classification under a generic QoS framework, the observed latency performance of Space-Based ADS-B can be regarded as operationally optimal and fully compliant within the context of global aviation surveillance systems.

3.4 Discussion of Anomalies and Regulatory Gaps

Although the measured latency values fully comply with ICAO and FAA performance requirements, several regulatory ambiguities become evident when existing international standards are applied to Space-Based ADS-B systems. EUROCAE ED-129B, while providing a comprehensive technical specification for ground-based ADS-B infrastructures, does not explicitly define performance metrics tailored to satellite-based surveillance architectures. As a result, compliance assessment for Space-Based ADS-B is often conducted using benchmarks originally intended for terrestrial systems, which may not fully reflect satellite-specific operational characteristics.

In addition, the comparison between ETSI-based QoS delay classifications and aviation surveillance performance requirements reveals a conceptual mismatch. Generic telecommunication QoS models are primarily designed to evaluate packet-based data transmission efficiency, whereas air traffic surveillance systems prioritize end-to-end operational timeliness, continuity, and reliability. Space-Based ADS-B introduces additional transmission segments—including satellite payload processing, inter-satellite links, cross-link routing, and centralized ground processing—which inherently influence latency behavior. Consequently, direct application of generic QoS delay categories may lead to oversimplified or potentially misleading interpretations of surveillance system performance.

These observations highlight the need for more harmonized and domain-specific regulatory frameworks that explicitly address the characteristics of satellite-based surveillance systems. Coordinated updates and guidance from international organizations such as ICAO and EUROCAE, in collaboration with service providers like Aireon, would support clearer performance definitions, enhance interoperability, and ensure that future standards accurately represent the operational realities of global Space-Based ADS-B surveillance.

4. CONCLUSION

The findings support the hypothesis that Space-Based ADS-B latency in the Jakarta and Makassar Flight Information Regions (FIRs) satisfies international aviation surveillance performance requirements and is suitable for real-time operational use in non-radar and remote airspace. The current evaluation analyzed the latency performance of Space-Based Automatic Dependent Surveillance–Broadcast (ADS-B) using secondary data from Aireon, focusing on trials conducted in the Jakarta and Makassar Flight Information Regions (FIRs). The results show an average latency of 0.46–0.48 seconds, which is well below the maximum thresholds defined by ICAO Doc 9924, FAA 14 CFR §91.227, and Aireon's Service Level Agreement (SLA), demonstrating that Space-Based ADS-B is capable of delivering real-time and reliable surveillance data for operational use. Although the observed latency is classified as "Poor" under a generic telecommunication-based QoS delay framework, it remains operationally satisfactory when evaluated against aviation-specific surveillance standards. These findings contribute to existing literature by providing a QoS-based latency assessment of satellite-based ADS-B implementation in Indonesian airspace and highlight the need for explicit satellite-oriented latency criteria within the EUROCAE ED-129B framework to support global regulatory consistency.

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REFERENCE

[1] Y. Li, P. Rao, Z. Li, and J. Ai, "On-board parameter optimization for space-based infrared air vehicle detection based on ADS-B data," *Applied Sciences*, vol. 13, no. 12, Jun. 2023. https://doi.org/10.3390/app13126931

[2] H. Ahmed, H. Khan, and M. A. Khan, "A survey on security and privacy of automatic dependent surveillance–broadcast (ADS-B) protocol: Challenges, potential solutions and future directions," *TechRxiv*, Jun. 2023. https://doi.org/10.36227/techrxiv.23535726.v1

[3] H. Yang, H. Li, and X. S. Shen, *Wireless Networks Secure Automatic Dependent Surveillance–Broadcast Systems*. Switzerland: Springer, 2023. https://doi.org/10.1007/978-3-031-07021-1

[4] S. Sundaresan, "Integrating artificial intelligence with space-based ADS-B for next-generation space traffic management," *Acceleron Aerospace Journal*, vol. 5, no. 2, pp. 1368–1376, Aug. 2025. https://doi.org/10.61359/11.2106-2548

[5] W. Ahmed, "State-of-the-art security measures for ADS-B: Analyzing current protocols and future directions," *Premier Journal of Computer Science*, Dec. 2024. https://doi.org/10.70389/PJCS.100005

[6] L. Pereira, "Space-based ADS-B receiver for ISTsat-1," Master's thesis, Instituto Superior Técnico, Univ. Lisboa, Lisbon, Portugal, 2019. [Online]. Available: https://scholar.tecnico.ulisboa.pt/records/9ZW0ZzNDWQ_1waOKHRprCWdgEur0upz2vyxA

[7] M. R. Manesh and N. Kaabouch, "Analysis of vulnerabilities, attacks, countermeasures and overall risk of the automatic dependent surveillance–broadcast (ADS-B) system," unpublished manuscript, 2018.

[8] S. Zappi and A. Niknejad, "Use of ADS-B in GNSS RFI monitoring," ICAO, Tech. Rep., 2020. [Online]. Available: https://www.icao.int/Meetings/SUR-Technologies/Documents/D3%20A.Niknejad%20ICAO%20Session%207-%20Use%20of%20ADS-B%20in%20GNSS%20RFI%20Monitoring%20-%20Abbas%20Niknejad.pdf

[9] X. Olive, J. Krummer, B. Figuet, and R. Alligier, "Filtering techniques for ADS-B trajectory preprocessing," *Journal of Open Aviation Science*, vol. 2, no. 2, Mar. 2025. https://doi.org/10.59490/joas.2024.7882

[10] F. A. P. Maharani, S. Soim, and M. Fadhli, "Design and implementation of an ADS-B receiver monitoring system based on Raspberry Pi and ground plane antenna," *PROtek: Jurnal Ilmiah Teknik Elektro*, vol. 9, no. 2, p. 111, Sep. 2022. https://doi.org/10.33387/protk.v9i2.4690

[11] Z. Wu, T. Shang, and A. Guo, "Security issues in automatic dependent surveillance–broadcast (ADS-B): A survey," *IEEE Access*, vol. 8, pp. 122147–122167, 2020. https://doi.org/10.1109/ACCESS.2020.3007182

[12] Aireon LLC, "ADS-B for air traffic surveillance," White Paper, 2023. [Online]. Available: https://aireon.com/wp-content/uploads/2024/05/Aireon-Datasheet_NatSec_ADS-B-Advantage_050624.pdf

[13] C. Li and Y. Bi, "Independently convolutional gated recurrent neural unit for space-based ADS-B signal separation with single antenna," *EURASIP Journal on Advances in Signal Processing*, vol. 2023, no. 1, Dec. 2023. https://doi.org/10.1186/s13634-023-01089-w
[14] C. Ashton *et al.*, "The search for MH370," *Journal of Navigation*, vol. 68, no. 1, pp. 1–22, Jan. 2015. https://doi.org/10.1017/S037346331400068X
[15] J. M. Cebrian, "From ground-based to space-based," SESAR/INDRA Webinar Presentation, 2019. [Online]. Available: https://www.sesarju.eu/sites/default/files/documents/webinars/webinar%20cns%20vision%20%20From%20ground%20to%20space%20%20Joan%20Manuel%20Cebrian%2C%20INDRA.pdf
[16] J. Budroweit, F. Eichstaedt, and T. Delovski, "Aircraft surveillance from space: The future of air traffic control? Space-based ADS-B, status, challenges and opportunities," *IEEE Microwave Magazine*, vol. 25, no. 12, pp. 68–76, 2024. https://doi.org/10.1109/MMM.2024.3443754
[17] W. Ahmed, "Securing ADS-B communication: A survey of cryptographic and machine learning approaches," *Premier Journal of Computer Science*, 2024. https://doi.org/10.70389/PJCS.100007
[18] G. Jaffer and R. A. Malik, "Design concept of cost-effective LEO satellite system for automatic dependent surveillance–broadcast (ADS-B)," *UCP Journal of Science and Technology*, vol. 1, Sep. 2023. https://doi.org/10.24312/ucp-jst.01.01.079
[19] T. H. Nguyen *et al.*, "Low-earth orbit satellite constellation for ADS-B based in-flight aircraft tracking," *Advances in Aircraft and Spacecraft Science*, vol. 2, no. 1, pp. 95–108, Jan. 2015. https://doi.org/10.12989/aas.2015.2.1.095
[20] T. Delovski, J. Bredemeyer, and K. Werner, "ADS-B over satellite: Coherent detection of weak Mode-S signals from low earth orbit," DLR Tech. Rep., 2016. [Online]. Available: https://elib.dlr.de/106316/1/188Delovski.pdf
[21] R. Van Der Pryt and R. Vincent, "A simulation of the reception of automatic dependent surveillance–broadcast signals in low earth orbit," *International Journal of Navigation and Observation*, 2015. https://doi.org/10.1155/2015/567604
[22] R. Van Der Pryt and R. Vincent, "A simulation of signal collisions over the North Atlantic for a spaceborne ADS-B receiver using Aloha protocol," *Positioning*, vol. 6, no. 3, pp. 23–31, 2015. https://doi.org/10.4236/pos.2015.63003
[23] R. Vincent and R. Van Der Pryt, "The CanX-7 nanosatellite ADS-B mission: A preliminary assessment," *Positioning*, vol. 8, no. 1, pp. 1–11, 2017. https://doi.org/10.4236/pos.2017.81001
[24] Aireon LLC, "Aireon datasheet: National security ADS-B advantage," Datasheet, 2023. [Online]. Available: https://aireon.com/wp-content/uploads/2024/01/Aireon-Datasheet_NatSec_ADS-B-Advantage_062123.pdf
[25] M. A. Garcia *et al.*, "A compilation of measured ADS-B performance characteristics from Aireon's on-orbit test program," ICAO Working Paper, 2018. [Online]. Available: https://www.icao.int/NACC/Documents/Meetings/2018/ADSB/App%206-Aireon%20Analysis%20of%20TPMs.pdf
[26] B. Vilain *et al.*, "Satellite-based ADS-B for lower separation minima application: Multi-source study report," European Commission, Tech. Rep., 2017. [Online]. Available: https://ec.europa.eu/research/participants/documents/downloadPublic?appId=PPGMS&documentIds=080166e5b5e99d33
[27] K. W. Baker and K. Baker, "Space-based ADS-B: Performance, architecture and market options," Summit Space Corp., White Paper, 2023. [Online]. Available: https://summitspacecorporation.com/uploads/1/2/3/6/123616403/summit-spaceats-survey-summary-ats-p-6202020-final-v5.pdf
[28] Aireon LLC, "Space-based ADS-B," ICAO Working Paper, 2016. [Online]. Available: https://www.icao.int/WACAF/Documents/Meetings/2016/Lisbon-2016/Sat-21/SAT21%20WP%2009%20%20Space%20Based%20ADS-B-Airon.pdf
[29] G. Dunstone, "Space-based ADS-B," Technical Presentation, 2019.
[30] O. L. Daulay, "Quality of service analysis on bandwidth management using hierarchical token bucket method," *JISTech*, vol. 5, no. 2, pp. 18–35, Jul. 2020. https://doi.org/10.30829/jistech.v5i2.6537
[31] V. Capezzuto and G. Dunstone, "Aireon space-based ADS-B implementation and operation," ICAO WASS Meeting, Presentation, 2018. [Online]. Available: https://www.icao.int/APAC/Meetings/2018%20WASS/3-1_Aireon%20Status%20Briefing_up_REV2.pdf
[32] A. M. Al-Binali and K. Al-Begain, "An overview of quality of service (QoS) and QoS routing in communication networks," Tech. Rep., 2014. [Online]. Available: https://www.researchgate.net/publication/228583111

[33] Aireon LLC, "En-route turbulence detection using Aireon space-based ADS-B," AIAA Paper, 2024. https://doi.org/10.2514/6.2024-4635
[34] Ministry of Transportation DGCA, "Feasibility study of Aireon space-based ADS-B in Indonesia," Tech. Rep., 2021.
[35] J. M. Pedersen *et al.*, "Using latency as a QoS indicator for global cloud computing services," *Concurrency and Computation: Practice and Experience*, vol. 25, no. 18, pp. 2488–2500, Dec. 2013. https://doi.org/10.1002/cpe.3081
[36] ICAO, *Doc 9924: Aeronautical Surveillance Manual*, 3rd ed., 2020.
[37] Federal Aviation Administration, "14 CFR §91.227—Automatic dependent surveillance–broadcast (ADS-B) out performance requirements," [Online]. Available: https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-91/subpart-C/section-91.227
[38] S. Yu, L. Chen, S. Li, and X. Zhang, "Adaptive multi-beamforming for space-based ADS-B," *Journal of Navigation*, vol. 72, no. 2, pp. 359–374, Mar. 2019. https://doi.org/10.1017/S0373463318000735
[39] ICAO APAC, "ADS-B implementation and operations guidance document," Ed. 15.0, 2022.
[40] R. Wulandari, "Quality of service analysis on internet networks," *Jurnal Teknik Informatika dan Sistem Informasi*, vol. 2, 2016. https://doi.org/10.28932/jutisi.v2i2.454
[41] B. Pamungkas and F. A. Sutanto, "QoS-based internet network quality analysis," *Jurnal Teknologi Informasi dan Komunikasi*, vol. 8, no. 2, Apr. 2024.
[42] Rasudin, "Quality of service in internet networks using hierarchy token bucket," Tech. Rep., 2014. https://doi.org/10.29103/techsi.v6i1.172
[43] IFATCA, "63rd annual conference," Conference Proceedings, Apr. 2024.
[44] C. Lihu *et al.*, "Design of space-borne AIS scene simulation based on global vessel density distribution," *IOP Conference Series: Materials Science and Engineering*, vol. 449, 2018. https://doi.org/10.1088/1757-899X/449/1/012003
[45] Z. Liu, S. Lo, and T. Walter, "GNSS interference source localization using ADS-B data," 2022. https://doi.org/10.33012/2022.18241
[46] Z. Liu, S. Lo, and T. Walter, "GNSS interference characterization and localization using OpenSky ADS-B data," *Proceedings*, 2020. https://doi.org/10.3390/proceedings2020059010
[47] Z. Liu, S. Lo, and T. Walter, "GNSS interference detection using machine learning algorithms on ADS-B data," 2021. https://doi.org/10.33012/2021.18111
[48] X. Li *et al.*, "Optimization of digital multi-beamforming for space-based ADS-B using distributed cooperative coevolution," *Chinese Journal of Aeronautics*, vol. 36, no. 10, pp. 391–408, Oct. 2023. https://doi.org/10.1016/j.cja.2023.03.008
[49] D. Gerhardt *et al.*, *Proceedings of the 30th Annual AIAA/USU Conference on Small Satellites*, 2016.
[50] ICAO, "ADS-B implementation and regulation meeting summary," Meeting Report, 2018.
[51] Transport Canada, "Advisory circular: Certification of automatic dependent surveillance–broadcast (ADS-B)," Jan. 2024. [Online]. Available: https://tc.canada.ca/sites/default/files/2022-05/AC_500-029_ISSUE_01.pdf
[52] ICAO, "Baseline ADS-B service performance parameters," 2007.
[53] EUROCONTROL, *Specification for ATM Surveillance System Performance*, vol. 2, 2015. [Online]. Available: https://www.eurocontrol.int/sites/default/files/2024-04/eurocontrol-eassp-specification-vol2-appendices-v1-1.pdf