Journal of Public Transportation Community
Vol. 6 No. 2, October 2026, pp. 97-108
Online: https://ejournal.poltekbangsby.ac.id/index.php/jptc/about
e-ISSN :2808-3393

Comparative Analysis of Asterix Ads-B Cat 021 Edition 0.23 And Edition 2.1 Data On Thales Ax680 Equipment At Perum Lppnpi Airnav Denpasar Branch

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Abstract

Automatic Dependent Surveillance-Broadcast (ADS-B) transmits aircraft target data to the ATC System using the ASTERIX (All Purpose Structured Eurocontrol Surveillance Information Exchange) Category 021 format. At Perum LPPNPI AirNav Denpasar Branch, the Thales AX680 ADS-B was upgraded from ASTERIX edition 0.23 to edition 2.1; within less than a year, aircraft targets intermittently disappeared and reappeared on the ATC System display, and the configuration was reverted to edition 0.23. This descriptive case study examines the problem by comparing the Cat 021 data items of both editions, using target recordings from the Tools Recorder and WireShark, Hexadecimal-Binary-Decimal conversion, and the Eurocontrol Cat 021 specification (Part 12). Edition 2.1 contains 23 data items compared with 15 in edition 0.23, including items that carry ADS-B version and quality information defined for DO-260B/ED-102A avionics. The most plausible explanation is that targets from aircraft with older DO-260/ED-102 avionics, which cannot supply these parameters, were handled inconsistently by the ATC System under edition 2.1; reverting to edition 0.23 restored stable target detection. The study highlights the importance of understanding surveillance data formats and fleet avionics readiness before migrating to a newer data standard, and of a staged migration with documented acceptance criteria.

Keywords: ADS-B, ASTERIX, Cat 021, avionics interoperability, aviation surveillance

Article History:
Received: 12 June 2026 ; Reviewed : 24 June 2026; Accepted: 24 July 2026; Published : 1 October 2026
DOI: 10.46491/jptc.v6i2.2854

How to cite : Wirawan, Y. Y., Prastiwi, N. S., & Dzulkefly, N. H. (2026). Comparative Analysis of ASTERIX ADS-B Cat 021 Edition 0.23 and Edition 2.1 Data on Thales AX680 Equipment at Perum LPPNPI AirNav Denpasar Branch. ***Journal of Public Transportation Community*****, 6(2), 97–108.** https://doi.org/10.46491/jptc.v6i2.2854

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Introduction

Air transportation plays a vital role for Indonesia as an archipelagic nation, so flight safety and orderliness depend heavily on the readiness of the air navigation facilities managed by Perusahaan Umum Lembaga Penyelenggara

Pelayanan Navigasi Penerbangan Indonesia (Perum LPPNPI/AirNav Indonesia). One surveillance facility used to monitor aircraft movement is Automatic Dependent Surveillance-Broadcast (ADS-B), equipment that uses the Global Navigation Satellite System (GNSS) to determine an aircraft's position, then broadcasts position, altitude, speed, and identification data on the 1090 MHz frequency to ground stations and to other nearby aircraft (Strohmeier et al., 2014).

Data received by the ADS-B ground station is forwarded to the ATC System using the ASTERIX Category 021 format, a surveillance data exchange standard published by Eurocontrol and widely used to carry Radar, ADS-B, and Multilateration (MLAT) data. Research on ADS-B has so far concentrated on the security of the unencrypted channel and of the ASTERIX protocol (Lee et al., 2014; Jančík et al., 2019; Strohmeier et al., 2015), on machine-learning-based anomaly detection (Abu Al-Haija & Al-Tamimi, 2024; Ahmed et al., 2025), and on fusion with radar to improve target continuity (Jeon et al., 2015).

The ASTERIX Cat 021 specification has itself been revised several times in line with the development of ADS-B avionics, which are commonly classified into three versions: Version 0 (DO-260/ED-102), Version 1 (DO-260A), and Version 2 (DO-260B/ED-102A), each adding position-integrity and accuracy parameters (Ho, 2020). Because the aircraft fleet in a given airspace contains a mix of these versions, migrating the ground system to a newer ASTERIX edition raises an interoperability question that a service provider must answer from field evidence. To the authors' knowledge, few published studies document such a migration case at an operational ATC unit and relate the behaviour of the ground system to the avionics version of the aircraft; this article addresses that gap.

At the CNS and Automation Engineering Unit of Perum LPPNPI AirNav Denpasar Branch, the Thales AX680 ADS-B had its configuration changed from ASTERIX Cat 021 edition 0.23 to edition 2.1. The trial use of edition 2.1 did not last a full year, because aircraft targets intermittently disappeared and reappeared on the ATC System monitoring display, particularly for aircraft whose avionics did not support the newer data edition, and the configuration was reverted to edition 0.23. The case shows why CNS technicians need to understand the structure and differences of ASTERIX editions: technical competence built through direct field involvement supports work readiness (Lubis, 2021; Darni et al., 2025), and insufficient understanding of technical standard documents is a recognized source of maintenance error (Olaganathan, 2024).

This article aims to (1) analyze the differences in ASTERIX Cat 021 data items between edition 0.23 and edition 2.1 on the Thales AX680 ADS-B, (2) identify the most plausible cause of the intermittent aircraft-target problem following the migration to edition 2.1, and (3) document the handling process, so that it may serve as a technical reference for other CNS and Automation units

planning a similar surveillance data-format migration. The contribution of the article is a documented field case that links the ASTERIX data-item differences to the avionics-version mix of the fleet and that derives practical migration recommendations.

Research Method

This study uses a descriptive qualitative method with a single-case study approach (Baxter & Jack, 2008), which suits the systematic description of how a technical problem was identified, analyzed, and handled in one unit of study using field data and technical standard documents, without aiming for statistical generalization. The analysis followed a root-cause-oriented sequence, from the reported symptom, through data recording and comparison against the standard, to the handling action and its verification.

Data were collected directly at the work site, at the CNS and Automation Engineering Unit, Perum LPPNPI AirNav Denpasar Branch, I Gusti Ngurah Rai International Airport, Bali, during the period of 4 October 2022-28 February 2023. The object of this study is the ASTERIX Category 021 data transmitted by the Thales AX680 ADS-B after the configuration was changed to edition 2.1. In this study, an "intermittent target" is defined operationally as a target whose symbol disappeared from the ATC System display and then reappeared without a corresponding change in the aircraft's flight, as reported by the operating personnel. The study is an analysis of one case and is qualitative; it does not report counts of dropouts per aircraft class (see Limitations and Future Work).

The tools and references used in the analysis were: the Eurocontrol Standard Document for Surveillance Data Exchange Part 12 Category 021 ADS-B Reports, edition 2.1 (Eurocontrol, 2011) and edition 0.23 (obtained from the Eurocontrol archive of earlier editions; Eurocontrol, 2012), as the reference for data-item structure and definitions; the Tools Recorder application on the Thales AX680 ADS-B to record and display target data; WireShark software to capture ASTERIX data packets through the ADS-B Hub Switch; and Hexadecimal, Binary, and Decimal conversion tables to read the content of the recorded ASTERIX data. Data items with the same name in both editions were treated as equivalent items.

The analysis stages carried out were as follows: (1) receiving a report that aircraft targets intermittently disappeared and reappeared on the ATC System display after the ADS-B began using ASTERIX edition 2.1; (2) collecting target recording data through the Tools Recorder and capturing data packets through WireShark on the ADS-B Hub Switch; (3) converting Hexadecimal numbers to Binary and Decimal to read the content of the ASTERIX data according to the CAT, LEN, and FSPEC (Field Specification) structure; (4) analyzing and

comparing the data items available between ASTERIX Cat 021 edition 0.23 and edition 2.1 with reference to the Eurocontrol document and the differences in DO-260/DO-260A/DO-260B avionics specifications across aircraft; and (5) handling the problem by reverting the ADS-B configuration to edition 0.23 and verifying the monitoring display and the stability of aircraft targets on the ATC System.

Results and Discussion

Object Profile and Scope of the Study

The object of this study is the ASTERIX Category 021 data transmitted by the Thales AX680 ADS-B equipment at the CNS and Automation Engineering Unit, Perum LPPNPI AirNav Denpasar Branch, which is responsible for managing air traffic services within Bali's airspace through the ADC, APP/TMA, ARO, and CNS units. The Thales AX680 ADS-B consists of several main modules: an AC/DC Power Supply, a Fan Unit, a Signal Processing Board (SPB3A), and a Position and Time Module (PTM), supported by an Uninterruptible Power Supply (UPS) and a Switch Hub connecting the data to the ATC System. As an international airport with dense domestic and international flight traffic, the reliability of surveillance data at I Gusti Ngurah Rai International Airport is an important factor in supporting daily flight operational safety.

ADS-B Working Principle and the ASTERIX Data Format

ADS-B works by using the Global Navigation Satellite System (GNSS) to determine an aircraft's position. The aircraft's transponder receives position information from GNSS, then broadcasts a signal on the 1090 MHz frequency using Downlink Format 17 (DF 17) to the ADS-B ground station and to other nearby aircraft, together with identification, altitude, and speed data (Sun et al., 2019). Data received by the ground station is then forwarded to the ATC System using the ASTERIX format, a surveillance data exchange standard set by Eurocontrol and widely used for Radar, ADS-B, and MLAT data (Lee et al., 2014). Evaluation of ADS-B data quality in its early implementation shows that the completeness and accuracy of the data received by the ground station are also influenced by the compatibility between the message standard broadcast by the aircraft and the processing capability of the receiving system (Ali et al., 2016; Zhang et al., 2011), while the development of Software Defined Radio (SDR)-based ADS-B signal-reception techniques with enhanced pulse detection and automatic gain control has also contributed to improving the accuracy and sensitivity of data reception under real operational conditions (Habibi Markani et al., 2023). The ASTERIX data structure generally consists of a 1-octet Category (CAT) field identifying the data category, a 2-octet Length (LEN) field indicating the length of the data block, and a Field Specification (FSPEC) identifying the

presence or absence of a particular data field within the record; each ASTERIX category has its own User Application Profile (UAP) documented in the Eurocontrol Standard Document for Surveillance Data Exchange. It is important to distinguish the two interfaces involved: the ADS-B version (DO-260, DO-260A, DO-260B) is a property of the aircraft avionics, whereas the ASTERIX edition is a property of the interface between the ground station and the ATC System. The ground station decodes the 1090 MHz message broadcast by the aircraft and populates the ASTERIX data items; parameters that older avionics cannot supply, such as the transponder version and the newer quality indicators, are therefore expected to be reported as absent or default values. The data path is: aircraft transponder (DF 17 message at 1090 MHz), ADS-B ground station (decoding), ASTERIX Cat 021 record, ATC System (processing and display).

Problem Identification

After the Thales AX680 ADS-B configuration was changed from ASTERIX Cat 021 edition 0.23 to edition 2.1, the trial use of edition 2.1 did not last a full year. The problem reported was that aircraft targets intermittently disappeared and reappeared on the ATC System monitoring display, particularly for aircraft whose avionics did not support the newer ASTERIX-related parameters. This condition could make it difficult for Air Traffic Controllers (ATCs) to monitor and control aircraft movement, so the configuration was reverted to edition 0.23 for the ATC System.

Analysis and Comparison of ASTERIX Edition 0.23 and Edition 2.1 Data Items

The analysis compared the data items available in ASTERIX Cat 021 edition 0.23 and edition 2.1, with reference to the Eurocontrol Standard Document for Surveillance Data Exchange Part 12 Category 021 (Eurocontrol, 2011, 2012). Comparing the data of the two configuration conditions follows the principle of narrowing down the source of a discrepancy before a handling action is decided. Table 1 presents the data items item by item, indicating whether each item is available in both editions or in one edition only.

Table 1 Data Items of ASTERIX Cat 021 Edition 0.23 and Edition 2.1 (Item-by-Item Comparison)

No.	Data Item, ASTERIX Cat 021	Availability
1	Data Source Identification	Both editions
2	Target Report Descriptor	Both editions
3	Position in WGS-84 Co-ordinates	Both editions
4	Target Address	Both editions
5	True Airspeed	Both editions
6	Flight Level	Both editions
7	Magnetic Heading	Both editions
8	Barometric Vertical Rate	Both editions
9	Target Identification	Both editions

10	Target Status	Both editions
11	Time of Day	Edition 0.23 only
12	Figure of Merit	Edition 0.23 only
13	Link Technology	Edition 0.23 only
14	Velocity Accuracy	Edition 0.23 only
15	Intermediate State Selected Altitude	Edition 0.23 only
16	Track Number	Edition 2.1 only
17	Time of Message Reception of Position	Edition 2.1 only
18	Time of Message Reception of Position – High Precision	Edition 2.1 only
19	Time of Message of Velocity	Edition 2.1 only
20	Quality Indicators	Edition 2.1 only
21	MOPS Version	Edition 2.1 only
22	Time of Report Transmission	Edition 2.1 only
23	Emitter Category	Edition 2.1 only
24	Selected Altitude	Edition 2.1 only
25	Service Management	Edition 2.1 only
26	Aircraft Operational Status	Edition 2.1 only
27	Message Amplitude	Edition 2.1 only
28	Data Ages	Edition 2.1 only

Table 1 shows that ten data items are common to both editions, five items appear only in edition 0.23, and thirteen items appear only in edition 2.1, so that edition 0.23 contains 15 data items and edition 2.1 contains 23. The items found only in edition 2.1 include MOPS Version, Quality Indicators, Time of Message Reception of Position (and its High Precision variant), Emitter Category, Aircraft Operational Status, and Data Ages. Several items of edition 0.23 appear to be superseded by items of edition 2.1: Time of Day by the time-of-message items, and Figure of Merit and Velocity Accuracy by Quality Indicators. This expansion is consistent with the DO-260B/ED-102A specification, which separates the reporting of position source and system integrity, adds Navigation Integrity Category (NIC) supplements, and adds the transponder-version indication. Table 2 summarizes the data content that each avionics version can make available to the ground station.

Table 2 ADS-B Avionics Versions and the Data Content Available to the Ground Station (Adapted from Ho, 2020)

ADS-B Version	Avionics Standard	Data Content Available to the Ground Station
Version 0	DO-260/ED-102	Basic position, velocity and identity; accuracy and integrity via NUCp and NACv; no transponder-version indication
Version 1	DO-260A	Adds transponder version, NACp, NIC and SIL

Version 2	DO-260B/ED-102A	Adds NIC supplements, SDA and ADS-B In capability indication

Table 2 shows that aircraft with Version 0 (DO-260/ED-102) avionics report accuracy and integrity only through NUCp and NACv and provide no transponder-version indication, whereas Version 1 and Version 2 avionics progressively add the transponder version, NACp, NIC, SIL, and the NIC supplements and SDA (Ho, 2020). Under edition 2.1, the ASTERIX record carries items such as MOPS Version and Quality Indicators; for aircraft with older avionics, these items would be absent or filled with default values. Because not all aircraft crossing Bali's airspace have the same avionics version, the most plausible explanation is that the ATC System processed such incomplete records inconsistently, for example where track display depends on quality parameters, so the affected targets appeared intermittently. This interpretation is supported by the report that the problem concerned mainly aircraft with older avionics and by the restoration of stable detection after the revert to edition 0.23. It remains an interpretation, because the internal processing logic of the ATC System was not examined in this study. Where such data are mixed, multi-source surveillance integration can help maintain target continuity (Jeon et al., 2015).

Figure 1 presents a flowchart of the analysis process carried out, starting from identifying the intermittent aircraft-target problem, collecting recorded data through the Tools Recorder and WireShark, converting and reading the ASTERIX data, through to analyzing the compatibility of aircraft avionics against the ASTERIX edition in use, up to the handling decision to revert the configuration to edition 0.23 if not all aircraft yet support the newer avionics version. If all aircraft were found to support edition 2.1, the configuration would be maintained and other causes (equipment, network, or ATC System configuration) investigated; after handling, target stability on the ATC System is verified, and if targets remain unstable, the analysis is repeated.

Handling and Verification

The handling was carried out by reverting the Thales AX680 ADS-B configuration on the ATC System from ASTERIX edition 2.1 back to edition 0.23, given that not all aircraft operating in Bali's airspace yet have avionics that fully support edition 2.1. Verification was carried out by observing the ADS-B Display monitoring appearance under both editions; the identified difference lay in the aircraft squawk-number information, which was not displayed under edition 0.23, whereas under edition 2.1 the aircraft squawk number could be displayed on the monitoring screen. After the configuration was reverted to edition 0.23, aircraft targets were again detected stably and consistently on the ATC System. The revert therefore involved an operational trade-off: continuity of target display was given priority over the additional information, including the squawk number, that edition 2.1 makes available. This trade-off indicates that a migration

should be planned so that the benefit of new data items is not obtained at the expense of target continuity, as discussed in the recommendations below.

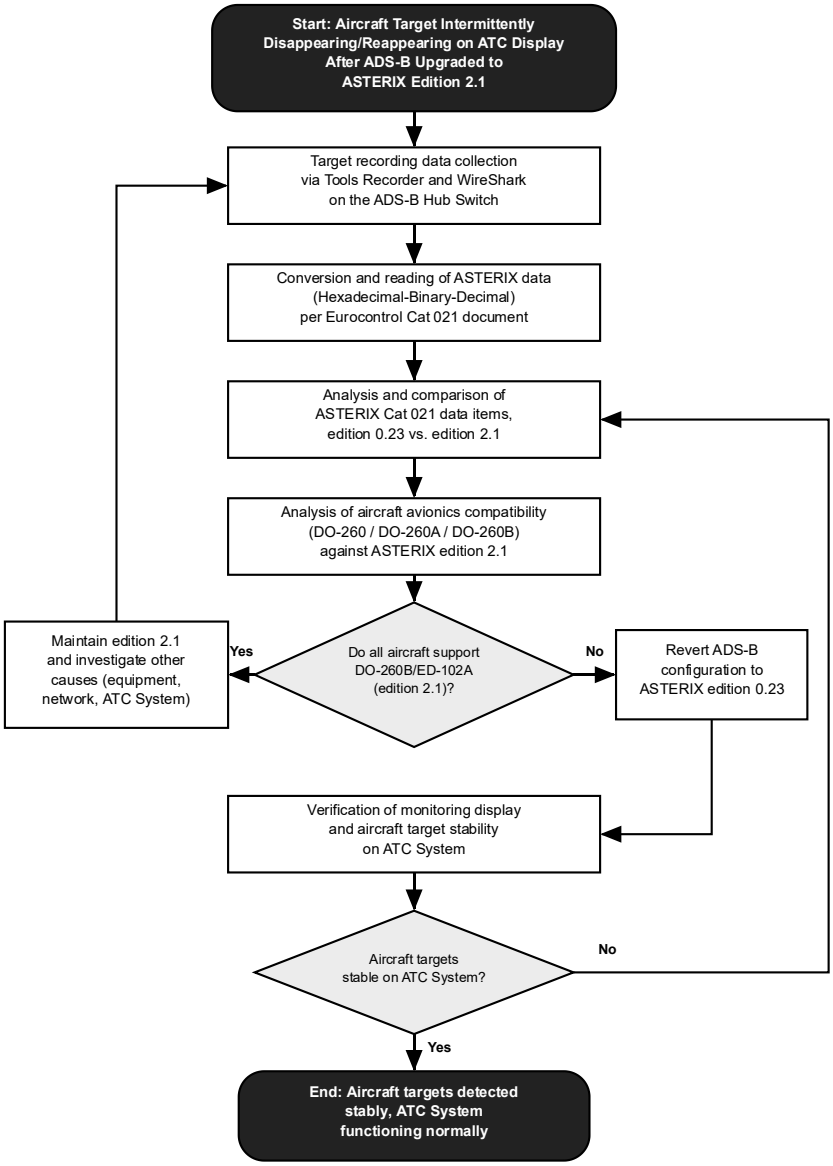


Figure 1 Flowchart of the ASTERIX ADS-B Edition 0.23 and Edition 2.1 Data Analysis at Perum LPPNPI AirNav Denpasar Branch (Source: Processed by the Authors, 2026)

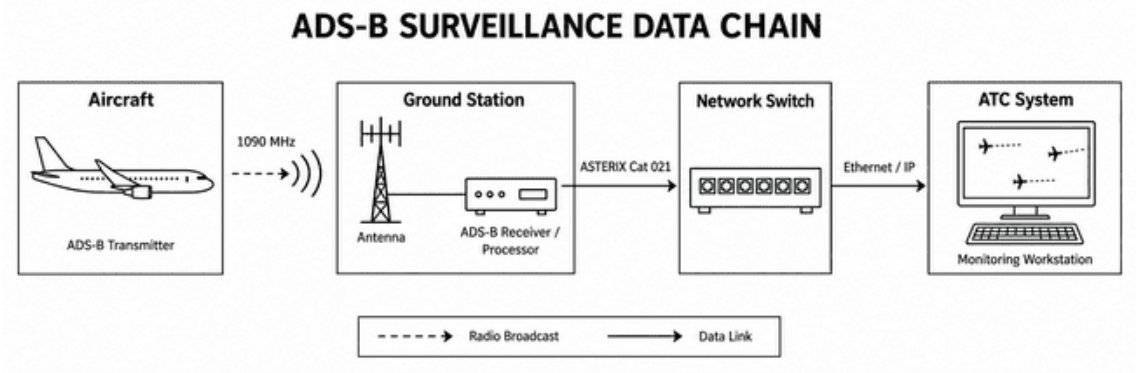


Figure 2 Conceptual Illustration of ASTERIX Data Exchange Between the Aircraft, the ADS-B Ground Station, and the ATC System (Source: Authors' illustration, based on Eurocontrol, 2011)

Figure 2 presents a conceptual illustration of the ASTERIX data exchange between the aircraft, the ADS-B ground station, and the ATC System, depicting the data flow starting from the aircraft's transponder broadcasting a signal on the 1090 MHz frequency, received by the ADS-B ground station, forwarded in ASTERIX Cat 021 format, through to being processed and displayed on the ATC System monitoring screen, as a visual complement to the explanation of the system's working principle described in the previous section.

Implications for Surveillance Data Quality and Technician Competence

Although the problem in this case was caused by a mismatch between the data format and the avionics readiness of the fleet, not by an attack, it is consistent with the broader observation that ADS-B data are exchanged over an unencrypted channel and that their quality must be monitored (Lee et al., 2014). Machine-learning-based anomaly detection can reach high classification accuracy for ADS-B messages (Abu Al-Haija & Al-Tamimi, 2024; Ahmed et al., 2025), and multi-sensor association and MLAT can complement ADS-B when some targets are unreliable (Osypiuk & Surma, 2025; Vico Navarro et al., 2025). Monitoring the consistency of target data therefore remains a useful element of preventive maintenance for surveillance equipment (Ali et al., 2015). The case also shows that data-format migration must refer to the official Eurocontrol document and to the avionics readiness of the aircraft, since configuration errors made without a thorough understanding of technical documents are a human-error factor in aviation maintenance (Olaganathan, 2024). Competence in reading and analyzing ASTERIX data is built through direct involvement in field problems, which contributes to work readiness and to alignment with industry work systems (Lubis, 2021; Darni et al., 2025).

Recommendations for Data-Format Migration

Based on this case, four practical recommendations are made for CNS and Automation units planning a similar migration. First, review the avionics-version mix of the aircraft in the airspace, using recorded ASTERIX data, before the new edition is activated. Second, introduce the new edition gradually, for example by evaluating it in parallel with the existing edition before it replaces it on the operational display. Third, define acceptance criteria in advance, including target continuity on the ATC System display, and monitor them during the trial. Fourth, document the data items and the display behavior under both editions, including information that is lost or gained, such as the squawk number in this case, so that the decision to keep or revert is made with full knowledge of the trade-off.

Limitations and Future Work

This study has several limitations. It is a single case at one unit, and it is qualitative: counts of dropouts per aircraft class and the share of aircraft by ADS-B version are not reported, and the cause is therefore presented as the most plausible explanation, not as a proven mechanism. The internal processing of the ATC System, and other possible contributors such as network conditions or time-related fields, were not examined separately. Future work should record the number and duration of dropouts, classify the affected aircraft by ADS-B version, for example by cross-checking against independent ADS-B sensor-network data (Schäfer et al., 2014), and test the ATC System behavior under both editions in a controlled evaluation.

Conclusion

The intermittent aircraft-target problem at Perum LPPNPI AirNav Denpasar Branch occurred after the Thales AX680 ADS-B was changed from ASTERIX Cat 021 edition 0.23 to edition 2.1. The comparison of data items shows that edition 2.1 contains 23 data items against 15 in edition 0.23, including items that carry ADS-B version and quality information defined for DO-260B/ED-102A avionics. The most plausible cause is a mismatch between this data format and the avionics readiness of part of the aircraft fleet in Bali's airspace. Reverting to edition 0.23 restored stable target detection, at the cost of information such as the squawk number on the display. The case indicates that a surveillance data-format migration should be gradual, based on the avionics mix of the fleet, with defined acceptance criteria and compliance with the standard documents, and that CNS technicians need the competence to analyze surveillance data.

Acknowledgements

The author expresses gratitude to the agencies, companies, and institutions that have offered support in conducting research and/or writing publications

AI Declaration

The author acknowledges the use of artificial intelligence (AI) tools in supporting the preparation of this manuscript. The author remains fully responsible for the accuracy, originality, and integrity of the research and its findings.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

No funding was received for this work.

References

Abu Al-Haija, Q., & Al-Tamimi, A. (2024). Secure aviation control through a streamlined ADS-B perception system. *Applied System Innovation, 7*(2), 27. https://doi.org/10.3390/asi7020027

Ahmed, W., Masood, A., Manzoor, J., & Akleylek, S. (2025). Automatic dependent surveillance-broadcast (ADS-B) anomalous messages and attack type detection: Deep learning-based architecture. *PeerJ Computer Science, 11*, e2886. https://doi.org/10.7717/peerj-cs.2886

Ali, B. S., Ochieng, W. Y., Schuster, W., Majumdar, A., & Chiew, T. K. (2015). A safety assessment framework for the Automatic Dependent Surveillance Broadcast (ADS-B) system. *Safety Science, 78*, 91-100. https://doi.org/10.1016/j.ssci.2015.04.011

Ali, B. S., Schuster, W., Ochieng, W., & Majumdar, A. (2016). Analysis of anomalies in ADS-B and its GPS data. *GPS Solutions, 20*(3), 429-438. https://doi.org/10.1007/s10291-015-0453-5

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report, 13*(4), 544-559. https://doi.org/10.46743/2160-3715/2008.1573

Darni, R., Harisman, Y., Sukma, D., Fitriana, E., Sulistiobudi, R. A., & Herayono, A. (2025). Work readiness in vocational education: Perception and correlation between measurement level and system integration. *TEM Journal, 14*(2), 1388-1397. https://doi.org/10.18421/TEM142-39

Eurocontrol. (2011). *Eurocontrol standard document for surveillance data exchange, Part 12: Category 021 ADS-B reports* (Edition 2.1). European Organisation for the Safety of Air Navigation. https://www.eurocontrol.int/publication/cat021-eurocontrol-specification-surveillance-data-exchange-asterix-part-12-category-21

Eurocontrol. (2012). *Eurocontrol standard document for surveillance data exchange, Part 12: Category 021 ADS-B reports (Editions 0.10 to 1.3, archive of earlier editions)*. European Organisation for the Safety of Air Navigation. https://www.eurocontrol.int/publication/cat021-eurocontrol-specification-surveillance-data-exchange-asterix-part-12-category-21

Habibi Markani, J., Amrhar, A., Gagné, J.-M., & Landry, R., Jr. (2023). NextGen ADS-B software-defined reception with enhanced techniques. *Applied Sciences, 13*(1), 493. https://doi.org/10.3390/app13010493

Ho, W. S. (2020). *Introduction to Automatic Dependent Surveillance – Broadcast* [Conference presentation]. ICAO Asia and Pacific Office ADS-B Webinar, Civil Aviation Authority of Singapore. https://www.icao.int/sites/default/files/APAC/Meetings/2020/2020%20ADSB%20Webinar/SP01_Introduction%20to%20ADS-B.pdf

Jančík, M., De Haan, J., & Jonáš, P. (2019). Security enhancements of the surveillance data exchange protocol "ASTERIX". *DEStech Transactions on Computer Science and Engineering*, (cscbd). https://doi.org/10.12783/dtcse/cscbd2019/30009

Jeon, D., Eun, Y., & Kim, H. (2015). Estimation fusion with radar and ADS-B for air traffic surveillance. *International Journal of Control, Automation and Systems, 13*(2), 336-345. https://doi.org/10.1007/s12555-014-0060-1

Lee, S.-H., Kim, Y.-K., Han, J.-W., & Lee, D.-G. (2014). Protection method for data communication between ADS-B sensor and next-generation air traffic control systems. *Information, 5*(4), 622-633. https://doi.org/10.3390/info5040622

Lubis, M. R. (2021). Pengaruh On The Job Training (OJT) Flight Operations Officer (FOO) terhadap kesiapan kerja [The influence of On the Job Training (OJT) for Flight Operations Officers (FOO) on work readiness]. SKYHAWK: Jurnal Aviasi Indonesia, 1(2), 85-91. https://doi.org/10.52074/SKYHAWK.V1I2.14

Olaganathan, R. (2024). Human factors in aviation maintenance: Understanding errors, management, and technological trends. *Global Journal of Engineering and Technology Advances, 18*(2), 92-101. https://doi.org/10.30574/gjeta.2024.18.2.0021

Osypiuk, R., & Surma, F. (2025). Uncertainty of aircraft localization with multilateration and known altitude. *Electronics, 14*(12), 2420. https://doi.org/10.3390/electronics14122420

Schäfer, M., Strohmeier, M., Lenders, V., Martinovic, I., & Wilhelm, M. (2014). Bringing up OpenSky: A large-scale ADS-B sensor network for research. In *IPSN-14 Proceedings of the 13th International Symposium on Information Processing in Sensor Networks* (pp. 83-94). IEEE. https://doi.org/10.1109/IPSN.2014.6846743

Strohmeier, M., Schäfer, M., Lenders, V., & Martinovic, I. (2014). Realities and challenges of NextGen air traffic management: The case of ADS-B. *IEEE Communications Magazine, 52*(5), 111-118. https://doi.org/10.1109/MCOM.2014.6815901

Strohmeier, M., Lenders, V., & Martinovic, I. (2015). On the security of the automatic dependent surveillance-broadcast protocol. *IEEE Communications Surveys & Tutorials, 17*(2), 1066-1087. https://doi.org/10.1109/COMST.2014.2365951

Sun, J., Vû, H., Ellerbroek, J., & Hoekstra, J. M. (2019). pyModeS: Decoding Mode-S surveillance data for open air transportation research. *IEEE Transactions on Intelligent Transportation Systems, 21*(7), 2777-2786. https://doi.org/10.1109/TITS.2019.2914770

Vico Navarro, J., Balbastre Tejedor, J. V., & Vila Carbó, J. A. (2025). A new association approach for multi-sensor air traffic surveillance data based on deep neural networks. *Sensors, 25*(3), 931. https://doi.org/10.3390/s25030931

Zhang, J., Liu, W., & Zhu, Y. (2011). Study of ADS-B data evaluation. *Chinese Journal of Aeronautics, 24*(4), 461-466. https://doi.org/10.1016/S1000-9361(11)60053-8