EXPERT'S REPORT

INTERNATIONAL CIVIL AVIATION ORGANIZATION

CHURKIN MOSCOW
INTERNATIONAL
MODEL UNITED NATIONS

‘ENSURING GLOBAL FLIGHT SAFETY IN THE EVENTS OF APPLYING TEMPORARY FLIGHT RESTRICTIONS OR GNSS SPOOFING/JAMMING’

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INTRODUCTION

The aviation industry has become an extremely vital way of transportation nowadays. It emerged as a driver for the globalization process, interregional and international connectivity, movement of people and goods. A bit less than 5 billion passengers boarded scheduled flights in 2024[1], reflecting a 9.4% increase over a previous year. In 2024, airports worldwide handled over 124 million metric tonnes of air cargo — that is a year-to-year increase of 8.4%. Aviation has revolutionized the meaning of transportation itself but it also has made a huge boost to global economic development, creating millions of jobs, and facilitating cultural exchange. It enables just-in-time supply chains, supports tourism, and makes distant markets accessible.

The aviation industry is a complex industry and its cornerstone is **flight safety**[2]. The trust of passengers, operators, regulators, and the public relies on the consistent ability to perform flights without accidents or crashes. Ensuring safety is not only a moral and legal obligation but also an economic and strategic necessity: disruptions, accidents, or safety breaches have huge effects on global trade, tourism, and national security, as well as flight operators (airlines) revenue. Modern aviation depends on a complex interaction of aircraft systems performance, air traffic management, regulatory oversight, and human performance; any compromise in these components can significantly increase risks. Therefore, maintaining and continuously enhancing flight safety is vital to preserving the reliability and growth of the global air transport system.

The aviation industry has faced thousands of problems that led to decrease of flight safety. But as our world develops, we all face new problems and the air transportation industry is not an exemption. Two issues have emerged as key concerns in recent years: the application of **Temporary Flight Restrictions**[3] and the deliberate or unintended disruption of **Global Navigation Satellite Systems** (*hereinafter referred to as GNSS*), particularly through **spoofing** and **jamming**.

[1] Tutkun A., Ates S.S., Yılmaz H. A. Comparative Analysis of Aircraft Accident Investigation Models for Enhancing Aviation Safety and Sustainable Infrastructure // Journal of Lifestyle and SDGs Review. 2025. Vol. 5, No. 3. P. 4

[2] Refer to glossary

The aviation industry has faced thousands of problems that led to decrease of flight safety. But as our world develops, we all face new problems and the air transportation industry is not an exemption. Two issues have emerged as key concerns in recent years: the application of **Temporary Flight Restrictions** and the deliberate or unintended disruption of **Global Navigation Satellite Systems** (hereinafter referred to as GNSS), particularly through **spoofing** and **jamming**.

While both measures or threats emerge from distinct contexts — the former rooted in legitimate airspace management decisions, the latter in hostile or accidental interference — their practical effects converge on the flight deck and in air traffic management systems. They increase pilot workload, reduce navigational certainty, and create risks of miscommunication or miscoordination among multiple stakeholders that could possibly lead to global flight safety level decrease and possible occurrence of flight incidents.[4]

This report examines the current legal and institutional framework, reviews documented cases, analyzes risks to flight safety, and evaluates international and national responses. It concludes with recommendations for strengthening information sharing, enhancing technical resilience, and improving awareness and training across the aviation sector. By doing so, it aims to support ICAO's ongoing aim to ensure global flight safety levels at the highest possible level.

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[3] FAA. Advisory Circular 91-63C: Temporary Flight Restrictions (TFRs/TFR) [Electronic resource]. – Washington, D.C.: U.S. Department of Transportation, 2004. – URL: [1] Tutkun A., Ates S.S., Yılmaz H. A. Comparative Analysis of Aircraft Accident Investigation Models for Enhancing Aviation Safety and Sustainable Infrastructure // Journal of Lifestyle and SDGs Review. 2025. Vol. 5, No. 3. P. 4

[4] International Civil Aviation Organization (ICAO). GNSS Vulnerabilities and Emerging Threats [Electronic resource]. – Presentation at the ICAO APAC Radio Navigation Symposium, New Delhi, India, 7 April 2025. – URL: icao.int›sites/default/files/APAC/Meetings/2025/...f (accessed: 30.08.2025).

PART 1. LEGAL FRAMEWORK FOR ENSURING FLIGHT SAFETY

1.1. ICAO and the Chicago Convention

The International Civil Aviation Organization (ICAO), established in 1944 under the Chicago Convention on International Civil Aviation, provides the foundational framework for international civil aviation. The Convention defines the rights and responsibilities of states in managing their airspace, ensuring safe flight operations, and facilitating international air transport in general. ICAO develops special documents called Standards and Recommended Practices (hereinafter referred to as SARPs) that cover all aspects of aviation safety, including airworthiness, flight operations, air traffic management, communications, navigation, and safety management.

SARPs are published in Annexes to the Chicago Convention, each dedicated to a specific domain of the aviation industry. For example, Annex 6 covers operation of aircraft, Annex 8 covers airworthiness, and Annex 19 establishes Safety Management System (SMS). Compliance with SARPs ensures flight safety policies harmonization across member states.

In addition to SARPs, ICAO [5] issues guidance materials, policy papers, and circulars addressing emerging threats, such as GNSS spoofing and jamming, cyberattacks risks, and other operational challenges. These documents guide states in applying both standard procedures and best practices to maintain a uniform, global level of safety.

1.2. What is Flight Safety

Flight safety is the core principle of civil aviation. Modern aviation is recognized as **the safest means of transport**, due to the integration of exceptional technical, operational, and human safeguards. Several key elements explain such a high flight safety level:

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1. **System redundancy in general**: approximately since 1980 critical systems in modern aircrafts, including flight controls, navigation, hydraulics, and electrical systems, are designed with multiple independent layers, so it basically means that if a component fails, backup systems will save the aircraft, maintain its control and operational stability. Navigation in modern aircrafts (*e.g. Airbus A320 family and newer aircrafts, Boeing B737 family and newer aircrafts*) is supported by multiple systems: GNSS, Inertial navigation system[6] (*INS*), and radio-based navigation[7] (*e.g. VOR, ADF, DME, NDB*). It means that operations can continue even if one system is disrupted.

2. **Safety Management Systems (SMS)**: ICAO commands that operators implement SMS, a structured framework to **proactively identify hazards, assess risks, and implement mitigations**. SMS integrates flight data monitoring, risk analysis, and safety reporting. A 'just culture' is encouraged, allowing personnel to report incidents and near misses without fear of punishment, supporting continuous improvement and knowledge sharing.

3. **Preventive Maintenance and Lifecycle Management**: Modern aircraft use **time-based and usage-based maintenance**, replacing components according to scheduled intervals accepted by aircraft manufacturer rather than waiting for failure. Predictive maintenance allows operators to solve potential issues before they affect operations. Critical parts are overhauled or replaced systematically, ensuring reliability over the aircraft lifecycle.

4. **Human Factors and Training**: Crew training is vital and recurrent in the air transport industry. Standard flight operating procedures accepted by airlines and checklists by aircraft manufacturers guide pilots, cabin crew, and maintenance personnel in handling normal, abnormal and emergency scenarios and situations. Crew resource management ensures coordinated decision-making, optimizing responses under stress.

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5. **Regulatory Oversight**: National civil aviation authorities ensure that operators comply with ICAO SARPs and national regulations. Authorities oversee certifications, audits, and inspections, enforcing operational and technical standards. While the FAA or EASA are often cited as examples of such authorities, all ICAO member states try to maintain oversight systems that integrate international and local safety requirements.

6. **Technological Safeguards**: Large aircraft (take-off mass higher than 5700 kg) are equipped with traffic collision avoidance system (TCAS), ground proximity warning (EGPWS), weather radar and other safety systems. These technologies allow early hazard detection, alerting crews and mitigating risks before an occurrence of a dangerous situation.

1.3. Role of National Authorities

National civil aviation authorities implement ICAO standards within their jurisdictions. Their functions include:

1. DEeloping and enforcing regulations consistent with SARPs.

2. Certifying operators, aircraft, and personnel.

3. Monitoring compliance through audits and inspections.

4. Coordinating air traffic management and implementing temporary or permanent airspace restrictions.

5. Managing GNSS risks, including spoofing and jamming.

Examples of authorities include the **Federal Aviation Administration (FAA)** in the **United States and European Union Aviation Safety Agency (EASA)** in the European Union, which provide guidance on TFRs, maintenance regimes, and operational safety. Similar authorities exist worldwide, applying ICAO standards locally while ensuring interoperability and global compliance.

PART 2. TEMPORARY FLIGHT RESTRICTIONS

2.1. Definition and Purpose

A **NOTAM** (*Notice to Air Missions*) is an official message issued by aviation governmental authorities to inform pilots and operators of **temporary changes or hazards** that could affect flight safety, including airspace restrictions, airport closures, equipment outages, or other operational conditions. NOTAMs are used and issued worldwide under ICAO guidance to ensure that pilots receive timely information about conditions that may impact navigation, aircraft operations, or airspace access. **NOTAMs are time-sensitive** — they remain valid only for the specified time period, after which the information is either removed or inserted into permanent aeronautical publications (Aviation maps — AIPs).

Temporary Flight Restrictions (*hereinafter referred to as TFRs*) are short-term regulatory airspace closures **issued via NOTAMs** to protect flight safety, national security or public safety. The problem starts over here — ICAO does not have a unified definition of TFRs. ICAO provides the basic framework for the issuance and management of NOTAMs, within which temporary airspace restrictions are categorized. National aviation authorities, such as the FAA, adapt this framework to their specific regulatory environments and operational needs[8].

In practice, countries use NOTAMs to announce temporary restrictions for similar purposes. TFRs are routinely imposed for reasons including **national security and VIP movements, civil or military emergencies, major public events or gatherings,** and **airspace hazard situations**[9].

[8] FAA. Temporary Flight Restrictions (TFR) and Flight Restrictions [Electronic resource]. December 9, 2015. URL: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_91-63D.pdf (accessed: 30.08.2025).

[9] Ibid.

2.2. Influence on Flight Safety

Implementing TFRs poses both operational and regulatory obstacles, that could influence Flight Safety:

1. Its **publication** is critical: TFRs must be published via NOTAMs in a timely, precise and clear format. Pilots and ATC must actively check for NOTAMs so as not to miss active TFRs[10]. However, the NOTAM system is often overburdened or outdated, raising concerns about information overload and clarity. For example, firefighting TFRs can be large, irregularly-shaped areas that shift as a wildfire spreads; pilots are warned that a TFR can migrate "enveloping your route" as conditions change. This dynamic nature increases pilot workload and necessitates constant updates.

2. **Harmonization and coordination** between jurisdictions can be difficult. A TFR issued in one State's flight information region[11] (FIR) may overlap another's airspace, requiring international coordination. For instance, the EUROCONTROL (**e.g. a pan-European, intergovernmental organization that supports aviation safety, efficiency, and environmental sustainability by coordinating air traffic management across 41 member states and acting as the Network Manager for European airspace**). Network Manager will reject filed flight plans that would violate published and working TFR restrictions[12].

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[10] FAA. Temporary Flight Restrictions (TFRs) [Electronic resource]. Last updated: March 10, 2025. URL: [8] FAA. Temporary Flight Restrictions (TFR) and Flight Restrictions [Electronic resource]. December 9, 2015. URL: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_91-63D.pdf (accessed: 30.08.2025).

[11] Refer to glossary

[12] EASA. Airspace of Ukraine (Conflict Zone Information Bulletin CZIB-2022-01 R12) [Electronic resource]. Issue date: 24 February 2022; Revision date: 31 July 2025; Valid until: 31 January 2026. Available at: [8] FAA. Temporary Flight Restrictions (TFR) and Flight Restrictions [Electronic resource]. December 9, 2015. URL: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_91-63D.pdf (accessed: 30.08.2025).

Yet scattered rules (*e.g. one country closes its airspace while neighbors do not*) can complicate planning and ATC[13] coordination. Situational awareness on both pilots and controller sides is also a challenge: controllers must quickly re-route traffic around a TFR, often in real time, and pilots must adjust navigation accordingly – any lapse can lead to confusion or airspace incursions.

3. **Enforcement and compliance** can strain resources. In the U.S., the FAA investigates all TFR violations, and pilots who enter a TFR without authorization face penalties 'ranging from warnings or fines to certificate suspension or revocation[14]'.

4. TFRs **impact civilian airspace users** by forcing reroutes, flight plan changes, delays and possible flight cancellations. Operators must often file new flight plans to avoid the TFR, incurring extra fuel cost and ATC workload. If a TFR overlaps high-volume routes, air traffic flow management (**e.g. holding patterns, orbits**) may be needed to maintain safety. All these factors underscore that TFR implementation requires real-time coordination and communication among Air Navigation Service Providers[15] (ANSP), pilots and operators. Their overload could possibly lead to deviation in flight safety.

5. **Risk in GNSS-Denied Environments:** In some conflict zones, air defenses or electronic warfare systems may interfere with GPS (GNSS) signals. When a TFR overlaps such a 'GPS-denied' area, pilots may suddenly find themselves without reliable satellite navigation while also having to navigate around restricted airspace.

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[13] Refer to glossary

[14] FAA. Temporary Flight Restrictions (TFRs) [Electronic resource]. Last updated: March 10, 2025. URL: https://www.faa.gov/uas/getting_started/temporary_flight_restrictions (accessed: 02.09.2025)

[15] Refer to glossary

This dual loss of navigation and TFR closure can force pilots to revert to backup procedures (like using paper charts) under high workload. ICAO and UN bodies have warned that the rise in GPS jamming near conflict zones poses a severe safety threat. In practice, this means that flights operating near TFRs in warzones face compounded hazards: they must avoid the restricted zone while also coping with potential electronic interference[16].

2.3. Illustrative Cases

1. UKraine: Following the beginning of the Russian Special military operation in Ukraine, Ukraine's aviation authorities closed the entire civilian airspace by publishing a NOTAM. EASA issued conflict-zone bulletins warning that all Ukrainian FIRs were closed, and that military activity posed a 'high risk for civil flights' – warning of intentional targeting or misidentification of civilian aircraft. Western states and airlines universally banned all flights over Ukraine.

2. **Middle East Conflicts:** In Syria's long-running civil war, EASA has repeatedly warned operators that the entire Syrian airspace carries a high risk at all altitudes due to ongoing combat and extensive anti-aircraft operations. EASA formally recommends avoiding Syrian airspace entirely. In Israel's recent conflicts (*e.g. war in Gaza region*), airlines have also faced rapid airspace restrictions.

[16] FAA. Temporary Flight Restrictions (TFR) and Flight Limitations [Electronic resource]. Date issued: December 9, 2015. Effective: November 9, 2015. URL: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_91-63D.pdf (accessed: 02.09.2025)/

For example, rocket attacks on Tel Aviv have led Israeli ATC to close Ben Gurion Airport on short notice, causing dozens of international carriers to cancel flights. During the Oct–Nov 2023 Gaza war, leading international airlines suspended or reduced flights to Israel's capital amid the conflict. Russia even imposed a temporary curfew on flights to Israel's airspace[17]. Israel's aviation regulatory body advised airlines to "review current security and threat information" and expect delays, while redirecting en-route traffic around sensitive areas.

3. **Russian Federation (in 2023–2025):** in response to a series of drone incursions — Russian aviation authorities (FAVT, Rosaviatsiya) imposed temporary restrictions on civilian flights at numerous airports across 2024–2025 more than 300 times. Following intense drone attacks, key facilities such as Sheremetyevo, Domodedovo, Zhukovsky, Vnukovo international airports of Moscow Aviation Hub (MOW), and regional airports in Kazan, Saratov, Ulyanovsk, Astrakhan, Nizhnekamsk, and Samara were temporarily closed to arrivals and departures to ensure passenger safety. These measures, often activated with minimal notice, disrupted thousands of flights across southern and central Russia, and forced significant rerouting and delays. For instance, in late 2024, several airports closed briefly after drone strikes, and in early 2025, widespread closures covered multiple regions following failed drone attacks. Despite frequent temporary airspace restrictions, operations typically resumed once the threat subsided, following coordination between Rosaviatsiya, airport operators, and air defense services.

2.3. Case Study: Near Mid-Air Conflict at Moscow Domodedovo

On August 23rd, 2025, at Moscow Domodedovo Airport, a serious near mid-air conflict was narrowly avoided in the context of a highly complex operational environment.

[17] RIA Novosti. Russian airlines' ban on nighttime flights to Israel extended until July 12 [Electronic resource]. June 25, 2025. URL: https://www.ria.ru/20250625/samolet-2025454076.html (accessed: 02.09.2025)

The complexity was triggered by the simultaneous introduction of “Kover plan” (*name of the TFR restriction, imposed by ‘Rosaviatsiya’, to ensure flight safety in events of drones attack, rocket launches, etc*) airspace restrictions at several airports due to a wave of Ukrainian drone attacks, which placed air traffic controllers under extreme workload pressure.

An S7 Airlines Boeing 737-800 (RA-73412) was operating a flight from Novosibirsk to Saint Petersburg, but later it was diverted to Moscow Vnukovo airfield due to restrictions at Pulkovo, was cleared for departure from Domodedovo directly toward the approach path of a Somon Air Boeing 737 (EY-777) arriving from Dushanbe and on final approach to the same runway. Because of an ATC error, the prescribed lateral separation interval was breached (*not less than 5 km in lateral interval between aircrafts in air should be provided at all times*).

The controller immediately instructed the S7 flight crew to execute an urgent right turn, preventing possible incident. The closest horizontal distance between the two aircraft was reduced to four kilometers. However, there were no reports from either flight crew of a Traffic Collision Avoidance System (TCAS) resolution advisory being triggered

This head-on departure/arrival sequencing procedure, with minimum separation maintained, had been introduced in May for use during “Kover” drone restrictions in order to minimize large-scale flight delays. The procedure was intended to improve airport throughput and reduce airborne holding times. However, the incident demonstrated that under conditions of operational stress and commercial pressure, safety must remain the overriding priority. Any compromise risks potentially catastrophic consequences

PART 3. GNSS SPOOFING AND JAMMING

3.1. Technical Overview and Risks

Global Navigation Satellite Systems (e.g. GPS, GLONASS, GALILEO, BEIDOU are all GNSSs) provide the primary source of position, navigation, and timing for modern aircraft[18]. GNSS jamming and spoofing exploit the low power and lack of authentication of civilian GNSS signals[19]. Jamming refers to intentional radio-frequency interference that overwhelms satellite signals so receivers can no longer lock on. Spoofing is the transmission of counterfeit GNSS-like signals that deceive onboard receivers into calculating an incorrect position. In practice, jamming causes a loss or degradation of navigation signals, whereas spoofing can mislead the pilot by producing false position, speed, or time data. Spoofing is generally considered worse than jamming, as it is harder to detect and may simultaneously affect multiple systems, potentially leading to multiple failures.

Because many aircraft systems rely on GNSS, interference propagates through avionics. For navigation, loss of GNSS may force reversion to dead reckoning or navigation using INS or radio navigation systems only. Many modern flight routes rely on satellite navigation systems to guide aircraft safely and accurately. Two common navigation procedures, called Area Navigation[20] (RNAV) and Required Navigation Performance[21] (RNP), depend on these satellite signals to ensure planes follow precise paths, even over oceans or remote areas. If the satellite signals are jammed, the aircraft can drift off course or temporarily lose guidance along its planned route. Spoofing, which involves sending fake satellite signals, can trick the aircraft into showing a completely wrong position, sometimes placing the plane miles away from its actual location.

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[18] Li, X., Zhang, X., Ren, X., Fritsche, M., Wickert, J., & Schuh, H. Precise positioning with current multi-constellation Global Navigation Satellite Systems: GPS, GLONASS, Galileo and BeiDou . Scientific Reports, 5, Article 8328. February 9, 2015.

[19] European Union Aviation Safety Agency. Global Navigation Satellite System (GNSS) Outages and Alterations Leading to Communication / Navigation / Surveillance Degradation. Issued: July 5, 2024; Revision: 3

[20] Refer to glossary

[21] Refer to glossary

Air traffic monitoring systems, which help controllers track and manage the positions of aircraft, are also affected. Interference can cause these systems to display incorrect positions or fail to show the aircraft at all. Onboard safety systems rely on satellite data as well. For example, the **Enhanced Ground Proximity Warning System (EGPWS)**[22] alerts pilots if they are at risk of flying into terrain, and the **Traffic Collision Avoidance System**[23] **(TCAS)** warns of potential collisions with other aircraft. If the satellite data feeding these systems is false or missing, they can trigger unnecessary alarms or fail to alert the crew when there is a real danger. False alarms can confuse pilots and force them to perform unnecessary maneuvers, while missed alerts could lead to unsafe situations.

To compensate for interference, pilots rely on backup methods of navigation, such as traditional instruments or ground-based navigation, and carefully cross-check their position and speed. They also need to communicate closely with air traffic controllers to maintain safe flight paths.
Because GNSS signals are inherently weak, interference may affect large areas. Pilots and operators reported thousands of anomalies in recent years, especially in regions close to armed conflicts. Data show a sharp rise in loss-of-GNSS events[24].

3.2. Documented Incidents

GNSS interference incidents have been reported across Europe and the Middle East. Earlier in 2024, repeated GPS outages compelled Finnair to suspend service to Tartu, Estonia, while nearby Finnish airports experienced

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[23] Refer to glossary

[24] European Union Aviation Safety Agency. Global Navigation Satellite System (GNSS) Outages and Alterations Leading to Communication / Navigation / Surveillance Degradation [Electronic resource]. Issued: July 5, 2024; Revision: 3. URL: https://ad.easa.europa.eu/ad/2022-02R3 (accessed 02.09.2025).

similar problems[25]. In these cases, pilots reverted to radar vectoring and conventional navigation, with air traffic controllers issuing manual headings to maintain separation.

In the Mediterranean and Middle Eastern corridor, widespread spoofing and jamming have emerged as a constant threat. Regional authorities complained that these disruptions posed dangerous risks to civil aviation, with some signals traced to military counter-drone operations that spilled over into civilian airspace[26].

Industry analyses highlight several 'hotspots' of GNSS interference[27]. Affected areas include the Eastern Mediterranean, Black Sea, Eastern Europe, the Baltic region, and parts of the Arctic. As a result, NOTAMs warning of GNSS degradation are now routinely issued for these regions.

3.3. Operational Impacts

GNSS interference imposes significant penalties on flight operations. Crews must immediately detect anomalies such as sudden position jumps, ground-speed discrepancies, etc. Spoofed signals can mislead the aircraft[28] Flight Management System (FMS)[29] into 'believing' the aircraft is elsewhere, leading to position drift.

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25. Schlappig, B. Finnair suspends route due to Russian GPS jamming [Electronic resource]. One Mile at a Time, April 29, 2024. URL: https://onemileatatime.com/news/finnair-suspends-route-russian-gps-jamming/ (accessed: 06.09.2025).

26. Villamizar, H. Impacts of GPS spoofing on commercial aviation [Electronic resource]. Airways Magazine, January 12, 2025. URL: https://www.airwaysmag.com/new-post/gps-spoofing-commercial-aviation (accessed: 07.09.2025).

27. International Air Transport Association (IATA). Global Navigation Satellite System GNSS Radio Frequency Interference Safety Risk Assessment [Electronic resource]. Version 4, September 2024. URL: https://www.iata.org/contentassets/c8e90fe690ce4047a8edfa97f4824890/iata_safety_risk_assessment_gnss_interference.pdf (accessed 07.09.2025).

28. Ibid

29. Refer to glossary

Pilots must report navigation displays freezing or wandering, and unexpected cockpit alerts referring to navigation systems failure to ATC, than proceed to abnormal procedures listed in their Quick Reference Handbooks (QRH)[30]. If not quickly identified, such errors can cascade across systems, producing false terrain or collision alerts and further complicating flight management.

Air traffic controllers also experience increased workload. With ADS-B[31] becoming unreliable, controllers often revert to radar surveillance and voice-based vectoring[32]. In some incidents, multiple aircraft lost GNSS simultaneously, forcing controllers to manage them manually using radar headings alone. Communication congestion rises sharply in these conditions, increasing the risk of separation errors.

3.4. Mitigation Practices

Aviation authorities and industry stakeholders have responded with multiple strategies. International Air Transport Association[33] (IATA) has identified GNSS resilience as a global safety priority, urging states to maintain conventional navigation aids and adopt contingency plans for outages[34]. Joint statements from international bodies call on governments to protect GNSS frequencies and take firm action against harmful interference. Regulators such as the FAA and EASA have issued safety bulletins, urging operators to prepare for GNSS-denied operations, update standard procedures, and train pilots to recognize and manage interference.

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[30] Refer to glossary

[31] Refer to glossary

[32] Lee, Y. H., Jeon, J. D., & Choi, Y. C. Air Traffic Controllers' Situation Awareness and Workload under Dynamic Air Traffic Situations. June 2012. Transportation Journal, 51(3), p. 338–355.

[33] Refer to glossary

[34] International Air Transport Association (IATA). Global Navigation Satellite System GNSS Radio Frequency Interference Safety Risk Assessment [Electronic resource]. Version 4, September 2024. URL: https://www.iata.org/contentassets/c8e90fe690ce4047a8edfa97f4824890/iata_safety_risk_assessment_gnss_interference.pdf (accessed 07.09.2025).

At the operational level, mitigation involves a layered approach. Manufacturers are equipping aircraft with multi-constellation receivers and integrating inertial systems as backups[35]. Airlines are training pilots in simulator scenarios to handle spoofing or jamming events, including recognition of mismatches in system data and reversion to ground-based navigation[36]. Controllers are prepared to vector aircraft using radar when GPS is unreliable. Some operators have begun deploying interference-detection tools and software that alert crews to potential spoofing activity.

[35] Gioia, C., & Borio, D. Multi-layered Multi-Constellation Global Navigation Satellite System Interference Mitigation. August 7, 2025. Sensors, 25(15), Article 3545.

[36] Durieux, M., Taylor, K. D., Kandel, L. N., & Gupta, D. GPS Spoofing Attacks and Pilot Responses Using a Flight Simulator Environment. Proceedings of the 7th IEEE International Conference on Trust, Privacy and Security in Intelligent Systems, and Applications, November 11–14, 2025.

CONCLUSION

The safety of global aviation depends on the reliable operation of both airspace management procedures and onboard navigation systems. Temporary Flight Restrictions (TFRs) and GNSS interference, including jamming and spoofing, present real and growing challenges to this safety. While TFRs are essential tools for protecting aircraft from hazards, managing conflicts, or securing sensitive areas, their implementation must be timely, precise, and coordinated to avoid unnecessary disruption. Similarly, GNSS vulnerabilities highlight the critical need for redundancy, backup systems, and robust operational procedures

The review demonstrates that aviation remains resilient due to multiple layers of safeguards: multi-constellation navigation, multiple layers of aircraft systems backups, extensive pilot and controller training, and regulatory oversight. International cooperation, particularly through ICAO, is vital for sharing information, standardizing responses, and maintaining operability across all regions worldwide.

The aviation community in general must continue to strengthen technical resilience, refine operational procedures, and promote global coordination. By implementing the recommended measures civil aviation can maintain the highest standards of safety, even under evolving threats. The combined efforts of authorities, operators, and international organizations will ensure that air transport continues to be a safe, reliable, and efficient connectivity service for passengers and cargo across the whole globe.

GLOSSARY

Flight Safety — The state in which risks associated with aviation operations are reduced and controlled to an acceptable level, ensuring the safety of passengers, crew, and aircraft.

Safety Management System (SMS) — A structured approach to managing safety, including policies, procedures, risk assessment, and continuous improvement, used by airlines and aviation organizations.

Inertial Navigation System (INS) — An onboard navigation system that calculates aircraft position, velocity, and orientation using motion sensors and gyroscopes, independent of external signals.

Radio-based Navigation — Navigation methods that use radio signals from ground-based beacons or satellites (e.g., VOR, DME, ILS, ADF) to determine aircraft position and correct flight path.

Flight Information Region (FIR) — A defined block of airspace in which flight information and alerting services are provided by a specific air traffic service unit.

Air Traffic Controller (ATC) — A licensed professional responsible for managing and directing aircraft movements on the ground and in the air to ensure safe and efficient operations.

Air Navigation Service Providers (ANSP) — Organizations that provide air traffic control, communication, navigation, surveillance, and other services to ensure safe and efficient air travel.

Area Navigation (RNAV) — A navigation method that allows aircraft to fly on any desired path within the coverage of ground or satellite-based navigation systems, rather than strictly from beacon to beacon.

Required Navigation Performance (RNP) — A type of RNAV that includes onboard performance monitoring and alerting, ensuring aircraft maintain high accuracy and reliability within defined airspace.

Enhanced Ground Proximity Warning System (EGPWS) — An advanced aircraft system that alerts pilots of potential collisions with terrain, obstacles, or runways, reducing the risk of Controlled Flight Into Terrain (CFIT) crashes.

Traffic Collision Avoidance System (TCAS) — An airborne system that monitors nearby aircraft equipped with transponders and provides pilots with alerts and obligatory maneuvers to avoid mid-air collisions.

Flight Management System (FMS) — A computerized system that automates navigation, performance calculations, and flight planning to assist pilots in managing the flight efficiently.

Quick Reference Handbook (QRH) — A manual kept in the cockpit containing checklists and procedures for handling abnormal and emergency situations. Written by aircraft manufacturers, but can include some specific airline procedures.

ADS-B (Automatic Dependent Surveillance–Broadcast) — A surveillance technology in which an aircraft automatically broadcasts its position, velocity, and other data via satellite navigation.