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ASSEMBLY — 42ND SESSION

TECHNICAL COMMISSION

Agenda Item 24: Aviation Safety and Air Navigation Priority Initiatives

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS) RADIO FREQUENCY INTERFERENCE (RFI)

(Presented by the Council of ICAO)

EXECUTIVE SUMMARY

This working paper presents the risks and consequences associated with GNSS RFI, actions and activities being progressed by the Organisation, as well as a report on the implementation of Assembly Resolution 41-8, *Consolidated statement of continuing ICAO policies and practices related to a global air traffic management (ATM) system and communications, navigation and surveillance/air traffic management (CNS/ATM) systems*, Appendix C, *Ensuring the resilience of ICAO CNS/ATM systems and services* and relevant ICAO initiatives and activities.

Action: The Assembly is invited to:

a) recognize ongoing technical efforts made to mitigate negative impacts related to GNSS RFI;
b) urge States, international organizations, donors and relevant stakeholders to support ICAO's efforts in addressing GNSS RFI, including providing voluntary contributions toward the validation and deployment of an implementation package (iPack) for the mitigation of GNSS RFI;
c) urge States to report GNSS RFI occurrences which cannot be resolved through routine national or international procedures to their accredited ICAO Regional Office, in addition to following the procedures outlined in the ITU Radio Regulations; and
d) adopt the proposed revision to Assembly Resolution A41-8, as presented in Appendix A.

Strategic Goal:	This working paper relates to *Every Flight is Safe and Secure*.
Financial implications:	The activities referred to in this paper will be undertaken subject to the resources available in the 2026-2027-2028 Regular Budget and/or from extra budgetary contributions and/or voluntary contributions.
References:	Doc 10209, *Report of the Fourteenth Air Navigation Conference* Doc 10184, *Assembly Resolutions in Force (as of 7 October 2022)* Doc 9849, *Global Navigation Satellite System (GNSS) Manual* ICAO/ITU/IMO Joint Statement on the protection of RNSS from harmful interference Electronic bulletin 2024/27

1. INTRODUCTION

1.1 Global navigation satellite systems (GNSS) is a crucial enabler for modern aviation services and technologies, such as performance-based navigation (PBN), automatic dependent surveillance – broadcast (ADS-B), and terrain awareness and warning system (TAWS) with a forward-looking terrain

avoidance function. GNSS provide highly precise positioning, navigation, and timing (PNT) which enable accurate location tracking and flight guidance. Additionally, GNSS provides accurate time synchronization for avionics, communication networks and operational systems, facilitating seamless communications and coordination between pilots, controllers and ground services, significantly enhancing safety and efficiency of flight operations and air traffic management.

1.2 Over time, civil aviation has become increasingly reliant on GNSS due to its significant benefits. Modern aviation relies heavily on systems capabilities which are GNSS-dependent. These systems include communications, navigation, surveillance, air traffic management automation system, airborne maps and displays as well as various airborne and ground-based automated systems. However, GNSS signals are vulnerable to radio frequency interference (RFI), which can degrade the accuracy, reliability and safety of flight operations. GNSS RFI comes mainly in two forms: jamming and spoofing. Jamming involves the intentional transmission of interference to prevent reception of GNSS signals. This can degrade navigation capabilities to an unusable level for users within the affected area. Spoofing, on the other hand, involves transmitting deceptive GNSS-like signals that mislead avionics into deriving incorrect time and/or computing incorrect positions.

2. RISK AND POTENTIAL CONSEQUENCES OF GNSS RFI

2.1 In recent years, GNSS RFI has become a recurrent and persistent challenge in several regions, posing significant and ongoing risks to civil aviation. While there are occurrences of RFI associated with conflict zones, many others are not. To date, while occurrences of GNSS RFI in or near conflict zones appeared not to intentionally target civil aviation, they exacerbate an already complex operational environment and could lead to serious safety and security impacts.

2.2 GNSS RFI can lead to a cascade of critical and immediate systems failures with widespread consequences. For instance in the case of spoofing, the flight management system (FMS) position can become degraded or fail entirely; the ability to comply with required navigation performance (RNP) may be disrupted; map shifts can occur (where the position indicated on navigation displays becomes misaligned with the actual position, potentially leading pilots to make incorrect decisions); and false ground proximity warnings may be triggered (warning of a potential terrain conflict when no actual danger exists, leading to unnecessary evasive action and crew confusion). Navigation errors due to the false calculation of position can cause aircraft to stray off their intended course, heightening the risk of midair collisions and inadvertent entry into restricted or prohibited airspace.

2.3 GNSS also provides essential time synchronization for aeronautical communications networks, necessary to ensure seamless data exchange between aircraft, ground stations and satellites. When GNSS timing is disrupted or de-synchronized, data flows across critical systems can be severely impacted and the effects can be widespread. For example, this may lead to datalink communication breakdowns resulting in the loss of contact between aircraft and ground control, undermining situational awareness. De-synchronized time can also cause ADS-B surveillance gaps and tracking errors, preventing controllers from properly monitoring aircraft.

2.4 GNSS RFI can have a serious impact on operational safety, potentially contributing to three global high-risk categories of occurrence (G-HRC): a mid-air collision (MAC), a controlled flight into terrain (CFIT), and a loss of control in-flight (LOC-I). In addition, it is likely to result in a significant operational and financial impact, including flight rerouting, delays, cancellations and increased workload for both controllers and pilots.

2.5 ICAO disseminated the OPSGROUP GPS Spoofing Workgroup report through Electronic Bulletin (EB 2024/27) on 18 December 2024 providing Member States and relevant industry stakeholders with essential information and awareness. The report includes useful technical information, details the impacts to aircraft handling and operation, promotes best practices for flight crew, as well as highlights safety concerns and recommendations for the attention of the global community.

2.6 Recognizing the significant risks and potential consequences of GNSS RFI on aviation safety and security, ICAO has outlined a set of short, medium, and long-term actions.

3. SHORT TERM ACTIONS

3.1 Regional activities

3.1.1 As part of ICAO's continued efforts to raise awareness and promote strategies to address GNSS RFI, several workshops and symposia were conducted and are scheduled. These events gather participants from Member States and international organizations to exchange insights and share best practices.

3.2 GNSS RFI- related NOTAM

3.2.1 Currently, GNSS RFI-related NOTAMs use a variety of codes. According to IATA, 18 different NOTAM Codes are used worldwide, rendering filtering mechanisms ineffective. Furthermore, it has been noted that different NOTAM text is used such as "GPS Unreliable," "GPS Jamming," "GPS signal interference," "GNSS interference,". This diversity creates challenges for operators attempting to efficiently identify and search in NOTAMs for information related to GNSS interference events.

3.2.2 The Fourteenth Air Navigation Conference (AN-Conf/14) acknowledged the absence of standardized NOTAM codes for GNSS RFI events and subsequently requested ICAO to develop additional NOTAM codes to enhance consistency and operational efficiency. Two codes for condition (interference and spoofing) as well as recommended text of NOTAM have been identified and will be included in the relevant ICAO documentation. Guidance on how pilots should interpret NOTAM is being developed by the expert groups.

3.3 Joint statement issued by ICAO, ITU and IMO, and enhanced reporting mechanisms

3.3.1 In line with Assembly Resolution A41-8 "*Consolidated statement of continuing ICAO policies and practices related to a global ATM system and communications, navigation and surveillance (CNS)/ATM systems, Appendix C, Ensuring the resilience of ICAO CNS/ATM systems and services*", Operative Clauses 5, 6, and 7, ICAO, the International Telecommunications Union (ITU) and the International Maritime Organization (IMO) have issued a joint statement to protect GNSS from harmful interference. The joint statement, in Appendix B, underscores the critical importance of protecting GNSS signals from harmful transmissions that could degrade, disrupt, or mislead their operation. The Organizations collectively call for stronger system resilience across sectors that depend on GNSS for , positioning, navigation and timing. They also emphasize the need to maintain conventional navigation infrastructure as a backup in the event of GNSS outages.

3.3.2 The statement highlights the urgency of developing effective mitigation strategies and fostering coordination among regulatory, aviation, maritime, defence and law enforcement authorities to address this global issue. It further encourages the prompt reporting of harmful interference affecting GNSS

to relevant radio regulatory, aeronautical and maritime authorities, as well as to the ITU Radiocommunication Bureau, to ensure effective monitoring and response.

3.3.3 A Memorandum of Cooperation (MoC) between ICAO and ITU was signed in 2012 for the enhanced cooperation on the protection of GNSS from harmful interference, with a potential impact of aviation safety. Its purpose was to benefit from potential synergies between the parties acting in their respective fields of responsibility and maximize the effectiveness of their joint efforts.

3.3.4 The reporting procedure outlined in the MoC has recently been improved, providing ICAO with access to ITU's Satellite Interference Reporting and Resolution System (SIRRS), to facilitate timely reporting and tracking of cases where an analysis would identify any significant impact on air navigation with an international scope. The SIRRS will also keep ICAO informed on the progress in applying the procedure outlined in Article 15, Section VI, of the Radio Regulations for cases of harmful interference to GNSS identified by ICAO. ICAO will also be notified as soon as the interference case is deemed resolved.

3.3.5 GNSS RFI occurrences should be reported to national radio regulatory authorities in accordance with the procedures laid out in the ITU Radio Regulations. For cases with cross-border impacts which cannot be resolved through such procedures, ICAO is developing guidance for regional reporting through SIRRS to ensure proper escalation. This guidance is scheduled to be finalized and disseminated by the fourth quarter of 2025.

3.4 Implementation package (iPack) for the mitigation of the impact of GNSS RFI

3.4.1 Stemming from Recommendation 2.2/2 of AN-Conf/14, ICAO has undertaken the development of a standardized iPack to mitigate GNSS RFI. The iPack will help States effectively manage GNSS RFI occurrences while ensuring uninterrupted, safe and efficient air navigation services. Based on existing guidance material from ICAO and other organizations, as well as best practices from different regions, the iPack will provide tailored solutions to address each State's unique challenges and needs. Through a combination of preventive and reactive measures, the iPack aims to minimize the likelihood and impact of GNSS RFI, ultimately strengthening the resilience of air navigation services.

3.4.2 The iPack will raise awareness of the effects of GNSS RFI on CNS/ATM systems, aviation operations and GNSS-based services. Through the provision of a risk mitigation framework that includes threat monitoring, risk assessment and the implementation of mitigation measures. Experts will work closely with States to provide hands-on support and guidance to develop essential policies, procedures and training requirements. The iPack will assist States in assessing their conventional navigation infrastructure, which will ensure a rationalized and efficient approach to right-sizing infrastructure. Upon its successful validation, the iPack implementation phase will be launched in the fourth quarter of 2025.

3.5 Other ICAO relevant activities

3.5.1 In response to the request made by the AN-Conf/14, through Recommendation 2.2/2, ICAO expert groups will continue assessing the impact of GNSS interference. This ongoing work focusses on identifying effective mitigation measures, the development of relevant guidance material, and the exchange of GNSS interference information. Moreover, it will involve enhancing civil-military coordination, particularly for cases where harmful interference to GNSS is caused or detected by military authorities.

4. MEDIUM- AND LONG-TERM ACTIONS

4.1 Positioning, navigation and timing (PNT) solutions

4.1.1 Assembly Resolution A41-8, Appendix C (Operative Clauses 1, 2, 3, 4, and 9), emphasizes the need for enhancing resilience to interference by maximizing the integration of all suitable ground infrastructure, space infrastructure and airborne components in a complementary and cooperative manner, to be as robust as possible to cases of satellite-based service disruption or environments where false or deceptive signals are present.

4.1.2 To deliver guiding principles to infrastructure providers, and ensuring that space-based, ground-based and airborne capabilities are provided efficiently, ICAO is working toward a concept of complementary PNT (C-PNT), which aims to improve multi-sensor integration. This will ensure that individual airborne systems cannot corrupt others; achieve a suitable balance between terrestrial, aircraft autonomous capabilities (inertial navigation system (INS) and other sensors) and space-based capabilities (legacy and dual-frequency multi-constellation (DFMC) GNSS); and facilitate multi-sensor integration and complementary performance monitoring to take the maximum advantage of all available sensors.

4.1.3 Additionally, C-PNT introduces the use of precise and GNSS independent time sources, enhancing the integrity of both air and ground systems by protecting them from corrupted time information when GNSS signals are compromised. For a seamless implementation, aircraft and avionics manufacturers must carry out the necessary upgrades, preventing the cross-contamination of avionics sensors caused by GNSS RFI. These ongoing actions for the C-PNT are expected be completed by 2030.

4.1.4 The successful development and implementation of C-PNT requires industry commitment and support: stakeholders must collaborate to secure the necessary resources. The industry must align their efforts with ICAO's initiative in developing solutions for C-PNT, by coordinating strategies, sharing expertise and investing in complementary solutions.

4.1.5 In the longer term, ICAO continues to study alternative PNT (A-PNT) solutions which are fully independent of GNSS. The A-PNT concept, currently under review by the relevant ICAO expert groups, may leverage methodologies such as advanced inertial navigation, terrain contour matching, star tracking and advanced magnetic navigation.

4.2 Resilient Navigation Operational Network

4.2.1 Recognizing the increasing occurrences of GNSS RFI and the envisaged increase of air traffic volume and complexity, there is a need to evolve the navigation minimal operational network (NAV MON) aviation system block upgrade navigation systems (ASBU NAVS) element to better support States in their transition from providing minimum navigational service levels to more resilient navigational services, ensuring operational safety and continuity during disruptions such as those cause by GNSS RFI.

4.2.2 To do so, ICAO is developing a resilient navigation operational network (RON) concept to provide guidance to States towards achieving a sustainable, cost-effective and appropriately-sized navigation capabilities network through the optimized deployment of terrestrial navigation aids based on traffic density, operational requirements and aircraft capabilities. The RON concept aims to better utilize combinations of available conventional terrestrial navigation aids (VOR, DME, ILS, NDB) to support GNSS reversion during GNSS RFI and other disruptions.

4.3 Dual Frequency Multiple Constellations (DFMC) GNSS

4.3.1 DFMC GNSS enhances global navigation by utilizing signals from multiple satellite constellations, such as GPS, Galileo, GLONASS, and BeiDou. This approach improves accuracy,

reliability, and resilience against interference compared to single-frequency systems. This will also help mitigate vulnerabilities in respect of RFI affecting a single frequency or constellation, ionospheric disturbances, and the risk of having insufficient satellites within a single constellation.

4.3.2 Although Amendment 93 to Annex 10, Volume I introduced provisions to support the implementation of DFMC GNSS, the timeline of industry developments suggests that the initial operational introduction of DFMC GNSS would begin to occur in the 2032 - 2035 timeframe. In the long term, it is expected that avionics capabilities will be available to enable the use of all DFMC GNSS elements and signals.

4.4 Galileo Open Service Navigation Message Authentication (Galileo OSNMA)

4.4.1 The European navigation satellite system Galileo is progressing towards the declaration of the Initial Service for Open Service Navigation Message Authentication (OSNMA). OSNMA will increase the resilience and robustness of Galileo service provision, ensuring that the received navigation message genuinely originates from Galileo satellites, as an additional security layer.

4.4.2 It is envisaged that the Standards and Recommended Practices (SARPs) for Galileo OSNMA navigation data authentication feature will be applicable in 2029. Furthermore, it is expected that Galileo authentication could be supported by a future generation of GNSS Receivers, together with authentication of satellite-based augmentation systems (SBAS).

4.5 GNSS interference monitoring

4.5.1 Many stakeholders have expressed the need for improved situational awareness of GNSS RFI impacted areas, both on the flight deck and in the air traffic control room. Currently ICAO expert groups are developing a concept of operation to outline how RFI monitoring capabilities, both in the short and long term, can better support operational decision-making by pilots and controllers. The goal is to help maintain safe and efficient air traffic management in an evolving GNSS RFI environment. In addition, the standardization of associated data exchange formats is also being considered.

4.6 SBAS Authentication

4.6.1 SBAS is used to enhance navigational accuracy by providing GNSS differential corrections and integrity monitoring. However, current SBAS signals are unencrypted and may be vulnerable to falsification. To address the safety risk of SBAS falsification, ICAO started the development of SARPs for SBAS Authentication in 2017. It is envisaged that the validation of the SARPs for the optional new authentication feature will be finalized in November 2027.

5. CONCLUSION

5.1 The recent and rapid rise in GNSS jamming and spoofing occurrences pose a challenge to the safety, efficiency and security of the air navigation system, given that GNSS is a crucial enabler for modern aviation services and technologies. In response, ICAO’s efforts and initiatives aim to provide further guidance to States and introduce new concepts to enhance the resilience of the air navigation system against GNSS disruption. States and industry should therefore align their efforts with ICAO’s initiatives by securing the necessary resources and remaining fully committed to advancing globally-agreed initiatives. Collaboration between ICAO, ITU and other relevant organizations should continue to prioritize the development of timely solutions for this significant concern.

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APPENDIX A

DRAFT RESOLUTION FOR ADOPTION BY THE 42ND SESSION OF THE ASSEMBLY

A42-X:	**Consolidated statement of continuing ICAO policies and practices related to a global air traffic management (ATM) system and communications, navigation, and surveillance/air traffic management (CNS/ATM) systems**

Whereas it is considered desirable to consolidate Assembly resolutions on the Organization's policies and practices related to CNS/ATM in order to facilitate their implementation and practical application by making their text more readily available and logically organized;

The Assembly:

1. *Resolves* that the Appendices attached to this resolution constitute the consolidated statement of continuing ICAO policies and practices related to CNS/ATM, as these policies exist at the close of the ~~41st~~ 42nd Session of the Assembly;

2. *Resolves* to continue to adopt, at each ordinary session of the Assembly for which a Technical Commission is established, a consolidated statement of continuing ICAO policies and practices related to CNS/ATM; and

3. *Declares* that this resolution supersedes ~~A35-15~~ A41-8.

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APPENDIX C

Ensuring the resilience of ICAO CNS/ATM systems and services

Whereas the CNS/ATM systems are evolving and so are the associated CNS threats and vulnerabilities;

Whereas the occurrences of interference against satellite-based CNS systems and global navigation satellite system (GNSS), in particular, have significantly increased;

Whereas CNS resiliency to interference needs to be addressed at a global level with a holistic approach, ensuring an efficient and coordinated evolution between the infrastructure architecture, improved technological capabilities, civil and military operational procedures, radio regulatory authorities and civil military coordination;

Recognizing that resiliency to interference needs to be improved by maximizing the integration of all suitable ground infrastructure, space infrastructure and airborne components in a complementary and cooperative manner, to be as robust as possible to cases of satellite-based service disruption or environments where false or deceptive signals are present;

Recognizing that both the aircraft on-board and ground infrastructure complementing the satellite-based CNS systems need to be adapted to include, where appropriate, interference detection, mitigation and reporting functions to support the resolution of operationally encountered performance anomalies;

Believing that, combined with the use of the appropriate legal framework, such capabilities and measures will allow for the relevant authorities to act upon harmful interferences caused by the illegal operation of transmitters and avoid the proliferation and the use of such illegal transmitters and the misuse of test and maintenance equipment;

Believing that, with appropriate coordination and application of best practices, military and State authorities can conduct GNSS-related testing and other interventions using radio equipment as necessary and without causing an undue impact on civil aviation;

Believing that civil-military coordination should facilitate the sharing of relevant information with airspace users, especially when flying in the vicinity of a conflict zone; and

Acknowledging that loss of crew's situational awareness from malicious origin is classified as a cybersecurity threat and cannot be tolerated in civil aviation; and that intentionally sending misleading signals to replace the accurate signal is a far more serious threat to flight safety than the loss of this signal.

The Assembly:

1. *Encourages* States to transition towards optimized, secure CNS systems based on complementary integration of suitable and independent aircraft capabilities, satellite- and ground-based infrastructure which maximize resiliency and robustness to any type of interference;

2. *Encourages* standardization bodies and industry to develop appropriate interference detection, mitigation and reporting capabilities for the aircraft on-board, satellite- and ground-based CNS system components, in order to ensure higher CNS resiliency, continuity of operations and prevent any cascading effects from the use of compromised position, velocity or time data;

3. Encourages States to ensure that ~~sufficient~~ resilient terrestrial CNS capabilities remain available to ~~ensure safe operations and~~ complement aircraft-level integration of position, ~~velocity~~ navigation and time (PNT) with independent surveillance information supporting resilient and safe operations;

4. *Invites* ICAO to develop high-level principles on how to integrate CNS ground, space and on-board systems and capabilities and evolve PNT solutions to obtain more resilient positioning and timing services;

5. *Encourages* standardization bodies and industry to collaborate with ICAO in advancing PNT solutions that align with ICAO initiatives;

~~5~~6. *Urges* States to apply necessary measures to avoid the commercialization/proliferation and the use of illegal transmitters such as jammers and the misuse of test and maintenance equipment which may impact CNS systems;

~~6~~7. *Urges* States to ensure close collaboration between aviation authorities, military authorities, service providers, radio regulatory and spectrum enforcement authorities to put in place any special measures required to ensure that the spectrum used by all CNS systems, and GNSS in particular, is free from harmful interference;

~~7~~8. *Urges* States to refrain from any form of jamming, or spoofing affecting civil aviation;

~~8~~9. *Urges* States to coordinate and notify to the maximum extent possible in advance with the air navigation services provider (ANSP) responsible for the affected airspace in case of military or other State-authorized security or defence-related operations or training, potentially causing any form of jamming, or spoofing affecting civil aviation; and

~~9~~10. *Urges* States and operators, when assessing the interference risks associated with conflict zones, to consider that the use of satellite-based CNS systems can potentially be impacted beyond those zones.

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APPENDIX B

JOINT ICAO/ITU STATEMENT ON PROTECTING GNSS FROM HARMFUL INTERFERENCE

Please refer to the *Joint ICAO, ITU and IMO Statement on Protecting GNSS from Harmful Interference* document on the Reference Documents page of the ICAO A42 public website.

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