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ORIGINAL ARTICLE

Impact of GNSS-Band Radio Interference on Operational Avionics

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Abstract

GNSS outages due to intentional jamming affecting the airspace over the Eastern Mediterranean have received significant attention in recent years. In an effort to better understand the phenomenon and its impact on aviation hardware, DLR sent a data collection flight to the area. The flight was conducted in an Airbus 320, which allowed a study of the behavior of regular avionics and aviation-grade GNSS receivers under jamming conditions. Part of the experimental instrumentation included a high-definition radio-frequency recording device, which allows in-depth pre-correlation analysis of the radio spectrum around the main GPS and Galileo carrier frequencies. The results confirm that the observed outages likely stem from man-made radio interference. They also provide an in-situ opportunity to study the behavior of commercial avionics under GNSS interference conditions.

1 | INTRODUCTION

It is a well-known and documented problem within the aviation community that outages in satellite navigation services make *performance-based navigation* (PBN) operations, as defined by ICAO (2008), using low *required navigation performance* (RNP) values impossible in various parts of the world (Berz, 2016). In these areas, Global Navigation Satellite System (GNSS) receivers do not always function as desired. *Radio-frequency interference* (RFI) has long been touted as the main reason for such outages in GNSS-based services, not only for aviation users but also for maritime applications (Pérez Marcos, et al., 2018).

Here, we summarize the findings of a test flight conducted specifically to assess the impact of the RFI on operational GNSS avionics' *multimode receivers* (MMR), such that the findings could be representative of a broader class of mainline passenger aircraft. The test flight included equipment to study the issue at different levels of abstraction: directly in the cockpit as observed by pilots in the operational environment, at the level of GNSS observables, and directly in the radio spectrum.

2 | EXPERIMENT DESIGN

One location that has reported difficulties with GNSS outages is the Nicosia Flight Information Region. The Department of Civil Aviation of the Republic

of Cyprus published a *Notice to Airmen* (NOTAM) stating, "GPS signal interruptions have been reported within Nicosia FIR. Pilots are requested to promptly report to Air Traffic Control (ATC) any GPS signal interruption experienced," (NOTAM A0211/20, 2020; see Figure 1). Outages of GNSS-based services are a hindrance to the efficient operation of the airspace and may prevent the implementation of PBN operations with low RNP values that cannot be achieved by classical hybridization of inertial measurements with ground-based navigation facilities.

To gain a better understanding of the effect these disruptions in GNSS-based services have on passenger aircraft, the German Aerospace Center (DLR), with support of EUROCONTROL and the DCA of Cyprus, flew its Airbus 320 test aircraft (registration D-ATRA) in the Nicosia Flight Information Region (FIR). Although D-ATRA features experimental flight-test installations in what would normally be the passenger cabin, its avionics are standard equipment for an A320. Similar to most modern transport aircraft, D-ATRA features two integrated Collins GLU920 MMRs for VHF Omnidirectional Ranging (VOR), Instrument Landing System (ILS), Distance Measuring Equipment (DME), and GPS. Each one of these primary MMRs is connected to one of two Rockwell Collins GNA-910 GPS L1 antennas. The effects of RFI on this MMR are somewhat specific to the aircraft type and design philosophy, but typical for large passenger aircraft.

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+  GPS SIGNAL INTERRUPTIONS HAVE BEEN REPORTED WITHIN NICOSIA FIR.
   PILOTS ARE REQUESTED TO PROMPTLY REPORT TO ATC ANY GPS SIGNAL
   INTERRUPTION EXPERIENCED.
   FROM: 11 FEB 2020 12:30    TO: PERM                          A0211/20
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FIGURE 1 Notice to Airmen (NOTAM) active for the Nicosia FIR on the day of the flight

FIGURE 2 The cockpit is connected to two primary GNSS antennas providing GPS-only L1 signals. The experimental equipment is connected to the experimental GNSS antenna and captures L1, L2, and L5 from GPS, GLONASS, and Galileo.

The experimental equipment in the cabin included a Collins GLU925 MMR and a Spirent GSS6450 I/Q radio frequency (RF) data recorder for inspection of the radio spectrum. The data recorder and the GLU925 were fed from an experimental ANTCOM 3GNSSA-XT-1 multiband GNSS antenna. This experimental antenna is a multi-band GNSS antenna installed on the upper side of the fuselage, behind the primary operational GNSS antennas as shown in Figure 2.

The signals at the L1 center frequency 1,575.42 MHz and the L5 center frequency 1,176.45 MHz were transformed to baseband and coherently sampled with 8-bit resolution and a 30.7-MHz sampling rate by the GSS6450. This allowed for a detailed analysis of the radio frequency spectrum in the frequency bands used by GNSS. The MMR in the experimental equipment granted access to more detailed measurements than the primary operational equipment allowed for. Most notably, this included quantities that potentially enable a detection capability of RFI events, such as readings of the *carrier-to-noise density ratio* (C/N_0) and measurements of individual pseudoranges and Doppler shifts.

2.1 | Flight Path

The test flight took place on February 13, 2020, taking off from Larnaca at 07:50 UTC and landing at 10:18 UTC back at Larnaca. The route of the flight, shown in Figure 3, initially went southeast towards waypoint APLON at Flight Level (FL) 300, turned east towards VELOX, then continued in northerly direction to DESPO and back to VELOX to enter a holding pattern there. After descending to FL210, we proceeded northeast towards ALSUS, then back westwards to enter holding at RUDER. In the hold, we descended to FL100 and, from there, continued toward Larnaca Airport (LCLK) conducting the VOR approach to Runway 04.

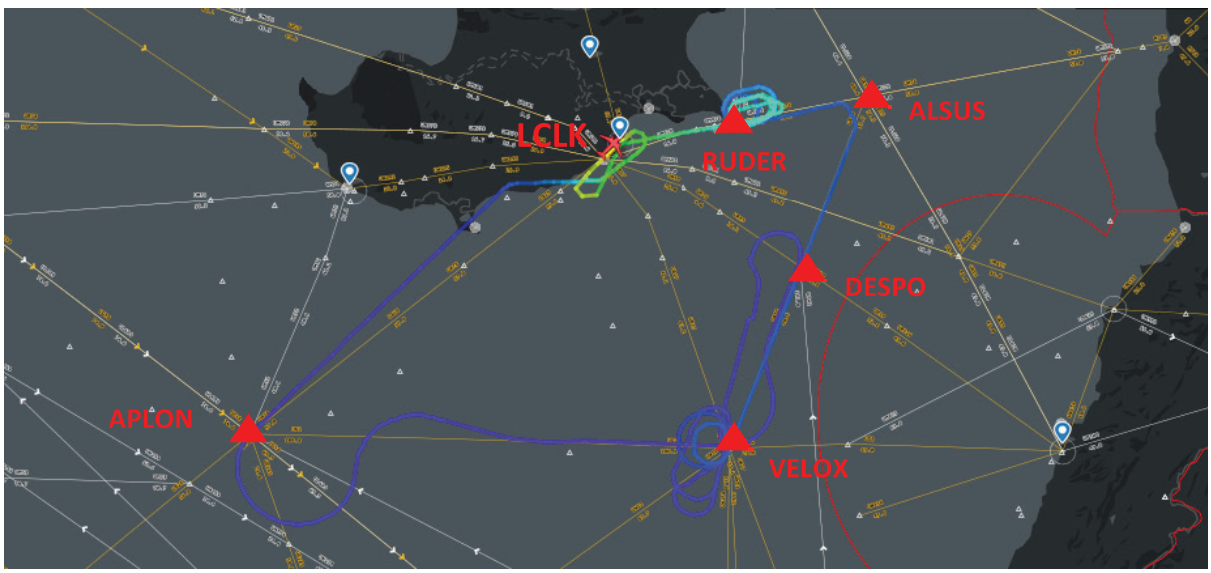

FIGURE 3 Trajectory of the measurement flight on February 13, 2020–the flight itself started and ended at Larnaca Airport (LCLK); we also indicate the waypoints of interest within the Nicosia FIR.

3 | RESULTS

The two types of equipment, experimental and operational, yield completely different insights. The observations in the cockpit are of interest for operational considerations, as there are lessons to be learned for future generations of avionics. By contrast, the response of the experimental MMR provides a more detailed view of the effects of RFI on hardware that is widespread in aircraft that operate in the very area where this RFI is being measured. Finally, we show the characteristic of the RFI signal in the time and frequency domain, which supports the claim that the disruptions to GNSS-based services stem from a man-made signal.

3.1 | Observations in the Cockpit

The loss of GPS navigation was not immediately apparent in the cockpit, as the aircraft coasted through GPS outages with its high-grade inertial reference systems. After approximately an hour of flying, which happened roughly at waypoint APLON (indicated in Figure 3) before turning toward waypoint VELOX to the East, both GPS receivers successively reported faults. These are shown in Figure 4 and indicate that the *actual navigation performance* (ANP) was greater than the RNP. At the same time, the primary flight display showed the message *GPS Primary Lost*.

For a pilot not explicitly looking for GPS interference, this would have been the first indication of a degraded navigation capability. A pilot actively looking out for RFI can have information displayed on the GPS status page of the multi-function control and display unit (MCDU), shown in Figure 5. This page is, however, not routinely monitored in regular commercial traffic.

FIGURE 4 *GPS 1 Fault* and *GPS 2 Fault* refer to the GPS part of the two MMRs that operate independently of each other as part of the standard A320 avionics in D-ATRA. The error message suggests that both GPS receivers have failed, when in reality, they are operational but no useful GPS signal is available to them.

FIGURE 5 When the number of available satellites drops below four, the receiver goes into *Aided Mode* in which navigation avionics use the inertial platform to coast the navigation solution as primary position and velocity.

3.2 | Experimental Multimode Receiver

The experimental MMR in the experimental racks (GLU925) is a newer generation of the primary MMR in the avionics bay (GLU920). The fundamental results will not change significantly, as the limitation in performance stems directly from the RFI signals. The experimental MMR provides the number of satellites tracked by the MMR and the C/N_0 estimate for each satellite.

In Figure 6, we show the number of GPS satellites tracked by the MMR for the entire flight. For most of the airborne time, fewer than four satellites were available to the MMR, making GPS unavailable. It should be noted, however, that the relatively short periods of GPS availability, visible in both graphs, were sufficient to recalibrate inertial systems, which in turn allowed the aircraft Flight Management System (FMS) to coast and continue providing navigation services.

The C/N_0 provided by the experimental MMR is visualized in Figure 7. Under nominal conditions, when the RFI does not affect the MMR, there is a spread of about 10 dB in C/N_0 between the best-received and the worst-received satellites. This is usually attributed to the fact that signals from satellites at different elevation angles experience different antenna gains and atmospheric effects. In Figure 7, it is evident that this condition is only given on the ground and at low altitudes, as it occurs only until shortly after take-off time (i.e., before 8:00 am) and before landing (i.e., after 10:00 am). Readers interested in the details of the antenna gain pattern on the experimental equipment may consult Caizzone et al. (2019).

Under RFI conditions, it is evident from Figure 7 that all satellites have degraded C/N_0. For some legs of the flight, this degradation leads to a loss of lock condition.

Notwithstanding, for some brief moments the experimental MMR is able to track satellite signals in flight and even compute GPS-based position solutions.

Overall, the experimental MMR was denied from computing a position solution for 80% of the experiment time; note that this includes taxiing, takeoff, and landing. The results in Figure 6 show the number of satellites available for a position solution for the entire flight route. At points with four or more available satellites,

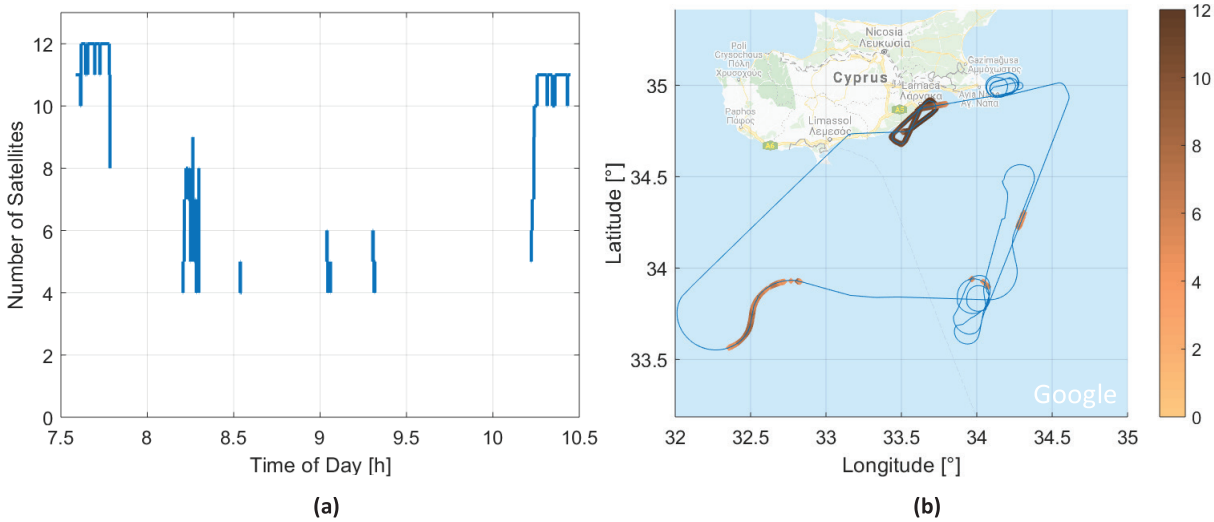

FIGURE 6 Number of satellites tracked by the experimental MMR: (a) shows the number over time, with higher numbers corresponding to taxiing, takeoff, and landing phases; and (b) shows the number along the flight path.

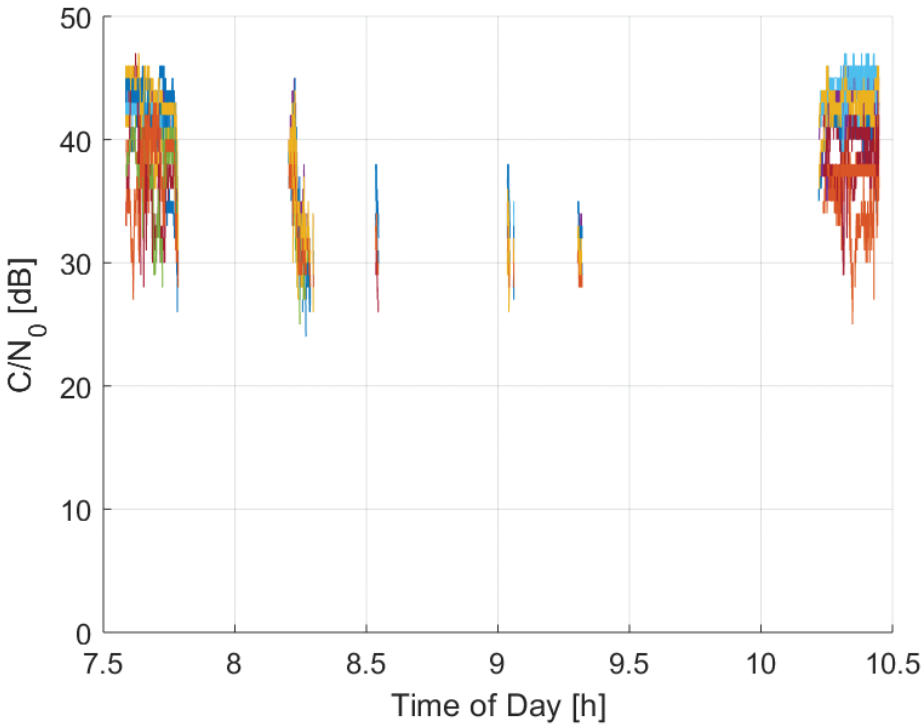

FIGURE 7 Carrier–to-noise ratio of the available satellite signals (gaps in the plot correspond to periods in which no satellites could be tracked at all due to the RFI)

the MMR computed the corresponding positions and the avionics were able to recalibrate the inertial sensors.

3.3 | Radio Spectrum

The graphic in Figure 8 is a spectrogram around the L1 and L5 center frequencies over a time period of 1.5 hours during the flight. The sampling time of the spectromgram was 10 s, in the sense that every 10 s, we computed the power spectral density over a Hamming window of 0.1 ms, for a total of over three million signal samples per epoch. In the L1 spectrum, we observed interference around the L1 center frequency, as well as 15 MHz above. The bandwidth of the interference at the center of the L1 frequency was 1 MHz. The averaged power ratio between the signal interference and the noise floor was 10 dB.

To better understand the time behavior of the RFI signal, we analyzed the signal in the L1 band over a shorter time. We computed the frequency with the maximum power spectral density over a few ms to better visualize the triangular frequency chirp, a telltale sign of intentional RFI. The excerpt in Figure 9 shows a section of 30 ms, starting at 09:00. The shape of the signal corresponds to a frequeny sweep with 1-MHz bandwidth and a period of approximately 1 ms. These parameters are very much in line with what can be expected from intentional, high-power RFI (Fernández Hernández, et al., 2019).

Another useful result of Figure 8 is that the interference signal shown has a peak power of at least 30 dB above the noise floor upon reception at the aircraft. This signal characteristic leads us to conclude that the RFI source could be a high-power interferer or J2, in the nomenclature of Fernández Hernández et al. (2019). This interpretation is also consistent with the observations reported in Murrian et al. (2019); the authors also provide a 95% confidence interval for the position of a J2

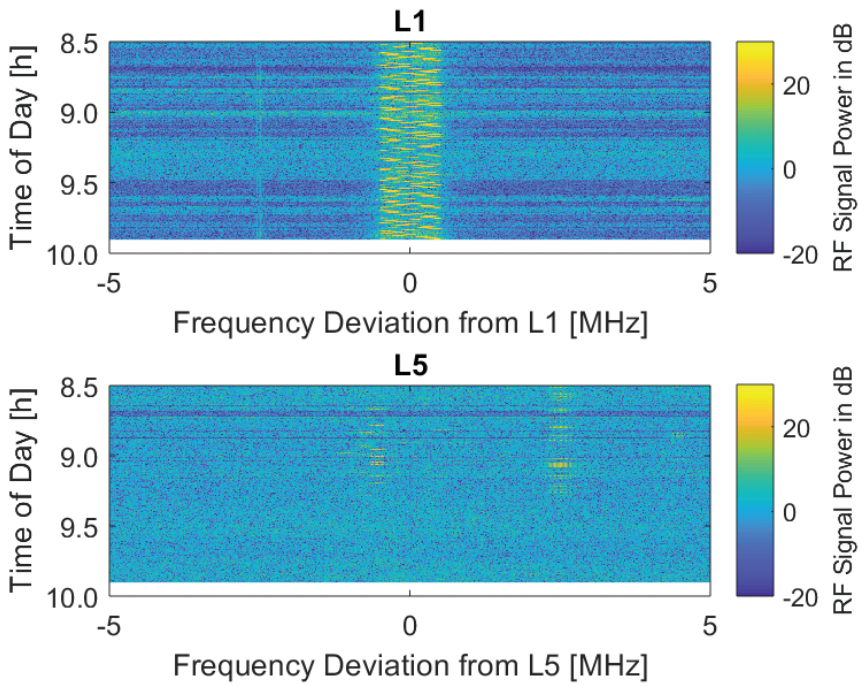

FIGURE 8 Waterfall diagram of L1 and L5 band during the flight–in the L1 band, the measurements show a sweeping behavior that is characteristic of intentional RFI. The signals in the L5 band likely stem from nearby terrestrial navigation aids, but show no sign of RFI.

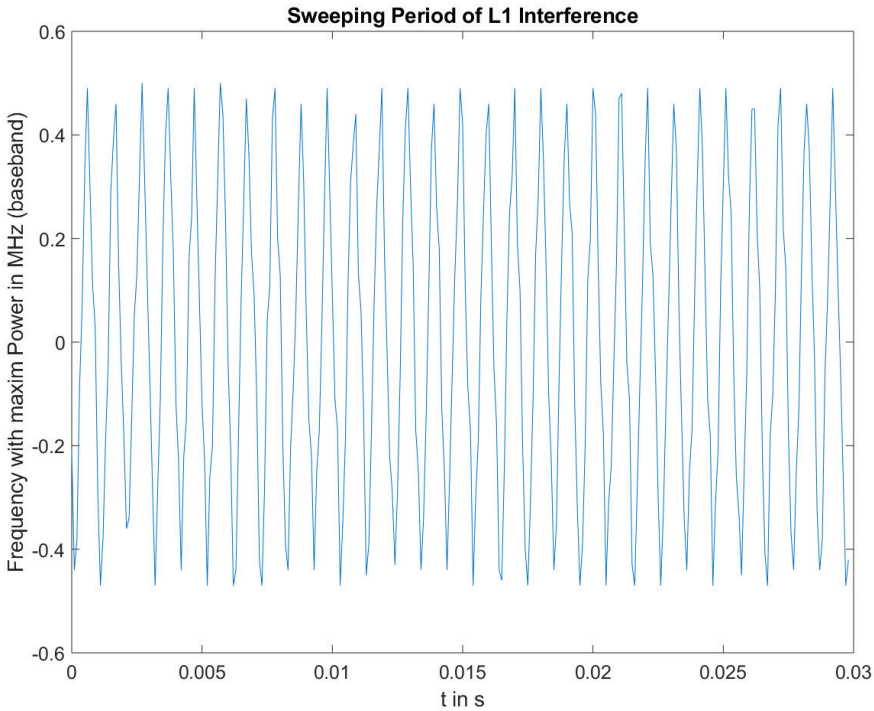

FIGURE 9 Time-domain behavior of the chirping signal at the L1 frequency; this type of triangle-wave frequency chirp is expected behavior for a high-power RFI source.

jammer that is consistent with the observations in this paper. Note that no significant interference signal appears in the L5 band.

4 | DISCUSSION

An immediate consequence of RFI in the Nicosia FIR is that GPS-based services are unavailable to aviation users. In particular, this applies to *performance-based navigation* (PBN), a class of services that aims to modernize air-traffic operations. While some PBN service types can continue operating during RFI by resorting to ground-based navigation infrastructure and inertial sensors, PBN operations with low RNP values can suffer timeouts if inertial sensor data are fused with GPS measurements. PBN operations that rely entirely on GPS (Localizer Performance with Vertical Guidance GPS Landing System) become unavailable. Furthermore, the Automatic Dependent Surveillance – Broadcast (ADS-B) functionality may be limited when integrity on the transmitted position information cannot be guaranteed, which is the case if GNSS is unavailable.

In practice, this means that aircraft need to accommodate greater safety margins, thus forcing greater separation between aircraft on adjacent routes. The lack of low RNP impacts the capacity of the airspace, as well as its operational efficiency (Aviation Intelligence Unit, 2021).

From an operational perspective, it is, of course, desirable to continue providing navigation services during GNSS outages. This type of service is commonly referred to as *alternative position, navigation, and timing* (APNT). The conventional view that APNT services are to bridge short-term outages is consistent with sparse, infrequent events of low-power, local RFI as described by Pullen and Gao (2012). Instead, our results show that APNT systems will likely be required to provide long-term, or even permanent, services to aviation users in some parts of the world.

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REFERENCES

Aviation Intelligence Unit. (2021). *Does radio frequency interference to satellite navigation pose an increasing threat to network efficiency, cost-effectiveness and ultimately safety?* EUROCONTROL. https://www.eurocontrol.int/sites/default/files/2021-03/eurocontrol-think-paper-9-radio-frequency-intereference-satellite-navigation.pdf

Berz, G. (2016). *ICAO GNSS RFI Mitigation Plan and associated EUROCONTROL Efforts.* Sochi: United Nations ICG. https://www.unoosa.org/pdf/icg/2016/icg11/wgs/6.pdf

Berz, G. (2019). Complementary terrestrial capabilities or "when things go wrong." *2019 EUROCAE Symposium and 56th General Assembly*, Toulouse, France, 243–249. European Organization for Civil Aviation Equipment.

Caizzone, S., Circiu, M.-S., Elmarissi, W., Enneking, C., Felux, M., & Yinusa, K. (2019). Antenna influence on Global Navigation Satellite System pseudorange performance for future aeronautics multifrequency standardization. *NAVIGATION, 66*(1), 99–116. https://www.ion.org/publications/abstract.cfm?articleID=102786

Fernández-Hernández, I., Walter, T., Alexander, K., Clark, B., Châtre, E., Hegarty, C., Appel, M., & Meurer, M. (2019). Increasing international civil aviation resilience: A proposal for nomenclature, categorization and treatment of new interference threats. *Proc. of the 2019 International Technical Meeting of the Institute of Navigation,* Reston, VA, 389–407. https://www.ion.org/publications/abstract.cfm?articleID=16699

ICAO. (2008). *Performance-based navigation (PBN) manual.* International Civil Aviation Organization.

Murrian, M. J., Narula, L., & Humphreys, T. E. (2019). Characterizing terrestrial GNSS interference from low Earth orbit. *Proc. of the 32nd International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2019)*, Miami, FL, 3239–3253. https://www.ion.org/publications/abstract.cfm?articleID=17065

Pérez Marcos, E., Konovaltsev, A., Caizzone, S., Cuntz, M., Yinusa, K., Elmarissi, W., & Meurer, M. (2018). Interference and spoofing detection for GNSS maritime applications using direction of arrival measurements and a conformal antenna array. *Proc. of the 31st International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2018),* Miami, FL, 2907–2922. https://www.ion.org/publications/abstract.cfm?articleID=15901

Pullen, S., & Gao, G. (2012). GNSS jamming in the name of privacy: Potential threat to GPS aviation. *Inside GNSS*. https://insidegnss.com/gnss-jamming-in-the-name-of-privacy/

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