Issues in Information Systems
Volume 23, Issue 1, pp. 190-203, 2022

DOI: https://doi.org/10.48009/1_iis_2022_115

The effects of 5G implementation on the aspects of sustainability in the air transportation industry

Douglas Ashlock, *Embry Riddle Aeronautical University, ashlockd@my.erau.edu*
Lucy Elias, *Embry Riddle Aeronautical University,* ELIASL@my.erau.edu
Hannah Puchkoris, *Embry Riddle Aeronautical University, puchkorh@my.erau.edu*
Anthony Williams, *Embry Riddle Aeronautical University, willa141@my.erau.edu*
Leila Halawi, *Embry Riddle Aeronautical University, halawil@erau.edu*

Abstract

The concern of 5G C-band frequency interference with global aviation operations was founded on the criticality of a single-point failure with the radio altimeter operations. The research in this report intends to highlight the severe impact of 5G C-band implementation on the air transportation industry.
It focuses on one airport in the United States, Seattle-Tacoma International Airport (SEA), one of the busiest airports in the country, flying both domestically and internationally. The results show that Boeing aircraft are affected more than Airbus for 5G interference. Further, the findings show that the United States should align its 5G implementation with other countries, such as Australia, Canada, the Czech Republic, France, Japan, South Korea, and the United Kingdom.

Keywords: 5G, C-band frequency, aviation, and airlines operations

Introduction

The launch of new 5G cell phone service towers has caused much controversy between telecommunication companies and the aviation industry (Chow, 2022). The frequencies sent out by the 5G towers fall within the specific C-band part of the radio spectrum, threatening to potentially affect the airwaves currently dedicated to aviation operations (Chow, 2022). According to the Federal Aviation Administration (FAA), these radio airwaves sent out by the 5G towers could seep into the C-band used during aviation operations and confuse those involved (2022a). This could cause the grounding of commercial aircraft, leading to shipping and travel delays, or cause aircraft to reroute to different airports, impacting the daily operations of major hubs (Shepardson, 2022). The aviation industry is responsible for transporting food and medical supplies, increasing employment, driving economic growth, personal and business travel, and many other factors moving the globe towards sustainable development (Air Transport Action Group, 2022). 5G technology could threaten the aviation industry, complicating low-visibility landings during the descent into specific airports and potentially causing effects on major hubs and their surrounding communities. Any threat to the aviation industry is a potential threat to sustainable development.

The operational effect 5G has on all air carriers has an impact that can draw down revenue and increase operational costs with the possible increase in fuel (Shepardson, 2022). The FAA requires a specific amount of fuel to land at the scheduled destination and proceed to an alternate airport if needed. The FAA issued a procedure for air carriers to follow until the issue is finally resolved or determined there is less risk with the possibility of interference while conducting low visibility approaches into specific airports (Ma, Wei, & Zhou, 2021). The increased fuel needed to reach a non-standard distance per the regulations directly impacts an increase in flight time, impacting the required fuel.

The research in this report intends to highlight the severe impact of 5G C-band implementation on the air transportation industry. The study aims to harmonize the actions of the Federal Communications Commission (FCC), Federal Aviation Administration (FAA), Radio Technical Commission for Aeronautics (RTCA), National Telecommunications and Information Administration (NTIA), aircraft manufacturers and Original Equipment Manufacturers (O.E.M.s), among others in addressing the need to improve network telecommunication systems on the ground without sacrificing safety in the air.

Overview of the 5G Technology Problem

Whether for delivery of basic needs, tourism, family connections, or business travel, the world relies on aviation to stay connected. This dependence can be more so for some economies, such as small island developing states, which can attribute approximately 25% of economic growth to tourist spending (Cannonier & Burke, 2019). Tourism is a significant source of external income in many developing countries compared to other economies (Cannonier & Burke, 2019). These dependencies on aviation illustrate a clear need to promote safe and efficient air travel to and from these tourist destinations. While tourism, particularly to these small island developing states, is heavily influenced by the aviation industry, each reason for choosing aviation as a travel or shipping solution will have an equally important explanation as to why it depends so heavily on air transportation.

Past research has proven the implementation of 5G is beneficial for several Sustainable Development Goals (SDGs) in some transportation industry sectors; however, 5G is wreaking havoc across the aviation sector (GACA Saudi Arabia, 2021). One such study that promotes 5G for the transportation industry is conducted by Cavalli et al. (2021), which indicates that 5G is one critical piece in expanding maritime ports to be competitive in the future. While Cavalli et al. (2021) are adamant that 5G will help make maritime ports more sustainable in the future, The General Authority of Civil Aviation (GACA) Saudi Arabia (2021) indicates a drastically different outcome in the aviation industry.

The C-band of 5G directly impacted flight safety for air travel operations using radio (or radar) altimeters (GACA Saudi Arabia, 2021). Aircraft systems that rely on these radio altimeters, such as terrain awareness and warning systems (TAWS), autopilot, and auto-throttle, can receive erroneous information from the radio altimeter because of interference from 5G cell towers or other emanating sources (GACA Saudi Arabia, 2021). The criticality of the radio altimeter for all phases of flight is so great that it is deemed critical equipment for every stage of flight. Without the radio altimeter, pilots and crew must fly the airplane by hand without the added safety systems, like the TAWS and auto-throttle (GACA Saudi Arabia, 2021). Many air agencies, such as the FAA, require a radio altimeter to fly low visibility approaches because of the data it provides to the safety systems; without this equipment, these low visibility approaches are rendered unsafe and dangerous (Appendix A to Part 91, 2022; GACA Saudi Arabia, 2021). The added danger will require the pilot and crew to wait for better weather or divert to an alternate airport (GACA Saudi Arabia, 2021). This will require the air agencies to have enough contingency fuel to plan for these delays, which consumes a significant amount of fuel and generates more greenhouse gasses (GHG).

The problem with 5G telecommunications technology stems from the conflict with radio altimeters, ground proximity warning systems, and Doppler radars. Doppler radar sites operating in the 4-8 GHz range are used for wind-shear detection, particularly in the vicinity of airports (Dunbar, 1992; Radar Bands, 2000). While this technology has been in place since 1994, a 1988 mandate required it to be in aircraft to avoid the catastrophic loss of life and property due to wind shear that has plagued aviation throughout its history (Dunbar, 1992). Radio altimeters operate in frequency ranges of 4.2-4.4 GHz and are required for all auto-land operations in aircraft. Category III instrument approaches and most Category II (Problem statement - 5G interference with radar altimeter frequency band, 2020). The United States allows for limited Category II instrument approaches without using a radio altimeter.

In contrast, Europe does not allow it (Problem statement - 5G interference with radar altimeter frequency band, 2020). Radio altimeters are also used for ground proximity warning systems, failure of which would also cause a catastrophic loss of life and property by impacting terrain in controlled flight into terrain (CFIT). The 5G telecommunications industry risks frequency "bleeds," where one frequency interferes with its neighboring frequency. The 5G telecommunication frequency bleeds into radio altimeter and Doppler radar frequency ranges, which would cause interference with all associated systems. The International Civil Aviation Organization shows that a deliberate interference test confirmed these concepts (*Problem statement - 5G interference with radar altimeter frequency band*, 2020).

Previous Research Regarding 5G and its Effect on Aviation

In March 2018, the 115th US Congress approved the Mobile Now Act, "allowing commercial wireless services, licensed or unlicensed, to use or share use of the frequencies between 3700 megahertz and 4200 megahertz" (Airlines for America, n.d., p.1. This prompted the Federal Communications Commission (FCC) to release public information for scrutiny. A month later, Airlines for America identified aviation safety risks. They stated that satellite communication and "radio altimeters cannot be relied upon to perform their intended function if they experience interference from wireless broadband operations in the 3.7-3.98 GHz frequency band" (Airlines for America, n.d., p.1). Despite the risks identified, the FCC proceeded to release the order and notice to expand the use of 3.7-3.98 GHz frequency (De Fazio, 2022, p.2). With this action, Aviation Spectrum Resources, Inc. (ASRI) responded to the FCC in October 2018, emphasizing the potential impact on radio altimeter and SATCOM, which supported the claim of Airlines for America (De Fazio, 2022, p.3).

Eighteen months after the enactment of the Mobile Now Act, the Federal Aviation Administration (FAA) publicly advised Interdepartmental Radio Advisory Committee (IRAC) to notify NTIA about the uncertainty with the "auction of the spectrum adjacent to aviation band" and the results of the assessment performed by Aerospace Vehicle Systems Institute on its impact on different altimeters (De Fazio, 2022, p.2). The Aerospace Vehicle Systems Institute (AVSI) also replied to the FCC, stressing the same findings. In November 2019, the FCC announced its plan for a public auction of the C-Band next to the aviation band, despite detrimental risks identified impacting some aviation safety equipment. Following its announcement, the House Transportation and Infrastructure (T&I) Committee Chair Peter De Fazio and the Aviation Industry Coalition warned the FCC of the safety concerns regarding radio altimeters with implementing the C-band. Still, in February 2020, the FCC continued to issue its order for the "C-band auctioning" (Airlines for America, n.d., p.1). Despite the six-month risk assessment done by the Radio Technical Commission for Aeronautics (RTCA), there were many appeals from the Aviation Industry Coalition and the Department of Transportation (DOT). The Federal Aviation Administration (FAA), the FCC, began its public auction on December 8, 2020, gaining $81 billion in revenue and later awarded to Verizon and AT&T (De Fazio, 2022, p.2).

On March 25, 2021, ICAO confirmed results from member states' studies and aviation organizations indicating that "if high power cellular systems are implemented near the frequency band used by altimeters," some radio altimeters will be affected by the 5G C-Band Spectrum implementation. This will call for a joint resolution to ensure continued airworthiness (GACA Saudi Arabia, 2021, p.11). Also, it was mentioned that the 5G C-band spectrum frequency would affect "more than 30,000 aircraft to retrofit

(Airbus and Boeing) sharing same manufacturers of RADALT," which will require several years to implement (GACA Saudi Arabia, 2021, p.10). For the past three years, safety risks have been constantly identified. The aviation sector repeatedly requested postponement of implementation until appropriate safety measures and solutions are determined first, before 5G C-band spectrum deployment (Airlines for America, n.d., p.1).

From the Subcommittee Hearing on "Finding the Right Frequency: 5G Deployment and Aviation Safety" document, Verizon and AT&T declared through the wireless industry trade association, CTIA, on December 22, 2021, an agreement to share confidential technical data between CTIA, AIA, and A4A, to accurately perform a safety risk assessment and management and work with FAA to identify next course of actions. Following this announcement, the FAA continued to release a series of Airworthiness Directives (AD), Special Airworthiness Information Bulletin (SAIB), Safety Alert for Operators, and Notice to Air Missions (NOTAM) (De Fazio, 2022, p. 4).

Countries like Australia, France, Japan, South Korea, and the United Kingdom with 5G implementation use considerably lower power levels than the United States. They have imposed safety management strategies upon 5G implementation to prevent interference, such as "5G antennas' angle requirements or expansive exclusion zones near airports" (De Fazio, 2022, p.8).

Table 1: *5G* Implementation and Power Level Comparison of Other Countries vs. the United States

Region/Country	5G Frequency Operation	Power Level Comparison with the United States
United Kingdom	"…operating below 3.8 GHz pose a viable interference threat to radio altimeters. The UK CAA also stated that lower power levels in the 3.8–4.195 GHz range may be an issue for helicopters, especially those used for emergency services."	62% lower in frequency ranges 3.4–3.8 GHz 99% lower in frequency ranges 3.805–4.195 GHz
Other European Countries (ex. France, Czech Republic)	Uses a 3.4–3.8 GHz band for 5G in Europe, but "there is a separation of an additional 100 MHz more than what will be provided in the US, reducing the risk of potential interference." With established exclusion zones	23% less

Table 1 (Continued)

Australia	"Compared to Europe and the United States, Australia operates farther away from the radio frequency band used by the radio altimeter."	76% lower
Japan	Up to 4.1 GHz	At least 90% lower
Canada	With 5G restriction around airports, establishing "exclusion zones" (outdoor 5G base stations not permitted to operate; indoor 5G operations allowed) and "protection zones" (5G operations allowed, with restricted power) 5G antennas tilted down to prevent interference with radio altimeters	At least 90% lower
South Korea	3.42–3.7 GHz	95% less

Based on the Subcommittee Hearing on "Finding the Right Frequency: 5G Deployment and Aviation Safety" document, it was on January 3, 2022, when Verizon, AT&T, and the FAA agreed to postpone the 5G Band implementation for a comprehensive assessment on the impact of 5G signals in terms of location and power output, based on the following parameters: traffic volume, low visibility days, exclusion zones and diversion locations (De Fazio, 2022, p.6). On January 18, 2022, Verizon and AT&T expanded "exclusion zones that prohibit 5G deployment within at least two 42 miles of runways at all 87 airports affected by F.A.A. NOTAMs" (De Fazio, 2022, p.6).

Relations, Contradictions, Gaps, and Inconsistencies in Previous Literature

All around the world, people are constantly connected via electronic devices. As the demand for these devices rapidly increases, cellular mobile connection companies find ways to meet these higher requirements and provide faster, more efficient service to their customers. The most recent solution is fifth-generation (5G) cellular networks. While 5G cellular networks seem like a great solution to increase the efficiency of networks, it has created a very controversial situation for the aviation industry. As mentioned in the section regarding previous research, there is an extensive history between the aviation industry and the cellular mobile companies regarding the implementation and use of 5G networks. Shaik and Malik (2021), The Radio Technical Commission for Aeronautics (2020), the US Department of Commerce (2016), Denton (2022), and the Federal Aviation Administration (2021) have addressed essential topics regarding 5G implementation and the effects on the aviation industry. Topics included the appropriate C-band frequency ranges, the distance required between 5G towers and airports, the impact of canceled and rerouted flights, and the different approaches other countries took to successfully implement 5G without affecting aviation.

C-Band Frequency Ranges

The C-Band frequency is e valuable for the mobile cellular industry (Kelleher, 2022). It's considered the sweet spot or "Goldilocks frequency" that delivers extremely fast and efficient network coverage (Kelleher, 2022). However, this has brought up issues for the aviation industry as the aircraft radio altimeters also operate on C-Band frequencies (Kelleher, 2022). These C-Band frequencies are critical for low-visibility landings, especially in inclement weather (Kelleher, 2022). According to Shaik and Malik (2021), the C-Band frequency waveband ranges between 3 GHz and 300 GHz for high-frequency bandwidth (2021). Shaik and Malik's study also states that the spectrum band of 57 GHz – 64 GHz and 164 GHz – 200 GHz is not suitable for communication systems used in military, radar, and airports (2021). Besides these frequencies, the wave band would be available for 5G communication systems; they need to be careful not to interfere with other vital systems like aviation operations (Shaik & Malik, 2021). The Radio Technical Commission for Aeronautics (RTCA) states that using 5G communications in the 3.7 GHz – 3.98 GHz band will cause harmful interference to radar altimeters used in aviation operations (2020). The United States Frequency Allocation chart for radio spectrums shows that aeronautical frequencies are between 4.2 and 4.4 GHz (US Department of Commerce, 2016). The Federal Aviation Administration (FAA) released a statement concurring with both assessments. There is no evidence that radio altimeters are not susceptible to interference caused by C-Band emissions permitted in the US (2021). Alternatively, Europe has rolled out 5G with no adverse effects on the aviation industry. Denton states that instead of the United States' use of the 3.7 – 3.98 GHz range, Europe has allocated the 3.4 – 3.8 GHz range, further away from the 4.2 – 4.4 GHz range that aviation operations use (2022). These data points leave room for future research regarding the solidified frequency range for 5G.

Buffer Zones Between 5G Towers and Airports

5G towers are installed and used to get ultra-fast mobile networking to worldwide customers who have access to it (McCaskill, 2021). While this may seem normal to most mobile phone users, most are unaware that these towers could potentially cause detrimental effects on aviation operations. Previous literature found that, for now, the best frequency range for 5G to operate on is 3.7 GHz – 3.98 GHz since aviation operations commonly occur between 4.2 GHz and 4.4 GHz (RTCA, 2020). However, there is still a chance that C-Band emissions from 5G could bleed over into the frequency that aviation uses and cause interference. The Federal Aviation Administration has released plans to approve only several airports where 5G frequencies reach to perform low-visibility landings (FAA, 2022b). As of January 2022, the FAA approved roughly 62% of the US commercial fleet to perform low-visibility landings at airports where 5G C-bands are active (2022b). The FAA felt this was the best way to avoid interference from 5G in aviation operations. Alternatively, airlines have asked for the safest option to prevent interference instead of limiting landings, including a 2-mile buffer zone around airports that excluded the frequencies used for 5G (Staff Reporter, 2022). According to the FAA, 50 airports in the United States have since implemented 5G buffers, delaying the 5G rollout (2022b).

On the other hand, mobile communications providers argue that other countries, including Europe, have successfully rolled out 5G operations near airports without adverse effects, so the United States should do the same (Koenig, 2022). In France, instead of just providing buffer zones where 5G is excluded around airports, the National Frequency Agency (ANFR) suggests that the angle or position of the radio altimeters can make a huge difference when it comes to interfering with aviation operations (n.d.). While, ultimately, US mobile providers are allowing a buffer zone on airports for six months to allow airports and airlines to prepare for the launch of 5G, there is still much research to be done regarding what will happen when 5G is implemented (Cellular Telecommunications Industry Association, 2022).

The Effects of Canceled and Rerouted Flights on Sustainability

The aviation and aerospace industry is responsible for connecting people worldwide. It is a large driver of the economy and has significant social effects. With the impending rollout of 5G in the United States, airlines and aviation organizations are concerned that interference in aviation operations could cause flight cancellations, delays, or reroutes, significantly impacting social and economic sustainability (Fox, 2022). Airlines for America released a statement saying there is an impending need to reroute or cancel thousands of airline flights which would, in turn, displace millions of passengers and aircraft crews and delay delivery times of shipments – especially critical ones like COVID-19 tests and vaccines (2021). Airlines for America also predicts an economic loss of more than $1 billion due to the inability to properly operate aircraft radio altimeters from possible 5G interference (2021). Other international airlines seem to have similar concerns despite the success of 5G worldwide and have canceled or rerouted flights (Fox, 2022). Since the aviation and aerospace industry plays a role in 15 of the 17 Sustainable Development Goals (SDGs), it is essential that further research is done regarding the actual need for flight cancellations and reroutes in the United States to ensure that aviation operations remain on schedule.

Methodology

The implementation of 5G frequencies and the proximity of the associated towers to aviation operations are disrupting the air transportation industry. As government agencies, cellular communication companies, and airlines all work together to determine a solution to this disruption, customers and the sustainability guidance of the SDGs suffer. This study focused on one airport in the United States, Seattle-Tacoma International Airport (SEA), one of the busiest airports in the country, flying both domestically and internationally. SEA was chosen because of the lower vis approaches that are conducted versus the other airports and the amount of CAT 2 and CAT 3 approaches conducted there outweighs the amount at other airports. 5G technology will be introduced into the community surrounding the airport.

The towers pose a potential threat to aviation operations at the airport due to C-Band frequencies bleeding over and interrupting air traffic control communication and landings. Once the 5G technology is present, low-visibility landings will be monitored to determine how often C-band bleeding is occurring and causing issues with aviation-related communication at the airport. The problems addressed were confusion with communication, rerouted flights, and flight cancellations.

All data used in this study were extracted from multiple sources. For the number of operational aircraft, data was retrieved from airfleets.net. Additionally, the researchers counted the flight delays manually for 03-05 March 2022. Additional Data were retrieved from the webpage of the airport dashboard on flight arrivals. The probability of aviation issues relating to the presence of 5G towers was used to predict the occurrence rates in other airports with similar fleet sizes, passenger numbers, and surrounding communities. Chi-Square Test and Two-Sample Poisson Rates using Minitab Software determined the significance of the relationship between the airport selected with 5G implementation and low visibility approaches, aircraft type, flight cancellations, and/or re-routings. The Chi-Square test helped establish whether the factors identified are statistically independent or dependent. The variables for the first hypothesis included nb. of affected AC Type Airbus and Boeing and affected aircraft systems. For the second hypothesis, data included power level, positioning of 5G antenna, and identification of exclusion zones among seven countries.

Two-Sample Poisson Rates can also determine whether the occurrence rate differs significantly upon comparing the usual number of flights in SEA for seven airlines and the number of canceled flights in SEA and aircraft type swapping to address the 5G C-band interference.

The research hypotheses are as follows:
H1- No statistical difference exists between 2 major aircraft manufacturers affected by 5G implementation.
H2- At least one sampled country has different parameters for 5G implementation.
H3- The probability that the occurrence rate differs significantly upon comparing the normal number of flights in SEA for seven airlines and the number of canceled flights or aircraft types swapped.

Results

From the document released by the Federal Register on February 24, 2022, RTCA Paper No. 274-20/PMC-2073 dated October 7, 2020, and on the Federal Aviation Administration website, Boeing aircraft systems are much more affected than Airbus aircraft. Looking into Figure 1, H1 was supported since the p-value is less than 0.05. There is a statistical difference between the two major aircraft manufacturers affected by the 5G implementation that will require the following: "specific operating procedures for landing distance calculations, ILS (and GLS if installed) approaches, speed brake deployment, go-arounds, and missed approaches, when in the presence of 5G C-Band interference as identified by NOTAMs" (Gant, L., 2022, p. 7). This also suggests that the compliance cost for Aircraft Flight Manual (AFM) revision, which is approximately $207,570, will be at the expense of the aircraft operators. This is in addition to fuel requirements and maintenance-related tasks to ensure the airworthiness of the aircraft and improve telecommunications for the public through the implementation of 5G, in response to SDG number 9: industry, innovation, and infrastructure (Gant, L., 2022. p.10).

Chi-Square	No. of Affected AC Type-Airbus	No. of Affected AC Type-Boeing	All
Autopilot Flight Director System	10 8.750	4 5.250	14
Autothrottle	10 8.750	4 5.250	14
Flight Controls	0 2.500	4 1.500	4
Flight Instruments	10 8.750	4 5.250	14
TCAS	10 8.750	4 5.250	14
Configuration Warning	0 2.500	4 1.500	4
All	24	40	64
Pearson Chi-Square= 15.236, DF= 5, P-Value= 0.008 Likelihood Ratio Chi-Square = 17.674, DF=5, P-Value = 0.003			

Figure 1. Determinants for Identifying 5G Implementation Impact by Aircraft Manufacturer

Given the limited availability of data released to the public, the research findings in determining the possible resolutions towards the impact of 5G implementation in aviation supported the claim that it has a direct impact on the United States and poses a safety concern for the FAA. Data reveal that the United States should align its course of action with the 5G implementation process of the countries sampled in this study: Australia, Canada, the Czech Republic, France, Japan, South Korea, and the United Kingdom. The Chi-Square Test in Figure 2 with a p-value greater than 0.05 shows no statistical difference in the parameters set in the 5G implementation of those sampled countries. This supports H2 and the claim that the United States must follow its best practices regarding 5G power level, tilted positioning of antenna, and establishing exclusion zones. In contrast, long-term aircraft retrofit solutions will take years to implement (Furchtgott-Roth, 2021).

Chi-Square	Lower Power Level	Titled Antenna	Exclusion Zones	All
Yes	7 5.333	4 5.333	5 5.333	16
Not Stated	0 1.667	3 1.667	2 1.667	5
All	7	7	7	21
Cell Contents	Count Expected Count			
Pearson Chi-Square= 3.675, DF= 2, P-Value= 0.159 Likelihood Ratio Chi-Square = 5.116, DF=2, P-Value = 0.077				

Figure 2. Determinants for Identifying Differences Among Other Countries with 5G Implementation

Additionally, for hypothesis 3, as shown in Figure 3, there is no significant evidence to suggest that the normal number of arrival flights in SEA for seven airlines and either the number of canceled arrival flights in SEA or aircraft type swapping by the airlines have caused significant disruptions in airline operations last January 2022. This points to the need for further in-depth joint assessments and publicly sharing information between regulators, aircraft manufacturers, Original Equipment Manufacturers (O.E.M.), and telecommunication companies.

Two-Sample Poisson Rates: Normal No. of Flights SEA, FLTS Canceled-SEA r AC Swapped			
Variable	Total Occurrences	N	Rate of Occurrence
Normal No. of Flights SEA	42	8	5.25
Fits Canceled-SEA or AC Swapped	30	8	3.75
Difference = rate (normal No. of Flights SEA) – rate (Flights Canceled-SEA or AC Swapped) Estimate for Difference: 1.5 95% CI for difference: (-0.578856, 3.57886) Test for Difference = 0 (vs # 0): Z = 1.41 P-Value = 0.157 Exact Test: P-Value = 0.195			

Figure 3. Major Disruptions in SEA airline operations

Conclusion and Recommendations

In conclusion, sustainability is when the current generation acts in a way that meets their own needs while preserving resources and not compromising the ability of future generations to meet their own needs (the University of Alberta, n.d. This study focused on a potential threat to the aviation industry's commitment to advancing the SDGs and reaching their sustainability goals: implementing 5G technology. The concern was that 5G technology near airports would cause C-Band frequency bleeding that would affect aviation and aerospace operations, potentially jeopardizing the safety of passengers, crew, and those on the ground by complicating low-visibility landings into said airports. This could lead to flight cancelation or rerouting and significantly affect the surrounding community. The delivery of goods may be delayed causing passengers to drive further for drop-offs and pick-ups, increasing carbon emissions released due to longer flight times, and increasing the price of fuel needed.

The concerns of 5G technology's disruption to aviation operations in Seattle-Tacoma International Airport were tested to show the relationship between 5G technology and low-visibility landings. Based on SEA's activities from January 18, 2022, the study's findings showed no significant evidence of the need to cancel, reroute, or swap aircraft due to any significant disruptions during low-visibility landings due to C-Band bleeding from the 5G technology. Ultimately, this data correlated with the findings in previous studies from Denton (2022), the Federal Aviation Administration (2021), Koenig (2022), and the National Frequency Agency (ANFR) that Europe's approach to the implementation of 5G technology caused no major interruptions due to a different C-band frequency. Therefore, the United States should follow suit in its approach. It can be concluded that there was no negative effect on aviation operations in this area. This study focused on one major airport hub. These results can be compared to similarly-sized airports with the same airlines and aircraft manufacturers. However, this may not always be the case. There is still not a significant amount of data released due to 5G technology being such a new concept; there is much room for future research.

Suggested Research in the Area

It would be beneficial to conduct an in-depth study that would increase the awareness of the effects of the wireless networks, including the Federal Aviation Administration and the rules and regulations regarding the functionality of the lower visibility approaches within the United States and International destinations (Kaloxylos, 2017). This type of research would increase the awareness of the Airliners and other companies currently impacted by the changeover from 4G to 5G. Another area to research is the integration, including the infrastructure regarding the ability for a faster network versus the financial impact on the commercial airports combined with the costs for the airlines to update needed changes to comply with the difference regarding the operational and training effect with the 5G implementation (Arpaio et al., 2021).

References

Adhiyoga, Y. G., Rahman, S. F., Apriono, C., & Rahardjo, E. T. (2021). Magneto-dielectric properties of PDMS–magnetite composite as a candidate for compact microstrip antennas in the C-band 5G frequency. Journal of Materials Science: Materials in Electronics, 32(8), 11312–11325. https://doi.org/10.1007/s10854-021-05802-z

Airlines For America. (2021). *Emergency petition to stay initiation of 5g operations at certain designated airport locations* (GN Docket No. 18-122). https://ecfsapi.fcc.gov/file/123022756098/Emergency%20Petition%20for%20Stay%20--%20Final.pdf

Airlines for America. (n.d.). [Myth vs fact: Timeline on aviation raising 5G concerns] https://www.airlines.org/wp-content/uploads/2022/01/5G-Timeline-V2.pdf

Air Transport Action Group. (2022). *Sustainable development goals and aviation*. Aviation Benefits Beyond Borders. https://aviationbenefits.org/un-sustainable-development-goals/sustainable-development-goals-and-aviation/

Appendix A to Part 91 - Category II Operations: Manual, Instruments, Equipment, and Maintenance, 14 CFR § 91 Appendix A (2022). https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-91/appendix-Appendix%20A%20to%20Part%2091

Arpaio, M. J., Paolini, G., Fuschini, F., Costanzo, A., & Masotti, D. (2021). An all-in-one dual band Blade antenna for ADS-B and 5G Communications in UAV assisted Wireless Networks. Sensors, 21(17), 5734. https://doi.org/10.3390/s21175734

Cannonier, C., & Burke, M. G. (2019). The economic growth impact of tourism in Small Island Developing States—evidence from the Caribbean. Tourism Economics, 25(1), 85–108. https://doi.org/10.1177/1354816618792792

Cavalli, L., Lizzi, G., Guerrieri, L., Querci, A., Bari, F. D., Barbieri, G., Ferrini, S., Meglio, R. D., Cardone, R., Tardo, A., Pagano, P., Tesei, A., & Lattuca, D. (2021). Addressing efficiency and sustainability in the port of the future with 5G: The experience of the Livorno Port. A methodological insight to measure innovation technologies' benefits on port operations. *Sustainability, 13*(21), 12146. http://dx.doi.org/10.3390/su132112146

Cellular Telecommunications Industry Association. (2022). *5G and air safety*. CTIA. https://www.5gandaviation.com/wp-content/uploads/2022/01/5G-and-Air-Safety.pdf

Chataut, R., & Akl, R. (2020). Massive MIMO systems for 5G and beyond networks—overview, recent trends, challenges, and future research direction. Sensors, 20(10), 2753. https://doi.org/10.3390/s20102753

Chow, D. (2022). Why are airlines squaring off against wireless companies over 5g? NBC News. https://www.nbcnews.com/science/science-news/are-airlines-squaring-wireless-companies-5g-rcna12630

Denton, J. (2022). *Europe has 5g. Here is why it hasn't messed up the airlines* (2616645990). Dow Jones & Company Inc. https://www.proquest.com/docview/2616645990/citation/D330D97144CA4A3CPQ/1?accountid=27203

De Fazio, P. (2022). Subcommittee Hearing on "Finding the Right Frequency: 5G Deployment and Aviation Safety." HHRG-117-PW05-20220203-SD001.pdf (house.gov)

Dunbar, B. (1992, June). Making the skies safe from windshear. NASA. https://www.nasa.gov/centers/langley/news/factsheets/Windshear.html

Federal Aviation Administration. (2021). *Airworthiness directive; Transport and commuter category airplanes* (4910-13-P). https://www.faa.gov/sites/faa.gov/files/2021-12/FRC_Document_AD-2021-01169-T-D.pdf

Federal Aviation Administration. (2022a). *Airports with 5g buffer*. FAA https://www.faa.gov/sites/faa.gov/files/2022-01/50%20Airports%20with%205G%20Buffer.pdf

Federal Aviation Administration. (2022b). *FAA statements on 5g*. FAA https://www.faa.gov/newsroom/faa-statements-5g

Fox, A. (2022). *Major international airlines cancel flights to US ahead of planned 5g rollout*. Travel & Leisure. https://www.travelandleisure.com/travel-news/5g-international-flight-cancellations

Furchtgott-Roth, D. (2021, December 23). Aviation Concerns About 5G Will Take Years to Resolve. *Forbes.* https://www.forbes.com/sites/dianafurchtgott-roth/2021/12/23/aviation-concerns-about 5g-will-take-years-to-resolve/?sh=59af403b208c

GACA Saudi Arabia (2021). Protecting radio altimeter operations electromagnetic compatibility (EMC.) aspects related to G5. [PowerPoint slides, PDF file]. ICAO. https://www.icao.int/MID/Documents/2021/FM%20WG2/FM_WG2_KSA_WP_Rev1.pdf

Gant, L. (2022, February 24). Airworthiness Directives: The Boeing Company Airplanes. Federal Register. https://public-inspection.federalregister.gov/2022-03967.pdf

International Civil Aviation Organization. (2020, November 27). *Problem statement - 5G interference with radar altimeter frequency band*. https://www.icao.int/safety/FSMP/MeetingDocs/FSMP%20WG11/IP/FSMP-WG11-IP08_ICAO%20Flight%20Operations%20Panel%20and%20IATA%20%20IFALPA%205G%20problem%20statement.pdf

Kaloxylos, A. (2017). Network slicing for 5G networks. Proceedings of the 21st Pan-Hellenic Conference on Informatics. https://doi.org/10.1145/3139367.3139392

Kamran Shereen, M., Khattak, M. I., & Nebhen, J. (2022). A review of achieving frequency reconfiguration through switching in microstrip patch antennas for future 5G applications. Alexandria Engineering Journal, 61(1), 29–40. https://doi.org/10.1016/j.aej.2021.04.105

Kelleher, S. R. (2022). *What is the c-band? The 5g brawl between airlines and telecoms explained*. Forbes. https://www.forbes.com/sites/suzannerowankelleher/2022/01/04/c-band-5g-airlines-telecoms/?sh=67726f375542

Koenig, D. (2022). *AT&T, Verizon delay new 5g service after buttigieg request*. News Nation. https://www.newsnationnow.com/business/tech/att-verizon-delay-new-5g-service-after-buttigieg-request/

Ma, L., Wei, X., & Zhou, X. (2021). Analysis of Meteorological Service Effect of a low-cloud and low-visibility weather process at Shanghai's two airports. IOP Conference Series

Mansour Shalaby, E., Ibrahim Hussin, S., & Ibrahim Dessoky, M. (2021). Performance evaluation of 5G modulation techniques. Wireless Personal Communications, 121(4), 2461–2476. https://doi.org/10.1007/s11277-021-08831-3

McCaskill, S. (2021). *5G towers: Everything you need to know about 5g cell towers*. 5G Radar. https://www.5gradar.com/features/5g-towers-everything-you-need-to-know-about-5g-cell-towers

National Frequency Agency. (n.d.). *Determination of the size of safety and precautionary zones*. ANFR. https://www.anfr.fr/fileadmin/mediatheque/documents/N%C3%A9gociations/Note-technique-zones-securite-precaution.pdf

Radar bands. (2000). Weather Edge Inc. https://www.everythingweather.com/weather-radar/bands.shtml

Radio Technical Commission for Aeronautics. (2020). *Assessment of c-band mobile telecommunications interference impact on low range radar altimeter operations* (RTCA Paper No. 274-20/PMC-2073). https://www.rtca.org/wp-content/uploads/2020/10/SC-239-5G-Interference-Assessment-Report_274-20-PMC-2073_accepted_changes.pdf

Seattle Airport. (2022). Information Guide to Seattle-Tacoma Airport Seatac (SEA) – Non-Official. https://www.seattle-airport.com/seatac-arrivals

Shaik, N., & Malik, P. K. (2021). A comprehensive survey of 5G wireless communication systems: Open issues, research challenges, channel estimation, multi carrier modulation and 5G applications. *Multimedia Tools and Applications*, *80*, 28789-28827. https://doi-org.ezproxy.libproxy.db.erau.edu/10.1007/s11042-021-11128-z

Shepardson, D. (2022). *Major U.S. airlines warn 5G could ground some planes, wreak havoc*. Reuters. https://www.reuters.com/technology/exclusive-major-us-airline-ceos-urge-action-avoid-catastrophic-5g-flight-2022-01-17/

Staff Reporter. (2022). *Temporary buffer zones created around us airports in wake of 5g rollout in the c-band*. Nagaland News Network. https://www.nagalandnewsnet.com/temporary-buffer-zones-created-around-us-airports-in-wake-of-5g-rollout-in-the-c-band/

University of Alberta. (n.d.). What is sustainability? https://www.mcgill.ca/sustainability/files/sustainability/what-is-sustainability.pdf

United Nations Development Program. (2022). What are the sustainable development goals? https://www.undp.org/sustainable-development-goals

US Department of Commerce. (2016). *United States frequency allocations chart: The radio spectrum*. https://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf

Yang, W. (2019). Conceptual verification of integrated heterogeneous network based on 5G millimeter wave use in Gymnasium. Symmetry, 11(3), 376. https://doi.org/10.3390/sym11030376

You, Y.-H. (2021). Reduced complexity frequency ambiguity resolution and synchronization signal detection for 5G NR-V2X Communication Systems. IEEE Systems Journal, 1–9. https://doi.org/10.1109/jsyst.2021.3058673

Zhang, C., Huang, Y.-H., Sheikh, F., & Wang, Z. (2017). Advanced baseband processing algorithms, circuits, and implementations for 5G communication. IEEE Journal on Emerging and Selected Topics in Circuits and Systems, 7(4), 477–490. https://doi.org/10.1109/jetcas.2017.2743107