5G C-Band and the Implications on Radar Altimeter Certification and Continued Operational Safety

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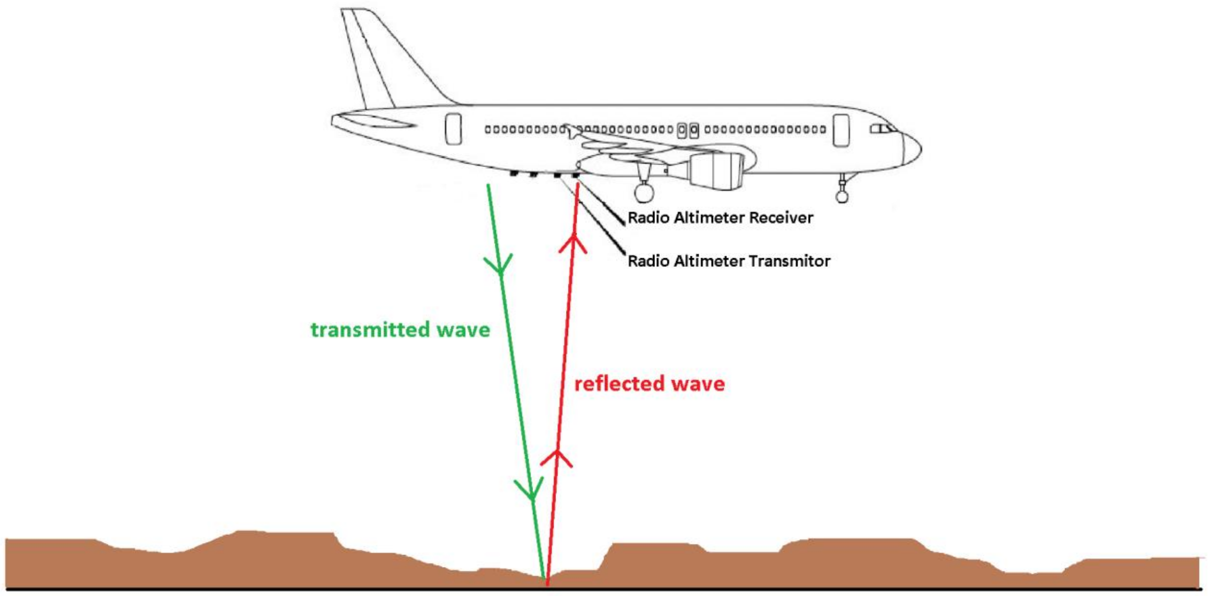
Introduction to Radar Altimeters

A Radar Altimeter is an Aviation instrument designed to measure height above terrain or obstacle. Its composed of a transmitter and receiver unit/section (with Antennas) and it emits a low power Radio Frequency (RF) Pulse from the aircraft down towards the terrain and receives the reflected signal back. The time recorded between the transmitted and received signal is translated into altitude which is reported to the cockpit and shared with other Avionic and Flight Control Equipment.

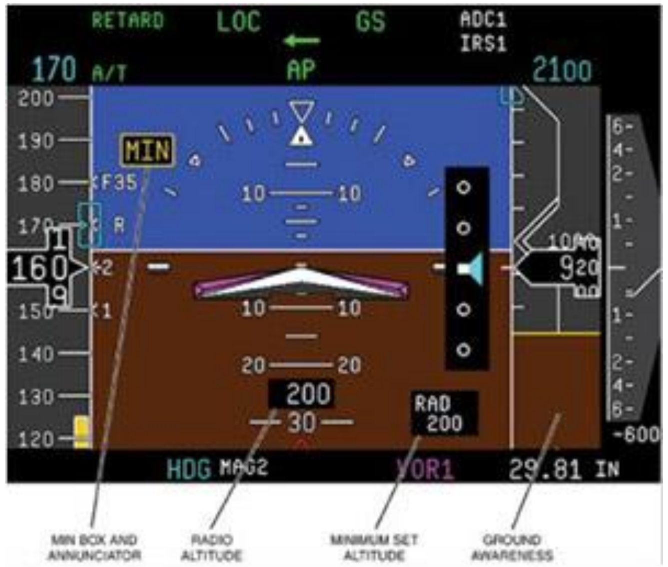


Rad Alts are used on all types of civil and military aircraft, including transport and cargo airplanes, private airplanes, helicopters, combat aircraft, missiles, UAVs, etc.

Radar altimeters are the only sensor onboard an aircraft which can make a direct measurement of altitude above ground. All other altitude sources, e.g. barometric, GNSS, etc. are referenced to an absolute datum (sea level or ellipsoid), and not relative to the terrain.

Radar Altimeters and Integration in Avionic Systems

Application / Integration of Radar Altimeters in Avionic Systems



- Primary Flight / Low altitude Operations.
- Autopilot / Flight Controls
- Precision Approaches
- Search And Rescue (SAR)
- Rig Approaches
- NVIS / NVG
- Situational awareness
- DMAP / HTAWS / Ground Proximity Warning Systems
- Vertical guidance on landings, including aural callouts (on both instrument and visual landings)
- Traffic Collision Avoidance System (TCAS)
- Flight of Terrain / Terrain tracking

Types of Radar Altimeters

Typical Radar Altimeter Types

- Radar Altimeters use several different modulation modes.

- The most common are Frequency Modulated Continuous Wave or FMCW and Pulsed Continuous Wave or PCW or also known PWCW. The later is typically found on older aircraft as almost all current aircraft utilize FMCW.

- Military versions are similar but also include proprietary modulation types, including Frequency Hoping, digitally cypher encoded, etc. types in some Mission critical cases.

- Frequency Range: 4.2 to 4.4 Ghz

- Typical transmission power levels are:
  - FMCW: 0.05 ~ 2 Watts
  - PCW: 1 ~ 10 Watts

Typical Radar Altimeter Performance

Operating Details

Radar Altimeters, by nature of operation, suffer from performance issues depending on the surface that the signal reflects off. This is more apparent for Helicopters than Fixed Wing aircraft.

The reason for these performance issues is the type of surface, (material, water, ice, tarmac, wet grass, etc.), which affects the return signal. This causes different degradations to the return signal such as fading, phasing, dispersion, absorption, etc.

All aircraft manufactures incorporate some type of “integrity validation” scheme for Radar Altimeter indications to the operators. These include averaging over several returns, consecutive valid returns, hysteresis of values for damping, etc.

Generally, Rad Alts are designed to track the valid target at the lowest range, corresponding to the minimum clearance height of the aircraft.

Regulatory Requirements for Radar Altimeters

Certification Requirements

Civil Rotorcraft utilize radar altimeters which have been approved by the FAA (or EASA) through the Technical Standard Order (TSO) using an STC or TC related process.

The current governing FAA / EASA requirements for Radar Altimeters are TSO-C87a (dt: 2012) with performance requirements being RTCA / DO-155 and EUROCAE ED-30 MPS.

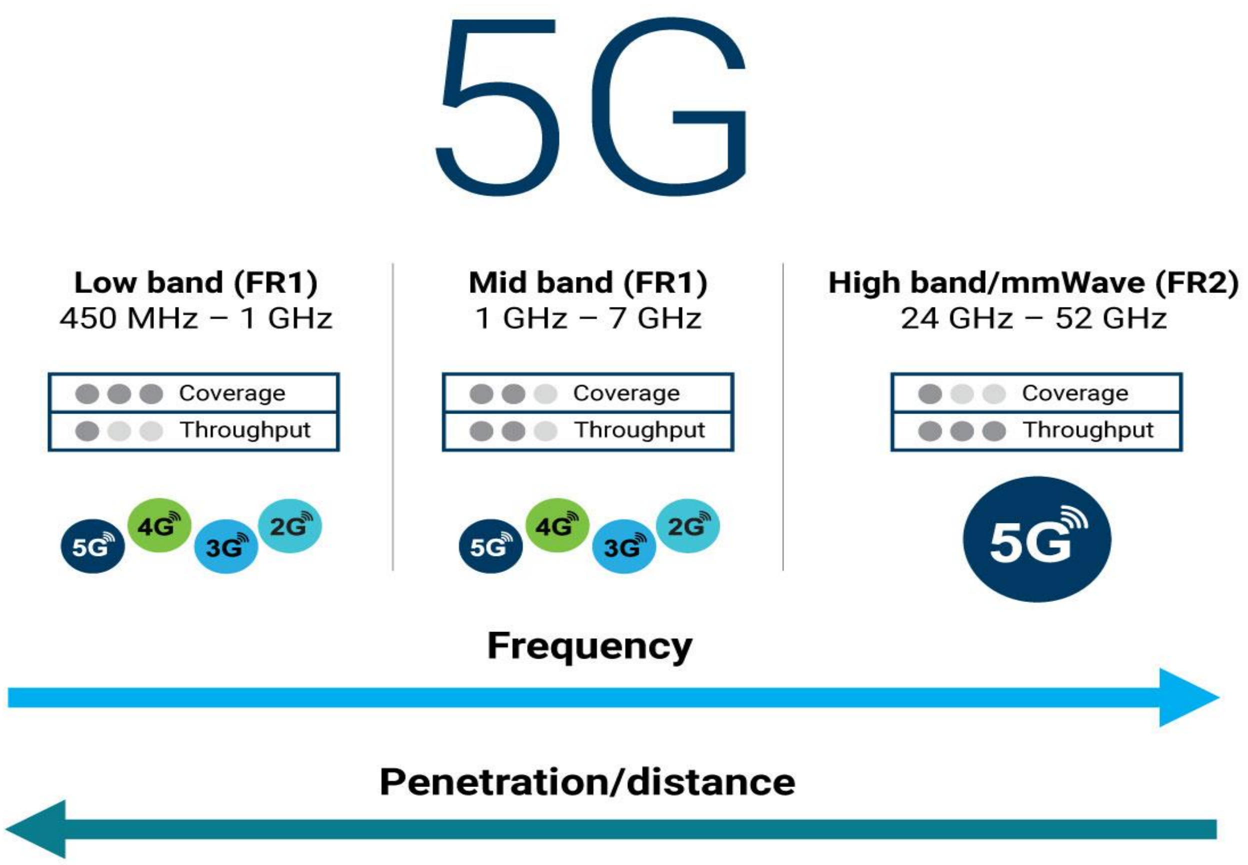
Of critical note is the fact that there are no requirements or limitations associated with reception bandwidth (aka reception mask) or spurious emission rejection or susceptibility.

The SC-239, Low Range Radar Altimeter, working group committee was established on December 19, 2019. Their charter was to update the current Minimum Operational Performance Standard, DO-155, for Low Range Radar Altimeters. The group also focused on protecting future Radar Altimeters from existing and planned IN BAND and OUT OF BAND inter-references and to better align DO-155 with ED-30.

5G C-Band Cellular Background

5th Generation Cellular Communication Background

5G can be a challenging technology to deploy given the characteristics of signal propagation. Mid-band spectrum in the 1 GHz - 7 GHz frequency range is considered ideal for 5G as it strikes the perfect balance between coverage and throughput. The 5G community finds the 3.3 GHz to 3.8 GHz mid-bands especially appealing because this will enable most countries to have a dedicated 5G band in the sub-7 GHz range.



5G C-Band Spectrum and the FCC

<u>FCC and 5G</u>

In March 2020 the FCC issued a Report and Order regarding opening up the 3.7 to 4.2 GHz spectrum for 5G use.

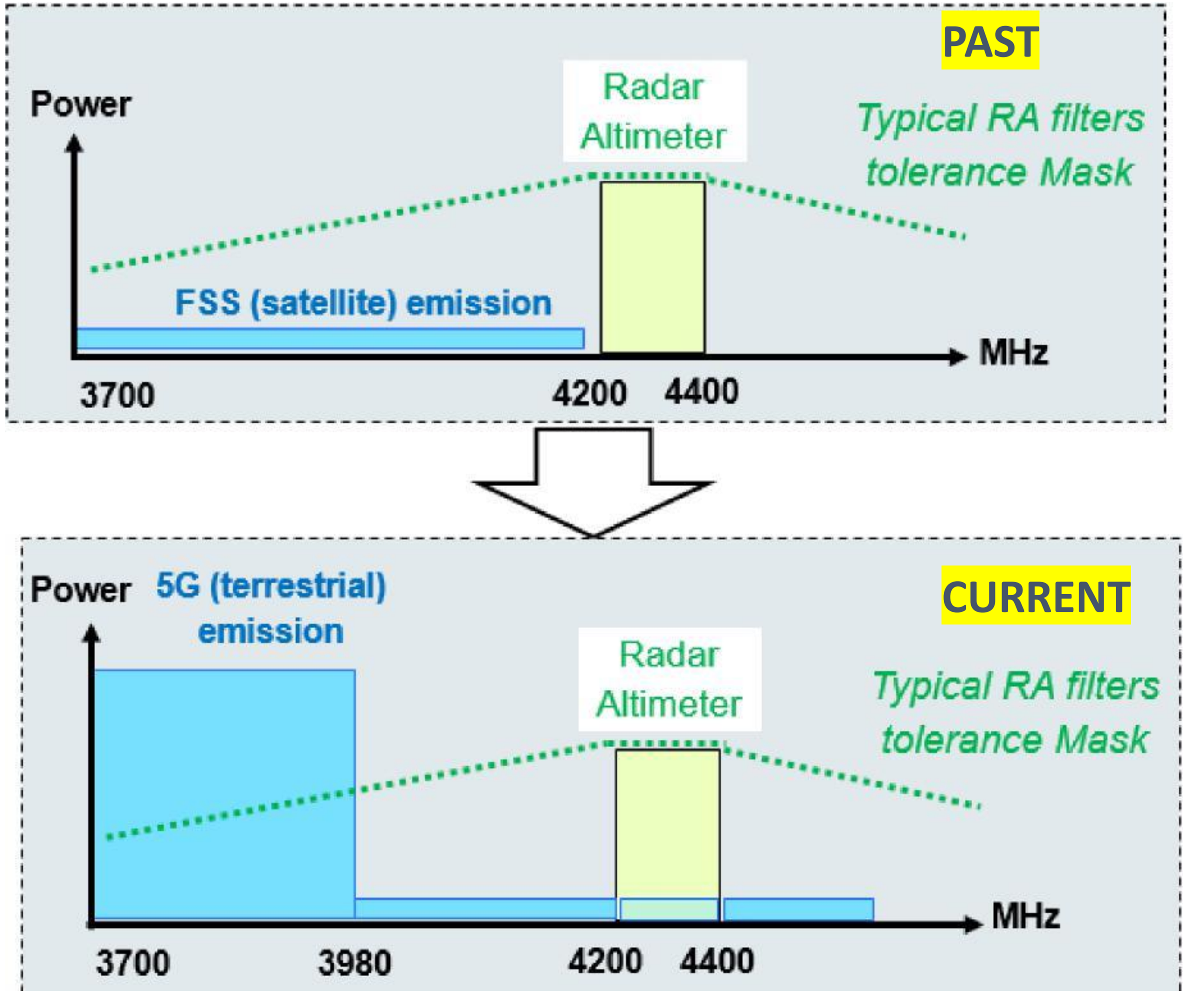
In response, the RTCA established a 5G Task Force within the existing Radrar Altimeter MOPS Special Committee SC-239 to investigate potential coexistence issues between 5G and radar altimeters. This was due to the proximity of the Radar Altimeter operating spectrum of 4.2 to 4.4 Ghz. This task force consisted of representatives from industry, the Air Line Pilots Association, airlines, and the FAA. On October 7th 2020, RTCA released their report (PDF) and submitted it to the FCC.

The report documented, using a small sample set of commercial RA's, that potential interference from either fundamental 5G emissions and/or 5G spurious emissions during laboratory tests.

Fundamental emissions have to do with potential RA receiver overload due to lack of adequate out-of-band rejection of the 5G signals and/or because the RA's reception mask extends beyond the allocated 4.2 to 4.4 Ghz. (NOTE Older DO-155 and ED-30 Requirements). The spurious emissions are potential frequency multiples emitted by 5G transmitters that have the potential of land in the 4.2-4.4 GHz range and/or because the RA's reception mask extends beyond the allocated 4.2 to 4.4 Ghz.

In December of 2020, the FCC auctioned off the 3.7 to 4.2 Ghz spectrum for several billion dollars to ATT and Verizon. This was done against the recommendations of the FAA, RTCA and Aviation community including HAI.

5G C-Band Interference Spectrum



The Issue: Radar Altimeters (RA) currently have no restrictions by any MOPS or regulations as to how "broadly" they can receive. Previous to FCC 5G C-Band spectrum allocations, RA's were designed to receive beyond their designated 4.2 to 4.4 Ghz spectrum.

Laboratory Testing by USG has confirmed that one of the main issues of 5G susceptibility by RA's is the receiver reception mask.

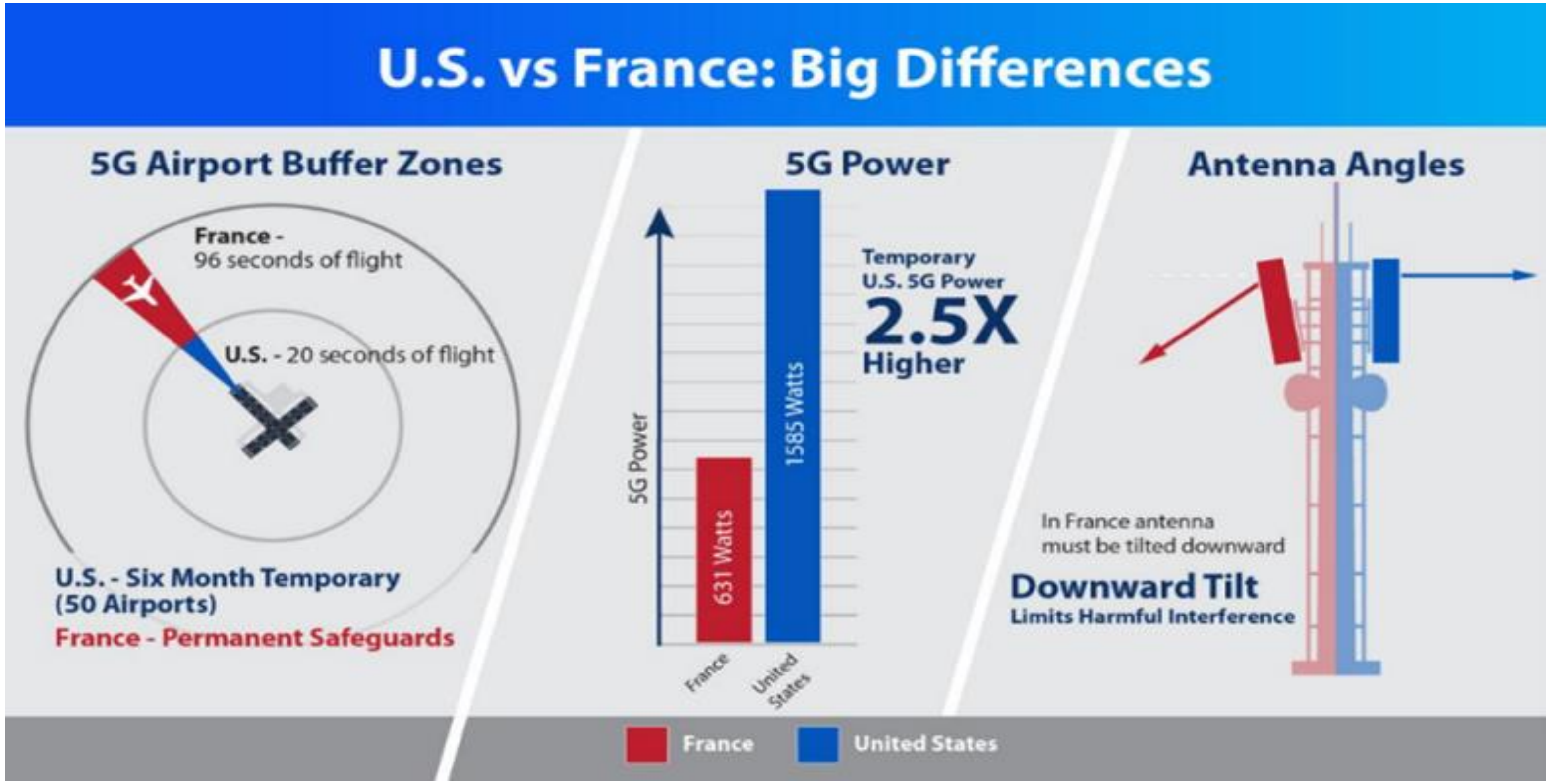
SC-239 will be restricting this reception mask to be within the allocated transmission spectrum. (This is still in committee).

The reception mask of the current RA's is not the only issue that contributes the interference. Spurious emissions still "leak" into the main RA band of 4.2 to 4.4 Ghz

5G C-Band Deployment Differences

<u>Why cant we all play together ?</u>

The United States did not follow the same type of 5G C-Band deployment as in Europe. So the ICAO and EASA analysis in not comparing the same standards. The FAA published a comprehensive analysis of the situation posted on its <u>website</u>.



The primary differences between the deployment in the USA and other regions of the world are the use of Higher Power Transmitters, Higher Density, Closer Proximity to Aerodromes/Airports, and the use of antenna arrays with no horizontal tilt on the arrays relative to ground.

As an example, the differences in 5B C-Band implementation between France and the USA is shown above from an FAA presentation.

5G C-Band Spectrum During 2021

During the 2021 period, and under pressure of Covid restrictions, The FAA, FCC, CTIA and Aviation industry begun focusing with greater depth into the potential implications of a 5G C-Band rollout by ATT and Verizon.

The FAA initially tried to coordinate with FCC on a delayed deployment but the cellular industry was not accepting of such impacts to what was considered a National (US) critical infrastructure. Any 5G delays where against the USG interests.

However, under a potential threat of a board US airline traffic shutdown (passenger and cargo), the White National Economic Council intervened between the two agencies and agreements was reached to delay 5G rollout until Jan of 2022, thus allowing time for the FAA and aviation industries to develop alternative solutions to the problem.

December 7, 2021, the FAA issued two Airworthiness Directives (AD), one of which applied to transport and commuter category airplanes (PDF) and the other to helicopters (PDF). These AD's stipulate that the locations affected by 5G C-Band transmissions will be identified by Notices to Air Missions (NOTAMs). The FAA also published a Special Airworthiness Information Bulletin (SAIB) concerning the potential effects of 5G deployment on radar altimeters (PDF).

In parallel the FAA initiated the Alternative Means of Compliance (AMOC) process. The process utilized FCC data sharing of tower locations and power levels, in conjunction with Radar Altimeter manufacturers

5G C-Band Interference Spectrum - Europe

<u>What was happening in the rest of the world ?</u>

In 2021, the ICAO Air Navigation Commission conducted a full review of the situation on a global level following which a State Letter (SL 022 – SP 74/121/22) was issued to all ICAO Member States.
The primary conclusion of the analysis conducted by ICAO was that “some radio altimeters will be impacted if high power cellular systems are implemented near the frequency band used by radio altimeters.” It was further concluded that “Several States have already implemented temporary technical, regulatory and operational mitigations on new 5G systems in order to protect radio altimeters while more permanent solutions are being devised.”

In Europe, European Union Aviation Safety Agency (EASA) issued a Safety Information Bulletin (SIB 2021-16) in December 2021. The SIB was developed by the agency following assessments conducted with aircraft manufacturers, national airworthiness authorities, and national spectrum regulators to identify the risk of radio altimeter interference by 5G transmissions, the effect of such interference on aircraft systems, and the subsequent effect on the safety of flight operations. The assessments concluded that at this stage, no risk of unsafe interference had been identified in Europe.

FAA 5G AD’s and Safety Advisory

FAA **SAIB AIR/21/18R1** dated 12/23/2021 – Risk of Potential Adverse Effects on Radio Altimeters

FAA **AD 2021-23-13** dated 12/09/2021 – This AD was prompted by a determination that 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 (5G C-Band). This AD requires revising the limitations section of the existing rotorcraft flight manual (RFM) for your helicopter to incorporate limitations prohibiting certain operations requiring radio altimeter data when in the presence of 5G C-Band interference in areas as identified by Notices to Air Missions (NOTAMs).

- Issued because 5G C-band interference could lead to loss of continued safe flight and landing
- Prohibits certain approaches in areas of 5G C-band interference as identified by NOTAMs
- NOTAMs allow for AMOCs to be issued to “clear” airports/runways based on Radio Altimeter performance

FAA 5G website – **https://www.faa.gov/5g**

Rotorcraft Issues List dated 7/18/2022 – Issue R-0313

5G Radar Altimeter Radius Estimator Tool

5G Protection Radius Estimator Tool

The FAA and aviation industry task force worked to standardize, to the best extent possible, the basis of radar altimeter Alternative Means of Compliance (AMOCs) process.

This tool is used to estimate operational protection criteria relative to hazards defined in FAA-issued Notice to Air Missions (NOTAMs), based on specific 5G interference tolerance criteria of commercial radar altimeters (RAs).

The intent is for RA manufacturers to provide verifiable parameter values based on (1) standardized or commonly understood values/parameters, (2) model-specific or manufacturer-specific values, and (3) RA model-specific test results. The tool computes a protection radius around C-Band 5G Base Stations inside which 5G emissions pose an unacceptable risk of interference to the specific RA model being analyzed. The tool generated data can then be used by aircraft manufacturers to assess aircraft-level risk based on the risk of interference to the RA(s) on board and operations in and around aerodromes identified in NOTAMs by comparing the protection radius for a given aircraft model with the requirements defined in those NOTAMs.

This comparison becomes the basis for filing an Alternative Means of Compliance (AMOC) with the FAA to enable additional operations that have been restricted in NOTAMs based on worst-case RA performance criteria.

The FAA AMOC Process for 5G

<u>The FAA AMOC process. “A Temporary Fix”</u>

<u>Process to obtain FAA letter of acceptance at the RA manufacturer level</u>

1. RA manufacturer submits 5G Protection Radius Estimator and statement of performance to FAA with reference to test report and/or drawing that defines test environment

2. FAA RA oversight office reviews submittal and coordinates with AIR-622 (responsible at discretion to coordinate with Spectrum) and AIR-722

3. AIR-722 processes a Letter of Acceptance to RA manufacturer or provides a Letter of Rejection to RA manufacturer

4. RA Manufacture provides Letter of Acceptance to aircraft OEM, STC holders, or field approval holders to support Aircraft level AMOC

The FAA AMOC Process for 5G

<u>The AMOC process. "A Temporary Fix"</u>

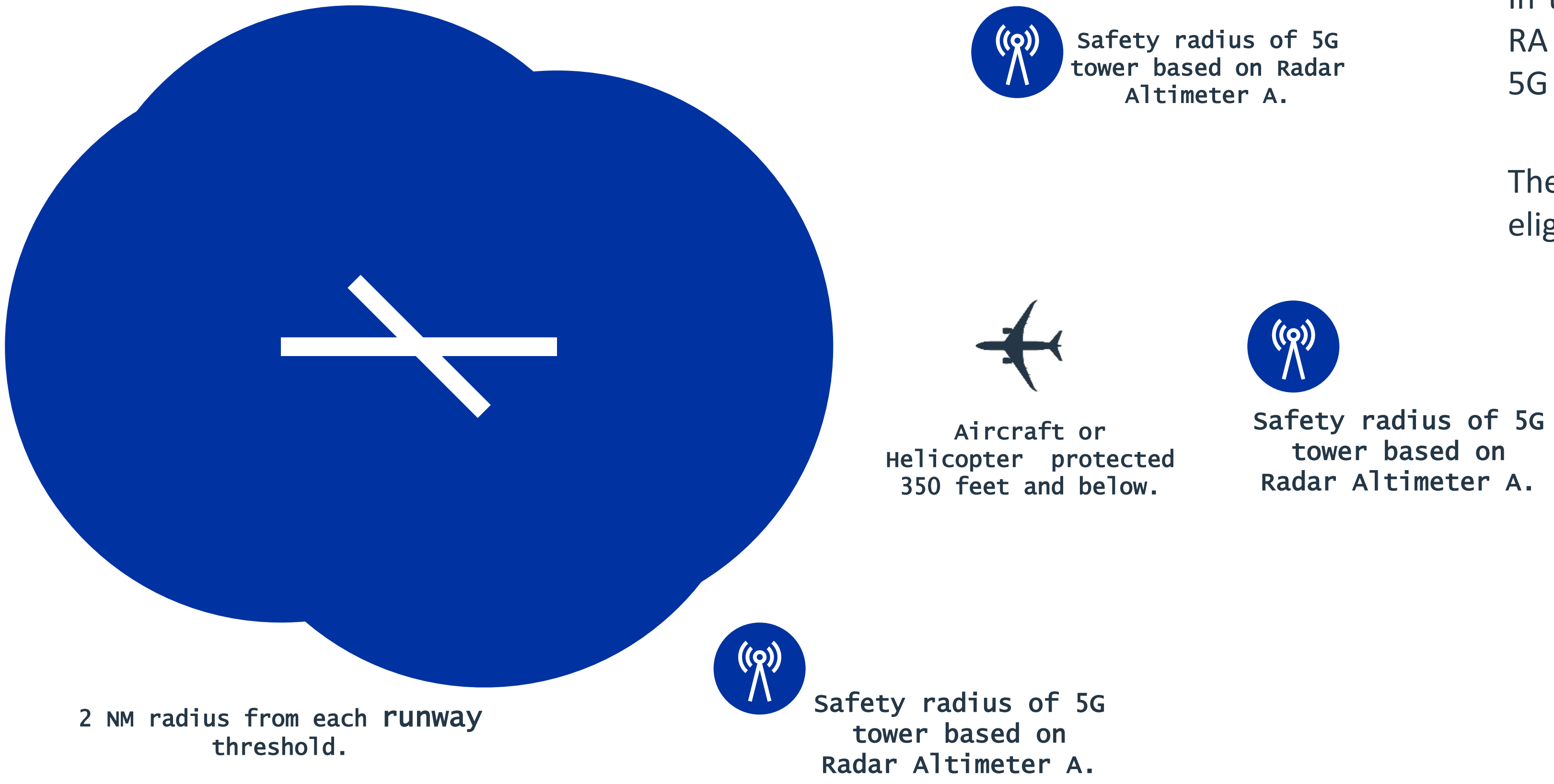
<u>Aircraft OEM level process to obtain AMOC approval based on RA data</u>

1. The aircraft OEM submits a global AMOC package to FAA with Aircraft model, RA model, including 5G Protection Radius Estimator and statement of performance to FAA with reference to test report and/or drawing that defines test environment (with or without RA manufacturer FAA letter of acceptance)
2. AIR-722 coordinates AMOC request with AIR-622 (responsible at discretion to coordinate with Spectrum)
3. FAA runs the ASPIRE tool to determine airports and runways with no 5G interference
4. FAA issues global AMOC approval letter identifying airports and runways with no 5G interference or rejection letter to aircraft OEM
5. Aircraft OEM communicates cleared airports or runways via service bulletin with global AMOC FAA approval letter to their operators

AMOC Examples

<u>AMOC Assessment Method Example 1 – Aircraft Qualified to Operate at Specific Airport or Heliport</u>.

Radio Altimeter Model A with Aircraft Model A



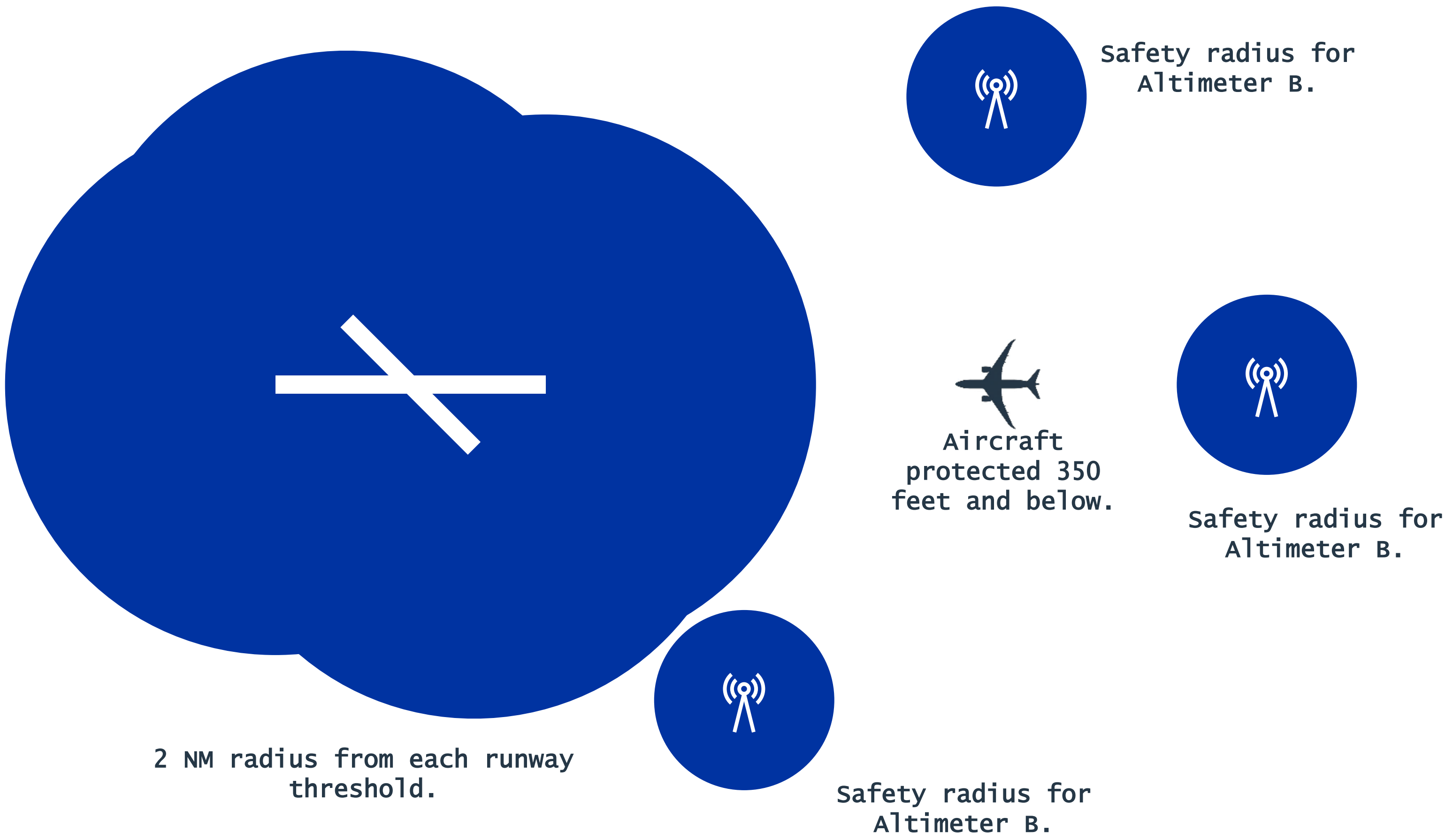
In this Scenario, Radar Altimeter Susceptibility data for RA Model A have been compared against the FAA / FCC 5G Database for the specific airport in question.

The FAA database do not overlap so Altimeter A may be eligible for an AMOC using the Version 1 FAA radius tool.

AMOC Examples

<u>AMOC Method – FAA Radius Tool Version 1</u>

Radio Altimeter Model B with Aircraft Model A



Regions do not overlap so Altimeter B may be eligible for an AMOC using the Version 1 FAA radius tool.

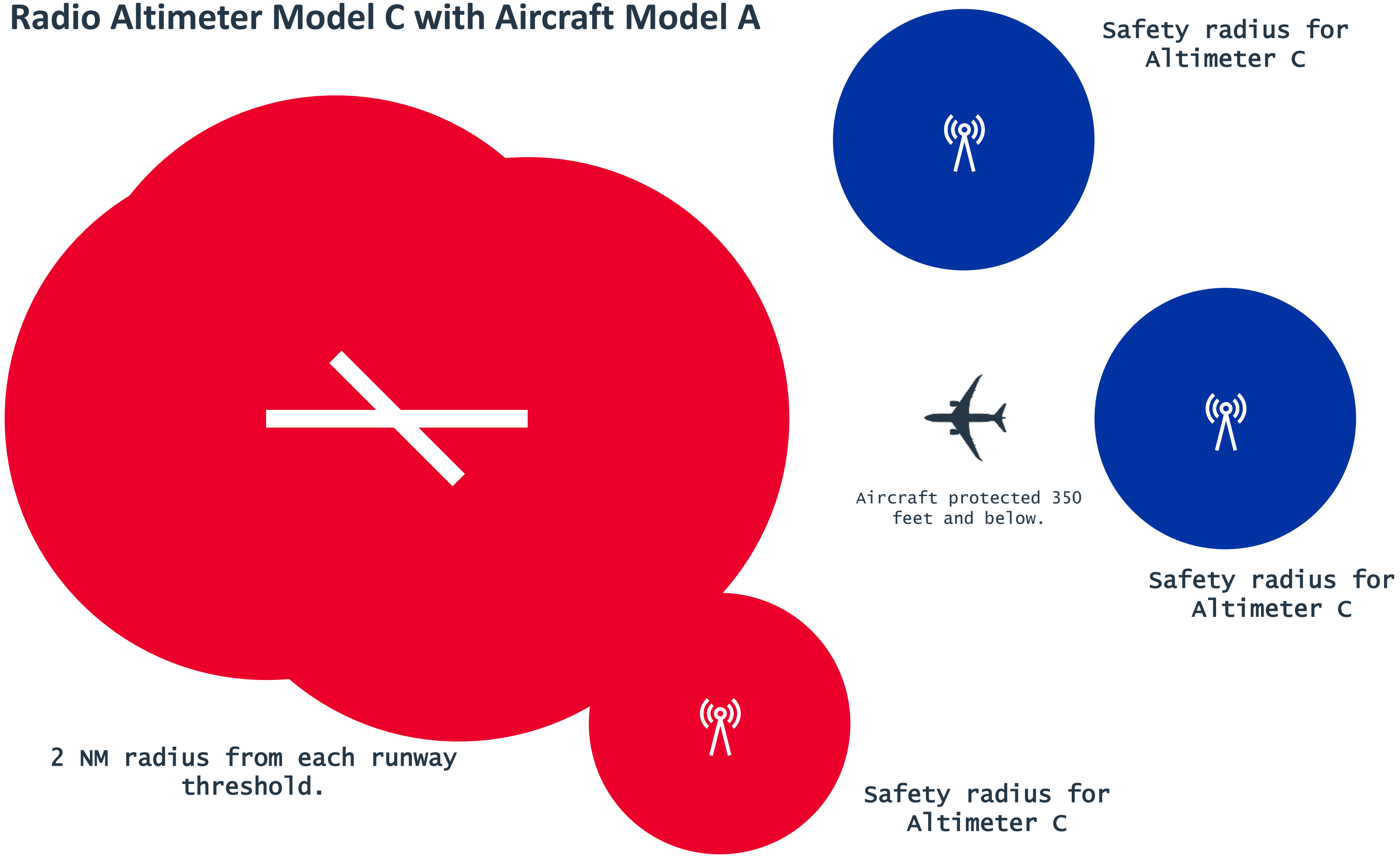
In this Scenario, Radar Altimeter Susceptibility data for RA Model B have been compared against the FAA / FCC 5G Database for the specific airport in question.

The FAA database do not overlap so Altimeter B may be eligible for an AMOC using the Version 1 FAA radius tool.

AMOC Examples

AMOC Method – FAA Radius Tool Version 1

Radio Altimeter Model C with Aircraft Model A



Regions overlap so Altimeter C is not eligible for an AMOC using the Version 1 FAA radius tool.

5G C-Band Interference

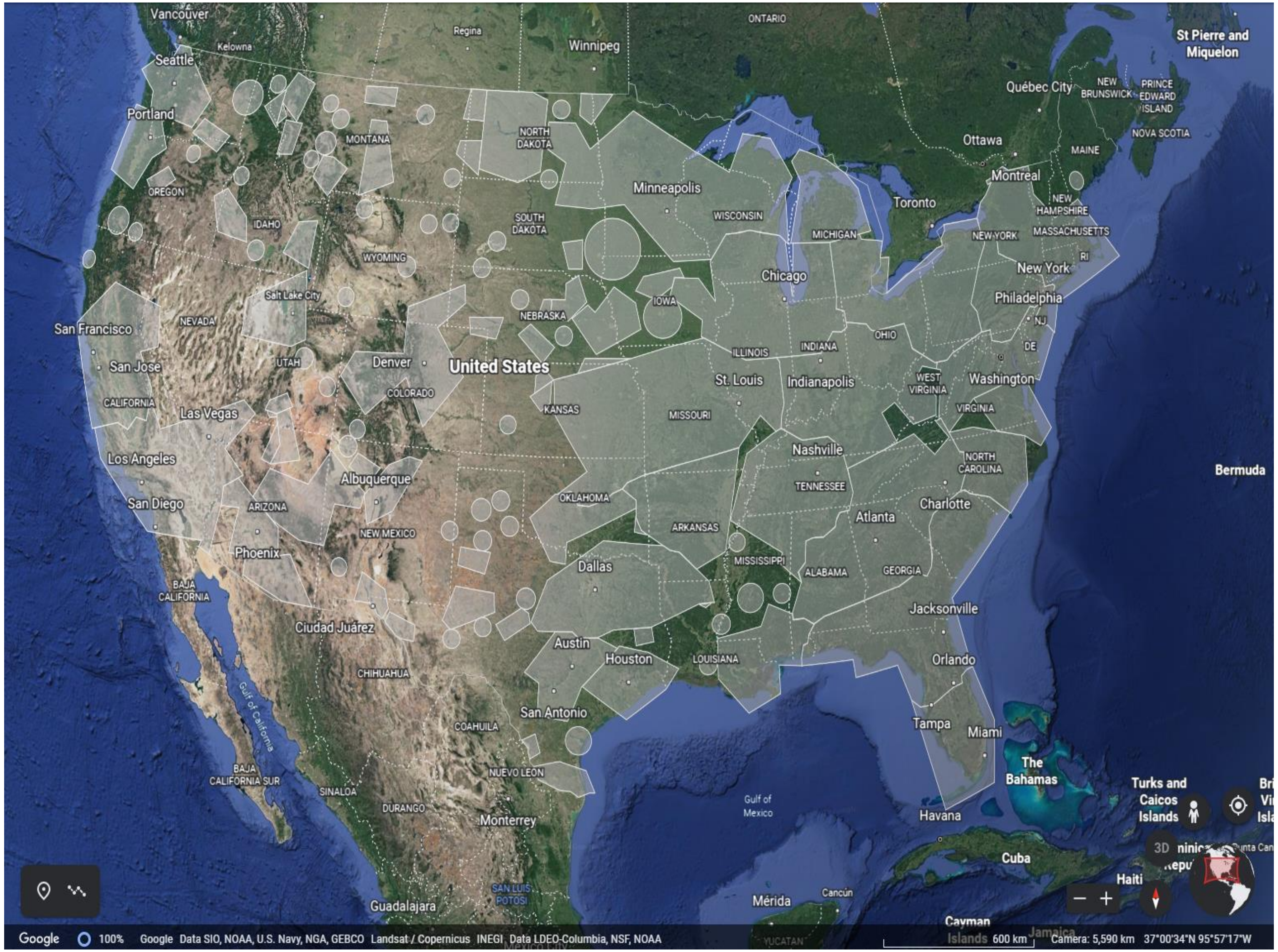
<u>NOTAMs and AMOC Process</u>

FAA NOTAMs have continued to expand as more 5G Towers are activated across the United States. As of this writing approximately 45,000 towers are operating in C-Band.

As a results of the NOTAMs being added / expanded the AMOC process is becoming unattainable.

Previously approved aircraft / RA models under the AMOC process are being denied operation on a month by month basis.

As of July 2023 a new approach will be required.



5G C-Band during 2022

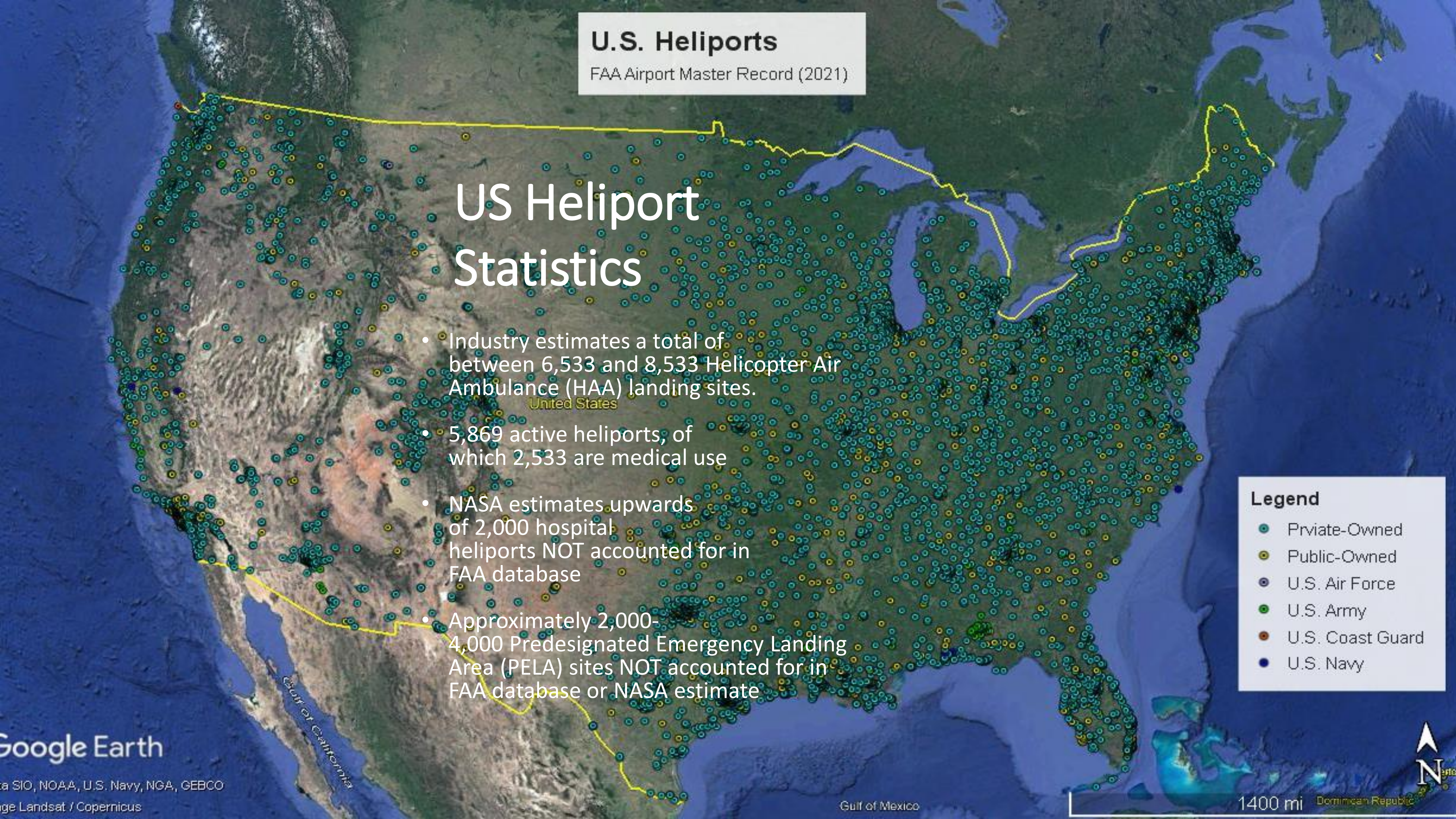
FAA FCC and industry stakeholders.

To date the cellular industry agreed to operate under reduced power levels (62 dBm / Mhz) within urban areas and at 38 dBm / Mhz within the vicinity of airports and no towers within 2 mile radii of airports.

These voluntary restrictions are set to expire July of 2023, where power levels are set to increase to 65 dBm / Mhz.

Over the past two years the FAA, and aviation industry have created the Aviation RA Technical Working group, which is engaged in weekly meetings and technical discussions in an attempt to drive the 5G RA interference issue to reasonable resolution. The group consists of Aircraft OEMs, RA Manufacturers, FAA, and Cellular industry experts, HAI, AIAA, and other experts.

The working group's efforts have been instrumental in keeping the Aviation industry operating safely under these challenging conditions.



US Heliport Statistics

- Industry estimates a total of between 6,533 and 8,533 Helicopter Air Ambulance (HAA) landing sites.
- 5,869 active heliports, of which 2,533 are medical use
- NASA estimates upwards of 2,000 hospital heliports NOT accounted for in FAA database
- Approximately 2,000-4,000 Predesignated Emergency Landing Area (PELA) sites NOT accounted for in FAA database or NASA estimate

Radar Altimeters and Rotorcraft

<u>Rotorcraft vs Fixed Wing</u>

Rotorcraft do not suffer from the same level of severity as Fixed Wings aircraft.

Fixed Wing aircraft have higher criticality to operations.

- Auto throttle
- Flap deployment
- Thrust reverser
- CAT 1 approaches
- Faster Closure rates (less reaction time)
- Etc.

Rotorcraft Criticalities are more operation specific, i.e. Rig Approach, LPV, NVG Ops, SAR, etc

Most CAT B operations do not require Rad Alt.

5G C-Band LM SAC Activities

- **S-92A** (307 aircraft) utilizes the Honeywell AA-300 Radio Altimeter System with the RT-300 transceiver unit. - Certification effort underway for Filter Install.

- **S76A/A+/A++** (309 aircraft) utilize the Collins ALT 50A - Approved AMOC

- **S76B** (103 aircraft)   80 aircraft have the Collins ALT-55 and 23 have the Honeywell RT-300 – Approved AMOC for Collins

- **S76C+** (148 aircraft) utilize the Collins ALT 55 - Approved AMOC

- **S76C++** (216 aircraft). These are distributed as follows:
  - Collins ALT 55 20 aircraft - Approved AMOC
  - Collins ALT 1000 93 aircraft - Approved AMOC
  - Collins ALT 1000 103 aircraft - Approved AMOC

- **S76D** (70 aircraft) utilizes the Thales AHV-1600 - Approved AMOC

5G C-Band Looking Forward

<u>The FAA, FCC and industry</u>

Both FCC and Cellular industry have stated that all voluntary power reductions and antenna activations will end on July 2023. Power levels will rise to 65dBm / Mhz across all geographic areas including airports.

Additional cellular providers will enter the C-Band frequency in July 2023. This will have an additive effect on spectrum and will increase spurious emissions.

The FAA currently is investigating how to replace the AMOC process with something more "robust". However, the airline industry is still working to certify RA's and aircraft with bandpass filters (or without depending on RA performance) prior to the end of the year. Supply chain shortages of filters and aversion to comply with FAA request is making this unlikely to be accomplished.

RA Manufactures cannot guarantee that current filtered RA's or plain RA's will be able to provide protection after July 2023.

SC-239 has not yet completed or finalized the new RA MOPS.

RA Manufacturers do not see a next generation of RA's being certified and released for installation until after 2024. That means industry rollout on aircraft may not begin to occur until 2025.

Real World Activities.

To date, out of hundred of thousand of flight hours, we do not have a confirmed case of 5G interference. This is a concern for the Aviation industry and the FAA.

While pilots have been instructed to be more “focused” on radar altimeter anomalous readings, and report them, all reports that have been investigated to date do not have a quantitative correlation to 5G interference.

The same applies to global 5G networks flight operations.

Many people (depending on interests), see this as proof that the FAA, RTCA and Aviation SMEs have over exaggerated the criticality and severity of “real world” operations.

LM SAC flights tests against mobile 5G Cellular Units have also shown no susceptibility to RA’s.

Many variables exist that can reason to such comments:

- Cellular towers are still increasing in the US, approx. 45,000 at present, to grow to 100,000 by end of first qtr 2023.
- Only two Cellular providers currently in C-Band. Spurious emissions not at worst case PSD.
- Power levels currently not at FCC max levels, 62dBm/Mhz (approx. 1.6 KW) vs 65dBm/Mhz (approx. 3.2 KW) after July 2023.
- Additional Cellular providers entering market/spectrum after July 2023.
- Power level restrictions in and around airports.

Real World Activities. (cont.)

The Department of Defense in 2022 conducted live test flights at Hill Air Force Base as part of the department's Joint Interagency Five G Radar Altimeter Interference, (JI-FRAI)

While JI-FRAI / US DoD military testing has correlated some of the RTCA lab results, but real world flights test not correlating susceptibility levels / performance.

The operational tests flew rotary and fixed wing aircraft in critical phases of flight profiles with a focus on answering what the impact C-Band 5G will have on DOD's fleet equipment.

The tests were critical to connect bench test results to a realistic representation of commercial and military deployments.

Tests at Hill captured aircraft RADALT Height Above Ground Level outputs to determine if radar altimeter interference was detected. Trials were run with 5G on and off to assist in ruling out other environmental factors. Aircraft flown included Boeing 777 and 737, UH-60 Blackhawk and FA-18 Hornet.

5G C-Band - Europe

- CEPT in Europe has harmonized 3.4-3.8 GHz for 5G spectrum auctions and deployments. The upper 100 megahertz, 3.7-3.8 GHz, is identical to the lowest 100 megahertz auctioned in the United States.
- **Finland's** carrier Elisa launched 5G service in the 3.4-3.8 GHz bandin 2018, with no interference complaints attributed to 5G*.
- **Switzerland's** Swisscom launched 5G in the 3.4-3.8 GHz bandin 2019, with no altimeter interference complaints.
- **Norway's** Telenor launched 5G in the 3.4-3.8 GHz band inMarch 2020, with no interference complaints.
- In **Italy,** Vodafone and other carriers have offered 5G service in the 3.4-3.8 GHz bandsince 2019, with no interference complaints.
- **Romania's** DIGI carrier launched 5G services in 3.6-3.8 GHzin 2019, with no reports of interference.
- In **Spain,** Vodafone, Masmovil, and Telefonica have all launched5G service in 3.4-3.8 GHz, with no reports of interference to aviation.
- Three carriers in **Ireland** have launched 5G in 3.4-3.8 GHz, with no reports of interference.
- **Hungary** haslaunched 5G service in the 3.4-3.8 GHz band, with no reports of interference.
- Since 2018,O2 has provided 5G service in the **Czech Republic** using the 3.7 GHz band, with no

5G C- Band - Asia

JAPAN

3.4 GHz 4.1 GHz 4.2-4.4 GHz 4.5-4.6 GHz

- Japan has 90,000 5G sites in service.
- Frequency separation is 100 megahertz, less than half of the 220 megahertz separation in the United States.
- No exclusions or power restrictions apply to 4 GHz and below.
  - A base station exclusion zone applies within the closest 100 MHz channels, e.g. 4.0-4.1 GHz, for 1 km x 200 m around airport landing approaches.
- No known reports of interference

SOUTH KOREA

- South Korea has deployed 195,000 5G sites in 3400-3700 MHz.
- No mitigations or exclusions are in place.
- No known reports of interference.

5G C-Band Challenges

The Aviation Industry has been actively examining the mitigations or solution they and the FAA can take to maintain operations and protect the safety of those operations.

Retrofitting radio altimeters with out-of-band filters in a timely fashion is a practical impossibility and does not offer a comprehensive solution to mitigate the risks. It also may require new mitigations post July 2023. RA Manufacturers expect this to be the case. Global supply chain management issues make this impossible to achieve by FAA's original request of end of 2022.

Operator-initiated limitations would also severely disrupt the National Airspace System; training would have limited effectiveness and cannot overcome loss of safety offered by reliably-functioning radio altimeters.

FAA options – issuance of Notices to Airmen, adoption of Airworthiness Directives, or taking Air Traffic mitigations – would result in material reductions to aviation operational capacity impacting the traveling public, critical services, and the economy.

The FCC must become more collaborative otherwise the FAA will have to enforce safety measures that will have direct impact on airline operations across the industry.

Retrofitting radio altimeters: Requires new standards to be developed and TSOs to be implemented. Not soon enough to be effective. Post 2025 at earliest.

Looking into the future

RTCA SC-239 continues to work jointly with EUROCAE Working Group 119 to develop new radar altimeter MOPS, which will include interference tolerance requirements and other parameters as part of current lessons learned from 5G deployments. No release date has been set.

New MOPS will only result in improved radar altimeter designs in the future—currently fielded radar altimeters will still be exposed to 5G. No good port July 2023 options.

FAA actions : The safety of the National Airspace System must be maintained, but it is unclear what specific actions the FAA can/will take without affecting Airline operations. Especially during a supply chain crisis period.

FCC action: FCC is under pressure by industry and USG to continue Broadband rollout. 5G is key to many aspects of trade, communication, military operations and commercial revenue. US is lagging global deployment. Starting July 2023 C-Band power levels will increase along with new Cellular providers and tower densities.

Out of the Box ideas: Use of new AGL sensor technologies to replace Radar Altimeters. LIDAR, Fusion Sensors, Laser Altimeters (good to 1500ft), etc.

Questions / Discussion