RTCA, Inc.
1150 18th Street, NW, Suite 910
Washington, DC 20036, USA

Report on Aeronautical Radio Frequency Systems, their Regulatory Framework, and Operational Considerations

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Prepared by: SC-242
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Copies of this document may be obtained from:

RTCA, Inc.
1150 18th St. NW, Suite 910
Washington, D.C. 20036, USA

Telephone: 202-833-9339
Facsimile: 202-833-9434
Internet: www.rtca.org

Please call RTCA for price and ordering information.

FOREWORD

This document was prepared by Special Committee 242 (SC-242) with EUROCAE Working Group 124 (WG-124) and approved by the RTCA Program Management Committee (PMC) on March 13, 2025 and by EUROCAE WG-124 on February 4, 2025.

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- coalescing aviation system user and provider technical requirements in a manner that helps government and industry meet their mutual objectives and responsibilities;

- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;

- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and

- assisting in developing the appropriate technical material upon which positions for the International Civil Aviation Organization and the International Telecommunication Union and other appropriate international organizations can be based.

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TABLE OF CONTENTS

1 SCOPE 1

2 USE OF RF SPECTRUM BY AVIATION 3

3 EVOLUTION OF AERONAUTICAL SPECTRUM NEEDS AND USAGE 7

4 HIGH-LEVEL AVIATION CONCEPT OF OPERATIONS 9

4.1 Aviation Safety Regulator and Air Navigation Service Providers 9
4.2 Airspace Design 11
4.3 Charted Procedures 12
4.4 Flight Operations 14
4.4.1 Flight Planning 14
4.4.2 Pushback and Taxi Out 15
4.4.3 Takeoff and Climb 16
4.4.4 Cruise 16
4.4.5 Descent and Approach 18
4.4.6 Landing and Taxi In 19
4.4.7 Search and Rescue 19
4.5 Future Technology Development and New Entrants 20
4.5.1 Future Technology in Development 20
4.5.2 Uncrewed Aircraft Systems / Advanced Air Mobility 20
4.5.3 Commercial Space Transportation 21

5 DESIGN, CERTIFICATION, AND INSTALLATION OF AVIATION SYSTEMS 23

5.1 Aircraft System Safety Assessment (SSA) 24
5.2 Development Assurance Levels 26
5.3 RF Performance Considerations 27
5.3.1 Safety Margin 28
5.4 Minimum Equipment List (MEL) / Dispatch Requirements 28
5.5 Process and timelines 29
5.6 Aviation Safety Management Systems Framework 31

6 HIGH LEVEL DESCRIPTION OF AVIATION RF SYSTEMS 33

6.1 Ground-Based Voice Communications Systems 33
6.1.1 VHF Transceivers 33
6.1.2 HF Transceivers 34
6.1.3 SELCAL 34
6.2 Ground-Based Data Communications Systems 34
6.2.1 ACARS/VDL Mode 0 (POA) 35
6.2.2 VDL Mode 2 36
6.3 Satellite Voice and Data Communications Systems 36
6.4 Other Aircraft Digital Communication Systems 37
6.4.1 AeroMACS 37
6.4.2 WAIC 37
6.4.3 UAS/RPAS CNPC Link System 38

6.5 Future Digital Data Communications Systems 38
6.5.1 LDACS 38
6.6 Navigation 38
6.6.1 NDB/ADF 38
6.6.2 VOR 39
6.6.3 ILS 40
6.6.4 Marker Beacon Receiver 42
6.6.5 DME 42
6.6.6 GNSS - Basic GNSS 43
6.6.7 GNSS – SBAS 43
6.6.8 GNSS - GBAS 44
6.6.9 GNSS Integrity Requirements 44
6.7 Enhanced Flight Vision Systems 45
6.8 Surveillance 45
6.8.1 Noncooperative Surveillance Systems 46
6.8.2 Cooperative Surveillance Systems 46
6.9 UAS/RPAS Surveillance 48
6.9.1 UAS/RPAS Ground and Airborne Surveillance Sensors 48
6.9.2 Conceptual UAS/RPAS A2X 48
6.10 Other Systems 48
6.10.1 Radar Altimeters 49
6.10.2 Weather Radar 50
6.10.3 ACAS/TCAS 50
6.10.4 GPWS/TAWS 52
6.10.5 Reactive and Predictive Windshear 52
6.10.6 Autoflight / Autoland 53
6.10.7 Takeoff Configuration 53
6.10.8 ELTs 53
6.10.9 GADSS 54

7 MEMBERSHIP 57

APPENDIX A ACRONYMS A-1

TABLE OF FIGURES

Figure 4-1: US Map with FAA ARTCC and TRACON boundaries 10
Figure 4-2: Terminal Traffic Flows Created by Airspace Design at Los Angeles International Airport (LAX) 12
Figure 4-3: Example Instrument Flight Procedures for Washington Dulles International Airport 13
Figure 4-4: Phases of a Typical Air Transport Flight 14

TABLE OF TABLES

Table 5-1: Relationship between Failure Condition Classification and Allowed Failure Rate 25
Table 5-2: Relationship between Failure Condition Classification and Development Assurance Level 27
Table 5-3: RF Systems Minimum Equipment List (MEL) Examples 29
Table 6-1: Typical GNSS Hazard Classifications 44

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1 SCOPE

This report provides high-level material to assist non-aviation stakeholders in understanding how aeronautical radio frequency (RF) systems operate and the performance required for safety-critical functions, such as availability, reliability, continuity, latency, etc.

The remainder of this report describes how aviation operates, how aviation systems are used, and the aviation lifecycle:

- Section 2 provides an overview of the use of RF spectrum by aviation.
- Section 3 describes the evolution of aeronautical spectrum needs and usage.
- Section 4 describes the high-level aviation concept of operations and how aeronautical RF systems contribute to the overall management of airspace.
- Section 5 describes the design, certification, and installation processes for avionics systems as well as the timeframes necessary for full implementation. Section 5 also includes a brief discussion of the Aviation Safety Management System Framework.
- Section 6 is a high level overview of aviation RF systems. It describes various Communications, Navigation, and Surveillance (CNS) systems and their uses.

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2 USE OF RF SPECTRUM BY AVIATION

In the century since air transportation has been in existence, aviation has evolved from a high-risk activity in its early days, to a significantly safer one where fatal accidents are extremely rare occurrences. This significant evolution has been facilitated by the use of RF devices for numerous functions enabling safety and regularity of flight.[1]

In the early days of aviation, aircraft contained basic instrumentation that allowed pilots to monitor their speed and altitude through devices that measured differences in air pressure, and their heading (direction) using magnetic compasses. Flight activity was restricted to good weather, as daytime navigation involved comparing maps and charts to ground features observed from the flight deck. At night, navigation was performed using networks of lighted ground beacons visible from the air, or by celestial navigation.

Initially, pilots were out of communication from takeoff until landing. This changed in the 1920s when the United States Post Office established a system for air mail flights, allowing pilots to communicate with flight dispatchers to report positions and obtain updated weather information via high frequency (HF) transceivers. After 1925, commercial airlines were established to carry mail and used similar dispatch methods. Air Traffic Control (ATC) began in the mid-1930s as a measure to prevent mid-air collisions as the number of flights increased. After World War II (WWII), the increase in air transportation along with the development of technologies like radar[2] increased the demand for air traffic separation services. Voice communications systems augmented HF with very high frequency (VHF), ultra-high frequency (UHF) for the military, and now satellite communications (SATCOM) for both ATC and dispatch communications, with HF remaining in use in oceanic and remote regions.

Data communications was established in the late 1970s as an additional means for pilots to communicate with their airline dispatch office, using VHF radio links. Since then, data communication has advanced to include HF, higher speed VHF, and satellite data links. In the 1990s, ATC began using data link[3] to control aircraft, initially in oceanic airspace with satellites, and now more widely with VHF ATC data links. For a variety of technical and operational reasons, including security, these data networks are largely separate from the Internet. Recently, aviation has started to make use of Internet Protocol (IP) technology and plans to adopt IP technologies for the future.

In the 1930s, navigation started using RF technology to improve the ability for pilots to navigate in or above clouds or at night by using radio waves and ground beacons to help pilots determine their aircraft's position and guide it to its destination. Early radionavigation stations included the Non-Directional Beacon (NDB), a fixed ground-based radio beacon operating in the low frequency (LF) or medium frequency (MF) bands, and the Four Course Range, which allowed for directional routes using similar frequencies. Over the past century, various navigation systems have been used such as Marker Beacons, VHF Omnidirectional Range (VOR), Instrument Landing Systems (ILS), Microwave Landing System (MLS), Distance Measuring Equipment (DME)/Tactical Air Navigation (TACAN), Omega, Long Range Navigation (LORAN), and Global Navigation Satellite

[1] Regularity of flight pertains to air-ground communications necessary for tracking aircraft and communicating with flights in relation to maintaining efficient and reliable schedules, which may include crew scheduling, maintenance information, flight times for both maintenance and crew tracking, and other items which may not rise to the level of safety of flight.

[2] Radar, which was originally an acronym for "radio detection and ranging," is a system that uses radio waves to determine the distance, direction, and radial velocity of objects relative to the transmit antenna.

[3] Data link refers to digital air/ground communications between aircraft and ground systems.

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Systems (GNSS), such as the Global Positioning System (GPS) and Galileo. Some of these systems are no longer in use and have been decommissioned (e.g. MLS and Omega). The global standardization of these systems has made international air travel possible by allowing equipped aircraft to fly anywhere in the world.

Initially, ATC separation used procedural rules and pilot reports of their position by HF or VHF voice transceiver as the surveillance source to manage aircraft separation. Air Traffic Controllers tracked aircraft locations using progress boards, which evolved to using manually updated physical markers placed on aeronautical charts. After WWII, this was replaced with radar systems – starting with Primary Surveillance Radar (PSR), which is a noncooperative surveillance system that independently identifies and tracks an aircraft's position using the reflection off the aircraft structure without the use of airborne equipment. This was later complemented by Secondary Surveillance Radar (SSR), which is a cooperative surveillance system based on military systems (e.g., Identify-Friend-or-Foe technology), that identifies and tracks an aircraft using interrogations and replies emitted from onboard aircraft transponders.

Today, transponders can transmit aircraft state information (e.g., the aircraft's identity, barometric altitude, position, etc.) using additional datalink capabilities and handle higher aircraft traffic densities as global traffic levels grow. The more recent surveillance capabilities include multilateration (MLAT) and Automatic Dependent Surveillance – Broadcast (ADS-B), which periodically broadcasts an aircraft's position and other information for reception by other aircraft as well as by ground- and space-based receivers. ADS-B can enable much better spectrum capacity efficiency, for example through passive surveillance techniques, resulting in the reduction of the required number of SSR/MLAT interrogations and replies. Onboard Airborne Collision Avoidance System (ACAS), which advises crews of potential conflicts with other aircraft in the vicinity, has been added to aircraft as another layer of collision avoidance.

Also, Airport Surface Detection Equipment (ASDE), or Advanced Surface Movement Guidance and Control Systems (A-SMGCS), is used at aerodromes to detect aircraft and vehicles on the surface of an airport. ASDE/A-SMGCS uses a combination of noncooperative surveillance systems, multilateration and ADS-B to determine aircraft, vehicles and other objects' position on the maneuvering area. ASDE/A-SMGCS has proven valuable in low visibility conditions where adverse weather and environmental conditions, like snow and smoke, increase the probability of collisions between maneuvering aircraft and vehicles authorized to operate in the vicinity of aircraft. ASDE/A-SMGCS is used by air traffic controllers to supplement visual observations.

In oceanic or remote regions out of range of ground stations, aircraft surveillance is accomplished using a combination of aircraft position reporting via satellite data links such as Automatic Dependent Surveillance – Contract (ADS-C) and ADS-B, but voice position reporting is still in use by some users in some airspace.

Several other surveillance systems are used for specialized purposes, which operate in nationally-, regionally-, or internationally-allocated frequency bands.

A specialized system used at aerodromes, using the same aircraft transponder equipment, is the Precision Runway Monitor (PRM), which enables the use of simultaneous instrument approaches to parallel runways separated by as little as 2500 ft. The PRM updates the controller display much more frequently than SSR systems, typically at once per second. PRM is migrating toward using ADS-B information. With appropriate controller and pilot training, PRM allows operations at aerodromes to maintain use of parallel runways when weather conditions would otherwise require that only a single runway be used. PRM

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approaches have been used at several airports in the United States (US) and also in Australia.

Precision Approach Radar (PAR) is a type of radar guidance system designed to provide lateral and vertical guidance to an aircraft pilot for landing, until the landing threshold is reached. Air Traffic Controllers monitoring PAR displays observe each aircraft's position and issue verbal instructions – usually via VHF radio – to the pilot that keep the aircraft on course and glidepath during final approach. Ground control approaches, like PAR, normally start with the controller relaying instructions to bring the aircraft into the glidepath and then begin any corrections needed to bring it onto the centerline.

Aviation makes extensive use of information from ground-based weather radars for flight hazard avoidance in flight planning, and traffic flow management around severe weather systems. These are the same weather radars[4] used in public news programs, and are operated for the benefits of many users beyond aviation. Pilots can also access this information in-flight using available resources, such as an Electronic Flight Bag (EFB), Fight Information Services – Broadcast (FIS-B), etc.

There are specialized aviation ground-based weather radars designed to detect hazardous conditions known as windshear.[5] These specialized radars are physically located to monitor the approach and departure paths at airports, and can provide an alert in the ATC tower to notify controllers of the presence of a windshear hazard.

There are several sensor systems on board the aircraft which use the RF spectrum to measure the aircraft's surroundings. For example, the radar altimeter (also called the radio altimeter) is a device used to directly measure the height above terrain and obstacles, which has helped improve safety especially when flying in low visibility or at night. Another sensor system is the airborne weather radar, which detects weather conditions like precipitation and windshear conditions ahead of the aircraft.

[4] For example, the WSR-88D "NexRad" radar has been deployed extensively across the US and is shared to public news organizations and emergency management organizations in addition to aviation weather services. WSR-88D operates at the 2 700 – 3 000 MHz band.

[5] For example, the US Terminal Doppler Weather Radar (TDWR), which operates at 5 600 – 5 650 MHz.

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3 EVOLUTION OF AERONAUTICAL SPECTRUM NEEDS AND USAGE

While aviation systems have evolved and adopted new technologies, the pace of change has slowed compared with the post-World War II period. In many cases this is because existing systems are providing a sufficient level of service to meet current operational and safety performance needs. This includes several systems whose performance standards were last standardized in the 1970s and 1980s, such as VHF voice, ILS, and DME.

In contrast with the slowing pace of change of technology, the aviation industry is growing dramatically: the International Civil Aviation Organization (ICAO) estimates that the number of passengers carried by airlines worldwide increased from 800 million in 1980 to 4.5 billion in 2019, a growth of about 560%.[6] Furthermore, newcomers to aviation including Uncrewed Aircraft Systems / Remotely Piloted Aircraft Systems (UAS/RPAS), Advanced Air Mobility (AAM), and Commercial Space Transportation (CST) are expected to further increase the demand for radio frequencies for flight control and payload communications. As a result, the currently deployed systems may not be able to meet anticipated growth in aviation in the future.

Given this expected growth in aviation and increasing demands from other industries, the aviation sector is considering the modernization of existing systems. The goal would be to provide better spectrum efficiency and increased capacity for new applications and newcomers. It will include efforts in digitalization of services and improved spectrum coexistence.

Aviation has achieved a high level of safety in part through the availability of complementary systems, thus avoiding single points of failure. As an example, while GNSS is the primary navigation source on most Instrument Flight Rules certified aircraft, VOR and DME are still available and required in cases such as loss of GNSS required navigational performance. Another example pertains to voice communications, where SATCOM voice services can be used to contact ATC in some remote areas where HF may have failed or experiencing disruptions. These solutions can ensure continued safety during a regional or global system disruption, but also allow for continued safe operation with minimal loss of efficiency for reasonable recovery periods.

In using spectrum to meet these needs, aviation will benefit from sound spectrum management practices exercised by national and international spectrum regulatory authorities. Careful planning for all necessary technical, operational, and regulatory changes must be taken into account when considering modifications to spectrum usage, so that aviation safety services are free from interference.

[6] ICAO, *Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis*, 27 April 2023. https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf.

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