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Evolving Avionics:
Meeting the Challenge of NextGen and SESAR

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1.1 Avionics: A Historical Perspective

1.1.1 Term

The term avionics was coined from “aviation” and “electronics” in the 1970s. If we broaden the definition to include instruments and mechanical systems, many systems such as radios, altimeters, radar, fuel gauges, and navigation instruments were used in the cockpit before the advent of electronics driven by the military.

1.1.2 Technology, Safety, and Regulations

Ever since the advent of powered flight in 1903, aviation has continuously progressed with a variety of advances in all fields, science and engineering of flight as well as how to control the skies for safety from collisions with other aircraft, terrain avoidance, weather avoidance, and safe landing and takeoff.

Industry leaders pushed to have common safety standards imposed by a government agency—the resulting Air Commerce Act in 1926 was the beginning of the federal certification authority in the United States. ATC centers were established in Newark, Cleveland, and Chicago to help pilots with en route directions. Traffic was controlled using blackboards and “shrimp boats” (paper boats signifying the airplane position) that were manually progressed depending upon the information from dispatchers, radio operators, and airports via telephone. In the history of the Federal Aviation Administration (FAA), two separate branches were created via Civil Aeronautics Act of 1938—one with the responsibility for Air Traffic Control (ATC) and another with the responsibility for safety rulemaking, accident investigation, and economic regulation of airlines. The early ATC based on visual signals and light beacons evolved to radar signals following World War II technical developments. The advent of jets and higher density of traffic provided more challenges for safety. Avoidance of midair collisions, terrain, and weather came to sharp focus with
each high-profile accident. A single department of transportation to cover all modes of transportation including air transportation was established in 1986 via congressional authorization for a cabinet department with a separate authority for accident investigation transferred to the National Transportation Safety Board. This act took the agency to become the Federal Aviation Administration that we have today. A number of rules and regulations have evolved with both the evolution of technology and the recognition of the need for new technology instigated by accidents, incidents, increase in traffic, and increase in operating costs.

1.1.3 Top Three Technologies and Air Traffic Control

The three essential technologies available to pilots in air and air traffic controllers on the ground that help tactical and strategic control of aircraft with coordinated functions are communications, navigation, and surveillance. The challenges of these systems include global compatibility and interoperability as well as affording the service to both military and civil aircraft.

The three aspects of avionics, namely, Communications, Navigation and Surveillance (CNS), have a parallel history in that advancements in one area necessitate advances in other areas. Wartime advances in navigation and radar detection required that communications be made more sophisticated. These advances were brought into civil aviation; the same radar technology that was used in military aviation was adapted to be used to control civil aviation. Increase in the air traffic necessitated more dependency on distributed CNS equipment both on ground and air to orchestrate traffic efficiently while avoiding conflicts. To address the high price of oil during the 1970s, more and more digital systems were introduced to more precisely control flight. As more and more instruments were introduced into the cockpit, some aids such as autopilots and warning systems had to be introduced to address pilot workload.

Navigation in general is determining own position and velocity so that position and velocity at a future time can be calculated with and without changes in velocity. Navigation of aircraft from a pilot point of view is to know where the aircraft is with respect to a planned track so that the aircraft motion can be controlled. Navigation consists of four functions, namely, planning, tracking, recording, and controlling the aircraft motion. Air navigation has evolved from early ship navigation. In the early days of air travel, avionics equipment for navigation was as rudimentary as following known landmarks such as rail tracks or rivers combined sometimes with sophisticated celestial navigation techniques until there was a need to fly in conditions where visibility was poor because of night flying or bad weather conditions. The basic idea of accurately locating own ship was increasingly important as the skies became crowded and they had to be strategically organized to fly specific routes via a centralized ground control. The first blind flight and landing based on navigation using gyroscopes and radio navigation aids was at the end of the 1920s. Today, aircraft could be flown under visual flight rules (VFR) or instrument flight rules (IFR). Accurate navigation technology has been used to maximize the airspace capacity while balancing safety. Navigation systems must satisfy four important categories of performance requirements, namely, accuracy, integrity, availability, and continuity of service.

The third aspect of surveillance is determination of the position and velocity of the aircraft as perceived from the outside of the aircraft (e.g., from the ground ATC). Most of the improvements in the CNS were a direct result of technologies developed during World War II. Radio beacons and directional beams came to being in the 1930s. The first ATC tower was established in 1935 at the Newark Liberty International Airport in NJ in 1935. There are two types of radar onboard the aircraft: primary surveillance radar and secondary surveillance radar. The primary surveillance radar is passive in that the ground detects the radar energy scattered from the surface of the aircraft to measure the distance and heading of the aircraft relative to the source of radar on the ground. The secondary surveillance radar is active in that the radar from the ground initiates a transponder on the aircraft that transmits a reply to the ground signal. This type of transmission can also be picked up by the surrounding aircraft to aid in collision avoidance. A unique address is given to each aircraft so that its transponder transmissions can be unambiguously identified. This addressing system is followed throughout the world so that the aircraft transponder is useful
in all airspace. Transponder signals, whether from primary surveillance radar or secondary surveillance radar, will be displayed on the ATC console. Radar signals have been extended to aid in detecting weather and terrain. Navigation and surveillance ideas have been combined using technology such as Automatic Dependent Surveillance-Broadcast (ADS-B) to accomplish avionics for collision avoidance for manned as well as unmanned systems, terrain avoidance, terminal avian hazard detection, and assistance in using parallel runways. These are only some examples of the ever-growing suite of avionics.

ATC has evolved into ATM, which is using processes, procedures, and resources to assure that aircraft are guided in the sky and on the ground. Aircraft safety is a responsibility shared and divided between the ground and the air. Since these responsibilities are so interconnected, the concepts of Required Communications Performance (RCP), Required Navigation Performance (RNP), and Required Surveillance Performance (RSP) have been introduced to support efficient separation between aircraft while addressing possible constraints of the equipment and related procedures. Thus, many of the avionics that are described in this handbook ultimately support the strategic management of aircraft in giving proper tools to the pilot.

1.2 Free Flight to NextGen/SESAR

The earliest ATC guiding multiple aircraft was in the early 1930s when the controllers tracked the position of planes using maps, blackboards, and “shrimp boats” with only telephone connections to airline dispatchers, radio operators, and other airport air traffic controllers. The same basic system continued as improvements were made to communications, radar sensor data, electronic displays, etc. Many discrete automation systems were introduced in different air traffic facilities as these were helping the ever-evolving complexity and decision making of the air traffic controllers. These systems introduced complexity in configuration management of existing functionality and any new introduction of functionality for interoperability. National Airspace System (NAS) plan was introduced by the FAA to systematically manage projected growth for air travel over the next 20 years. This plan proved to be too ambitious; a new Free Flight program was introduced to take advantage of newly developed GPS technology. This concept took NAS from a centralized command-and-control system between pilots and air traffic controllers to a distributed system that allows pilots, whenever practical, to choose their own route and file a flight plan that follows the most efficient and economical route. This concept made way to a distributed ATM, which combined distributed decision making for traffic separation and self-optimization. These traits demand that the aircraft have specific capabilities measured as required performance in CNS. The resulting concept is known as performance-based navigation, which is one of the primary concepts of NextGen and SESAR. In other words, NextGen and SESAR are programs that implement technology that will allow Free Flight concepts to be used safely and securely in an environmentally responsible manner; the concepts include transformation of the air transportation system by changing technologies, infrastructure, and procedures. The resulting demands on avionics suite to be used by aircraft are RCP, RSP, and RNP.

RCP defines the required performance of each element of the communications network, including the human element. Each element must perform with certain specifications in order to maintain defined aircraft separation standards. RCP has specific time requirement in seconds for messages sent and then received. The complete end-to-end communication limit is either 240 or 400 s based on aircraft equipment and the ability to have an alternate means of establishing communication if the primary fails.

RSP defines system technical performance requirements independent of technology and architecture to be met by an air traffic service (ATS) surveillance system in order to support a particular ATS service or function. Similar to RCP, RSP also has specific performance requirements in seconds for messages sent and received. The completed end-to-end communication cycle is either 180 or 400 s based on aircraft equipment and whether there is an alternate means of establishing communication if the primary fails.

RNP is “a statement of the navigation performance accuracy necessary for operation within a defined airspace.” There are two values that express this qualification—a distance in nautical miles called
“RNP type” and a probability measure that is 95% for 1 X RNP and 99.999% within 2 X RNP. For example, an airplane is qualified to operate in an RNP 4 airway; the aircraft must have a demonstrated capability of its navigation system to result in the airplane being within 4 nmi of the indicated position on the navigation system at least 95% of the flight duration within a given flight segment or phase. It is also necessary for the navigation system to issue a warning to the pilot when this condition cannot be met. Within the “containment limit” of twice the RNP, in this example, 8 nmi of the indicated position, the indicated position on the navigation display panel which includes the total system error is expected to not exceed the designated RNP number at least 99.999% of the flight duration within the same segment or phase.

Required total system performance (RTSP) is a combination of RNP, RSP, and RCP as well ATC surveillance capability, which defines a benchmark for separation minima and collision safety risk. The required performances are operationally derived without any dependency on any specific techniques, technologies, and/or architecture.

Evolution in ATM impacts airborne avionics equipment, flight planning, airspace planning, ground infrastructure, procedures used for managing flight traffic, certification, and related activities and stakeholders. This evolution can be viewed by many of these perspectives; indeed there have been many industry activities that have contributed to this evolution.

### 1.3 NextGen

GPS technology has given pilots the tools needed for planning point-to-point flights rather than planning via way points. This satellite-based system will allow for shorter routes, savings in time and fuel, reduction of delays, and increase in en route capacity by giving pilots the tools to fly closer together on direct routes. Better communication between pilots and ground controllers will accommodate an efficient use of airports. Data fusion is being planned to collect global weather observations into a common weather picture.

![Diagram of NextGen core set of tools](https://www.faa.gov/about/office_org/field_offices/fsdo/orl/local_more/media/fy13summit/NEXTGEN_MCO_Safety_Summit.pdf)

**FIGURE 1.1** Core set of tools for NextGen. (Courtesy of Federal Aviation Administration, Washington, DC, Available online at: https://www.faa.gov/about/office_org/field_offices/fsdo/orl/local_more/media/fy13summit/NEXTGEN_MCO_Safety_Summit.pdf, accessed on April 27, 2014.)
to enable better tactical and strategic traffic management decisions. These various goals are being accomplished by a core set of tools shown in Figure 1.1: NAS Voice System (NVS) accommodates the key voice communication component of NextGen, System-Wide Information Management (SWIM) allows sharing of information, Common Support Services Wx (CSS-Wx) is used for disseminating weather information via SWIM, Collaborative Air Traffic Management Technologies (CATMT) provides enhancements to existing traffic flow management systems and works with SWIM, ERAM processes flight radar data and provides real-time aeronautical information, and ADS-B increases situational awareness. While some of the following goals are still experimental, some have already been realized in the field as published/updated by the FAA:

1. Use of GPS and ADS-B to create a single real-time display of air traffic that has the same information disseminated to both pilots and air traffic controllers. The use of satellite-based precision approach procedures can be done even in low visibility, without needing ground-based landing systems; many small airports may have only one or no instrument landing system.
2. Creation and provision of a common weather picture across the national airspace. Many different tools provide icing and turbulence information at different altitudes to pilots.
3. Greater use of data communications via data link for routine messages between pilots and controllers.
4. Use of a single voice communication system for air/ground and ground/ground communications.
5. Integration of unmanned aircraft system into the airspace

NextGen utilities and concepts are being put into place in a number of airports with decidedly positive results.

SWIM is the key tool that is used in common with international systems to make NextGen compatible with SESAR. SWIM is used for collecting and sharing system-wide information of aircraft and ground facilities. SWIM services handle five data domains, namely, flight data, aeronautical data, weather data, surveillance data, and capacity and demand data. SWIM was adopted by ICAO in 2005. This service-oriented architecture uses existing networks, off-the-shelf hardware, and SWIM-compatible software tools to provide sharing of near real-time information by airline operations, air traffic managers and controllers, and the military (Figure 1.2).

FIGURE 1.2 (See color insert.) Tomorrow: Evolved sector with data comm. (Courtesy of Federal Aviation Administration, Washington, DC, Available online at: https://www.faa.gov/about/office_org/field_offices/fsdo/orl/local_more/media/fy13summit/NEXTGEN_MCO_Safety_Summit.pdf, accessed on April 27, 2014.)
1.4 SESAR

Since Europe is made up of different countries, there is no single management of air navigation services. ATC over Europe is extremely busy and dense. These factors make for a very complex system. The initiative of Single European Sky was introduced to provide a uniform level of safety and efficiency for all of Europe by reorganizing and restructuring European airspace without being constrained to national borders. SESAR is a joint undertaking among all of the stakeholders to define, develop, and deploy a high-performance ATC infrastructure. Converting from airspace-based management to trajectory-based operations and employing an integrated data communication system are the important features of SESAR, just as NextGen. A set of key performance areas has been defined to focus and measure the progress. These performance areas are interdependent but have to be balanced in making trade-off decisions. The performance areas focus on accommodating increase in traffic in a safe and efficient manner with environmentally friendly methods. SESAR trials have proven success in select airports.

1.5 Summary

For both concepts, NEXTGEN and SESAR, the operations are based on shared net-centric information to aid collaborative decision making by all stakeholders and trajectory-based operations for efficient use of resources in both air and ground. There are differences between the two systems in the way the data are compiled and distributed, while NextGen is more centralized, SESAR is distributed. NextGen is mainly government controlled to ensure interoperability of components, while SESAR is a single multi-stakeholder consortium. Both NextGen and SESAR represent enormous challenges since the change is one of a paradigm shift and adaptation to new technology. European and American authorities have an agreement on interoperability between their respective ATM infrastructures, thus allowing for uniformity in required avionics capabilities as well.

Further Reading

