APPENDIX A

Basics of Air Traffic Control

APPENDIX A BASICS OF AIR TRAFFIC CONTROL

The Air Traffic Flight Procedure Evaluation (Flight Procedure Evaluation) report often references air traffic control (ATC); therefore, the best way to understand the information presented in the report is to have a basic understanding of ATC requirements. This appendix provides basic background information on the National Airspace System (NAS), the role of ATC, the aircraft flow within the NAS, the type of ATC facilities, ATC requirements, and the Federal Aviation Administration's (FAA's) Next Generation Air Transportation System (NextGen)[28] program.

A.1 NATIONAL AIRSPACE SYSTEM

Under the Federal Aviation Act of 1958 (49 U.S.C. § 40101 et seq.), the FAA was delegated control over use of the nation's navigable airspace and the regulation of domestic civil and military aircraft operations in the interest of maintaining safety and efficiency.[29] To help fulfill this mandate, the FAA established the NAS. Within the NAS, the FAA provides air traffic services for aircraft takeoffs, landings, and the flow of aircraft between airports through a system of infrastructure (e.g., ATC facilities), people (e.g., air traffic controllers, maintenance, and support personnel), and technology (e.g., radar, communications equipment, and ground-based navigational aids [NAVAIDs[30]]). The NAS is governed by various FAA rules and regulations. The NAS comprises one of the most complex aviation networks in the world. The FAA continuously reviews the design of all NAS resources to ensure they are effectively and efficiently managed. The FAA Air Traffic Organization (ATO) is the primary organization responsible for managing airspace and flight procedures in the NAS. When changes are proposed to the NAS, the FAA works to ensure the changes maintain or enhance system safety and improve efficiency. One way to accomplish this mission is to employ emerging technologies to increase system flexibility and predictability.[31]

A.2 AIR TRAFFIC CONTROL IN THE NATIONAL AIRSPACE SYSTEM

The combination of infrastructure, people, and technology used to monitor and guide (or direct) aircraft within the NAS is referred to collectively as ATC. It is the responsibility of ATC to maintain safety and to expedite the flow of traffic in the NAS by applying defined minimum distances or altitude between aircraft (referred to as "separation"). This is accomplished through required communications between air traffic controllers and pilots and the use of navigational technologies.

Described in Title 14 Code of Federal Regulations (CFR) Part 91, aircraft operate under two distinct categories of flight rules: Visual Flight Rules (VFR) and Instrument Flight Rules (IFR).[32] These flight rules generally correspond to

[28] The Next Generation Air Transportation System (NextGen) is a portfolio of multiple programs to modernize America's air transportation system to make flying even safer, more efficient, and more predictable.

[29] Title 49 United States Code, Section 40101(d)4.

[30] NAVAIDs are facilities that transmit signals that define key points or routes.

[31] U.S. Department of Transportation, Federal Aviation Administration, *FY 2018 Organizational Success Increase/Measures*, December 12, 2017, https://www.faa.gov/about/plans_reports/media/fy18_osi_osm.pdf (accessed September 12, 2018).

[32] Title 14 Code of Federal Regulations 91.151 through 91.193, "Visual Flight Rules" and "Instrument Flight Rules."

two categories of weather conditions: Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC).

VMC generally occur during fair to good weather, when good visibility conditions exist. IMC occur during periods when visibility falls to less than 3 statute miles or the cloud ceiling (i.e., the distance from the ground to the bottom layer of clouds, defined as the point where the clouds cover more than 50 percent of the sky) drops to lower than 1,000 feet, Correspondingly, a pilot is responsible to "see and avoid" under VFR to maintain safe separations from other aircraft and obstacles. IFR are designed for use when separation from other flying aircraft and terrain is maintained by cockpit instrument reference and radar separation. Under IFR, aircraft operators are required to file flight plans, maintain two-way radio communications, and use navigational instruments to operate within the NAS. Pilots must follow IFR during IMC. Regardless of weather conditions, most commercial air traffic operates under IFR.[33]

Depending on whether aircraft are operating under IFR or VFR, air traffic controllers apply various techniques to maintain defined minimum distances (referred to as separations) between aircraft,[34] including the following:

- **Vertical or "Altitude" Separation**: separation between aircraft operating at different altitudes
- **Longitudinal or "In-Trail" Separation**: separation between two aircraft operating along the same flight route, referring to the distance between a lead and a following aircraft
- **Lateral or "Side-by-Side" Separation**: separation between aircraft (left or right side) operating along two separate but nearby flight routes
- **Divergent Heading**: separation between two aircraft operating from the same runway must be going away from each other (diverging) at least at 15 degrees (or 10 degrees if both aircraft are assigned an RNAV procedure, previously termed as Equivalent Lateral Spacing Operations [ELSO]) from each other based on assigned (issued by ATC or indicated on a procedure) headings from the departure end of the runway

Air traffic controllers use radar to monitor aircraft and to provide services that ensure separation. Published instrument procedures provide pilots and controllers predictable, efficient routes that move aircraft through the NAS in a safe and orderly manner. These procedures reduce verbal communication between air traffic controllers and pilots.

Published instrument procedures may be categorized as conventional or Performance Based Navigation (PBN). Conventional procedures are predicated on ground-based NAVAIDs, while PBN utilizes satellite-based navigation and cockpit Flight Management Systems (FMS) .[35]

In its effort to modernize the NAS, the FAA has implemented multiple instrument procedures that use advanced PBN technologies. A primary technology in this effort is Area Navigation (RNAV). RNAV uses technology, including

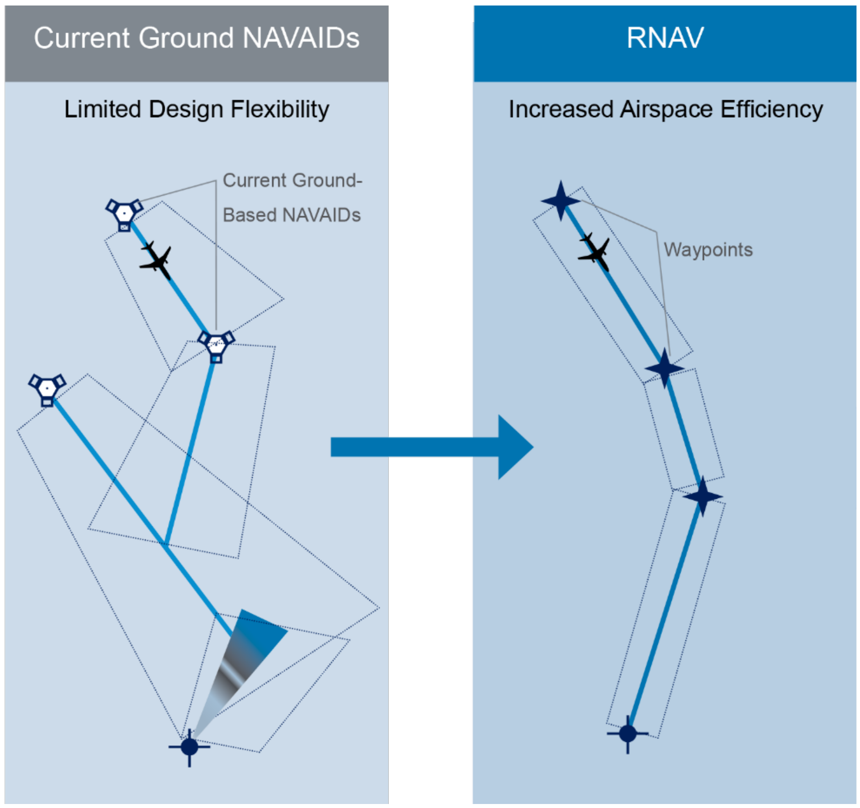
[33] Title 14 Code of Federal Regulations Part 121, "Operating Requirements: Domestic, Flag, and Supplemental Operations," October 2, 2018.

[34] Defined in FAA Order JO 7110.65X, *Air Traffic Control,* October 12, 2017.

[35] Flight Management System (FMS) is an onboard navigation system that includes a navigation database, positioning sensors, automatic flight guidance, and a flight management computer. As a system, it references the entered flight path, uses various sensors to determine the aircraft's position, and provides automatic flight guidance to fly the aircraft or to assist the pilot along the designated flight path laterally and vertically.

Global Positioning Satellites (GPS),[36] to allow an RNAV-equipped aircraft to fly a more efficient route that is not solely dependent upon ground-based NAVAIDS. This route is based on instrument guidance that references an aircraft's position relative to ground-based NAVAIDs or satellites. **Exhibit A-1** compares a conventional procedure to an RNAV procedure.

EXHIBIT A-1 COMPARISON OF ROUTES FOLLOWING CONVENTIONAL VERSUS RNAV PROCEDURES



NOTES:
NAVAIDS – Navigational Aids
RNAV – Area Navigation
SOURCE: U.S. Department of Transportation, Federal Aviation Administration, June 2016.

In addition to published instrument procedures, air traffic controllers use a variety of methods and coordination techniques to maintain safety and efficiency within the NAS:

- **Vectors**: FAA ATC issues directional headings to pilots to provide navigational guidance and to maintain separation between aircraft and/or obstacles.
- **Speed Control**: FAA ATC issues instructions to pilots to reduce or increase aircraft speed to maintain separation between aircraft.

[36] Global Positioning System (GPS) is a space-based radio-navigation system consisting of a constellation of satellites and a network of ground stations used for monitoring and control.

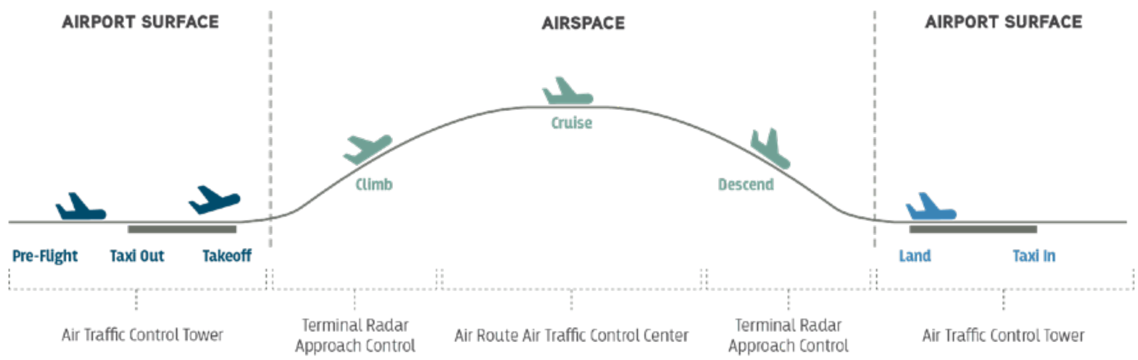
- **Reroute**: FAA ATC may change an aircraft's route for a variety of reasons, such as avoidance of inclement weather, to maintain separation between aircraft, and/or to protect airspace.
- **Point-out**: An FAA ATC controller issues a notification when an aircraft might pass through or affects another controller's airspace and radio communications will not be transferred.
- **Holding Pattern/Ground Hold**: FAA ATC controllers assign aircraft to a holding pattern in the air or hold aircraft on the ground before departure to maintain separation between aircraft and to manage arrival/departure volume.
- **Altitude Assignment/Level-off**: FAA ATC controllers assign altitudes to maintain separation between aircraft and/or to protect airspace. This may result in aircraft "leveling off" during ascent or descent.

A.3 AIRCRAFT FLOW IN THE NATIONAL AIRSPACE SYSTEM

As an aircraft moves from origin to destination, ATC personnel function as a team and transfer control of the aircraft from one controller to the next and from one ATC facility to the next. An aircraft traveling from airport to airport typically operates through six phases of flight (plus a "preflight" phase). **Exhibit A-2** depicts the typical phases of flight for a commercial aircraft. These phases include:

- **Preflight (Flight Planning)**: the preflight route planning and flight checks performed in preparation for takeoff
- **Pushback/Taxi/Takeoff**: the aircraft's transition across the airfield from pushback at the gate, taxiing to an assigned runway, and takeoff from the runway
- **Departure**: the aircraft's in-flight transition from takeoff to the enroute phase of flight, during which it climbs to the assigned cruising altitude
- **Enroute**: generally, the level segment of flight (i.e., cruising altitude) between the departure and destination airports
- **Descent**: the aircraft's in-flight transition from an assigned cruising altitude to the point at which the pilot initiates the approach to a runway at the destination airport
- **Approach**: the segment of flight during which an aircraft follows a standard procedure that guides the aircraft to the landing runway
- **Landing**: touchdown of the aircraft at the destination airport and taxiing from the runway to the gate or parking position

EXHIBIT A-2 TYPICAL PHASES OF A COMMERCIAL AIRCRAFT FLIGHT



SOURCE: Ricondo & Associates, Inc., February 2019.

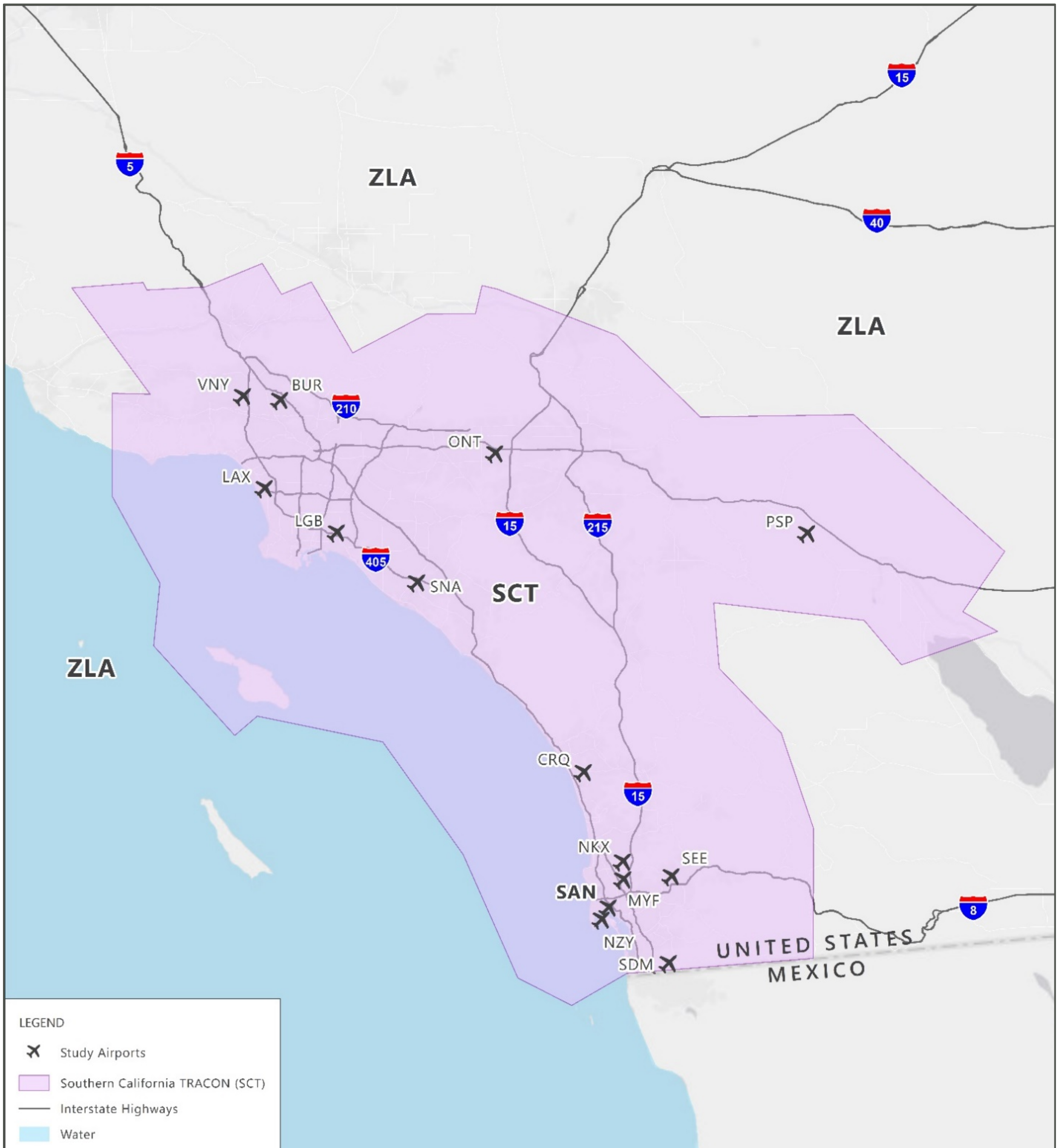
A.4 AIR TRAFFIC CONTROL FACILITIES IN THE NATIONAL AIRSPACE SYSTEM

Multiple FAA ATC facilities manage and coordinate the flow of traffic in the NAS. The NAS is organized into three-dimensional areas of navigable airspace that are defined by a floor, a ceiling, and a lateral boundary. Each is controlled by different types of ATC facilities:

- **Airport Traffic Control Tower**: Controllers at an Airport Traffic Control Tower (ATCT) located at an airport provide air traffic services for phases of flight associated with aircraft takeoff and landing (including final approach to runway). The ATCT typically controls airspace extending from the airport out to a distance of several miles. For San Diego International Airport (SDIA), the ATCT manages airfield taxiway movements, takeoff and landings on Runway 9-27, final approach to the runway, and initial departure headings from the runway. The Flight Procedure Evaluation seeks to evaluate design concepts that do not affect the ATCT's ability to manage traffic safely and efficiently, and it will not propose changes to ground control procedures and final approach or reduce available departure headings.
- **Terminal Radar Approach Control**: Controllers at a Terminal Radar Approach Control (TRACON) provide air traffic service to aircraft as they transition between an airport and the enroute phase of flight, as well as from the enroute phase of flight to an airport. This includes the departure, descent, and approach phases of flights. This part of the airspace managed by a TRACON is typically called the "terminal airspace." The TRACON airspace is broken down into sectors. As an aircraft moves between sectors, responsibility for it transfers from controller to controller. Air traffic controllers maintain separation between aircraft that operate within their sectors. The terminal airspace in the Southern California area, which includes SDIA traffic, is referred to as the Southern California TRACON (SCT TRACON) and is depicted on **Exhibit A-3**, with SDIA's location depicted for reference. SCT TRACON controllers provide air traffic services for terminal airspace from the surface to as high as 17,000 feet mean seal level[37] (MSL). ANAC Recommendations 14, 15, and 16 suggest flight procedure changes that are managed by SCT TRACON.

[37] Mean sea level is the altitude in feet compared to the average sea level (referenced with a 0 altitude).

EXHIBIT A-3 SOUTHERN CALIFORNIA TERMINAL RADAR APPROACH CONTROL (TRACON) AREA



NOTES:

ZLA – Los Angeles Center
LAX – Los Angeles International Airport
NZY – North Island Naval Air Station (Halsey Field)
SDM – Brown Field Municipal Airport
SCT – Southern California TRACON
LGB – Long Beach Airport (Daugherty Field)
ONT – Ontario International Airport
SEE – Gillespie Field Airport
BUR – Bob Hope Airport
MYF – Montgomery Field Airport
PSP – Palm Springs International Airport
SNA – John Wayne – Orange County Airport
CRQ – McClellan-Palomar Airport
NKX – Miramar Marine Corps Air Station
SAN – San Diego International Airport
VNY – Van Nuys Airport

SOURCE: Esri, HERE, Garmin, OpenStreetMap Contributors, and the GIS User Community, January 2019 (basemap); Natural Earth, 2019 (ocean); U.S. Census Bureau, Geography Division, TIGER/Line Shapefiles, 2019 (roads); U.S. National Atlas Airports, 2018 (airports); Federal Aviation Administration, February 2019 (SCT TRACON boundary)

- **Air Route Traffic Control Centers**: Air traffic controllers at Air Route Traffic Control Centers (ARTCCs or Centers) provide air traffic services during the departure phase outside of TRACON airspace, the enroute phase of flight, and the descent phase outside of TRACON airspace. Similar to TRACON airspace, the Center airspace is broken down into sectors. Within the study area for the Flight Procedure Evaluation, the Los Angeles Air Route Traffic Control Center (ZLA ARTCC) is responsible for departures and descents above and/or outside the delegated airspace to the SCT TRACON facility. This evaluation focuses on procedure designs within SCT TRACON airspace, and it will not change procedures that involve ZLA ARTCC control.

The following section provides an overview of how air traffic controllers at these ATC facilities control the phases of flight of IFR aircraft. The discussion is organized by departure flow, which includes the phases of flight from departure to enroute, and arrival flow, which includes the enroute to the descent and approach phases of flight.

A.4.1 DEPARTURE FLOW

As an aircraft operating under IFR, also known as an "IFR aircraft," departs a runway and follows its assigned heading, it moves from the ATCT airspace, through the terminal airspace, and into enroute airspace where it proceeds on a specific path[38] to its destination airport.

Within the terminal airspace, TRACON controllers provide services to aircraft departing from the ATCT airspace to transfer control points referred to as "exit points." An exit point represents an area along the boundary between terminal airspace and enroute airspace. Exit points are generally established near commonly used paths to efficiently transfer aircraft between terminal and enroute airspace. When aircraft pass through the exit point, control transfers from TRACON to ARTCC controllers.

At busy airports like SDIA, departing IFR aircraft use a procedure called a Standard Instrument Departure (SID). A SID provides pilots with defined lateral and vertical guidance to facilitate safe and predictable navigation from an airport through the terminal airspace to a specific high-altitude route in the enroute airspace. A "conventional" SID follows a route defined by ground-based NAVAIDs; it may be based on air traffic controller–issued headings or vectoring, or both. Because of the increased precision inherent in RNAV technology, an RNAV SID defines a more predictable path through the airspace than a conventional SID through the combination of GPS and aircraft FMS. Some RNAV SIDs may be designed to include routes called "runway transitions" that serve specific runways at airports. Transitions are a series of fixes leading to/from a common route. A runway transition serves as a defined route from a runway to join a specific point or commonly used route. A runway transition may be based on an ATCT-issued heading towards a waypoint or a well-defined route starting near the departure end of a runway. A SID may have several runway transitions serving one or more runways at one or more airports. After the runway transition, aircraft may operate along a common path before being directed along one or several diverging routes referred to as "enroute transitions." Enroute transitions may terminate at exit fixes or continue into enroute airspace where aircraft join a specific high-altitude route.

[38] FAA standard procedures refer to a line between two fix points (e.g., waypoints, fixes, or NAVAIDS) as a "route." FAA standard procedure plates depict the defined route. Procedure design may not translate to an aircraft located exactly on the route, especially if the route involves turns. For purposes of this evaluation, the expected location of an aircraft on a standard procedure is referred to as a "path." Differences between the definitions for "route" and "path" are applied to avoid confusion between the FAA's definition of a route and where aircraft are expected to be located.

A.4.2 ARRIVAL FLOW

An aircraft begins the descent phase of flight within the enroute airspace. During descent, the aircraft transitions into the terminal airspace through an “entry point” bound for the destination airport. The entry point represents a point along the boundary between terminal airspace and enroute airspace where control of the aircraft transfers from ARTCC to TRACON controllers.

Aircraft that arrive in a busy terminal airspace, like SCT TRACON, normally follow an instrument procedure called a Standard Terminal Arrival Route (STAR). Conventional and RNAV STARs are similar to conventional and RNAV SIDs. Aircraft leaving enroute airspace and entering terminal airspace may follow an enroute transition route from an entry fix to the STAR’s common route in the terminal airspace. From the common route segment, aircraft may follow a runway transition route that directs aircraft along a path to a point near an airport or to a point where an instrument final approach starts (called the initial approach fix) before joining the final approach to an airport. The final approach is the segment of flight along which an aircraft is aligned with the landing runway and operates along a straight route at a constant descent rate to the runway. A STAR can also provide partial guidance through the terminal airspace (e.g., it may not include runway transitions, so air traffic controllers would vector aircraft to the final approach to a runway). To efficiently manage the merge of arrivals from multiple directions on to a final approach to a runway, air traffic controllers typically direct pilots to turn and descend at various locations. Once an aircraft is established on the final approach to a runway and is between 4 to 5 nautical miles (NM) from the runway, TRACON transfers control to ATCT. ATCT monitors the aircraft on final approach and clears the pilot to land on the runway.

A.5 AIR TRAFFIC CONTROL REQUIREMENTS

As controllers manage the flow of aircraft into, out of, and within the NAS, they maintain some of the following separation distances between aircraft[39]:

- **Altitude Separation** (vertical): When operating below 41,000 feet MSL, two aircraft must be at least 1,000 feet above/below each other until or unless lateral separation is ensured.
- **In-Trail Separation** (longitudinal): Within a radar-controlled area, the minimum distance between two aircraft on the same route (i.e., in-trail) can be between 2.5 and 10.0 NM, depending on factors such as aircraft class, weight, radar coverage, and type of airspace.
- **Side-by-Side Separation** (lateral): Similar to in-trail separation, the minimum side-by-side separation between aircraft must be at least 3.0 NM in terminal airspace and 5.0 NM in enroute airspace.
- **Visual Separation**: Aircraft may be separated by visual means when other approved separation is assured before and after the application of visual separation.

[39] For a detailed explanation of separation standards, see FAA Order 7110.65X, *Air Traffic Control*, October 12, 2017.

A.6 NEXTGEN PROGRAM OVERVIEW

NextGen is a portfolio of multiple programs to modernize America's air transportation system to make flying even safer, more efficient, and more predictable.[40] One of the NextGen programs is the PBN program, which is the FAA's long-term plan to modernize the NAS from a ground-based system of ATC to a GPS-based system of air traffic management that allows for the development of PBN procedures.[41] Achieving the NextGen system requires implementing RNAV and/or Required Navigation Performance (RNP)[42] PBN procedures to take advantage of readily available aircraft "auto-pilot" and FMS capabilities. Instead of relying on ground-based navigational aids, aircraft may operate along routes using waypoints. Waypoint locations are not dependent upon ground-based navigational aids; therefore, not limited to where a waypoint may be located. With less limits, routes between Point A and B can be shorter. More than 90 percent of U.S. scheduled air carriers are equipped for some level of FMS systems capable of navigating PBN RNAV procedures. Because RNAV and RNP capabilities are now readily available on aircraft, PBN can serve as the primary means aircraft use to navigate along a route in the NAS.

The following subsections describe the two types of PBN procedures, RNAV and RNP, in greater detail.

A.6.1 AREA NAVIGATION

Exhibit A-4 compares conventional and RNAV routes. Conventional procedures rely primarily on ground-based NAVAIDs. Routes based on ground-based NAVAIDs rely on the aircraft equipment directly communicating with the NAVAID radio signal, and they are often limited by issues such as line-of-sight and signal reception accuracy. NAVAIDs such as Very High Frequency (VHF) Omnidirectional Ranges (VORs) are affected by variable terrain and other obstructions that can limit their signal accuracy. RNAV enables aircraft traveling through terminal and enroute airspace to follow any desired flight route within the coverage of ground-based NAVAIDs or GPS-based navigational aids, rather than flying a point-to-point route over NAVAIDs following a conventional procedure. RNAV enables aircraft traveling through terminal and enroute airspace to follow more accurate and better-defined routes compared to conventional procedures. This results in more predictable routes and altitudes that can be preplanned by the pilot and ATC. Predictable routes improve the ability to ensure vertical, longitudinal, and lateral separation among aircraft.

Consequently, a route that is dependent upon ground-based NAVAIDs requires at least 6 NM of clearance on either side of its main path to ensure accurate signal reception. As demonstrated by the thin black lines on Exhibit 3-4, this clearance requirement increases the farther an aircraft is from the VOR. In comparison, RNAV signal accuracy requires only 2 NM of clearance on either side of a route's main path.

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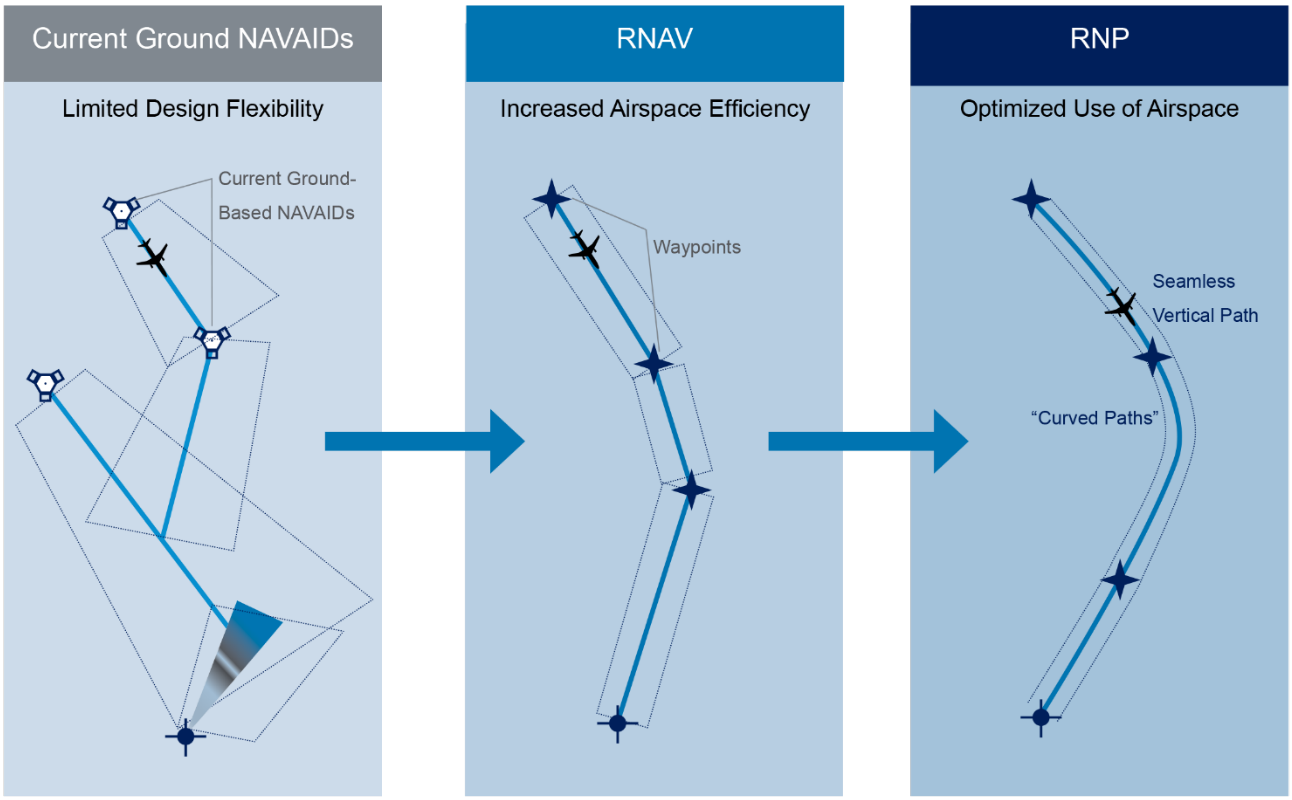
[40] U.S. Department of Transportation, Federal Aviation Administration, Modernization of U.S. Airspace, "What is NextGen?" May 7, 2018, https://www.faa.gov/nextgen/what_is_nextgen/ (accessed October 5, 2018).

[41] U.S. Department of Transportation, Federal Aviation Administration, Modernization of U.S. Airspace, "New Technology," August 31, 2018, https://www.faa.gov/nextgen/how_nextgen_works/new_technology/ (accessed October 5, 2018).

[42] Required Navigation Performance (RNP) is an RNAV procedure with signal accuracy that is increased through the use of onboard performance-monitoring and alerting systems. RNP enables the aircraft navigation system to monitor the navigation performance it achieves and to inform the pilots if the requirement is not met during an operation. An RNP value indicates how far an aircraft can be from a designed route. The lower the number, the closer an aircraft must be to the route to maintain compliance. An RNAV procedure that requires greater accuracy (less than 1 nautical mile on either side of a route) requires additional onboard performance-monitoring and alerting equipment, as well as special pilot training.

EXHIBIT A-4 COMPARISON OF ROUTES FOLLOWING CONVENTIONAL VERSUS RNAV AND RNP PROCEDURES



NOTES:
NAVAIDS – Navigational Aids
RNAV – Area Navigation
RNP – Required Navigation Performance
SOURCE: U.S. Department of Transportation, Federal Aviation Administration, June 2016.

A.6.2 REQUIRED NAVIGATION PERFORMANCE

RNP is an RNAV procedure with signal accuracy that is increased using onboard performance monitoring and alerting systems. An RNP is an RNAV procedure that requires greater accuracy of onboard performance-monitoring and alerting equipment, as well as special pilot training. A defining characteristic of an RNP operation is the ability for an RNP-capable aircraft navigation system to monitor the accuracy of its navigation (based on the number of GPS satellite signals available to pinpoint the aircraft location) and to inform the crew if the required data becomes unavailable.

Exhibit A-4 compares conventional, RNAV, and RNP procedures. It shows how an RNP-capable aircraft navigation system provides a more accurate location (down to less than a mile from the intended path) and will follow a highly predictable path. The enhanced accuracy and predictability make it possible to implement procedures within controlled airspace that are not always possible under the current air traffic system.