A. Basic Concepts of Performance Based Navigation (PBN) and Air Traffic Control (ATC)

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A.1 Air Traffic Control and the National Airspace System

The following sections provide basic background information on air traffic control and the NAS. This information includes a description of the NAS, the role of air traffic control (ATC), the methods air traffic controllers use to provide services within the air traffic control system, and the different phases of aircraft flight within the NAS.

A.1.1 National Airspace System

Under the Federal Aviation Act of 1958 (49 USC § 40101 *et seq*.), the FAA is delegated control over use of the nation's navigable airspace and regulation of domestic civil and military aircraft operations in the interest of maintaining safety and efficiency. 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., air traffic control facilities), people (e.g., air traffic controllers, maintenance, and support personnel), and technology (e.g., radar, communications equipment, ground-based navigational aids [NAVAIDs],[1] etc.). The NAS is governed by various FAA rules and regulations.

The NAS is 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 to the NAS are proposed, the FAA works to ensure that 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.[2]

A.1.2 Air Traffic Control within the National Airspace System

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

Aircraft operate under two distinct categories of flight rules: Visual Flight Rules (VFR) and Instrument Flight Rules (IFR).[3] Under VFR, pilots are responsible to "see and avoid" other aircraft and obstacles such as terrain to maintain safe separation. Under IFR, aircraft operators are required to file flight plans and use navigational instruments to operate within the NAS. The majority of commercial air traffic operates under IFR.

Depending on whether aircraft are operating under IFR or VFR, air traffic controllers apply various techniques to maintain separation between aircraft,[4] including the following:

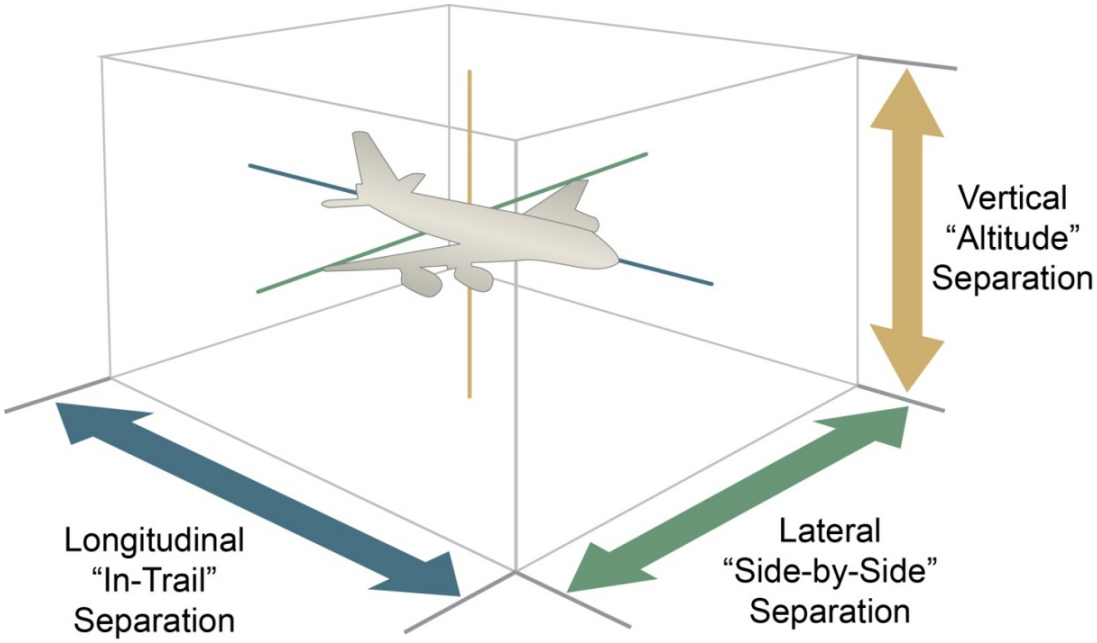
- **Vertical or "Altitude" Separation:** separation between aircraft operating at different altitudes

1 NAVAIDs are facilities that transmit signals that define key points or routes.
2 U.S. Department of Transportation, Federal Aviation Administration, FAA Order JO 7400.2M, Change 3, *Procedures for Handling Airspace Matters*, Section 32-3-5(b) "National Airspace Redesign," April 10, 2008.
3 14 Code of Federal Regulations (C.F.R.), Part 91.
4 Defined in FAA Order JO 7110.65Z Basic with Change 1 and Change 2, *Air Traffic Control*. May 5, 2021.

- **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.

Exhibit 1-1 depicts the three dimensions around an aircraft used to determine separation.

Exhibit 1-1 Three Dimensions Around an Aircraft



Source: ATAC Corporation, December 2012
Prepared by: ATAC Corporation, September 2022

In its aim to modernize the NAS, the FAA is developing instrument ATC procedures that use advanced technologies. A primary technology in this effort is RNAV. RNAV uses technology, including Global Positioning System (GPS), to allow an RNAV-equipped aircraft to fly a more efficient route. This route is based on instrument guidance that references an aircraft's position relative to ground-based NAVAIDs or satellites.

ATC uses a variety of methods and coordination techniques to maintain safety within the NAS, including:

- **Vectors:** Directional headings issued to aircraft to provide navigational guidance and to maintain separation between aircraft and/or obstacles.
- **Speed Control:** Instructions issued to aircraft to reduce or increase aircraft speed to maintain separation between aircraft.
- **Holding Pattern/Ground Hold:** 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:** Controllers assign altitudes to maintain separation between aircraft and/or to protect airspace. This may result in aircraft "leveling off" during ascent or descent.
- **Reroute:** Controllers 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:** Notification issued by one controller when an aircraft might pass through or affect another controller's airspace and radio communications will not be transferred.

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. In addition to ATC as the human element of airspace management, there are specific procedures that exist to provide the standardized guidance for aircraft operating under IFR to follow under a complex set of rules, regulations, and operational practices. Each of these components are driven by safety and standardization criteria.

A.1.3 Instrument Flight Procedures

An instrument flight procedure[5] (IFP) is a series of predetermined maneuvers for aircraft operating under instrument flight rules, i.e., IFR conditions, when visual flight is not possible due to weather or other visually restrictive conditions. These maneuvers allow for the orderly transition of the aircraft through a particular airspace. The term "instrument flight procedure" refers to instrument approaches, instrument departures, and instrument en route operations.

IFR approach procedures are developed and approved for a specific airport. These procedures are critical to flight safety and safe operations during periods of marginal weather/visibility and in areas of adverse terrain.

Instrument approach procedures also allow for the transition from en route operations to the terminal area for landing at the destination airport. The instrument approach procedure uses ground- or satellite-based systems to provide guidance and obstruction clearance to the runway or to an altitude from which visual operations for landing can begin.

Departure procedures allow for orderly movement along a specified route providing obstruction clearances from the point of departure to a position at which en route operations can begin.

A.1.3.1 Standard Instrument Departure

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 route in the en route airspace. A "conventional" SID follows a route defined by ground-based NAVAIDs, may be based on vectoring, or both. Because of the increased precision inherent in RNAV technology, an RNAV SID defines a more predictable route through the airspace than a conventional SID.

5 FAA text located at https://www.faa.gov/air_traffic/flight_info/aeronav/faq

Some RNAV SIDs may be designed to include paths called "runway transitions" that serve particular runways at airports. Transitions are a series of fixes leading to/from a common route. They serve as the entry and exit points into terminal and en route airspace. A SID may have several runway transitions serving one or more runways at one or more airports. From the runway transition, aircraft may follow a common path before being directed along one or several diverging routes referred to as "en route transitions." En route transitions may terminate at exit fixes or continue into en route airspace where aircraft join a specific route.

A.1.3.2 Standard Terminal Arrival

Aircraft that arrive in the terminal airspace normally follow an instrument procedure called a Standard Terminal Arrival (STAR). Aircraft leaving en route airspace and entering terminal airspace may follow an en route transition 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 before making an approach to the airport.

A.1.3.3 Instrument Approach Procedure

An Instrument Approach Procedure (IAP), also referred to as a Standard Instrument Approach Procedure (SIAP), is more generally a series of predetermined maneuvers for the orderly transfer of an aircraft under instrument flight conditions from the beginning of the initial approach to a landing or to a point from which a landing may be made visually. An IAP covers that portion of approach and landing using instruments for navigation guidance based on an instrument approach procedure. There are two methods for executing instrument approach operations associated with a runway or runways:

- A two-dimensional (2D) instrument approach operation, using lateral navigation guidance only[6]
- A three-dimensional (3D) instrument approach operation, using both lateral and vertical navigation guidance

Further, each IAP has multiple segments that influence airspace design, aircraft operations, and the expected locations of aircraft around airports depending on what segment of the IAP is being used by an arriving aircraft. More information about how aircraft typically use the available airspace depending on the phase of flight is covered in Section 1.1.4.

- **Initial Approach:** The segment between the initial approach fix and the intermediate fix or the point where the aircraft is established on the intermediate course or final approach course.
- **Intermediate Approach:** The segment between the intermediate fix or point and the final approach fix.
- **Final Approach:** The segment between the final approach fix or point and the runway, airport, or missed approach point.
- **Missed Approach:** The segment between the missed approach point or the point of arrival at decision height and the missed approach fix at the prescribed altitude.

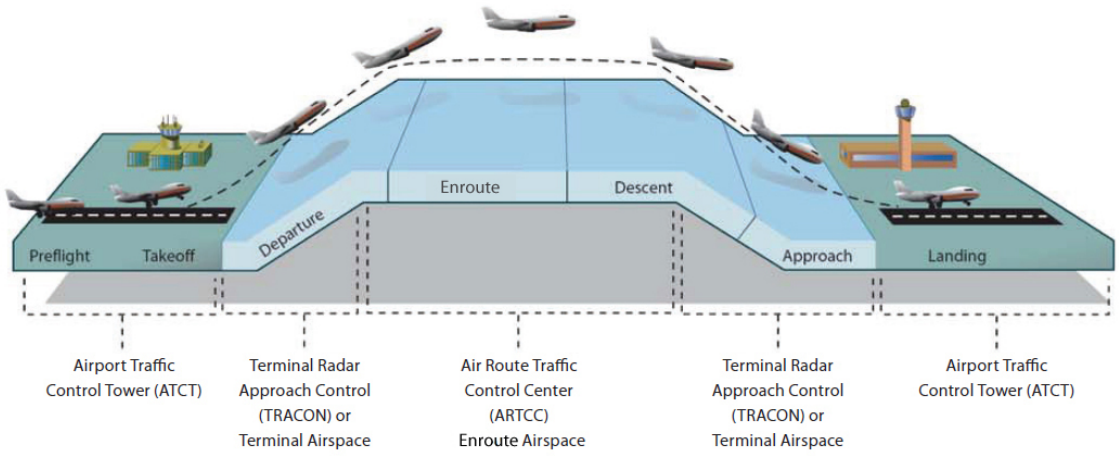
6 Lateral and vertical navigation guidance refers to the guidance provided either by: (a) a ground-based radio navigation aid; or (b) computer-generated navigation data from ground-based, space-based, self-contained navigation aids or a combination of these.

A.1.4 Aircraft Flow within the National Airspace System

An aircraft traveling from airport to airport typically operates through six phases of flight (plus a "preflight" phase). **Exhibit 1-2** 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.
- **Push Back/Taxi/Takeoff:** The aircraft's transition across the airfield from push-back at the gate (i.e., backing away from the gate), taxiing to an assigned runway, and takeoff from the runway.
- **Departure:** The aircraft's in-flight transition from takeoff to the en route phase of flight, during which it climbs to the assigned cruising altitude.
- **En Route:** 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:** Touch-down of the aircraft at the destination airport and taxiing from the runway to the gate or parking position.

Exhibit 1-2 Typical Phases of a Commercial Aircraft Flight



Source: U.S. Department of Transportation, Federal Aviation Administration, Houston Area Air Traffic System (HAATS), Airspace Redesign, Final Environmental Assessment, Figure 1.1.1-1, March 2008
Prepared by: ATAC Corporation, September 2022

The following sections discuss how air traffic controllers at these ATC facilities control the phases of flight for aircraft operating under IFR.

A.1.4.1 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 en route airspace where it proceeds on a specific route 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 en route airspace. Exit points are generally established near commonly used routes to transfer aircraft efficiently between terminal and en route airspace. When aircraft pass through the exit point, control transfers from TRACON to ARTCC controllers as the aircraft joins a specific route.

A.1.4.2 Approach Flow

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

Aircraft that arrive in the terminal airspace normally follow an instrument procedure called a Standard Terminal Arrival (STAR). Aircraft leaving en route airspace and entering terminal airspace may follow an en route transition 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 before making an approach to the airport.

A.1.4.3 Required Aircraft Separation

As controllers manage the flow of aircraft into, out of, and within the NAS, they maintain some of the following separation distances between aircraft:[7]

- **Altitude Separation (vertical):** When operating below 41,000 feet above mean sea level (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 nautical miles (NM),[8] depending on factors such as aircraft class, weight, 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 three NM in terminal airspace and five NM in en route airspace.
- **Visual Separation:** Aircraft may be separated by visual means when other approved separation is assured before and after the application of visual separation.

7 For a detailed explanation of separation standards, see FAA Order 7110.65Y.
8 A nautical mile is equivalent to 1.15 statute miles.

A.1.5 Next Generation Air Transportation System

The NextGen program is the FAA's long-term plan to modernize the NAS from a ground-based system of air traffic control to a GPS-based system of air traffic management that allows for the development of PBN (Performance-Based Navigation) procedures.[9] The modernization of airspace to PBN is a key step in the overall process of transitioning to the NextGen system. Achieving the NextGen system requires implementing RNAV (Area Navigation) and RNP (Required Navigation Performance) PBN procedures and aircraft "auto-pilot" and Flight Management System (FMS) capabilities.[10] RNAV and RNP capabilities are now readily available, and PBN can serve as the primary means aircraft use to navigate along a route. More than 90 percent of U.S. scheduled air carriers are equipped for some level of RNAV. The following sections describe PBN procedures in greater detail.

A.1.5.1 RNAV

Exhibit 1-4 compares conventional and RNAV routes. RNAV enables aircraft traveling through terminal and en route airspace to follow more accurate and better-defined routes. This results in more predictable routes and altitudes that can be pre-planned by the pilot and air traffic control. Predictable routes improve the ability to ensure vertical, longitudinal, and lateral separation between aircraft.

Routes based on ground-based NAVAIDs rely on the aircraft equipment directly communicating with the NAVAID radio signal and 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. Consequently, a route that is dependent upon ground-based NAVAIDS requires at least six NM of clearance on either side of its main path to ensure accurate signal reception. As demonstrated by the dashed lines in **Exhibit 1-4**, this clearance requirement increases with an aircraft's distance from the VOR. In comparison, RNAV signal accuracy requires only two NM of clearance on either side of a route's main path.

RNAV routes can mirror conventional routes or, by using satellite technology, provide paths within the airspace that were not previously possible with ground-based NAVAIDs.

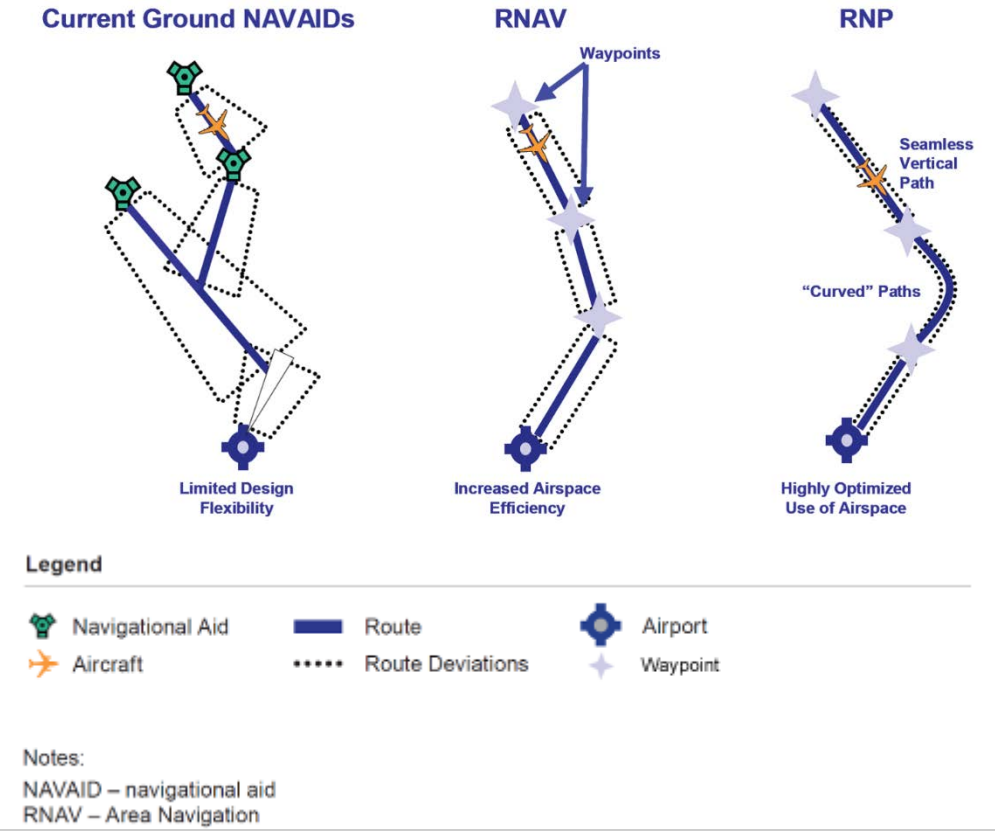
A.1.5.2 RNP

RNP is an RNAV procedure with signal accuracy that is increased through the use of onboard performance monitoring and alerting systems. 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 inform the crew if the required data becomes unavailable.

Exhibit 1-4 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.

9 U.S. Department of Transportation, Federal Aviation Administration, Fact Sheet, "NextGen Goal: Performance-Based Navigation," April 24, 2009 [http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=8768 (accessed April 11, 2012)].
10 A Flight Management System (FMS) is an onboard computer that uses inputs from various sensors (e.g., GPS and inertial navigation systems) to determine the geographic position of an aircraft and help guide it along its flight path.

Exhibit 1-4 Navigational Comparison – Conventional/RNAV/RNP



Source: U.S. Department of Transportation, Federal Aviation Administration, "Performance-Based (PBN) Brochure," October 2009
Prepared by: ATAC Corporation, September 2022

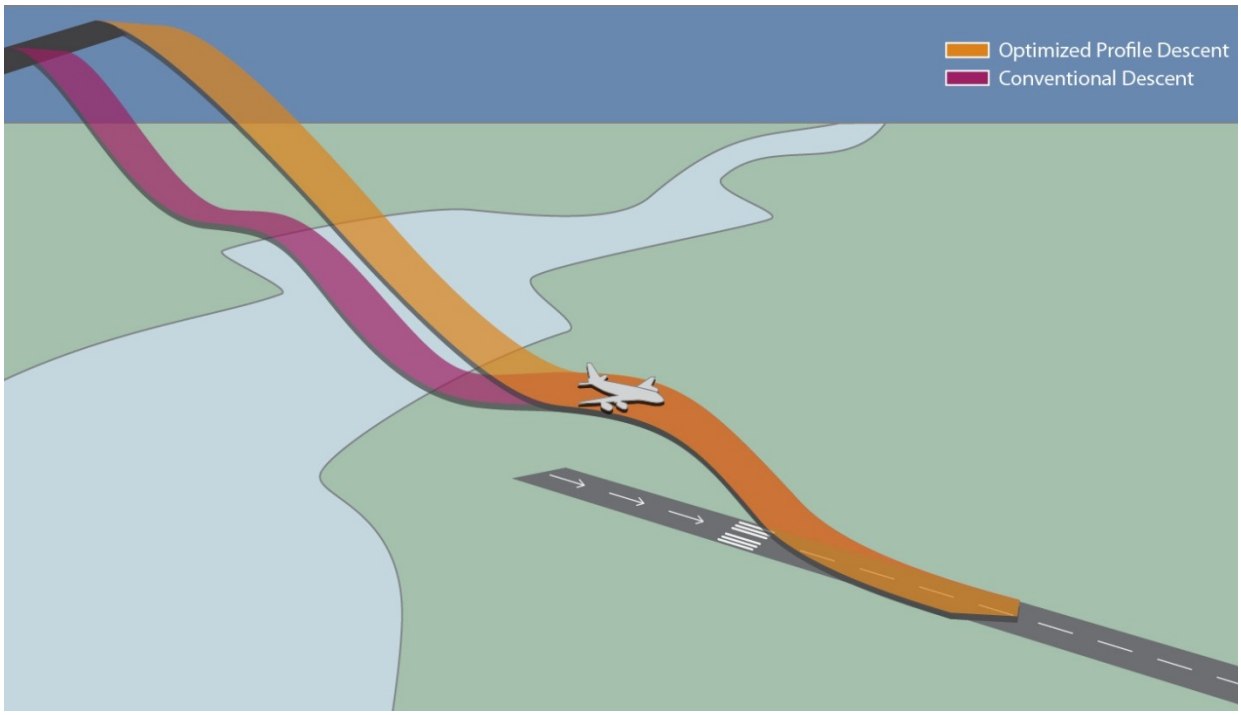
A.1.5.3 Optimized Profile Descent

An Optimized Profile Descent (OPD) is a flight procedure that allows an aircraft using FMS to fly continuously from the top of descent to landing with minimal level-off segments. **Exhibit 1-5** illustrates an OPD procedure compared to a conventional descent. Aircraft that fly OPDs can maintain higher altitudes and lower thrust for longer periods, thereby reducing emissions and noise. As level-off segments are minimized, OPDs reduce the need for communication between controllers and pilots.

A.1.5.4 Optimal Profile Climb

An Optimal Profile Climb (OPC) is similar to OPD, but relates to departures. An OPC is a flight procedure that allows an aircraft using FMS to fly continuously from the runway to the top of climb with minimal level-off segments. Aircraft that fly OPCs can get to higher altitudes sooner with minimal changes in thrust. As level-off segments are minimized, OPCs reduce the need for communications between controllers and pilots.

Exhibit 1-5 Optimized Profile Descent Compared to a Conventional Descent



Source: ATAC Corporation, December 2012
Prepared by: ATAC Corporation, September 2022

A.2 Conclusion

The FAA ATC system is designed for the safe and orderly flow of all the widely varying aircraft going to and from airports under both IFR and VFR conditions. While this Appendix is intended as an introduction to relevant concepts, terms, and concise explanations of processes, the FAA has multiple resources available for public access that further explain and define all elements of this Appendix. Below is a list of relevant publications and resources the FAA offers that can assist in furthering a deeper level of knowledge and understanding of ATC in the NAS.

- *Modernization of the National Airspace System* found at https://www.faa.gov/nextgen
- *Air Traffic Plans and Publications* found at https://www.faa.gov/air_traffic/publications/
- FAA Order JO 7110.10 – *Flight Services* found at https://www.faa.gov/air_traffic/publications/atpubs/fs_html/
- FAA Order JO 7110.65 – *Air Traffic Control* found at https://www.faa.gov/air_traffic/publications/atpubs/atc_html/
- FAA Order JO 7400.2N - *Procedures for Handling Airspace Matters* found at https://www.faa.gov/air_traffic/publications/atpubs/pham_html/
- *Aeronautical Information Manual* found at https://www.faa.gov/air_traffic/publications/atpubs/aim_html/