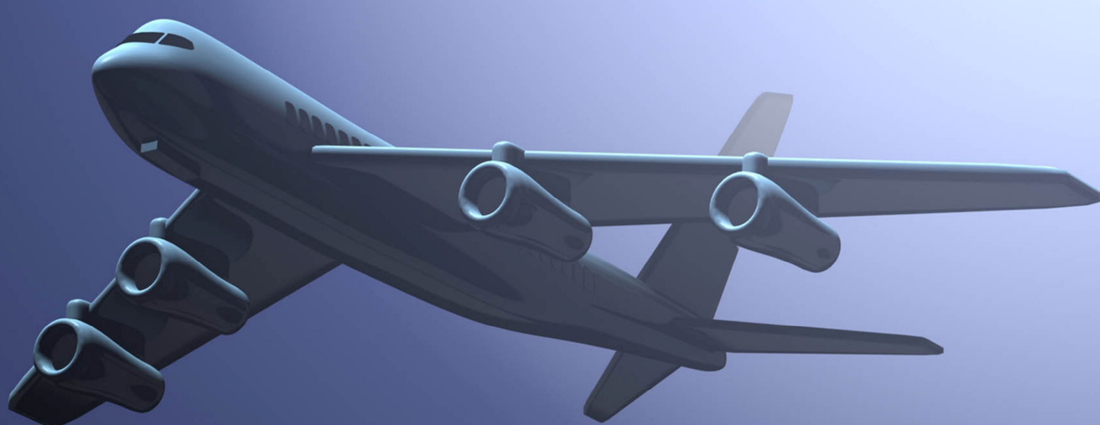
Joint Planning and Development Office

JPDO Trajectory-Based Operations (TBO) Study Team Report

December 4, 2011



Next Generation Air Transportation System
Joint Planning and Development Office

Preface

The Joint Planning and Development Office (JPDO) formed a government/industry study team in December 2009 to develop operational scenarios and architectural use cases to help define Trajectory-Based Operations (TBO). The study team's approach was to create some gate-to-gate flights and ask questions on how TBO would work beyond the 2025 timeframe. This TBO Study Team's processes included input to the Integrated Work Plan (IWP), findings and recommendations, and a decomposition of the narratives into discrete action steps called use cases. These use cases are being used to develop changes to the Next Generation Air Transportation System (NextGen) Enterprise Architecture.

This final version of the report contains recommendations on new operational improvements, research, policy, and procedures that would be necessary to implement TBO. This report is useful in defining a far-term operational approach for TBO. The Federal Aviation Administration (FAA) has developed an operational approach for the initial mid-term use of trajectories, called trajectory operations (TOps), that is linked to the FAA's mid-term (2012-2018) concept of operations.

While the TBO Study Team was focused on a far-term timeframe defined by the FAA as 2018 to 2025, TBO will require considerable research and engineering development. While elements of TBO may start in the 2018 to 2025 timeframe, full use of the advantages of TBO are expected to occur beyond 2025.

Operational scenarios presented do not represent the final concept of operations for TBO, rather they are a starting point to begin the dialog on what TBO is and how it will operate in NextGen. The team agrees that the main purpose is to begin the dialog on the functional requirements for TBO and to make the transition from use of trajectories in TOps to TBO as seamless as possible, especially to the users of NextGen. Many terms and procedures discussed in the report require refinement by research and development.

Table of Contents

List of Figures

List of Tables

1.0 Executive Summary

The objective of this report is to describe Trajectory-Based Operations (TBO) for flight planning, surface movement, climb, cruise, and arrival using four-dimensional trajectory (4DT) management starting in the 2018 to 2025 timeframe, leading to broader implementation and use of TBO as a central element of NextGen. The report begins with a general discussion of TBO and then applies this information to three operational scenarios. The first is an air carrier flight from Phoenix (PHX) to Miami (MIA). The second is also an air carrier description involving a flight from Detroit (DTW) to Washington, DC (IAD), where merging into an overhead stream of en route traffic is described. Scenario two also provides a description of the use of TBO leading to an approach to a closely spaced runway. The third scenario features a general aviation (GA) flight from PHX to Bozeman, Montana (BZN).

Performance-based operations are added to set parameter values for TBO. These values require research, but for the purposes of the scenarios they describe what is possible in initial use of TBO. The Required Navigation Performance (RNP) values used in this report are likely to be very close to what is needed, and RNP is maturing at a fast pace. The same cannot be said for separation distances. While the targeted goal is three miles everywhere in domestic airspace, we will not see this until the surveillance data network is providing fused information, and the number of Automatic Dependent Surveillance-Broadcast (ADS-B)-equipped aircraft is sufficient to support three miles. Likewise, the TBO Study Team has used a notional Required Time Performance (RTP) concept that requires development. It is important to note that the transition to use of RNP required considerable pilot and air traffic controller training. TBO will be no different.

While the scenarios cover nominal operations, there is also a discussion of the use of TBO in four particular off-nominal conditions: a severe convective weather event at a high-density airport, a runway closing at a high-density airport, a loss of Global Navigation Satellite System (GNSS) due to interference impacting a high-density airport, and a security incident (non-conforming and non-responsive air carrier aircraft).

TBO is a very significant and transforming change on the path to NextGen. The approach has been to expand the value of flight planning and recognize that the traffic volume will exceed what the air traffic controller can handle today. It relies on automation to perform separation based on a combination of present aircraft position and a future position in time. There is conformance monitoring both in the cockpit and with the Air Navigation Service Provider (ANSP), and conformance to a negotiated and agreed-upon trajectory forms a contract between the operator/user and the ANSP.

The separation automation must maintain a high degree of availability and integrity. Airborne and ground elements of automation must be certified to provide separation assurance. While changes in the approach to doing separation represents a significant cultural shift, increased collaboration through network-centric operations to improve common situational awareness will provide significant improvements in efficiency and capacity. Significant issues remain in assured separation, using a combination of airborne and ANSP automation.

It is important to emphasize that TBO is about choices. Once received, choices are negotiated, accepted, and then executed with precision. As the airspace traffic density increases, there is greater need for precision performance. But TBO can function at any level of precision. It is the execution of the agreement that assures separation. Strategically, automation must provide choices to the operator/user that resolve downstream conflicts and address flows. Weather is integrated into the decisions that must be made both strategically and tactically. As the number of strategic decisions rise, the number of tactical interventions will diminish, balancing workload both in the air and on the ground. However, the amount of pre-planning for the flight will likely increase, and the interchange between airline operations and the ANSP will rise as trajectories are used to strategically manage the volume of traffic.

In communications, TBO is highly dependent on ground-ground connectivity for network-centric operations and data link for negotiations, agreement, and validation of execution of any given 4DT. But one data link pipe does not represent a single solution. Because TBO communications are mostly in a strategic time frame, the urgency of connectivity is unnecessary for a majority of the transactions. Multiple paths of communications can be used. The Study Team has made several recommendations on developing the messaging content and requirements for TBO because of the urgency in getting to a set of requirements. The requirements are more about the information flows between systems than about the performance of the link. A total of 46 recommendations have been offered for further action, ranging from better definitions of operational improvements to initiating the safety case for TBO.

With respect to aviation security, TBO represents one of the layers of adaptive security. Intent is a powerful tool in monitoring conformance. Likewise, in flight planning there are opportunities to build in authentication, from submittal of a plan to starting the aircraft. In-flight performance puts bounds around the aircraft and deviations from these bounds have separation consequences that must be addressed.

Environmentally, TBO provides an opportunity to meet improved noise performance by more closely defining flight tracks. TBO offers savings in fuel burn, at the airport, during climb, through the use of cruise climb, and the optimized arrivals to an airport. Noise, emissions, and fuel savings translate into tangible environmental benefits and the procedures lead to saving cost of operations.

Finally, The TBO Study Team recognizes that this is the start of a greater debate on the details of TBO. Our approach was to provide information on how TBO would work in the context of operational scenarios. Much work must follow. Critical among this work is the beginning of a safety case and the necessary analyses to reach decisions on fundamentally changing how aircraft are separated. This safety case is followed by the functional requirements for TBO and a significant discussion on definition of requirements for automation's performance.

2.0 Overview

The objective of this report is to describe TBO for flight planning, surface movement, climb, cruise, and arrival using 4DT management starting as early as 2018 and leading to initial implementation and use by 2025. This 2018 to 2025 timeframe represents "far-term" in the Federal Aviation Administration's (FAA) NextGen planning. Full use of TBO would then mature across the airspace and airports as demand rises. 4DT operations are central to the NextGen (and Single European Sky ATM Research [SESAR]) concept of use, and follow the limited use of trajectory operations in the en route environment that is a mid-term initiative of the FAA. TBO migrates from strategic traffic flow management and en route cruise to arrivals within the mid-term timeframe, linking en route trajectories to top of descent (TOD) and then through Optimized Profile Descents (OPDs) to approach and landing. 3D trajectories (3DT) (lateral, longitudinal, and time) are used in surface movement, with introduction of surface movement management tools for sequencing aircraft for departures.

By 2012, the transition from TOps to TBO is defined with a performance framework that describes aircraft and ANSP requirements. This framework allocates aircraft and ground system performance for the safe and efficient sequencing, spacing, and separation of aircraft based on their trajectories.

This report started with development of nominal descriptions of TBO activities on three flight segments. The first is from Phoenix (PHX) to Miami (MIA) using expected flight operational procedures that would exist in a 2025 timeframe, and incorporating opportunities for a mix of domestic and offshore airspace. A second flight segment is built around a flight from Detroit (DTW) to Washington (IAD) to explain how TBO would work in a flow-constrained airspace, with merging of flights from DTW into crossing over-flight traffic and very closely spaced parallel runway (VCSPR) operations at IAD[1]. A third is a flight segment highlighting GA capabilities between PHX and Bozeman (BZN). These three scenarios represent the team's estimate of what could be possible, subject to further research and further definition as to safety, security, efficiency, capacity, and the necessary functional requirements to make TBO possible.

These three scenarios were then deconstructed in a timed sequence to build use cases. A use case captures each action in the scenario and documents the actor or initiating activity, the action, the recipient of the information about the action, and the result of this interaction. Use cases help to identify missing elements of the scenarios and support architecture development that can support defining necessary redundancies and performance. Once defined for the nominal case (how TBO would work in a perfect case), the scenarios are then expanded to deal with off-nominal conditions—where TBO performance degrades or conditions are imposed for safety or security. The scenarios presented here represent a 2018 to 2025 starting timeframe that describes NextGen capabilities, from flight planning through flight performance. It starts in a mixed equipage environment and transforms to extensive use of TBO.

---

[1] Washington-Dulles International Airport does not have and has no plans to build a closely-spaced parallel runway, but for purposes of this scenario it has been added so that procedures and benefits can be described.

TBO flows from experience gained in mid-term implementation of trajectory operations. TBO is the concept of an Air Traffic Management (ATM) system in which every aircraft that is operating in and managed by the system is represented via a 4DT. A 4DT includes a series of points from departure to arrival representing the aircraft's path in four dimensions: lateral (latitude and longitude), vertical (altitude), and time. Every managed aircraft known to the system has a 4DT either provided by the user or derived from a flight plan for the type of operation. Increasingly, the trajectories used are much more accurate than those in use today. High performing aircraft are flying the trajectory via Flight Management System (FMS), using more precise navigation capabilities. The nature of the aircraft's adherence to the trajectory is based on the aircraft's capabilities and the type of operation being conducted. In this way, operations are performance based, meaning that improved services are available to better-equipped aircraft.

The 4DT is quite complex. Its creation must consider not only the individual aircraft performance, but also the interaction of the aircraft with other aircraft in the airspace. The 4DT extends its complexity to consider weather, security, user preferences, the airspace and airport configuration, flight procedures, and environmental performance. The 4DT itself can have performance tolerances that vary with the conditions and density of the traffic. For example, the time element of the 4DT can be seconds or minutes. Altitude can be either an assigned altitude or a block of altitude. Lateral precision, normally measured in RNP, can have values in miles in low-density airspace to fractions of a mile on approach. This is why the 4DT starts with pre-negotiation flight planning and is followed by negotiation with the ANSP. Once agreed to, the 4DT is executed as planned. This is not to mean that the operator/user can expect to have a clear path to top of descent at destination top of descent from takeoff. Updates by the aircraft, based on its performance, will require periodic update with more current information to support separation based on TBO. Changes can be expected from the ANSP based on changes in flow constraints. Execution of the 4DT is impacted by the addition or subtraction of downstream constraints, winds aloft, the need to protect airspace for other aircraft, and changes in use of airspace.

To the extent possible, trajectories, from initial flight plans through any subsequent changes, are managed through negotiations among the users and the ANSP. Trajectories are used for flight planning, advisory services, airspace security, sequencing, spacing, separation, and congestion management. Any changes to the flight (aside from time-critical safety clearances) are communicated through or to the trajectory. To be effective, the trajectory must be maintained and updated at all times to reflect the latest flight plan, intent information, or clearance.

During pre-flight, the users share trajectory intent information with the ANSP and have improved awareness of current and predicted availability of National Airspace System (NAS) resources, including expected constraint information. The ANSP aggregates the trajectory intent information across all user classes for improved planning. The resulting negotiated trajectory reflects user intent and provides a common basis for access to resources and knowledge of system constraints. While flights are airborne, the ANSP uses the trajectory to manage separation with support from problem detection/resolution automation. Throughout the day, the trajectories are aggregated by ANSP flow management automation to assess potential congestion problems, evaluate alternatives collaboratively, and then implement strategies with aircraft-specific clearances. After flight completion, trajectories are used for post analysis and monitoring of system performance by the ANSP and by the users. At the end of the mid-term for NextGen, initial applications such as paired approaches, pair-wise delegated separation, and Required Time of Arrival (RTA) clearances will be available.

Trajectory operations are enabled by improved utilization of current and emerging aircraft capabilities—Area Navigation/Required Navigation Performance (RNAV/RNP), FMS, ADS-B, and data communications—and improvements in ground automation/infrastructure: data communications, surveillance, net-centric data operations, and ANSP and Flight Operations Center (FOC) automation. Surveillance accuracy using ADS-B has a direct functional relationship to improved navigation performance accuracy because ADS-B uses the same GNSS source. These enablers result in increased accuracy of the aircraft surveillance information, increased accuracy in navigation of the intended path, new capabilities to deliver clearances more efficiently and accurately, and increased timeliness in executing an Air Traffic Control (ATC) clearance or meeting an aircraft-specific flow constraint. As a result, the trajectory is more accurate in execution and more predictable in time and position. Improvements in trajectory precision can then lead to reductions in separation and manage more aircraft in the airspace. These improvements are leveraged through system-wide sharing of information with all authorized users via net-centric data operations and data communications with the aircraft. Better information and seamless information access provide the users and operators of the NAS with common awareness, a more accurate view of the system, and improved decision-making.

While trajectory operations begin with limited capabilities focused mainly on using TBO strategically, TBO rounds out the performance capabilities by incorporating tools and procedures to implement gate-to-gate use of trajectories for both strategic and tactical management of operations. TBO is the use of 4DT for planning, sequencing, spacing, and separation based on where the aircraft will be, with measured progress and conformance to its clearance, and using ground automation in determining and de-conflicting downstream flows of aircraft.

TBO is based on a significant change in separation. Today, there is procedural separation involving position reporting when outside of the surveillance area of the ANSP. In the presence of surveillance, aircraft are separated based on their known position. Under TBO, current position is still used, but separation is based on where the aircraft is *and* where the aircraft will be at a time in the future. This is why conformance monitoring is important. The progress toward that point in space at a time in the future must be tracked to separate based on TBO.

3.0 Definition of Terms

Trajectory Operations – The concept of an ATM system in which every aircraft that is operating in or managed by the system is represented by a 4DT. Every managed aircraft known to the system has a 4DT either provided by the user or derived from a flight plan or type of operation. Trajectory operations, or TOps, represent a mid-term implementation strategy to gain capacity and efficiency.

Trajectory-Based Operations – Extends TOps and provides separation, sequencing, and merging and spacing of flights based on a combination of their current and future positions. TBO operates gate-to-gate, extending benefits to all phases of flight operations. TBO uses the 4DT to both strategically manage and tactically control surface and airborne operations. Aircraft are handled by their trajectory.

4DT – Defined laterally and longitudinally by latitude and longitude, vertically by altitude and with time. Surface movement is a 3DT—lateral, longitudinal, and time.

Closed Trajectory – The ANSP automation, the controller, and the aircraft automation have the same view of what the aircraft is doing. There is agreement between automation on the ground and in the air, and actions are synchronized.

Open Trajectory – The aircraft is no longer flying to an agreement with the automation. The aircraft and the ground are not in synchrony and the aircraft is flying off the agreed-upon trajectory for operational reasons like weather avoidance, a vector for sequencing or spacing, and/or a speed adjustment that will impact timing.

Conformance Monitoring – Monitoring of the aircraft's position, altitude, and time performance against the agreed-upon 4DT. Monitoring is against performance requirements for the flight maneuver or surface movement. Conformance monitoring occurs both in the air and within ground automation.

Conformance Alerting – Alerts are generated if the aircraft is not meeting its 4DT performance.

Self-separation – Delegation of separation responsibility to the flight crew for specific maneuvers or operations in designated airspace.

Flight Object – An extensible and dynamic collection of data elements that describes an individual flight. It is the single common reference for all system information about that flight. Authorized system stakeholders and the ANSP may electronically access consistent flight data that is tailored to their specific need and use. The flight object facilitates the sharing of common flight information between systems and enables collaboration using a common reference framework.

Flight Plan – A subset of the flight object information used for flight planning prior to departure that carries basic information about the flight and route to be followed.

Flight Following – An additional subset of the flight object used to track the flight and evaluate performance.

Intent – What the aircraft is planning to do. Intent is provided by ADS-B for air-to-air and air-to-ground surveillance. This is ADS-B intent. The flight object also carries intent information and it is the intent sent by data link between the aircraft and the ANSP that represents the confirmation of intent, execution of the 4DT, and forms the basis for conformance monitoring. This intent is called data communications intent. As the aircraft progresses in the flight, supplemental intent messages are sent to the ANSP to provide updates of progress and changes in 4DT performance.

Uncertainty – Used throughout the report to describe the amount of variability in position in all three dimensions and time. Uncertainty from the cockpit perspective can be considered an area of containment, but from a conformance monitoring perspective it also includes anticipated non-containment, especially in terms of time.

4.0 Background

TBO is based on a combination of “closed” and “open” trajectories. A closed trajectory is one where the pilot, aircraft automation, the controller, and ground automation all have the same view of what the aircraft is doing, from start of taxi through termination of flight operations. Closed trajectories are a necessary element for automation to compare aircraft to each other and evaluate flow situations. Closed trajectories are accurate and kept updated so that there are defined limits of acceptable ambiguity between the air and the ground. Since separation is based on where the aircraft will be at a prescribed position in space and time, the more closed trajectories that exist, the more successful the operations under TBO.

TBO recognizes that not all trajectories can be closed. A simple example is when a controller gives a new vector, taking the aircraft on a new trajectory without changing the conditions within the automation, both on the ground and in the aircraft. An open trajectory must subsequently be closed by changing the 4DT in both air and ground automation. Clearances for open trajectories would typically be used to maneuver in the airspace—for weather, tactical traffic conflicts, or to begin a different flight path pending update of the 4DT. Once an aircraft is flying off the predefined 4DT, with no fixed turn-back to rejoin, make up time, or correct the information contained in the original closed trajectory, the trajectory is now open. The chain of intent and progress has been broken.

It is difficult for automation to deal with open trajectories. The uncertainties that open trajectories introduce affect more than just the aircraft in question and may impact downstream flows, and even lead to a conflict requiring intervention to assure safety. Likewise, an aircraft that does not meet its prescribed 4DT can affect downstream traffic sequencing, spacing, and separation. A closed trajectory becomes an open trajectory when there is non-conformance with the pre-defined and agreed-upon 4DT. This does not mean that open trajectories are bad; what it means is that the parameters of conformance monitoring must be changed and new intent messages must be generated until there is a closure of the trajectory. These intent messages are conveyed to all parties—pilot, ANSP, and the AOC.

TBO conformance is monitored both in the aircraft and on the ground against the agreed-upon 4DT. In the air, this monitoring (and alerting) includes lateral deviations based on RNP (actual lateral position compared to intended position), longitudinal based on flight progress in the FMS, vertical based on altimetry, and time from the FMS or other “time to go” aids.

Independent of the aircraft, the ANSP uses ADS-B position reporting for lateral and longitudinal progress, altitude reporting for vertical, and tools that measure the time progression for the flight track. Data link provides aircraft intent information. Combined, this position and timing information is then compared to a performance requirement for the airspace and the operation. For example, the minutes or seconds of precision needed to arrive at a particular point in space will vary based on the density of traffic and the nature of the operation.

In framing the required performance for conformance monitoring, TBO recognizes that traffic density drives needed performance. There may be departures where a lateral precision of RNP 0.3 is required close in to the airport, and where time is measured in seconds. Required Time of Performance, or RTP[2] is used as a tool to separate crossing traffic, and where vertical altitude restrictions are necessary. All of these factors must be considered in defining the parameters for conformance monitoring. Conformance monitoring has an expected ground track, climb performance (based on known aircraft type, weight, and preferred profile), and time performance. In conformance monitoring, the aircraft is on a closed trajectory.

Conformance monitoring from the ground is the process of assuring that an aircraft is within a volume of airspace. This four-dimensional airspace is defined by the 4DT and aircraft's intent—where the aircraft will be at a prescribed time. This volume of airspace travels with the aircraft and the airspace boundaries and structure are defined by the aircraft's performance. In the climb, the conformance monitoring airspace is centered on the cleared flight track, compensates for aircraft vertical, lateral and longitudinal uncertainty, and is shaped much like a horn, where vertical uncertainty causes the shape to be spread vertically more than horizontally. The bottom of this fan-shaped horn represents the minimum climb performance; the top is a calculated maximum climb performance. The further out from the aircraft position, the wider the horn, reflecting the uncertainty of the vertical position. RNP sets the lateral uncertainty required for the maneuver and represents the acceptable bounds for performance.

[2] RTP is used here as a placeholder for the acceptable time variability at a point in space, similar to lateral performance with RNP. RTP is executed in the cockpit using the RTA functions of the FMS. Within ANSP automation, an estimated time of arrival (ETA) or controlled time of arrival (CTA) is used. RTCA has also identified "Time of Arrival Control" or TOAC for use on the flight deck (see RTCA DO 236B). Harmonization of terminology for both air and ground is needed.

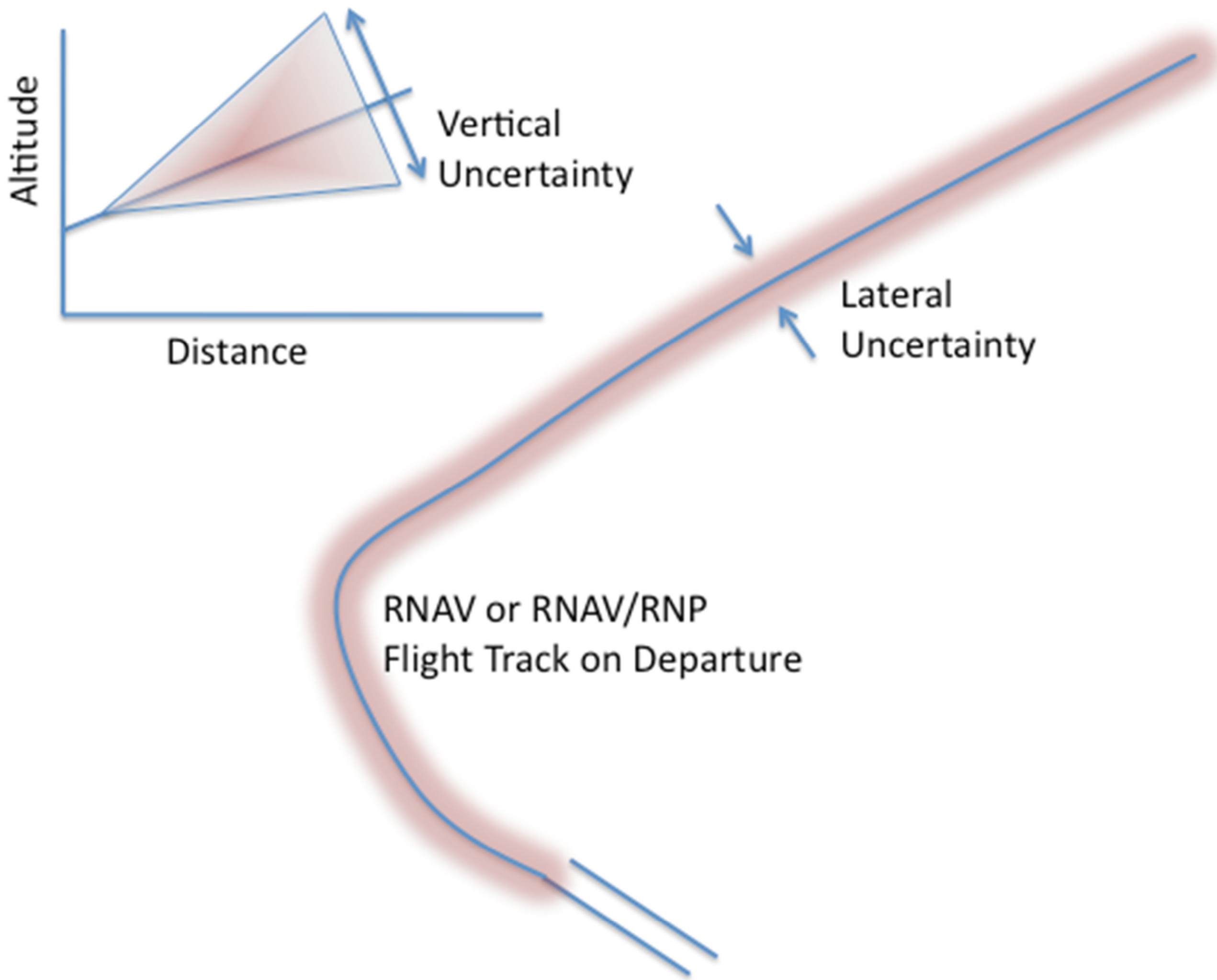


Figure 1. Position Uncertainty

As the aircraft approaches level-off and cruise, the shape of the protected airspace morphs into more of an elliptical 3-D shape, where the aircraft is positioned in the narrow end of the elliptical shape, with the wake vortex "tail" as its aft bound and vertical, lateral, and longitudinal uncertainty defining the flexible airspace. No two elliptical shapes can overlap if separation is to be assured. In this case, Aircraft A and Aircraft B have crossing trajectories. Aircraft A's protected space is smaller because it has less uncertainty than Aircraft B. The trailing area of protection may reflect wake turbulence requirements. The lateral protection is the uncertainty in navigation performance, while the leading distance along the flight path represents the time uncertainty. In level flight, the vertical altitude dimension is quite small.

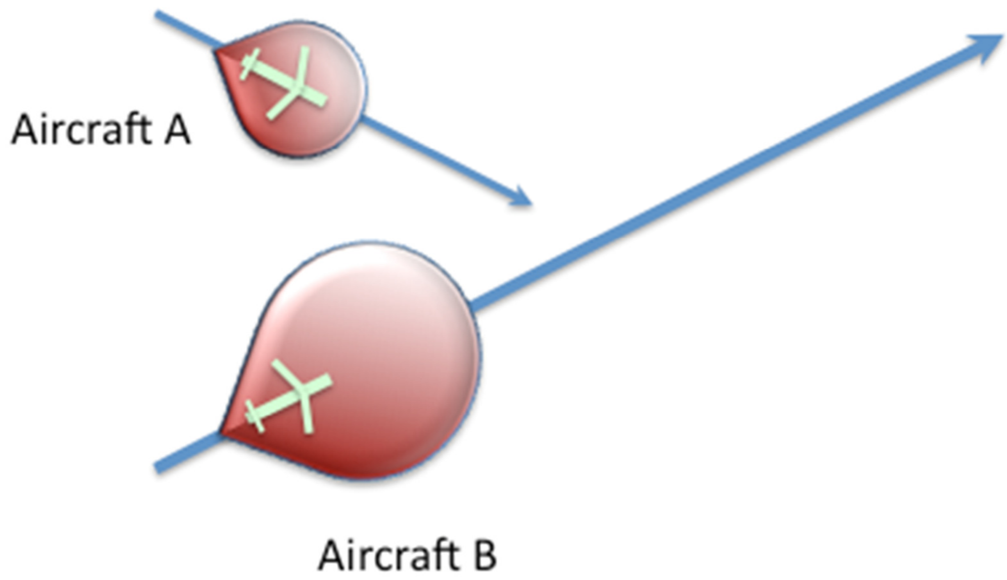


Figure 2. En Route Uncertainties Defining Conformance Boundaries

On arrival, the shape of uncertainty projects downward, based on the descent profile. RNP controls lateral displacement, and time is projected forward to points in space for metering, merging, or initiating the approach as needed for separation, sequencing, merging, and spacing. As the aircraft moves closer to the airport and landing, the uncertainty of vertical profile decreases and the aircraft is now flying in more of a tube-shaped bounded uncertainty, defined laterally by RNP and vertically by the altitude restrictions for the arrival.

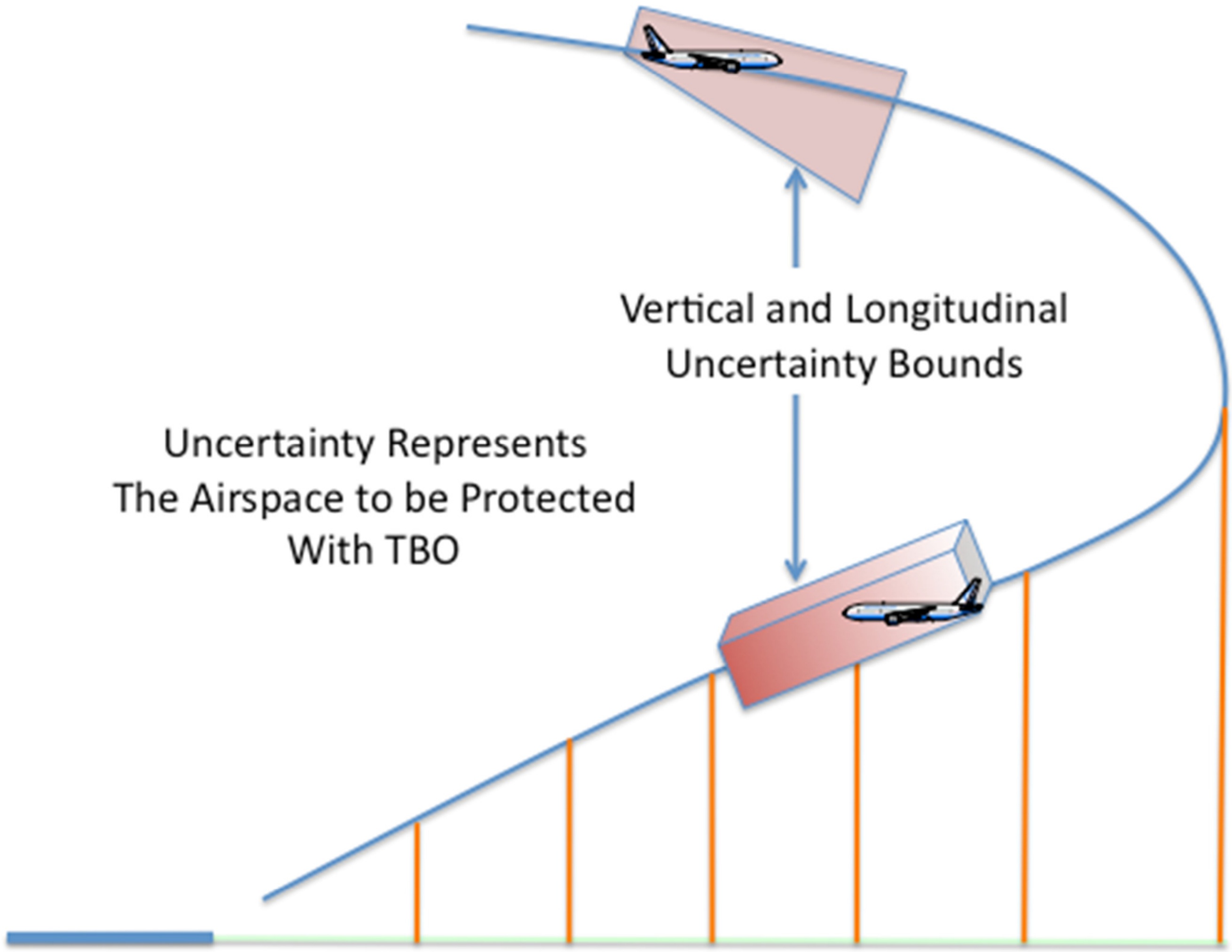


Figure 3. Transition from Arrival to Approach

The conformance parameters are tied to the flight object, the TBO 4DT, intent, and information about the aircraft's performance. Since aircraft performance is a function of aircraft weight, conformance-monitoring software has weight information to help define the conformance airspace volume. Once defined, ground automation monitors the aircraft flight path, looking for deviations from the protected airspace volume. Conformance monitoring has parameters that can be set by the controller for alerting.

Alerting is triggered by automation and alerts the controller to transgression from the conformance airspace, and may be set as alerts for measuring progress. By setting progress alerts, the controller has an aid to measure progress in meeting the 4DT.

From the cockpit, the pilot can monitor performance, as well. Most of the tools are already used. Altitude alerts exist. RNP can be monitored, and the progress can be provided by the FMS. What is needed is the cockpit display of traffic information (CDTI) with tools for merging, spacing, and separation. These tools will help the pilot monitor other traffic as well as progress in meeting the 4DT. The pilot sets the alerting parameters in the respective automation.

TBO relies on data link for the majority of the air-to-air, air-to-ground and ground-ground communications. There may be multiple data links involved in TBO, ranging from delivery of advisory information to the actual loading of a new 4DT that affects the flight path of the aircraft. This variation in message content drives different data link performance requirements. Much of the messaging is advisory in nature, but the actual clearance for the 4DT and confirmation of use of this information have higher performance requirements. An aircraft may be connected to network-centric operations over multiple data links, but there will be a specified, performance-driven path for the critical communication of 4DT information. Figure 4 is a depiction of notional communication flows.

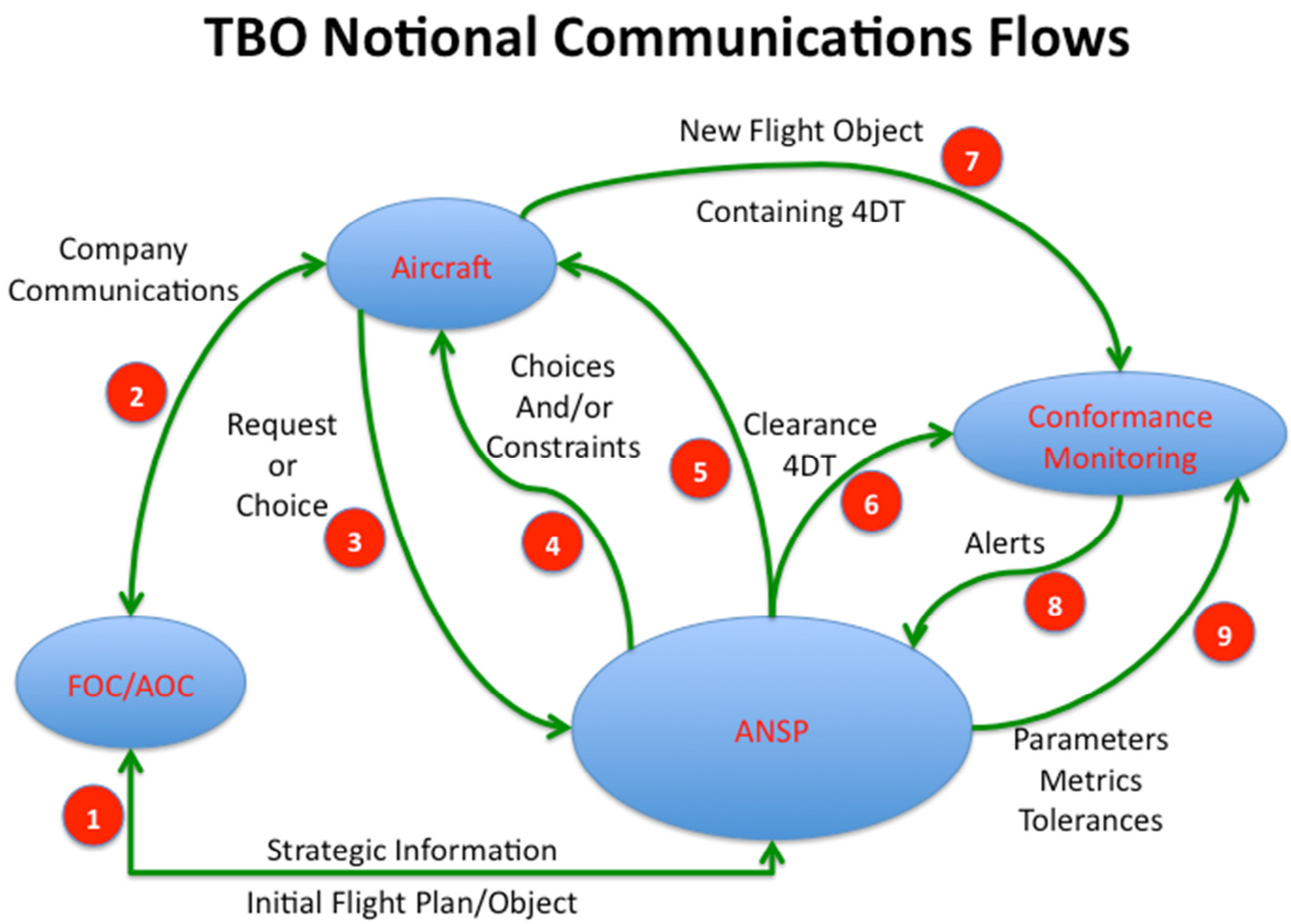


Figure 4. TBO Information Flows

The numbers in Figure 4 identify the possible communications paths. Path 1 is the network-centric operations connectivity, a ground-ground communications used by the airline, military, or larger GA operation with dispatch services that connects the operator to the ANSP. For those operators lacking a dispatch service, this communications path may be supported by a third-party vendor and used by pilots to plan a flight and provide their desired 4DT to the ANSP. Path 1 is the principal path for flight-following activities by the airlines. Path 2 represents a user-specified performance for exchange of information between the flight crew and operations. For strategic changes to the 4DT under TBO, this communications path could be used to coordinate between the flight crew and operations, and then the Airline Operations Center/Flight Operations Center (AOC/FOC) could negotiate with the ANSP. Path

2 is not an ANSP owned/operated data link. Paths 3 and 4 are used for negotiation of trajectories and receipt of advisory information and may be either a third-party vendor-provided data link or a data link provided by the ANSP. Since most of the transactions are strategic in nature, it is likely that a broadband data link would be used to meet the bandwidth needs to handle graphical information.

Paths 5, 6, and 7 represent the actual TBO 4DT exchange. The clearances delivered from the ANSP to the aircraft can be acknowledged and loaded into the FMS. When executed, the aircraft sends a confirming message that verifies what was sent is actually being used. Path 6 is a ground-ground path to the conformance monitoring function. These paths also provide the update of performance information from the aircraft to the ground or any changes in performance required by the ANSP. Conformance monitoring compares the input from the ANSP and what is sent from the aircraft as execution of the new clearance. The conformance monitoring function closes the loop and verifies that what was sent from the ANSP is what the aircraft is executing. Paths 8 and 9 are ground-ground links. Path 8 is the alerting path between conformance monitoring and the controller, and Path 9 is the path by which the controller sets the parameters, metrics, and tolerances for monitoring conformance.

5.0 Information Exchanges

TBO starts with flight planning. Surface operations are normally a closed trajectory—a defined taxi route. On takeoff, the aircraft starts another closed trajectory. This closed trajectory represents the 4DT that was selected by the operator of the aircraft as part of flight planning and updated with the takeoff time. As the aircraft progresses, onboard capabilities are used to update aircraft performance through use of data link. In most cases, the aircraft is best qualified to refine the 4DT and report on performance. This aircraft-provided information is an update to the aircraft intent.

The start of a 4DT goes through a process involving pre-negotiation, negotiation, an agreement accepting the trajectory, and execution of the 4DT.

5.1 Pre-negotiation

Pre-negotiation starts with flight planning and includes access to all known or projected constraints available through network-centric information systems. The operator defines the trajectory objectives (the business trajectory), including where the operator wants to fly, when, and how they get there. The operator considers known and projected constraints and preferences and also provides the ANSP with operator constraints/preferences that will affect the 4DT. These operator constraints/preferences may be related to crew qualifications, aircraft capabilities and limitations at dispatch, and any special conditions relating to the flight. The dispatcher may, because of expected constraints at the departure or arrival airport, add or swap constraints on the subsequent flight of this aircraft.

5.2 Negotiation

During the negotiation phase, the operator negotiates with the ANSP to determine if the business trajectory can be met considering all other traffic and system constraints. If the desired trajectory can be supported, then the operator and the ANSP move to the agreement phase. If not, then the ANSP provides options for the operator to select from. Once constraints are dealt with, this phase moves to approval.

In the air, the negotiation phase is not unlike in-flight requests today that reflect necessary changes. Negotiation leads to a change that maintains the closed trajectory and leads to a clearance where aircraft and ground intent are in synchronization. Negotiation can also be a simple request like an altitude change or a limited deviation for weather.

5.3 Agreement

The agreement is quick. It involves the final request, acceptance by the ANSP, and assignment and acceptance of a 4DT clearance. The clearance represents a "contract" to be executed. This clearance may be for the entire flight or a segment that is not unlike a clearance limit today. Both the operator and the ANSP are committed to execute the 4DT using TBO.

5.4 Execution

During the execution phase, the aircraft maintains the trajectory within the window defined in the clearance, with performance that satisfies the agreement. The aircraft and the ANSP monitor compliance with the agreement through conformance monitoring. If the operator is unable to meet the agreement, then negotiations start again to change the closed trajectory, or the controller may intercede and provide a route or time change, creating an open trajectory while the automation on the ground works a new 4DT.

5.5 Negotiating Trajectories – Air-Ground

Negotiation implies a constrained resource in some sense, such that not all participants can necessarily achieve all their goals and will negotiate a best compromise. In many cases, just as today, flight operator requests are immediately granted because there is nothing to prevent this. The term "negotiation" also implies decision-making between options; actions taken for immediate safety considerations, such as tactical separation management, are not considered negotiation.

The ANSP's authority over the airspace and the flight crew's authority over the aircraft's trajectory (FAR 91.3) do not change with trajectory negotiations. FOC responsibility for the safety of flights under their jurisdiction is not changed. However, the shift from tactical to more strategic decision making potentially expands the role of the flight planner during execution of the flight as discussed below.

By 2025, there will be a wide range of aircraft and operator capabilities, from sophisticated FOCs managing highly-equipped fleets to single-aircraft owner-operators flying aircraft with today's equipage. Some large operators will want, and will be capable of, an operator-centric approach that maximizes their flexibility in proposing trajectories. Small operators will want a turnkey service that would give them an acceptable trajectory without any investment in expensive aircraft equipage or dispatch services. Much negotiation, and likely all pre-flight negotiation, will take place using network-centric operations, allowing access to the negotiation process for nearly all users. Data link will be widely employed by 2025 for transmitting trajectories, trajectory constraints, and similar data with equipped aircraft in flight, but voice communication will remain available for all aircraft. Some airspace and operations will be limited to requiring aircraft with advanced capabilities including data link, but much airspace and operations will be available to aircraft with present-day capabilities.[3]

[3] By 2020, aircraft receiving ANSP services in defined airspace will be required to use RNAV and ADS-B Out for airspace defined in the ADS-B Out rule.

Trajectory negotiation is likely to prove more complex in a mixed capability environment, and this will contribute to the determination of performance requirements for selected airspace and operations. The following negotiation discussion is focused on operations in congested airspace, usually affecting those operators who fly in present Class A and B airspace, and examines trajectory negotiation from three different perspectives:

- The ANSP may initiate trajectory revisions for the same reasons they do today, but with much greater flexibility and accuracy, improved ability to evaluate alternatives, and improved capability to safely grant operator requests.
- A dispatcher or flight planner, responsible for either a single flight or for multiple flights, will negotiate the initial trajectory, as well as revise trajectories to achieve the operator's business or other objectives.
- The flight crew may initiate trajectory revisions and can negotiate using much improved information pertinent to the flight.

5.6 What Gets Negotiated

There have been a number of early research projects involving air-ground trajectory negotiation, starting in the 1970s with Automated En Route ATC (AERA) research and Center/TRACON Automation System (CTAS)/FMS trajectory exchange, and continuing through recent Optimized Profile Descents, Tailored Arrivals, Continuous Descent Profiles, and Airborne Merging and Spacing. In nearly all of these research projects, the approach that has proven to be most effective is to have the ANSP communicate (via data link in the experiments) constraints to the aircraft in response to an operator request that cannot be satisfied, or to convey a need for adjusting the current trajectory. Then the aircraft can generate a 4DT, which is communicated via data link back to the ANSP and FOC. If that trajectory isn't satisfactory, then the ANSP adds or changes the constraints and the process is repeated until a mutually satisfactory trajectory is agreed to or until the remaining time allows no more negotiation, in which case the ANSP will assign a new trajectory that conforms to system safety and capacity requirements, and is within the aircraft capabilities. When an FOC is negotiating the trajectory on behalf of an aircraft, a similar approach is used, with the ANSP providing trajectory constraints to the FOC, which then generates a trajectory to meet the constraints, although data link is not needed for such negotiations and a ground-ground connectivity exists through network-centric operations instead.

Both pre-flight and during flight execution, ANSP constraints are imposed as needed to reduce demand to meet capacity or to provide more structured flow so that capacity of a given airspace increases to meet demand. Constraints imposed on a flight during the execution of the flight will be limited to what the aircraft can achieve, just as today. Examples include en route traffic management initiatives (TMIs) to meter traffic through or around a flow-constrained area, or arrival metering to a high-density airport.

Constraints on a flight trajectory (both before and during the flight) typically fall into the following types:

- 2D Constraint
    - One or more specific waypoints or latitude/longitude points to pass through
- Altitude Constraint
    - Maintain altitude at a specific point or along a segment
    - Can be *at*, *at or above*, *at or below,* or *between*

- Timing Constraint
    - Window for arrival at specific waypoint or boundary
    - Could be *at*, *at or before*, *at or late,* or *between*

5.7 ANSP-Initiated Trajectory Negotiation

From the ANSP perspective, the main emphasis will be on planning and enhanced system prediction, with the objective of making most strategic ATM actions prior to flight departure or, where this is not practical, before the flight is forecast to enter a block of airspace or an airport terminal area where a constraint exists. The ANSP moves towards "Management by Exception," maximizing collaborative pre-flight iterative planning, and refining the proposed trajectory using all available relevant information as the takeoff time approaches, minimizing the need for in-flight intervention. The SESAR concept of Reference Business Trajectory (RBT) is useful here because the RBT represents the best compromise between the flight operator's objectives for the flight and the trajectory that the ANSP can agree to support. The trajectory that exists for a flight as it commences incorporates all the known constraints for that flight, providing significantly improved predictability for the flight over today.

No matter how good the planning, and even under the most nominal conditions, nearly all trajectories will need revision as the flight progresses. A continual trade-off exists between efficiency, capacity, flexibility, and rate of update of trajectories that also depends on weather, traffic density, and the type of operation. 4DT management and improved weather prediction will support some advance de-confliction of traffic flows, thus reducing the need for tactical interventions during flight. How this will finally be implemented will depend on research, as well as on mid-term implementation, but some general possibilities are provided.

It is likely that most problems, whether flow management involving many aircraft or separation management involving two aircraft, will be solved as early as practical, as soon as the information about the problem is good enough to support deriving an acceptable solution, with low probability that the "problem" was a false alert, or that the "solution" fails to solve the problem. This is to give the best chance of minimizing deviations from the operator's desired trajectory and to promote overall trajectory stability and predictability. Thus, the ANSP will initiate negotiation earlier rather than later.

The ANSP will generally try to make minor trajectory changes through timing or speed adjustments where possible for separation, initiating airborne merging and spacing or other aircraft procedures, and flow management. Path modification would be used when timing adjustments are insufficient or not the best solution. The overriding objective will be to maintain trajectory stability (and thus the ANSP prediction functions) and minimize the need for tactical vectoring, but how this is achieved will depend on the conditions and type of operation. Minor trajectory updates will replace most of today's open-loop vectors for spacing or separation. Vectors are not really a negotiation in that the flight crew will accept the clearance unless they have an overriding safety reason to not do so. Vectors take the aircraft onto an open trajectory that subsequently must be closed with a new 4DT.

The pilot must also work to close the trajectory. Pilots will need to update waypoints leading to a closed trajectory in the FMS, and work to follow the timing constraints by flying speed controls. Under dense traffic conditions, buffers will be needed in the system so that local trajectory changes can be made without propagating beyond the aircraft initially affected. ANSP automation will predict conditions when it will become infeasible for aircraft to meet future constraints, and will propose trajectory updates to the controller, possibly before the aircraft start requesting them, both to optimize overall system flows and to reduce communications. For instance, if winds are more strongly out of the west than forecast at Dallas-Ft. Worth (DFW), all the flights from the west coast will be arriving early, and those from the east coast will be arriving late. This will trigger revised times at the arrival fixes. Users may include predefined preferences (similar to the FMS cost index function) with the filed flight plan for ANSP automation to consider in proposing alternative trajectories.

The ANSP may negotiate by proposing revised constraints to the aircraft or the FOC, and let the operator choose a preferred trajectory to meet the constraints. This new preferred trajectory could then become the authorized trajectory that now has to be renegotiated if a further change is required. This is likely to be the case when the ANSP is using the trajectory for separation management.

Performance requirements for airspace and operations will generally be set before flight, but occasionally might be used opportunistically during flight. This might occur, for instance, during en route convective weather, where the ANSP negotiates optimal routes for high-performing aircraft (data link, low RNP) through gaps in the weather, and lower performing aircraft are routed around it. In this example, the better-equipped aircraft gets the advantage of using the more direct route.

5.8 Flight Planner-Initiated Trajectory Negotiation[4]

The dispatcher is typically a person responsible for managing flights; one or more dispatchers perform their work in a FOC. For single-aircraft operations, the flight planning function may be performed by the pilot in command, member of the flight crew, or another entity on their behalf such as a flight service station, or to a third-party company who offers collaborative air traffic management (CATM) service to Part 91 operators.

The flight planner's horizon for negotiating a flight may vary from tens of minutes to weeks. Typical reasons for negotiating a trajectory with the ANSP include the following:

- For an airline, build and update a schedule for its overall flight operation to meet the schedule
- Get best initial trajectory for individual aircraft before takeoff
- Prioritize among multiple flights (under the flight planner's jurisdiction) entering congested airspace or terminal area
- Re-route, delay or substitute one or multiple flights around weather or congestion to maintain business objectives
- Diversion from original planned destination due to severe conditions, weather, fuel needs, aircraft emergency, passenger considerations, etc.

The FOC will maintain a model of the aircraft performance and other key characteristics to anticipate the expected flight progress in the given environment, fuel usage, etc. This information informs the flight planner of what trajectory options are feasible for the aircraft when negotiating a new trajectory

[4] In negotiating flights with the ANSP, one of the factors affecting the options available to the operator is equity. It is assumed that there is policy in place for addressing equity among flight operators. The rules that define equity are beyond the scope of this report. Likewise, CATM is explored further in the RTCA Trajectory Operations Concept of Use efforts and is not duplicated here.

with the ANSP. New processes and protocols by which revised trajectories are negotiated and approved between the FOC, ANSP, and aircraft may be needed. This may include some form of partly automated negotiation to replace the daily and hourly teleconferences between the ANSP and various FOCs to strategize about weather and other events.

Preflight planning and flight following are key roles of the FOC in order to develop and maintain the business plan and business trajectory of the operator through optimization of both the individual aircraft and the fleet. This includes specification of the airframe to be used to conduct the operation, fuel decisions, and flight crew assignments. Once payload and fuel decisions have been made and the fuel for the flight has been loaded, flexibility is very limited. This is especially true for very long haul flights limited by weight. Typically, these decisions are made anywhere from a few hours before the flight up to the time of departure, depending on the latest payload, weather, and other related information. As with the ANSP, the objective is to make most strategic decisions before the flight commences. Even during the flight, the dispatcher is the primary and preferred decision maker for strategic negotiations with the ANSP because the FOC has access to more information, and the negotiation can take place over net-centric operations. The cockpit is also part of net-centric operations and works with their dispatcher in concurrence on changes. The FOC will generally be negotiating trajectories greater than 20 to 30 minutes into the future with the ANSP, and their role in negotiation diminishes relative to the flight deck as the time gets closer to the event for which the negotiation was initiated. Once a revised trajectory is negotiated, this new trajectory is conveyed to the pilot for approval and execution. The expanded role for the FOC enabled by the shift to more strategic decision-making will need to be refined.

The ANSP provides a forum to facilitate collaboration between flight planners representing multiple FOCs when there is a system-wide event or constraint. Among multiple operators, aggregate solutions to demand/capacity imbalances may be proposed to and by the ANSP. They should provide improved operations within the context of the operator's business objectives in comparison to solutions that might be individually imposed by the ANSP. Common situational awareness across the flight planning participants improves the options for dealing with constraints.

5.9 Pilot-Initiated Trajectory Negotiation

During the flight, the flight crew complies with the cleared trajectory except in emergencies; non-emergency changes are negotiated and agreed to before being executed. Flight crews will have access to 4D weather and NAS status information relevant to their flight through network-centric operations. Some aircraft may have sophisticated flight-planning functionality onboard, including trial planning and evaluation of proposed trajectories. However, even with advanced airborne decision-support automation, pilot-initiated trajectory negotiations may be limited by workload considerations.

The pilot monitors progress toward meeting assigned constraints and initiates negotiation directly or through the FOC if projected to be unable to meet a constraint. If the aircraft can still meet the constraints of the 4DT, but would prefer to renegotiate the constraint for efficiency or scheduling reasons, the pilot or FOC may request negotiation of the constraint, or the preferred constraint changes may be listed as alternatives in the flight plan. When a pilot requests a minor trajectory change that still meets all constraints, this trajectory change should be a fairly easy process expedited by local ANSP automation. Negotiating a change in constraints can be much more complex, since constraints have typically been negotiated and agreed upon through collaborative air traffic management (CATM) procedures.

For most airspace and operations, trajectories will include some flexibility (sometimes referred to as "windows") that allows the operator to optimize within limits without renegotiating the trajectory. This might apply to an aircraft choosing a path in real time between thunderstorms. Conformance monitoring on the ground considers the range of these windows, so minor maneuvering is authorized within the context of the 4D contract.

In 2025, aircraft will vary widely in their ability to accurately adhere to a 4DT and in their ability to exchange trajectory information with the ground. At the lower end of performance, some aircraft are only capable of adhering to wide lateral trajectories and flexible timing requirements (windows), while high-performing aircraft can transmit via data link detailed 4D trajectories that can be executed with high accuracy. In general, NAS operations and ANSP decision-support automation must be designed to deal with the entire spectrum of aircraft capabilities. However, significant operational efficiencies can be gained by taking advantage of the additional information-sharing capabilities and performance accuracies of high-performing aircraft.

The far-term JPDO Operational Improvements include a self-separation capability, which may be restricted to airspace where only self-separating aircraft can operate[5] or may include mixed-equipage environments where some aircraft are self-separating while others are ANSP-managed[6]. There are also a number of pair-wise delegated separation operations in mid- and far-term NextGen, such as airborne merging and spacing, parallel runway operations, and oceanic procedures. Self-separating aircraft separate themselves using ADS-B as the primary means of airborne surveillance. ADS-B provides the location and velocity vector, plus the near-term intent of other self-separating aircraft in the vicinity. Research is required to determine how to safely and effectively utilize the capabilities of these advanced aircraft in increasing efficiency and throughput of NextGen operations. When an aircraft has been delegated some separation responsibility; there needs to be sufficient flexibility in the trajectory that maneuvers for separation can be accomplished without trajectory negotiation. In this case, the trajectory might be constrained only sufficiently to support traffic flow management and would be virtually useless for separation management decisions. However, these self-separating aircraft are themselves operating based on highly accurate trajectories, which are continuously maintained to be conflict free using onboard strategic and tactical conflict detection and resolution functionality.

To ensure predictable operations, trajectory changes that result in the near-term generation of new conflicts are not acceptable. To sustain situational awareness, the new trajectory path is broadcast via ADS-B before the aircraft begins maneuvering. This is especially important outside of the range of any ANSP surveillance. If this highly accurate trajectory were made available to the ground via data link, then the ANSP decision-support automation could accurately predict the movement of both self-separating and delegated-separation aircraft. If future ANSP separation management decision-support automation were designed to effectively use this more accurate information for conflict detection and resolution functions, then more effective use of airspace capacity should result. Thus, an open research question is whether there should, in fact, be two trajectories in effect for these aircraft: a negotiated

[5] OI-0362 Self-Separation Airspace Operations
[6] OI-0363 Delegated Separation – Complex Procedures

trajectory used for traffic flow management that provides sufficient flexibility for self-separation maneuvers, and a highly accurate "4DT intent" used for separation management that is periodically updated by the aircraft without negotiation. NAS operational efficiency would probably benefit from having access to 4DT intent information from all aircraft that are capable of generating, transmitting via data link, and performing to a highly accurate 4DT.

6.0 Performance-based TBO

NextGen and SESAR are built around the concept of performance-based operations, and TBO is no exception. Within TBO, precision of planning and execution are coupled with precision of expectation: how well will the aircraft conform to its 4DT? This raises the question of "how good is good enough?" What are the specific performance requirements for the given airspace? By 2025, there will be a significantly diverse fleet with respect to equipage. Some aircraft will be more precise in their execution of the 4DT than others. Likewise, some airspace will require that aircraft fly with specified precision (at least during peak periods of operation) that takes advantage of performance-based operations. Global harmonization becomes important relative to the airspace. There is already a difference in RNP as to the sources of precision. It is important to understand that TBO can operate with any precision, and that it is the predictability of conformance to the 4DT that is more important than the numerical value, but this value must be known. What TBO cannot tolerate is variability in performance. For example, if it is known that an aircraft will arrive at the TOD point—as defined by the aircraft and agreed to by the ANSP—with a time tolerance of ± three minutes, then the impact is fewer aircraft within three miles of that same airspace. In essence, precision in the performance parameters in each of the four dimensions leads to fewer conflicts and necessary accommodations that must be resolved during the flight.

6.1 Horizontal Performance

The most mature element of performance-based operations is satellite-based navigation and the use of area navigation, or RNAV. When RNAV is combined with performance monitoring and alerting in the cockpit, the aircraft can support RNP. Typical RNP values expected are RNP 10, RNP 4, RNP 2, RNP 1, RNP 0.3, and RNP 0.1. Additional smaller RNP values may be defined by 2025 for applications such as VCSPR approach operations. These lateral boundaries represent the 95 percent containment area. RNP is expressed in terms of lateral displacement in nautical miles (nm). An RNP 4.0 means that the aircraft is expected to stay within four nm of a prescribed trajectory or ground track. This is four miles on either side of centerline. An RNP 0.1 is one-tenth of a nautical mile, or 607.5 feet. Two times the RNP tolerance represents the safe containment area. If flying an RNP 1 en route, the total safety containment area would be two miles on either side of the prescribed flight track.

The use of RNP opens up more airspace for use and improves separation. Parallel arrivals can be created that are separated by RNP. For this reason, the TBO Study Team believes that when the airspace separation moves to three nm everywhere in the contiguous United States, this will be done in conjunction with RNP 1.0 flight tracks in that airspace. To improve arrivals, the aircraft will start at TOD with RNP 1.0 and transition to RNP 0.3 for terminal maneuvering, and then transition again to RNP 0.1 for the approach to a precision landing.

Departures can also take advantage of RNP 0.3 for separating aircraft, meeting environmental noise flight tracks. As the aircraft moves further from the airport, it would transition to RNP 1. By improving the precision of departure paths, new arrival paths can use the previously protected airspace. There is no equivalent RNP value for surface movement, but as the visibility drops, cockpit guidance provided by GNSS moving maps is for advisory use only and visual aids are used even in the lowest visibility. There is a lateral opportunity here to use enhanced vision that relies on infrared sensors to provide eyes in the fog.

6.2 Longitudinal Performance

Longitudinal performance is a combination of absolute and relative longitudinal distances and can be managed by an assigned speed (time plus distance), time, or distance, or based on merging and spacing software. More advanced aircraft will have conflict and detection software that can be used to select and track other aircraft. If the pilot is assigned a relative longitudinal performance, it is in the context of a follower of a lead aircraft. In maneuvering, it may be that one aircraft is expected to pass behind, climb through the altitude of another, or pass. Merging and spacing software and conflict detection and resolution software are used to execute these relative separation maneuvers.

Absolute longitudinal separation under TBO would be set by the 4DT and would likely be a point in space with time as the separating metric. The concept of using time for separation, and therefore setting the longitudinal performance, is a basic concept of TBO. The objective is to remove the existing variability and increase the precision of distances between the aircraft being separated.

6.3 Vertical Performance

Vertical performance is not a discrete altitude unless in level flight. The climb and descent performance are impacted by aircraft weight, winds, configuration, and the business case for the trajectory. In today's environment, the vertical uncertainty leads to intermediate level offs, stepped climbs, progressive descent profiles, and other maneuvers to accommodate the ANSP's need to protect airspace for other users and preserve separation. In the far term, ANSP decision support automation will monitor vertical performance and accurately predict 3D conflicts, freeing controllers from having to manually predict 3D conflicts, and allowing a transition from separating airspace to separating aircraft in 3D. Considerable improvements can be realized through knowing a closer approximation of vertical performance. The aircraft is in a position to tell the ANSP the vertical performance. This is the basis of the OPD, where the aircraft tells the ANSP its vertical performance to meet flows and time.

The TBO Study Team examined opportunities for using information from the aircraft to reduce the uncertainty of vertical flight segments, refine the 4DT, and release airspace for use by others. One such technique is the optimized performance climb that operates much like the OPD. Another is greater use of cruise climb, a slow climb from initial cruise altitude to a higher optimum cruise altitude. Both of these procedures improve efficiency and reduce fuel consumption.

The concept of vertical performance will likely need to start as boundaries of vertical airspace, similar to what is used in an instrument approach:

3000 – Cross at 3,000 feet

3000 – Cross below 3,000 feet

3000 – Cross above 3,000 feet

3000 – 7000 – Cross between 3,000 and 7,000 feet

These boundaries would represent known constraints that the aircraft would be capable of meeting, but would allow the aircraft to set the most optimum climb or descent profile to pass through these boundaries of vertical space. The vertical boundaries are tied to a 2D point in space. This waypoint could have a time performance, as well. The ANSP would use these boundaries for conformance monitoring, and the vertical airspace boundaries would represent conformance constraints. In selecting the altitude windows that become conformance boundaries, the ANSP would initially use information in the flight object relating to the requested climb profile provided in flight planning. After takeoff, as the aircraft begins its climb, it could provide a new vertical intent to the ANSP to narrow the airspace that must be reserved for the flight.

7.0 The Fourth Dimension of Time

TBO is dependent on time, and this time must be the same in automation, both in the air and on the ground. At a minimum, clocks must be synchronized to the nearest second and set before taxi out. Time can be derived from GNSS, uplinked as part of a broadcast message, or set manually using an approved source of time. This synchronization is verified by the transmission of onboard time in data link messages. While the time precision of flight performance is greater than a single second, seconds of precision are specified for certain airspace and traffic density.

RTP varies with the flight operation and the density of traffic. Representative time performance considers significant reductions in variability over the current NAS that, by itself, will gain capacity and efficiency. For example, a reduction in landing runway occupancy time—from over the threshold to exiting the runway—from 60 seconds to 45 seconds can produce 20 more arrivals per hour for that runway. To realize this reduction in variability, TBO plans and provides for the time precision required for the situation.

As an example, on departure, a time to reach a position in space may be provided as a controlled time of arrival, expressed in seconds, to avoid or merge with crossing traffic, or to enable an uninterrupted climb without intermediate level offs and greater power requirements. Time becomes the controlling element for de-conflicting traffic and managing downstream flows.

There are two types of time: absolute and relative. In absolute time, the aircraft is proceeding to a defined location in space at a prescribed time (hours, minutes, seconds of coordinated universal time

[UTC]). In relative time, the aircraft is following another aircraft and is required to stay behind that aircraft measured in seconds or minutes (e.g., provide 70 seconds spacing and follow Sunset 42).

In high-density airport traffic situations, TBO delivers aircraft to the runway threshold with a variability of ± three to four seconds[7]. To achieve this precision, aircraft work back from the runway to a point in space approximately three miles from the runway retaining the three to four seconds since this flight segment must be a stable segment of the approach. This is known as the stabilized approach point (SAP) and is designed as a point where the pilot is fully configured for landing at the proper approach speed, so as to prevent high kinetic approaches. This means that this point in space off the runway is the timing point needed for maximum throughput of the runway, where the pilot's focus is no longer on meeting points in space at required times, but on landing the aircraft. Throughout the report, this point in space off the runway is set to 1,000 feet above ground level (AGL), the point at which a stable speed and proper configuration for landing is achieved.

Between TOD and this point, approximately three miles out from the runway, time performance is dependent on the aircraft type, weight, performance, and winds. TBO must also consider merging and spacing requirements to sequence multiple aircraft and provide not only the sequence for landing, but also the time intervals during the descent for each aircraft. During descent, it is easier to lose time than to make it up. Techniques like path stretching, maintaining a specified speed, or similar energy management techniques can add multiple seconds for spacing. Aircraft can be late to their TOD point. But they cannot be so early that they cannot lose that time in the descent. If late, the point of start of descent is shifted closer to the airport, but along the same flight track. If early, the aircraft can only lose so much time in descent. For purposes of discussion, an assumption is that the aircraft will arrive at a pre-determined TOD some 80 to 120 nautical miles from the airport with a time performance in the range of plus one minute and minus three minutes. On the minus side, TOD would be delayed and on the plus side, energy management would be used to slow the aircraft. Since the TOD point need not be the same for arriving aircraft and is not a metering fix, the sequence of landing must be known by the ground automation in advance of TOD. The 4DT would be updated to reflect actual aircraft time performance against all other traffic designated to use that runway.

Time can be lost or gained in cruise reaching back from TOD. But for en route, time management is not focused on the acceptance rates for the runway, but rather dealing with flow contingencies and maintaining downstream separation. The basis of TBO is to provide conflict-free separation at a prescribed future point in space and time. Separation cannot be assured without some level of precision for all four dimensions. Time-precision performance is dictated by the 4DTs of multiple aircraft and is worked with a 20 to 30 minute look ahead by the ANSP's automation. Depending on traffic density, en route precision can range widely, from minutes to seconds. RTP determines the proximity and required precision of en route waypoints with controlled time of arrival (CTA). CTAs are executed in the FMS with RTA. If on a closed trajectory, a nominal performance for time is on the order of (±) one to three minutes. On an open trajectory, time assumes larger variability and looks more like an estimated time of arrival (ETA) up to ±15 minutes for en route.

---

[7] This value is based on reducing the arrival variability between operations to gain increased throughput for the runway, and requires research to achieve the actual value for performance.

Climb timing is also dependent on separation requirements downstream. Closer to the departure airport, time performance may need to be measured in seconds (e.g., ± 30 seconds), whereas away from the airport, time can be anywhere between an ETA and ± one to three minutes for a CTA.

From an aircraft performance perspective, an RTP is executed by the FMS (with or without auto-throttles) to a time performance capability of that FMS or individual pilot performance. In the FMS, time is input into the RTA function of the system. For aircraft without an FMS, the time precision is based on the ability of the pilot to fly a ground speed along a flight path that may be aided by tools that show aircraft progress in meeting time.

Surface operations also have a time precision supported by the taxi-out time and the expected takeoff time. This time is measured in minutes, with the actual takeoff being used to reset the TBO time within ground automation.

Just as with RNP, where lateral performance is expressed in different miles and fractions of miles, time is expressed in minutes and fractions of minutes (seconds). One performance does not fit all. In fact, TBO for arrivals at most U.S. airports can function with the use of the precision of an ETA. But at large hub airports or in metroplex airspace, time gets refined to seconds of performance.

Table 1 provides some examples of representative time values for RTP. With review of surveillance information from ADS-B, actual variability can be measured starting at the landing runway threshold and working back to variability in takeoff times. Values in Table 1 represent a starting point for definition of actual requirements. As ADS-B becomes the norm, time performance requirements for traffic density and airspace complexity can be defined. The needed RTP is then compared to what the aircraft is capable of meeting and is adjusted accordingly. Note that Table 1 is built from the landing at the destination airport—the most deterministic portion of a flight—and built back to taxi-out at the departure airport.

The TBO Study Team created the concept of RTP and has provided representative RTP values as goals and to serve as a starting point for time performance discussions. Variability and values require research to define. In today's NAS, the current variability is unknown. Without this information, the actual time performance target for TBO cannot be set. RTP is being used because it is similar to the well-established RNP for navigation. RTP is the time performance that is executed in the FMS as an RTA. In cockpits without FMS, RTP becomes a progress check built on ground speed. In ground automation, RTP is represented as a CTA. While RTA and CTA represent a discrete time value, RTP is meant to specify a specific time window for performance, the margin needed to sustain one aircraft's time dimension against all other aircraft.

Table 1. Representative RTP Values

High-Density Airports	**RTP Value**	**Notes**
Landing Threshold	3-4 Seconds (RTP 0.03-0.04)	For convention, seconds are listed to the right of the decimal, and whole minutes are whole numbers to the left of the decimal with + or – values possible
3-mile Final	3-4 Seconds (RTP 0.03-0.04)	
Metering Fix	12-18 Seconds (RTP 0.12-0.18)	Approximately 20 miles out and a point where no further changes in the 4DT would normally be made
Top of Descent	1 Minute (RTP 1.0)	Tolerance RTP +1.0 to -3.0
Medium Density Airports		
Landing Threshold	5-10 Seconds (RTP 0.05-0.10)	
3-mile Final	5-10 Seconds (RTP 0.05-0.10)	
Metering Fix	20-30 Seconds (RTP 0.20-0.30)	
Top of Descent	3 Minutes (RTP 3.0)	Tolerance RTP +3.0 to -3.0
Low-Density Airports		
Landing Threshold	20-30 Seconds (RTP 0.20-0.30)	
3-mile Final	20-30 Seconds (RTP 0.20-0.30)	
Metering Fix	1 Minute (RTP 1.0)	
Top of Descent	5 Minutes (RTP 5.0)	Tolerance RTP +5.0 to -5.0
Cruise	2 – 5 Minutes (RTP 2.0 – 5.0)	Varies with proximity to TOD and ability to meet that time
Top of Climb	5 Minutes (RTP 5.0	
Top of Climb to Merge in Overhead Stream	1 Minute (RTP 1.0)	
Takeoff	1 Minute (RTP 1.0)	Varies with need to use TBO at the airport. Many airports would have no need for this precision

8.0 Flight Planning Aspects of TBO

The NextGen Concept of Operations (ConOps) is not detailed enough in the area of flight planning to be used in describing TBO. Work is underway within the FAA on collaborative traffic flow management that will expand the concepts. For now, TBO starts well before the flight plan and represents a significant level of coordination, information gathering, and calculation of fuel requirements to support the 4DT. The TBO Study Team has provided in Appendix B a detailed description of the flight dispatch information used, and this section covers the functions commonly used by U.S. commercial carriers. Each description also includes the applicable regulations and the existing operational improvements already identified for the NextGen ConOps (i.e., OI-xxxx) This information sets the stage for recommendations on expanding the NextGen ConOps to include dispatch and flight following functions. This description applies to each of the scenarios for the air carrier participants.

A flight plan is created for every flight in U.S. commercial operations. The Aircraft Dispatcher creates the flight plan and shares joint responsibility with the Pilot in Command (PIC) as stated in Federal Aeronautical Regulations (FAR) 121.533, 121.593, 121.631, 121.639, and 121.647. With these planning standards duplicated, a high level of safety is achieved. PICs and dispatchers take the same written test and are required to train to proficiency for the aircraft and airspace they operate in. Many corporations' risk management departments have determined the value of a Licensed Aircraft Dispatcher and use them in such operations as charter services, fractional ownership, and large flight departments. However, the regulations currently only require commercial carriers to provide this level of safety (OI-3101-3103).

The dispatcher plans the flight by comparing, verifying, and cross referencing several individual components independently, and aggregates information for the flight (OI-0305, OI-3109). These parts can be compared to a spider web intricately woven together to catch all available information and details, and as a web, the flight plan has many support strands that provide stability, with each element of information important as the next. The checks and balances are numerous, requiring both simple and complex evaluation, cognitive and deductive reasoning, and logical and prudent decision making. In flight planning, it is imperative to use all resources and to be aided by technology because of the sheer volume of information that must be examined in preparing an aircraft for flight (OI-0408).

The flight plan is a conglomeration of various aspects of the flight. It must navigate several areas to be a complete document. But many times, outside influences force changes that must be addressed, and the flight plan, by design, is a living document. It is frequently renegotiated with the AOC, flight deck, and ANSP. The flight plan is a legal contract between the parties, and all parties must agree and accept its initial form and any subsequent changes thereafter (FAR 121.687), since each individual (or group) has its responsibility to maintain a safe and legal operation meeting their own department standards and requirements.

The following section details the items reviewed and/or required for creating the flight plan, together with several flight plan scenarios.

By 2025, the FOC[8] and flight handlers have integrated their flight planning system into the network-centric operations based on standards and procedures driven by System Wide Information Management (SWIM) to enable all users of the NAS to review the communicated intent and actions for the individual flight. Common situational awareness and open communication is paramount to success and is conducted via data communications backed up by voice communication. Constant connectivity is vital for efficient, professional, economical, competent, safe, and ecologically aware operation in the NAS.

---

[8] AOC and FOC are used interchangeably. However, in some airlines, the AOC is an overarching strategic and tactical operations center, while the FOC is the dispatch and flight following function subordinate to the AOC.

The operation extends from departure gate through flight to destination gate, encompassing all aspects of the trip. The dispatcher will access multiple parts of the network-centric operation, monitoring input from ground automation systems (surface movement), airport systems (facility availability and runways-taxiways), navigational systems (ground and space-based), ANSP systems (flow constraints), Special Use Airspace [9](SUA) systems (constrained areas or flight levels and times), weather information systems (constrained areas or altitudes), the Aircraft Situational Display (ASD), and aircraft systems (constraints, limitations with systems or weights) to prepare the flight plan (OI-0408). The dynamics are fluid, and within the FOC, personnel attend to and monitor each system event available through networks, and transfer relevant data into their main operating network platforms of that specific airline so the dispatcher has a consolidated view of the NAS. The FOC and its handling agents have personnel who monitor the data feeds and participate in teleconferencing about any anticipated constraint by time, distance, and volume that may impact the operator. By 2025, it is expected that teleconferencing will be conducted through network-centric operations to improve the richness of shared common situational awareness. This constant monitoring and participation is managed via a secure, authenticated process that is provided by the ANSP in real-time so that all possible and actual constraints are known. Constraints, along with the SUA information, allow dispatchers to react to evolving situations in conjunction with active FMS downlinks from the flight deck of winds aloft, temperature, and turbulence. These, along with the airline meteorologist weather predictions, are compared to the data feed of automated reporting stations with full NextGen Net-centric Common Weather Level 3 throughout the NAS (OI-0385). Outside of the network-centric operation, but within the individual platform for each operator, is additional information to maintain legal and essential requirements for management of the flight.

In addition to the internal data set forth in several possible flight plans (OI-0305) and with constant feedback through network-centric operations, the dispatcher plans for a variety of situations, including contingencies. The specific scenarios may be closed trajectories, avoiding certain traffic, SUA, or weather with a strategy to return an open trajectory in the flight plan to the required 4DT within tolerance to meet the RTP (OI-0361). This multi-plan aspect is a major component of the NextGen dispatch release with numerous prioritized plans for each of the flights on file with the ANSP. This offers flexibility to the ANSP to adjust for the variables that are inhibiting maximum efficiency of the NAS. This multi-plan approach affects fuel loads, and at pushback the number of choices the aircraft can accommodate is limited by the decisions made before departure.

At approximately 90 minutes prior to wheels up time, the dispatcher sends the multiple flight plans to the ANSP who will process the options within the automated negotiation/separation management tool. The ANSP responds back to AOC within 15 minutes for acceptance or negotiation by the dispatcher (OI-0350, OI-0351, OI-0369). The ANSP sends the acceptable options back to the AOC. Once the ANSP responds, the FOC has 15 minutes to accept or re-negotiate the primary route. If the flight plan is negotiated, the ANSP has the same 15 minutes in which to accept or send a final plan. At a maximum of one hour and minimum of 45 minutes prior to departure, the fuel slip is sent into the automated ground network to load fuel to the aircraft for the expected 4DT with necessary contingencies, and the flight plan is filed with the ANSP.

[9] SUA is an existing terminology for dedicated airspace for military use. Under the mid-term FAA ConOps, a new concept of Special Activity Airspace (SAA) is introduced. This concept is less known operationally so SUA is used in the scenarios with military examples.

A message is then sent to dispatch, which can generate a flight release with all contingencies reviewed and appropriately planned. It is then placed in the queue for the crew who will receive the flight plan data through a data link message called the pre-departure clearance (OI-0352). The release can be uploaded or printed and will detail the filed flight plan along with subsequent contingent flight plans. If the ANSP has an off-nominal trajectory modification, or they are aware of any other contingencies, then the flight deck and dispatch can be notified and they can execute a contingency plan within the limits of the fuel load. Response to an ANSP flow contingency is prioritized within the set of options planned by the airline. Each of these contingencies considers the fuel load for the flight.

For 4DT changes that are open and have no set trajectory defined to destination, limited contingency fuel is placed on board the aircraft for a set time or distance. This enables flight deck and dispatch to actively negotiate new trajectories with a new RTA into the FMS to meet the CTA provided by the ANSP. Again, this negotiation is between ANSP, dispatch, and flight deck for accepting open trajectories with limits of time or distance, and actively re-negotiating into a closed trajectory and managing constraints.

As an example, SUA discussions relating to access of the airspace were ongoing during flight planning, and the airline is advised of possible extension (OI-0346) of the SUA operating timeframe. Prior to departure an alert is activated through network-centric operations where the ANSP has published the change information that, within 20 minutes prior to departure, the SUA timeframe was extended (OI-0365), closing off the route selected. The dispatcher and crew are notified concurrently that their active flight plan is no longer acceptable. Dispatch reviews proposed routing for any additional changes from the original plan and sends a message (within five minutes) to the crew and ANSP that route choice #5 avoids the SUA and this is best for operation at that time. The ANSP runs this new scenario updating the flight plan and sends the crew and the AOC acknowledgement of the new route and plan (within five minutes) (OI-0303).

This modification is also pushed through network-centric operations, so that affected stakeholders have the information on the SUA and flight plan changes. This action sets a new 4DT before departure (OI-0382).

The GA user is not excluded from these negotiations even without the dispatch function or handling service. Pilots can use network-centric operations established through SWIM access and technology and gain the same benefits (OI-0306).

Part of negotiation after filing numerous options for flight plans involves negotiating surface movement. The ANSP's Tower Flight Data Monitor (TFDM) is an attempt to relieve surface congestion by managing push backs (OI-0327). From a dispatcher perspective, the goal is to safely hit schedule. If a TMI (OI-0331) is discussed within the progressive data forum (OI-0327) in the CATM data conference to restrict the departure, or if there is a constraint, the dispatcher would gather relevant data. If the ANSP advises that the new takeoff time is 34 minutes after the hour, and taxi time from the gate to the departure runway today is 13 minutes, the aircraft can push back at 21minutes after the hour. Network-centric operations provide a dispatcher (OI-0320, OI-0321) with more information to manage a want or a need, and negotiate the pushback time, runway selection, departure modification, etc. to meet economic constraints or ANSP requirements (OI-0307). One option to achieve the objective for the constraint is by telling the ANSP what the departure runway priorities are (e.g., DTW RWY 22L), and the airline will accept a 13-minute delay to get that runway based on performance, route of flight and any other consideration the dispatcher wishes to put into the mix. However, if the delay for RWY 22L goes to 14 minutes, then the airline will accept RWY 21R with performance limits (8,500 feet runway, with noise/environmental limits [OI-6014]) as the trailing aircraft in a paired departure (OI-0356, OI-0387, OI-4000), provided there is less than 10 minutes delay to meet the RTP at top of climb (OI-0339, OI-0370).

The re-negotiation continues as final (actual) weight numbers are transmitted via data link to aircraft from AOC (load control), performance limits are rechecked against the ANSP (OI-0360) and the ability to meet the RTP of the NAS with runway and route selected (OI-0331). The takeoff gross weight also plays a role with the ANSP's departure management to estimate the climb performance for the 4DT and conformance monitoring.

Another example of the dispatch/flight planning functions relate to responsibilities for flight following. Throughout the flight, network-enabled discussions are being driven by weather. The weather pattern has migrated into the flow corridor (OI-0337) forcing eastbound transient departing flights from a major city to move east onto a more dynamic reroute (OI-0350), taking the aircraft further south than normal to subsequently reconnect to the flight planned 4DT. This creates projected conflicts leading to the need for an open trajectory and for use of airborne merging and spacing (OI-0360). The ANSP sends requested changes to crew and dispatch simultaneously, but dispatch, having utilized network-centric information, has already planned a contingency in the variable routes, as well as contingency fuel for off-nominal time, distance, or speed deviations (fuels noted in flight planning guide) (OI-0361). Dispatch planned for the greatest constraints and was still able to meet performance limits on all runways. The first choice was optimal and the remaining choices negotiable. The dispatcher's role includes development of flight path and time changes that are strategic in nature and provide both the crew and the ANSP with updated information. The flight is not complete until the crew navigates to the landing airport gate. The dispatcher again plays a role in providing the best arrival aircraft configuration to specific runways to meet RTP, as well as recommending operational taxiways to minimize taxi times and gate delays.

The flight planning advantages are not limited to commercial operations, and as previously stated the GA pilot is not excluded and can use a laptop or similar electronic device to access network-centric operations to obtain information on forecast weather, airport, and airspace restrictions. After reviewing the constraints and submitting trial plans, the pilot may consider submitting various alternatives along the route of flight, or some more direct routing but at a lower altitude. Other possible combinations may be considered before settling on a route(s) and altitude(s). The developed flight plan can then be downloaded to the Electronic Flight Bag (EFB). The EFB contains identical flight planning software as the personal computer, and is configured to interface with the network-enabled operations to access airspace constraints, update weather information, and file flight plans. The EFB remains connected electronically (Wi-Fi, ethernet, or a mobile wireless) to communicate through network-centric operations at the airport (access is likely provided by the fixed-base operator [FBO]), and a final check of weather and airspace constraints can be made prior to departure. The EFB information is synchronized with the navigational system and feeds all data into various aircraft systems.

Appendix B contains a listing of items and FARs that apply to dispatch, along with a representative flight plan. Readers are encouraged to review the extent of the information necessary to launch a flight and gain a better appreciation for the necessary links between the airlines' automated tools and the ANSP's automation through network-centric operations. Common situational awareness is critical to improved flight planning and flight following.

9.0 Scenario Development

To help describe TBO, three operational scenarios have been developed. Each is based on gate-to-gate flight segments that cover surface movement: takeoff/climb, en route, arrival, approach, touchdown and taxi-in. While flight planning is the same for each air carrier in the scenario, there are differences with the GA scenario. The TBO Study Team has chosen a flight from PHX to MIA to take advantage of an offshore flight segment and mixed equipage operations at MIA. The second scenario is a departure out of DTW with an overhead merge into traffic flows and arrival at IAD, where the Study Team has added a closely space parallel runway to illustrate some TBO concepts. The last flight scenario provides a general aviation emphasis on a flight from PHX to BZN. The "players" in these scenarios are described in detail in Appendix A. The operational scenarios are not the concept of operations for TBO. They represent a starting point for development of actual concepts and are the beginning of a process to define how TBO will be integrated into operations and system requirements.

10.0 Scenario Introductory Information

10.1 Surface Movement

TBO migrates from limited trajectory operations in en route cruise through arrivals within the mid-term timeframe, linking en route trajectories to TOD, and then through OPDs to approach and landing. 3DT (lateral, longitudinal, and time) are used in surface movement with introduction of surface movement management tools for sequencing aircraft for departures.

TBO starts with flight planning activities. Surface operations are a closed trajectory—a defined taxi route to take the aircraft to and from the runway. On takeoff, the aircraft starts another closed trajectory. This closed trajectory represents the 4DT that was selected by the operator of the aircraft as part of flight planning and updated with the actual takeoff time.

The concept of TBO is from gate-to-gate, not just today's ANSP-defined movement area beyond the gate and parking area. In the mid-term, this surface movement is largely the responsibility of the operator and the ground controller. The intent is to reduce variability in surface movement by using trajectories with a single takeoff time performance working back to pushback, or start of taxi from a hardstand or gate. This expected takeoff time for surface movement extends the TBO concept into flight with the actual takeoff time resetting the 4DT.

Efficiency and safety of surface traffic management is increased, with corresponding reduction in environmental impacts, through the use of improved surveillance, automation, on-board displays, and data link of taxi instructions. Equipped aircraft and ground vehicles provide surface traffic information in real-time to all parties of interest. A comprehensive view of aggregate traffic flows enables the ANSP to project demand, predict, plan, and manage surface movements, and balance runway assignments. This facilitates more efficient surface movement and arrival/departure flows. Automation monitors conformance of surface operations and updates the estimated departure clearance times to renegotiate the 4DT. Surface optimization automation includes activities such as snow effect prediction, runway snow removal, aircraft deicing, braking action, and runway configuration. Layered adaptive security extends to the flight deck with the use of biometrics and authentication through imbedded codes in the 4DT provided for approval to taxi.

10.2 Takeoff and Climb

The greatest uncertainty in TBO is capturing accurate information on climb, the vertical part of 4DT as defined by time. The variability in climb will require protection of vertical blocks of airspace bounded by the uncertainty of climb performance. The TBO Study Team examined this area and is recommending development of an Optimized Profile Climb (OPC) tailored to the aircraft type and its takeoff weight. This will allow less uncertainty in providing airspace for the climb. This new concept will help save fuel, emissions, and optimize the operator/user's profile. Just like the arrival OPD, altitude gates would be provided to gauge climb performance for conformance monitoring.

The aircraft is most capable in defining and reporting climb performance. The ANSP does need the takeoff gross weight for super-density airports in order to identify the amount of vertical airspace to reserve, and whether the aircraft can meet a proposed climb gradient. Pilots and flight planners can calculate their vertical profile given the crossing altitude constraints.

10.3 En Route Cruise

During the cruise segment, TBO operations should generally support user preferences for efficiency and weather avoidance. Fewer constraints exist in this phase of flight. By the 2025 timeframe, aircraft will have been operating for over eight years in the en route environment using trajectory operations that were created in the mid-term. Refinements will include a tighter coupling between airborne and ground automation, greater use of merging and spacing, some self-separation, and a reduction in separation standards to three miles in some airspace based on navigation improvements and use of ADS-B.

10.4 Arrival/Approach and Landing

TBO in the arrival segment seamlessly delivers the aircraft from TOD to the runway exit. The arrival segment consists of three sub-segments: arrival, approach, and landing. At high-density terminal areas, arrival time-based metering providing CTAs to RTA-capable, FMS-equipped aircraft, and there are metering advisories to controllers (OI-0318). RNAV/RNP procedures within the transition and terminal airspace (OI-0325) will be fully exploited, allowing for greater flexibility and increased throughput (OI-0355). Operations in 2025 will support OPD operations, even under heavy traffic conditions. RNAV STARS will be seamlessly connected to RNAV/RNP approaches. Arrival paths will be increased through the use of RNP 0.3 performance closer in toward the airport. TBO provides operational improvements and environmental benefits such as minimizing air/ground communications, reducing arrival/approach emissions, fuel burn and noise, and improving predictability and safety (OI-0309, OI-0329, and OI-6008). These procedures will help offset the environmental impacts from increased traffic demand.

The conformance monitoring and alerting functions of the ANSP's automation support both separation assurance and security functions. Deviations are quickly detected when flight exceeds the performance boundaries, and security functions can be built into the software that alert to specific flight profiles during arrivals.

Consistent with integrated arrival/departure airspace management (OI-0307), there will be a number of pre-defined configurations for arrival/departure airspace—including arrival/departure routes, airspace boundaries, etc.—that are tailored to typical flow patterns and weather events. Certain routes can be bi-directional and used for either arrival or departure, depending on the traffic situation and the location of severe weather and visibility/ceiling conditions (OI-0303 and OI-0389).

In future high-density airspace, the arrival sub-segment will begin at an arrival meter fix before TOD and end at an initial approach fix/merge point. Throughout the arrival and approach sub-segments, aircraft will perform OPDs with either ground-based CTA, time-based spacing, or airborne merging and spacing decision support tools managing spacing with CTA and/or relative spacing and time. A follower's time is relative, while a leader's time is absolute. The selection of optimal TOD point is an important aspect of performing an OPD. By 2025, a high-density metroplex airspace will have perhaps as many as 20 or 30 different arrival meter fixes fanning out from initial points in the STARs. These arrival meter fixes will be much further out than the 50 nm typical of today's TRACON. In less dense terminal airspace, published arrival meter fixes won't be required.

The increased number of operations anticipated by 2025 will place a severe strain on the NAS, especially in major metropolitan terminal airspace[10]. Traffic flowing in and out of the congested terminal area will make more effective use of the airspace by extending terminal separation standards (i.e., three nm instead of five nm lateral separation) and other terminal procedures (i.e., diverging courses) to airspace farther away from today's TRACON boundary. ANSP decision support tools will help ensure efficient and smooth traffic flow into and out of high-density expanded terminal airspace. Planning horizons are lengthened, allowing optimal runway sequencing. Arrivals are still far from destination airports, and departure slots can be more easily reserved in arrival flows when necessary. This is the great enabler that TBO brings. By projecting forward in time and space, each aircraft's performance can be combined to set the sequence and landing times for capable aircraft. Aircraft unable to perform TBO would either be restricted from the high-density airspace, or be handled on a time- and slot-available basis.

New procedures and airborne equipage will allow the use of very closely-spaced parallel runways (VCSPR) in Instrument Meteorological Condition (IMC), with the same throughput as in Visual Meteorological Condition (VMC). Arrival management ANSP decision support tools will assign pairings of aircraft for landing prior to entry into the expanded terminal airspace. An aircraft can typically be paired with another aircraft arriving from any of the other streams/STARS, and two consecutive aircraft from the same STAR may be paired. The coupling point occurs on the final approach approximately 12 nm from the runway threshold, and the two aircraft must maintain relative longitudinal positioning within a "conformance zone" from this point through landing. Separation

[10] The recession and continuing slow recovery have resulted in reduced airline capacity and decline in operations. Whether or not 2025 represents a targeted year when demand exceeds capacity is in question. However, the lead times for TBO development are such that the current economic impacts on aviation should not be used as a predictor for targeting NextGen.

responsibility is delegated to the flight deck before the paired aircraft vertical separation is reduced below 1,000 feet and before they intercept the glide slope.

When traffic demand approaches airport capacity levels, runway and routing preference will be given to aircraft equipped for capacity-enhancing operations, such as airborne merging and spacing and parallel runway operations. Aircraft without advanced equipage may be assigned to less advantageous routes and runways, or have to wait until an arrival push has ended for airport access.

By 2025, the STAR paths will merge seamlessly into the approaches. This continuous flight track is important to sustaining a closed trajectory. The approach sub-segment begins at an initial approach fix, which is a waypoint on the STAR and ends at touchdown. An approach will typically have multiple initial approach fixes leading from different STARs that merge into the approach route. The final approach fix (FAF) is a point that varies along the glide slope based on a number of factors, and its location may even be dynamically transmitted by the ground automation via data link.

The landing sub-segment begins at touchdown and ends at the runway exit. Taxi-in to the gate or parking is a function of surface movement.

11.0 Scenario Assumptions and Conditions

- The scenarios' "actors" have their equipage defined in Appendix A.
- The rule requiring ADS-B Out equipage is in effect in 2020, so aircraft operating under Instrument Flight Rules (IFR) and requesting services from the ANSP are equipped.
- Most, but not all aircraft operating in high-density airspace also have CDTI and tools for merging, sequencing, and spacing.
- Data link is used to negotiate trajectories, receive clearances, and report relevant 4D information for the purposes of sequencing, spacing, and separation.
- Environmental benefits are realized in terms of noise, fuel burn, and emissions through increased efficiencies realized from TBO.
- ANSP automation de-conflicts multiple aircraft 4DTs.
- Surveillance comes from a combination of multilateration close to and on the airport, as well as ADS-B.
- Intent is a product derived from aircraft automation and sent via data link message.[11]
- Layered adaptive security is provided through conformance monitoring.
- Aircraft equipped with RNP, data link(s), CDTI, and conflict detection and resolution software are capable of self-separation in designated airspace.

[11] At this point, the message content is unknown. Trials are being conducted in Europe under SESAR using VDL Mode 2 controller/pilot data link communications. Research to define intent and compare intent performance with the available spectrum is required. Standards are needed on intent so that both automation and communications can be defined.

12.0 Pre-conditions Relative to the TBO Scenarios

- Aircraft equipage that meets performance requirements for lateral, longitudinal, vertical, and time-based positioning and navigation
- ANSP automation tools to manage 4DT-based sequencing, spacing, and separation
- ANSP, dispatcher, and pilot procedures
- Performance measurements to determine when and in what airspace density will warrant TBO
- Research is completed on the necessary acceptable time variance for the traffic density. The greater the traffic density or complexity of the airspace, the more precise the time requirement.

In addition to the assumptions made in Appendix A, there are some assumptions and conditions tied to the different phases of flight for the individual scenarios.

12.1 Flight Planning Assumptions

The dispatcher (FOC) is fully integrated in network-enabled operations through SWIM standards, and is exercising the full leverage of this information during all phases of flight. Data communications feeds prioritized information to the flight deck and ANSP to allow quick, concise, and safe business decisions that ensure best possible operating efficiency that meet or exceed current or established safety metrics.

12.2 Flight Planning Preconditions

Human workload, though improved data communications, presents all participants with choices to consider, negotiations to accomplish, and agreements to be reached.

All operators meet the same standard for data processing and have the ability to receive data at correct moment when the information is needed, and with no delay—the right information, at the right time, in the right location, to make the right decision.

The dispatcher's role is expanded to include extended strategic planning and interface with the ANSP for making strategic changes (greater than 30 minutes or more) to the 4DT. The dispatcher works with the ANSP's strategic controller on necessary flight changes that can be resolved at least 20 minutes before a change is required. Anything less than that is resolved by the flight crew and tactical controller. For operations that do not rely on a dispatcher, the negotiations and agreements occur between the pilot and the strategic controller.

12.3 Surface Movement Assumptions

The following surface movement assumptions reflect availability of current and future systems:

- FAA surface movement programs: Airport Movement Area Safety Program (AMASS), Service Life Extension (SLEP), Airport Surface Detection System Model X (ASDE-X) (today at DTW), Terminal Departure Flow Management (TDFM) and Tower Flight Data Monitor (TFDM) are in place
- Mode C on surface, ADS-B Out mandate is in effect
- MLAT multilateration exists at larger airports

- The FAA's Taxi Path Clearance, Departure Clearance (DCL), D-TRAFFIC, and D-TAXI are available
- There is operator equipage for CDTI supporting surface moving map, and
- There is operator equipage for Enhanced Flight Vision Systems (EFVS) where the investment makes the business case.

Certified on-board systems are composed of all or part of the following:

- Airport moving map systems
- Cockpit displays and controls
- Traffic computer with ADS-B and/or Traffic Information Services-Broadcast (TIS-B) capability
- Enhanced Vision (Heads-Up Display [HUD]/SGS, EVS)
- Communication Management Unit (CMU)
- Potential database server
- Braking systems
- Flight controls and auto-throttle

Applicable NAS/NextGen Enterprise Architecture Operational Improvements for surface movement include the following:

OI-0320 Initial Surface Traffic Management
OI-0321 Enhanced Surface Traffic Operations
OI-0322 Low Visibility Surface Operations
OI-0327 Full Surface Traffic Management with Conformance Monitoring
OI-0331 Improved Management of Arrival/Surface/Departure Flow Operations
OI-0339 Integrated Arrival/Departure and Surface Traffic Management for Metroplex
OI-0340 Provide Surface Situation to Pilots, Service Providers, and Vehicle Operators for Near-Zero-Visibility Surface Operations
OI-0370 Trajectory-Based Management - Gate-to-Gate
OI-0381 Ground-Based Automation System (GBAS) Precision Approaches
OI-0383 Improved Runway Safety Situational Awareness for Controllers
OI-0384 Improve Runway Safety Situational Awareness for Pilots
OI-0386 Expanded Radar-Like Services to Secondary Airports
OI-0409 Remotely Staffed Tower Services
OI-0410 Automated Virtual Towers
OI-2023 Initial Integration of Weather Information into NAS Automation and Decision Making
OI-5002 Improved Strategic Management of Existing Infrastructure (Airside)
OI-5006 Coordinated Ramp Operations Management
OI-5010 Advanced Winter Weather Operations - Level 1
OI-5110 Advanced Winter Weather Operations - Level 2
OI-5111 Advanced Winter Weather Operations - Level 3

12.4 Climb Assumptions

Pre-departure clearances will be given by data link for Transcon and Sunset, and by voice for N72MD.

Transcon 1324's pre-departure clearance includes precise timing constraints and altitude windows for the OPC for entry into congested en route airspace, and for an in-trail following application behind a Westair Boeing 767.

Sunset 42's pre-departure clearance includes a tailored OPC with more relaxed timing constraints.

12.5 En Route Cruise Assumptions

Air Carrier PHX to MIA:

- Westair 351 (Louis Armstrong New Orleans International Airport [MSY]-MIA) is added to the scenario. Westair equipage is as listed in the scenario file of Appendix A, with the exception that it does not have self-separation capability
- "Managed aircraft" (controlled by ANSP) is also allowed in self-separation airspace
- Self-separation aircraft must maneuver as necessary to avoid conflicts with managed aircraft in self-separation airspace
- Ground-based surveillance is available within this scenario's self-separation airspace (needed to illustrate conflict between self-separating and managed aircraft)

Air Carrier DTW to IAD:

- FMS capable of sharing entire profile ahead of aircraft to the runway with ATC via data link
- Single RTA capability with the FMS
- Full aircraft performance database in the airborne system, full vertical navigation (VNAV)

General Aviation PHX to BZN:

- Aircraft equipped w/ GNSS, Satellite-Based Augmentation System (SBAS), RNP 0.3, autopilot /no auto-throttles, Synthetic Vision System (SVS), ADS-B In/Out, moving map w/ Terrain Awareness and Warning System (TAWS), satellite weather, CDTI, and EFB with CDTI and self-spacing software
- Pilot is proficient IFR pilot with commercial and instrument ratings. Aircraft is certified for flight into known icing.
- Weather is forecast:
    - Storm system moving into western Montana with snow showers, chance of moderate to severe icing in clouds and snow showers, and moderate to severe turbulence
    - Various cloud layers along route with light to moderate turbulence before 1300 local, moderate to severe turbulence after 1300 local
    - BZN forecast for ETA is 10,000 broken to overcast, 20 nm visibility. Winds are from the WNW at 10-15 mph, occasional gusts to 25 until 1500 local, then ceiling becoming

overcast and gradually decreasing to 1,000 feet with chance of heavy snow showers, gusts to 40 knots and icing in clouds and snow showers.

12.6 Arrival/Approach and Landing Assumptions

For parallel runway operations:

- While there are no current plans at IAD, many hub airports (including IAD) may have new parallel runways, spaced as close as 750 feet from an existing runway, by 2025. In order to show how closely spaced parallel runway operations work in concert with airborne merging and spacing and time-based spacing, a new parallel runway has been created for the IAD arrival scenario that is 750 feet from an existing runway.
- The DTW to IAD scenario is based on one of several proposed concepts for closely spaced parallel runway operations. The concept is designed to accommodate dependent pairing of aircraft with dissimilar final approach speeds. The conformance zone is defined only by wake avoidance. The aircraft with the faster Final Approach Speed (FAS) is initially positioned behind the aircraft with the slower final approach speed. After the coupling point when the aircraft slow to their respective final approach speeds, before the SAP, the trailing faster aircraft may safely overtake the slower lead aircraft and move some distance ahead before landing, still staying within the conformance zone. Future research will determine whether passing can be safely conducted at runways spaced laterally as close as 750 feet. If passing is not supported, then aircraft pairs must have much closer final approach speeds.
- Similar to dynamic wake spacing, the size of the conformance zone varies dynamically with environmental conditions, especially crosswind speed and direction.
- The parallel runway breakout maneuver is not a 4DT since it does not specify the aircraft's position as a function of time, but rather relative to the point at which the breakout is initiated. When an aircraft conducts a breakout maneuver, it has an open trajectory until closed by the ANSP.
- An aircraft is not allowed to overtake another aircraft in the same stream/STAR unless they are traveling at different altitudes.
- Much of the information exchange between the flight deck and ANSP will be via data link. For example, rather than today's Automatic Terminal Information Service (ATIS) messaging, the aircraft will receive a data link message with current weather and airport configuration information.
- By 2025, STARs supporting OPDs will be created for all arrivals for high-density airports. These OPD STARs will have a defined 2D route, but will have waypoint altitude crossing restrictions defined as a range of altitudes, defining a vertical volume designed to accommodate a variety of aircraft with different weights and performance characteristics.
- In high-density traffic, an arrival stream will contain a string of aircraft conducting airborne merging and spacing to a runway. A complicating factor in spacing is the need to accommodate stabilized approaches for aircraft with different final approach speeds (i.e., the aircraft must slow to its appropriate approach speed and be configured for landing before descending below 1000 ft AGL). The spacing 4DTs must include a buffer to accommodate differences in approach speeds because a faster aircraft will be gaining on the aircraft ahead, while a slower aircraft will be falling behind the aircraft ahead during the last three nm of the approach.

- ANSP will delegate lateral separation to the flight deck for RNP operations that are less than the capability (< three nm) expected from the 2025 ANSP surveillance.
- By 2025, improvements in barometric altimetry will enable vertical separation less than 1,000 feet in terminal airspace and altitudes less than FL290.
- Decision support tools will include wake turbulence separation applications providing dynamic, pair-wise, lateral, longitudinal, and vertical separation requirements for trajectory management based on aircraft and weather conditions in real time (OI-0387). "In real time" means wake spacing can be updated during the day, but not after the aircraft has reached TOD.
- The RTP timing requirement varies along route as follows; Arrival Meter Point/TOD ± one minute, FAF/Touchdown ± 3 seconds.
- Similar to RTCA Trajectory Operations, there is no need for FMS to handle multiple RTAs. This would be very costly for airlines. The RTA will be applied relatively short-term (< 30 minutes) at various points along the route.

For landing and taxi:

- Ability of TBO closed trajectory ending at runway exit requires research. The exit times will have to be generous and consider varying aircraft approach speeds based on weights, environmental conditions, minimum equipment list item consideration (e.g., thrust reverser inoperative), and runway turnoff, high speed exits, parallel taxiway design, and alignment amongst others. Regulatory requirements will exist covering available runway needed, stopping distance, approach, and landing climb limits. If precise 4DTs for landing and runway exit are desired, it is likely they will have to be provided by the operator because the operator will have access to all the necessary information, some of which will be proprietary information.
- While some aircraft have avionics to help the pilot decelerate to meet an exit (e.g., Airbus's Brake-to-Vacate), this capability would need to be on most aircraft to significantly affect runway throughput.
- Research may lead to removing the 250-knot maximum speed restriction below 10,000 feet AGL, so as to support best possible lift over drag and increase the options for design of the arrival paths.

13.0 PHX To MIA Scenario

13.1 Surface Movement

The PHX ground control position provides taxi instruction to pilot via data communications. Surface movement taxi guidance arrives via data link and is presented on the CDTI. The pilot of Sunset 42 acknowledges taxi instructions and coordinates pushback with ramp control. The ANSP ground controller issues further taxi instructions based on changes such as TMI and departure sequence changes.

The ground controller and the pilot monitor taxi conformance. The primary responsibility for safety during taxi operations rests with the pilot, who follows the assigned taxi route. The ANSP provides an extra layer of protection for blunders by others, including runway incursions and unforeseen weather conditions.

In the scenario, ground control from the ANSP provides the rest of the taxi instruction, corrective action, or new clearance taxi route to RWY 25R.

Ground control then coordinates with the local controller for RWY 25R. The ground control then issues handoff to local controller. The pilot of Sunset 42 monitors EFVS to maintain taxiway centerline at night and in low-visibility. Own-ship surface movement alerting is also employed for indication of the correct runway identifier and insufficient runway length alerting. The information for the departure has been delivered before taxi-out and the ANSP local controller will provide the takeoff clearance. The pilot of Sunset 42 takes off to slot into a departure stream to join the overhead flow. The takeoff event time is distributed through network-centric operations for common situational awareness and to update automation used for TBO.

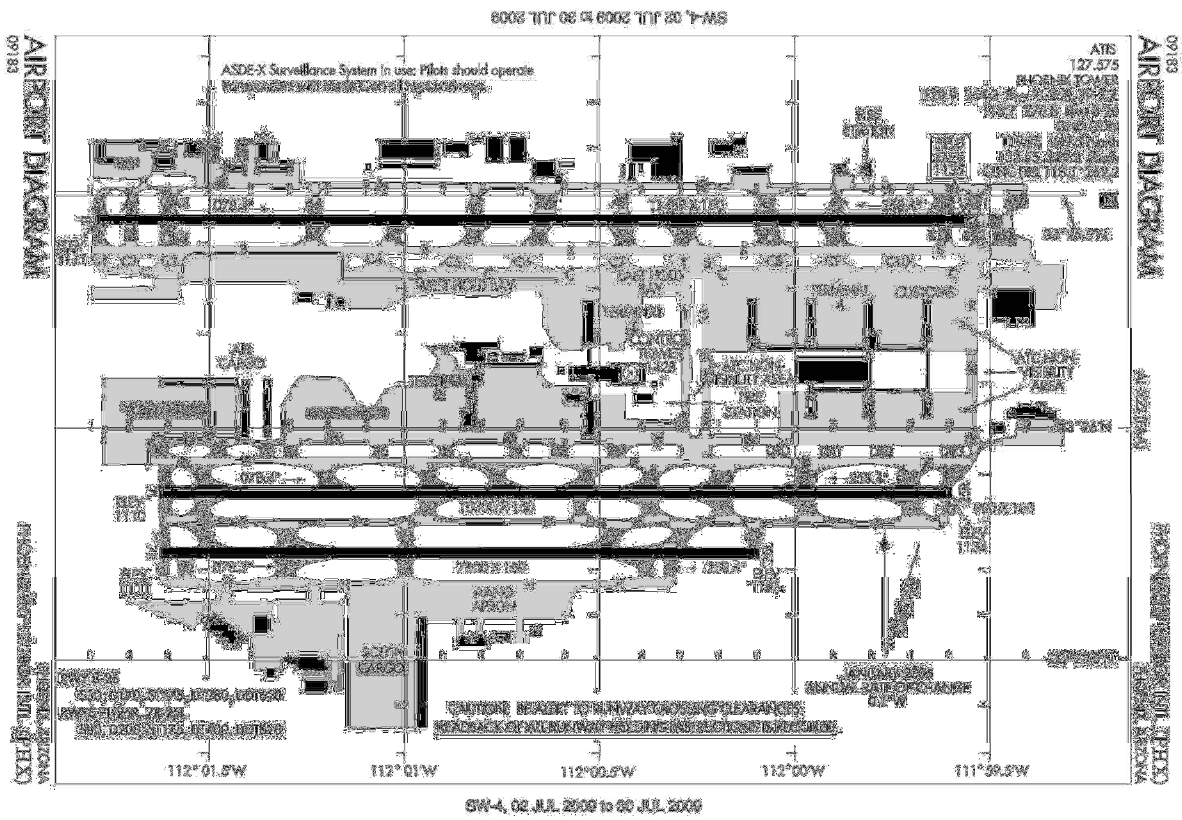


Figure 5. PHX Surface Layout

13.2 Phoenix Takeoff and Climb

Sunset 42 is departing on RWY 25R and will be continuing initially to the west for noise abatement. An RNP 0.3 dynamic OPC is negotiated between PHX Departure and Sunset 42 dispatch after pushback. This happens as soon as the aircraft's actual weight (final PAX and fuel on board) and performance have been confirmed. Trajectory management automation at PHX provides OPCs that are separated from arrival and other departure flows for less equipped aircraft. In this case, an OPC tailored to Sunset 42's departure direction can be accommodated because the weather is clear and traffic is relatively light. The agreed-upon departure OPC is data linked to Sunset 42, acknowledged, reviewed, accepted and auto-loaded by the flight crew. This transaction happens at the gate or during taxi-out if the takeoff numbers are not available from dispatch. Dispatch has already worked calculations of the proposed climb based on altitudes that must be met by certain points in the departure. These were provided by the ANSP during flight planning. The planned profile is then updated for weight and winds and provided back to the crew. Once received by the crew and entered into the FMS, it is followed by an intent message from the aircraft to the ANSP verifying that the 4DT is set. The 4DT includes a takeoff time that the flight crew will have to meet during the taxi portion of the flight. The moving map actually displays required progression of time during taxi-out for takeoff.

When reaching the runway end for departure, the number of aircraft in the queue is low because taxi-out is managed from the gate. The ANSP clears Sunset 42 for takeoff. As the aircraft rolls down the runway and lifts off, the surveillance system logs liftoff time from ADS-B. This information is sent to the TBO strategic evaluation service to re-compute the 4DT and identifies any downstream strategic changes that may be necessary. Takeoff time is also used in the TBO departure automation module to calculate time performance for conformance monitoring.

Once a positive rate of climb is established, Sunset 42's flight crew retracts the landing gear and executes the prescribed sequence of climb speeds and flap retractions. Once established on the climb, the FMS updates climb performance and refines the vertical profile. This new vertical profile is sent to the ANSP via data link as part of an intent message. The ANSP can then update the vertical windows, narrowing the amount of vertical airspace required to support the departure. Over time, the surveillance capabilities of the ANSP have learned the bounds for this aircraft type; weight load and information can then be used to reduce the required reservation of airspace due to shrinking the variability of performance.

The flight crew monitors their in-trail spacing and relative altitude behind a heavy jet that took off just prior to them (two-minute separation is not required due to crosswind) using their CDTI. Sunset 42 lifted off earlier on the runway than the heavy and immediately climbed above the heavy's altitude along the same flight track. The CDTI provides a history tail of the lead aircraft so that the crew can plan wake vortex avoidance whether in visual or instrument flight rules by selecting data through the CDTI.

As the aircraft climbs through 2,000 feet AGL, the tower transfers control of the aircraft within ANSP automation to departure control. An unobtrusive tinkling chime reminds the flight crew that they are no longer in contact with tower voice communications and can expect routine communications with ATC through data link. A "channel open" light on the data link control panel indicates a data link "handshake" has been made with the ANSP and a voice channel is available if needed.

Prior to 2,500 feet AGL, they engage lateral navigation (LNAV)/VNAV and begin the tailored OPC. This sends an automatic message to ground automation to update the 4DT performance, so that conformance monitoring automation can be updated. The aircraft climbs away from the airport along an optimized vertical profile, exiting the high-density terminal airspace to the west with a climbing left turn once above noise sensitive areas.

The heavy jet ahead of Sunset 42 is not a factor, as its departure speed is higher. Although not cleared for any separation tasks, the flight crew monitors traffic on nearby dynamic RNAV/RNP OPDs from southern California since they are passing relatively close below these arrival paths.

Above 10,000 feet AGL, the crew reviews and briefly discusses updated timing constraints related to the cruise portion of the flight, and whether a speed change will be needed to meet them. Since the aircraft also has conformance monitoring capabilities through the FMS, the crew notices that they are climbing slower than expected to meet top-of-climb and makes a vertical adjustment, trading optimum climb to meet optimum time.

As Sunset 42 continues on its 4DT track, transfer of control and changes in frequency arrive on the flight deck automatically, for both the data link and voice communications channels.

ANSP trial planning automation detects an upcoming conflict with WestAir 834 approaching from the southwest at FL240. With projected loss of separation 12 minutes out, the strategic TBO evaluation automation estimates that instructing WestAir to reduce its speed slightly will prevent the conflict from developing. The strategic TBO evaluation automation calculates that this resolution will not interrupt WestAir's OPD timing, and will maintain Sunset 42's schedule to meet en route timing constraints.

The strategic TBO evaluation automation prepares the 4DT modification for the tactical controller's review and acceptance, and then the controller sends it to WestAir. Sunset 42 is aware that WestAir is to the southwest of their position, but the potential conflict and its resolution are transparent to them. The FMS automatically generates and sends an intent report giving the aircraft's status when the RNP departure is complete. The ANSP monitors Sunset 42 as it exits its departure RNP path at the initial cruise altitude. Since this is an intent message that is used for conformance monitoring, the message also contains what the crew has set in the FMS for the next segment of the flight, projecting forward the 4DT. Conformance monitoring on the ground is using surveillance information and clearance information to track the aircraft's compliance with the flight trajectory. Parameters in flight performance are set by a combination of the clearance and the ANSP's strategic controller. At initial climb level off, the controller has set an RNP value of 2, a vertical tolerance of ± 50 feet, and a time to the next turn of - one minute and + three minutes as recommended by the TBO strategic evaluation automation. This timing bound is set because of crossing traffic. The TBO strategic evaluation has also set a five nm separation requirement for this airspace.

13.3 Phoenix to Miami Cruise Segment

During the cruise portion, Sunset 42 flies in TBO airspace along the U.S.-Mexico border before proceeding over the Gulf of Mexico. While flying near the border, Sunset 42 encounters dynamic special use airspace areas and Unmanned Aircraft Systems (UAS) operations. Once over the Gulf, Sunset 42 transitions into self-separation airspace and encounters a large low-pressure system. It then re-emerges into TBO managed airspace as it approaches the Florida coastline, prior to commencing its descent—an OPD to MIA.[12]

Other relevant aircraft in the cruise segment include Winds Air 134 and Westair 351. Winds Air 134 (Houston George Bush International Airport [IAH]-MIA) is a self-separating aircraft and Westair 351 (MSY-MIA) is a managed aircraft unequipped for self-separation. Both interact with Sunset 42 in self-separation airspace.

[12] The assumption is that in self-separation airspace, the aircraft is free to maneuver, and as such is on an open trajectory, but not without conformance monitoring from the ground that is tracking progress. The trajectory is closed before exiting self-separation airspace.

Sunset 42 begins the cruise segment when it levels off at its initial cruise altitude. After settling into cruise, Sunset has a conflict with a UAS conducting border surveillance flights. Being in TBO airspace not designated for self-separation, the ANSP has responsibility for resolving the conflict. En route TBO automation detects the conflict approximately 30 minutes out and applies right-of-way rules to determine that Sunset 42 should maneuver. Once detected as a conflict, the automation proposes a conflict resolution and the controller uplinks it to Sunset 42. The pilot then accepts it, sends a Will Comply (WILCO) back to the ANSP, and loads the updated 4DT into the FMS. When executed, a data link message from the aircraft will provide confirmation of the new intent. Sunset is on a closed trajectory for the entire conflict resolution. The resolution is a turn to a waypoint slightly off-course, followed by a turn back to intersect the original path. Since this is a planned deviation with a path to the original 4DT, it is a closed trajectory where both air and ground automation remains in sync for conformance monitoring. After the pilot accepts the resolution, the controller's automation is updated to reflect the new 4DT. This new trajectory becomes the basis for conformance monitoring on the flight deck and on the ground. By making small heading changes early on, most downstream calculated conflicts can be resolved.

As the flight progresses, the crew receives updated weather information about the low-pressure system over the Gulf. This system is spawning significant convective activity that will affect all flights in the area. Improvements in weather forecasting ensure that convective weather predictions are as reliable over open water as they are over land. A common source of weather data provides consistent information to applicable pilots and the ANSP. Weather information is incorporated into decision support tools to help participants make more informed decisions about available sector capacity and re-routing. Algorithms consider a range of pertinent data that have been shown to contribute to pilots' decision to deviate, including reflectivity, echo tops, vertically integrated liquid, and instability. These algorithms incorporate probabilistic forecasts to better estimate uncertainty at different time horizons. Using the most recent weather, Sunset 42's pilots begin to plan for possible deviation strategies when they approach the storm.

Shortly after the weather update, Sunset 42 commences a planned cruise climb. This climb is within tolerance of the original trajectory plan approved by the ANSP, and does not require further coordination. The latest 4DT includes the block of vertical airspace identified for the cruise climb maneuver at the point where cruise climb is planned.

Sunset 42 approaches a restricted area that has been designated for dynamic use by civilian aircraft. Prior to the flight, the military coordinated with the ANSP to release a portion of their airspace for civil traffic, based on the military's predicted mission needs. Sunset 42's 4DT has been established to fly through a temporarily unused portion of airspace. To accommodate needed flexibility, the military may work with the ANSP to change Sunset 42's 4DT if it determines that it must use the airspace it previously released. In this case, it would negotiate with the ANSP to provide a minimal impact change to the Sunset 42 flight. The SEVEN software[13] provides decision support for airspace release

---

[13] System Enhancements for Versatile Electronic Negotiation (SEVEN) is a NextGen concept for managing en route congestion and enabling NAS customers to submit cost-weighted sets of alternative trajectory options for their flights. SEVEN provides traffic managers with a tool that algorithmically considers customer trajectory costs, as it assigns reroutes and delays to flights subject to traffic flow

and any needed re-acquisition. For this flight, however, the military's mission needs are as originally planned, and Sunset 42 can maintain its original 4DT.

In addition to the weather over the Gulf, convective activity has intensified in South Florida. New probabilistic forecasts show an increased chance of convective weather that will reduce airport capacity near the time of Sunset 42's arrival. Using decision support tools incorporating this probabilistic weather, the MIA ANSP, in coordination with the ANSP's Command Center, has decided to reduce the airport acceptance rate. Time-based metering is extended to a longer planning horizon. The ANSP contacts Sunset 42 via data link with a new RTP at a point just prior to TOD. The flight crew uses the RTA functions in the FMS to set this time performance requirement. This solution allows adequate time for Sunset 42 to reduce speed to a more economical setting and prevents the need for inefficient delay maneuvers when closer to the airport. The Sunset crew acknowledges the change and executes the new RTA in the FMS. When the crew executes the change in the FMS, a confirmation of the change is sent to the ANSP via data link. Based on onboard FMS calculations, Sunset 42 can meet the RTA by maintaining its current flight profile at a slower speed.

Sunset 42 crosses the Gulf coastline and proceeds toward self-separation airspace. The aircraft receives a data link message from the ANSP advising the crew of the change in separation responsibility from the ANSP to the flight crew prior to reaching the airspace boundary. The message confirms the boundary marking the beginning of self-separation airspace and formally hands off separation responsibility to the flight deck. Sunset 42 acknowledges the message and accepts responsibility for its own separation when entering the airspace. The ANSP then confirms receipt of this handoff with an additional message.

Self-separation airspace includes mixed operations for separation management. These operations include appropriately equipped and participating aircraft that separate themselves from all other traffic, based on right-of-way rules. The airspace also includes ANSP-managed aircraft that are unequipped for self-separation. While in self-separation airspace, equipped and participating aircraft are responsible for resolving their own traffic conflicts and avoiding trajectory changes that create near-term conflicts for others. Onboard automation, called Conflict Detection and Resolution (CDR), provides clear guidance for pilots, enabling them to accomplish these tasks. Priority flight rules are embedded in conflict-alerting algorithms, and the automation notifies the appropriate flight crew when its aircraft must resolve a conflict. Flight rules always require self-separating aircraft to maneuver to avoid controller-managed traffic. In self-separation airspace, the ANSP remains responsible for resolving conflicts between ANSP-managed aircraft (those not equipped for self-separation). However,

---

constraints. This concept reduces traffic manager workload and allows more control over traffic in uncertain weather situations. SEVEN also gives NAS customers greater flexibility to operate flights according to business priorities under TBO. SEVEN recaptures system capacity, currently lost due to severe weather or other capacity-limiting factors. Presently, the Collaborative Decision Making (CDM) Future Concepts Team (FCT) is evaluating SEVEN through a series of storyboards, simulations utilizing Integrated Simulation Environment (ISE) and Human-In-The-Loop (HITL) exercises with aviation stakeholders, as a part of the Concept Engineering and Development (CED) process.

if under surveillance and communications, the ANSP automation continues to monitor and alert on separation conflicts.

Self-separating aircraft may change their trajectory without ANSP coordination provided they continue to comply with ANSP-provided downstream constraints. In the case of Sunset 42, any trajectory changes must still enable it to reach its TOD at the assigned RTA. If it can no longer meet this constraint, it must negotiate a change with the ANSP.

In order to ensure that the ANSP can safely maneuver managed aircraft when they conflict with each other, the ANSP and all flights operating in the airspace must maintain a consistent understanding of each aircraft's commanded trajectory (defined to be the trajectory the aircraft will fly if the pilot does not change the automation). Self-separating aircraft are responsible for broadcasting their updated intent to other nearby aircraft and to the ANSP. This comes in two forms. The first is ADS-B, with air-to-air messages of short-term intent, and another data link message that reflects any changes to the 4DT. When resolving conflicts, self-separating aircraft are encouraged to execute closed-loop trajectory changes. When needed to resolve short-term conflicts, self-separating aircraft may use open trajectories (e.g., constant heading or vertical speed to an altitude), but should return to a 4DT as soon as possible. While maneuvering in an open trajectory, self-separating aircraft remain responsible for safely separating from all other aircraft.[14]

Self-separation may be bounded in any dimension. There may be a block of vertical airspace released for maneuvering. Lateral limits may be placed on the aircraft in the airspace based on other traffic needs and the density of traffic. Free maneuvering in vertical and horizontal position and time is also possible where traffic density allows.

After entering self-separation airspace, Sunset 42 selects a new strategic path that avoids the most concentrated area of weather. It makes tactical trajectory changes as needed to avoid patchy build-ups. Prior to each trajectory change, the pilots use onboard conflict detection and resolution capabilities to ensure the new path will not create a conflict with another aircraft.

About 30 minutes into the airspace, onboard automation notifies Sunset 42 of a conflict with Westair 351, an ANSP-managed aircraft. The pilot requests a resolution and the conflict detection and resolution automation proposes a new route that resolves the conflict with Westair, avoids a potential conflict with nearby Winds Air 134, avoids severe weather areas, and continues to adhere to the downstream RTA assigned previously by the ANSP. The pilot accepts this resolution, uploads it into the FMS, then activates and executes it. At this point, the onboard automation automatically broadcasts the updated trajectory to all nearby aircraft through ADS-B and to the ANSP. This updated trajectory forms the new basis for conformance monitoring on the ground and in the aircraft. If under surveillance and communications coverage, the ANSP's automation maintains a track and conformance monitoring, and will alert the controller of any potential conflicts. The controller's interest is on alerts of self-separating aircraft to ANSP-controlled aircraft, much like in today's environment where IFR traffic is alerted to detected VFR traffic.

---

[14] A policy and leadership construct is needed for changing the OIs and concept of use to reflect a TBO-based approach to self-separation, as well as the relationship between aircraft intent and use by tactical controllers who are controlling other traffic in the airspace.

Winds Air 134 is another self-separating aircraft that is closing on Sunset 42 on a converging path and will pull nearly parallel with Sunset 42, as they both have chosen a clear path through the building weather. Sunset 42 is faster than Winds Air 134, so the CDR has recommended a transition from a converging path to a parallel path. For nearly 20 minutes the aircraft will be in parallel as Sunset 42 pulls ahead. Winds Air 134 decides to use Sunset 42 as a weather ship[15] and activates merging and spacing tools to set up a spacing interval to follow Sunset 42. This tactic will work until exiting designated self-separation airspace.

Although the CDR automation on both aircraft attempts to simultaneously resolve all of the constraints, some conflict situations may be overly constrained. In these cases, the automation will progressively eliminate lower priority constraints, beginning with the least important (such as RTAs or conflicts that are further away). Pilots may need to defer handling of longer-term conflicts or constraints until those that are more time critical are handled.
Nearing the exit boundary of self-separation airspace, the ANSP sends a message to Sunset 42 that returns separation responsibility after it crosses the defined boundary.[16] The crew acknowledges the message. No trajectory changes are needed because Sunset 42 is still able to comply with its assigned RTA and original route for this portion of the flight. In this flight, Sunset 42 has remained on a closed trajectory. Even with maneuvering, the aircrew calculated its trajectory changes and broadcast the information to others.

As it approaches TOD, time-based metering at MIA is working on an arrival sequence, based on revised 4DTs of incoming aircraft and an updated weather picture that gives a more current estimate of the available arrival capacity. All inbound commercial flights are expecting an OPD to join the approach or to position the aircraft on a downwind. Adjustments are made to each aircraft's flight object placeholder descent profile that it has been carrying since the beginning of the flight. At this point, runway configuration and available terminal routes (based on dynamic weather conditions) are more assured. Inbound flights are assigned a sequence, scheduled time of arrival at the meter fix, terminal area route assignment, and runway prior to crossing the "freeze horizon."[17] The freeze horizon is located about 20 minutes prior to the TRACON boundary meter fix. It is at this point that the balance of the flight is untouched in terms of its 4DT.

13.4 Phoenix to Miami Arrival/Approach and Landing
This scenario consists of the following sequence of arriving aircraft:

- Northeast 416, Seminole SZW Arrival Meter Point, CTA to RWY 9
- Winds Air 134, Key West EYW Arrival Meter Point, spacing behind Northeast 416
- Sunset 42, Seminole SZW Arrival Meter Point, spacing behind Winds Air 134
- Ariba 151, Taylor TAY Arrival Meter Point, ANSP-managed to RWY 12

---

[15] A weather ship is a leading aircraft that is picking its way through weather and followed by others based on a flight path avoiding the most serious weather.
[16] In every case of entry and exit from self-separation, there is a predefined point for transfer of control responsibility for separation. This point is part of the 4DT, flight plan, and flight object.
[17] The "freeze horizon" is that time when the 4DT is frozen and further changes are only made as needed to adjust that aircraft's timing. There may be a different freeze horizon for aircraft with different capabilities.

When Sunset 42 was approximately 700 nm west of MIA, a new 4DT was negotiated due to severe convective weather approximately 550 nm west of MIA along the original route. The Sunset AOC had negotiated with the ANSP, through CATM, a new set of constraints for the Sunset 42 flight. The set consists of two new waypoints to route around the convective weather cell and to de-conflict with Northeast 416 and Ariba 151 with a new, later CTA for the Seminole SZW Arrival Meter Point to MIA. The Sunset 42 crew had previously slowed to accommodate reductions in acceptance rates at MIA and now selects the new constraints on the FMS that had been previously loaded. This generates a new 4DT to meet the constraints, which is downlinked to the ANSP and accepted. The flight crew then initiates the new 4DT, and the FMS initiates a turn and reduces speed 10 knots to match the new 4DT as it leaves the self-separation airspace and heads for TOD.

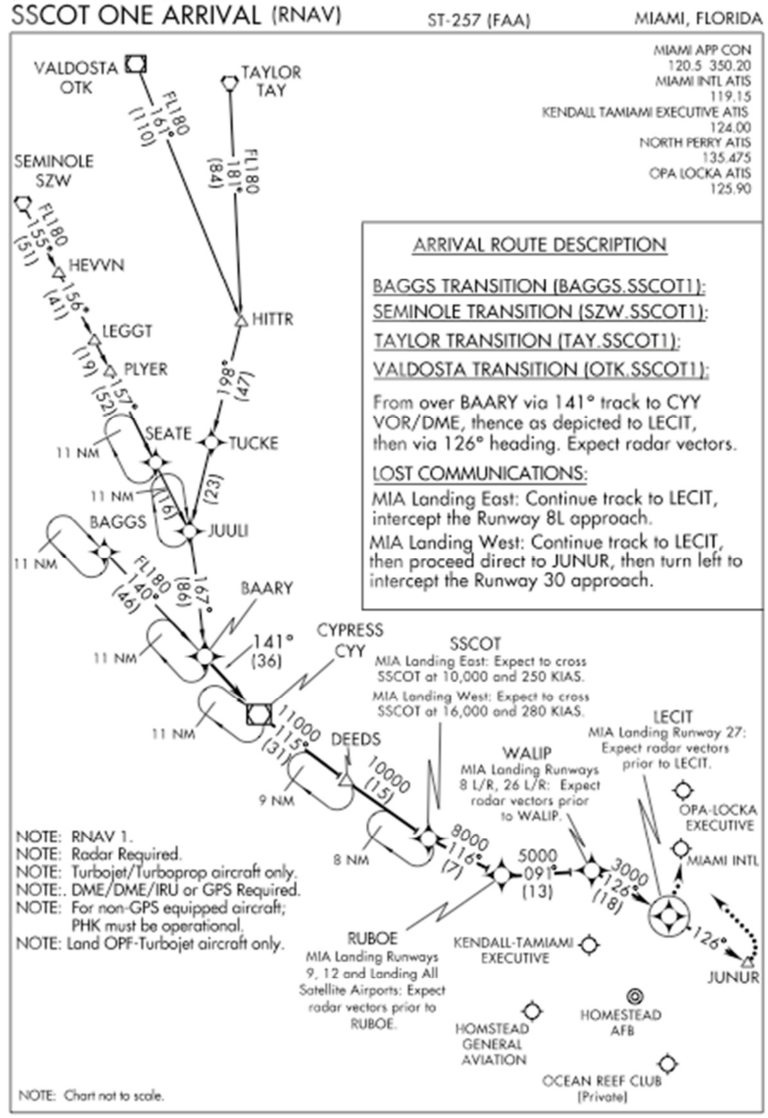


Figure 6. Current SSCOT ONE ARRIVAL (RNAV)

Northeast 416 arrives at the Seminole SZW Arrival Meter Point from the west ahead of Ariba 151 and Sunset 42. The ANSP's arrival management decision support automation has assigned Northeast 416 to be the first in a string of arriving aircraft landing after a number of departures on the runway, so it will be conducting a time-based approach rather than airborne merging and spacing. Before reaching the Arrival Meter Point, Northeast 416 receives a runway assignment to RWY 9, via SSCOT ONE ARRIVAL (RNAV) STAR and RNAV (RNP) Y RWY 9 Approach, with a CTA to the RWY 9 threshold.

The Northeast 416 flight crew enters the runway threshold CTA into the FMS as their RTA and generates an OPD descent 4DT through landing, including selection of an optimal TOD point. The flight crew downlinks the changed 4DT to the ANSP automation. The FMS-generated 4DT conforms to the assigned STAR and approach. The STAR has a predefined 2D route with lateral 0.3 RNP that improves on today's RNP 1 path and has altitude-crossing restrictions at each fix defined as 3000-foot windows. This allows for enough vertical flexibility to accommodate OPD trajectories for a variety of aircraft with different weights and performance characteristics. The STAR does not have speed profiles other than the requirement of maximum speed of 250 knots below 10,000 ft. The RNAV (RNP) Y RWY 9 Approach begins at the RUBOE waypoint on the SSCOT ONE STAR.

This RNP approach has crossing speed restrictions at the HODLE and DOXSI fixes.

Before reaching the Taylor TAY Arrival Meter Point, Ariba 151 receives a runway assignment to RWY 12 and is assigned the SSCOT ONE ARRIVAL (RNAV) STAR and RNAV (RNP) X RWY 12 Approach. Ariba 151 arrives at the TAY Arrival Meter Point to MIA from the north and enters the SSCOT ONE STAR. Because Ariba 151 is NextGen Classic-equipped, with minimal onboard capability, the ANSP uses ground-based automation to issue speed-based clearances to manage it. The ANSP automation has assigned Ariba 151 a CTA to a fix at the RWY 12 threshold, and has generated a 4DT to the CTA. The ANSP is managing Ariba 151 in a time-based manner with respect to other traffic, but the Ariba flight crew only deals with following the assigned 3D route at the assigned speed. The ANSP must retain larger RTP buffers around the CTA timing because of Ariba's reduced timing accuracy.

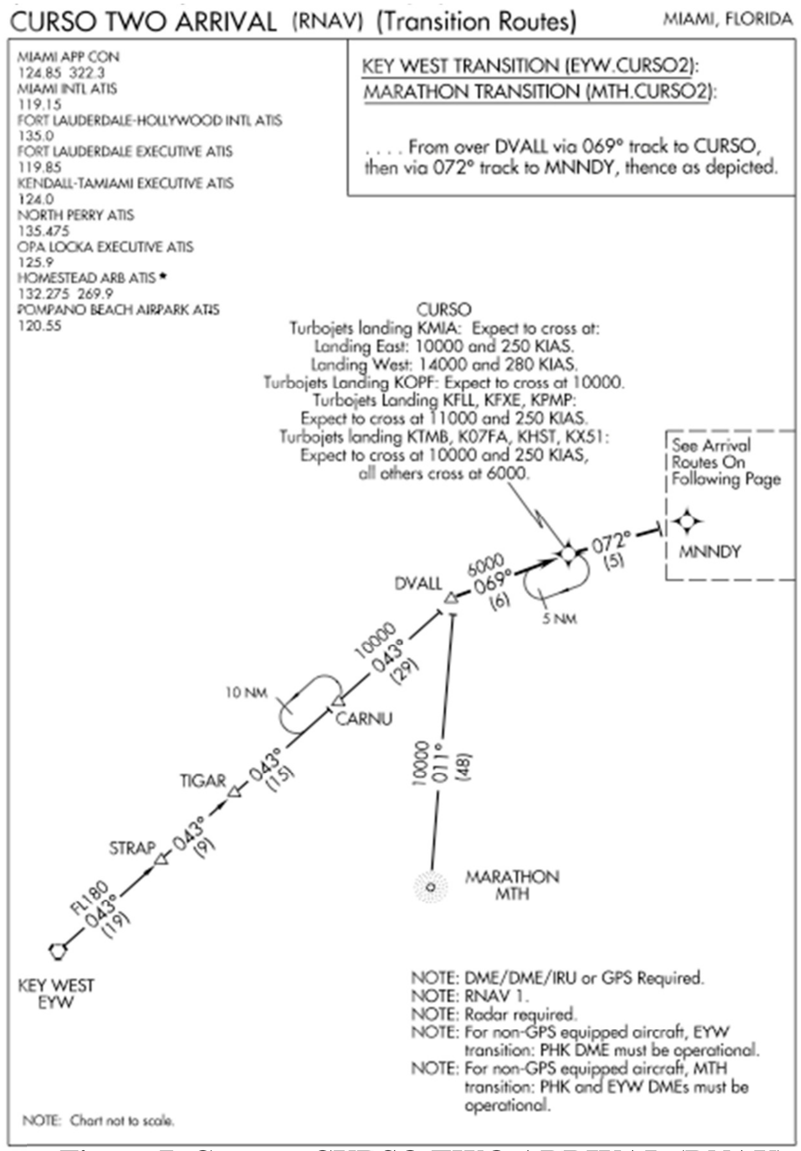


Figure 7. Current CURSO TWO ARRIVAL (RNAV)

Winds Air 134 is approaching the southwest Key West EYW Arrival Meter Point, and receives the following assignments: CURSO TWO ARRIVAL (RNAV) STAR to RNAV (RNP) X RWY 9 Approach, airborne merging and spacing behind Northeast 416, with 2.4-minute separation at runway threshold. Using ADS-B, state information to determine Northeast 416's current position and speed, together with additional ADS-B intent information such as Northeast 416's planned FAS. The Winds Air 134 conflict detection and resolution capability projects when Northeast 416 will cross the DOXSI final approach fix and the runway threshold, and the FMS generates an OPD 4DT to arrive with the proper spacing behind Northeast 416. Northeast 416 is arriving via a different STAR and entering the RNAV (RNP) X RWY 9 Approach from a different waypoint, but Winds Air 134 was data linked Northeast's arrival and approach routes, so it can accurately calculate Northeast's path and time to the runway threshold.

Winds Air 134 will continuously monitor Northeast 416's position and speed, making small speed adjustments as needed to complete the approach with the proper spacing, and will merge in behind Northeast 416. This is an example of using relative time in a leader-follower situation, as opposed to absolute time used by Northeast 416 to set up the arrival stream.

Before arriving at the Seminole SZW Arrival Meter Point, Sunset 42 receives the following assignments: SSCOT ONE ARRIVAL (RNAV) STAR to RNAV (RNP) X RWY 9 Approach, airborne merging and spacing behind Winds Air 134, with five-minute separation at runway threshold. The Sunset 42 FMS generates an OPD 4DT to arrive at the threshold with the proper spacing behind Winds Air 134, which the flight crew downlinks to the ANSP automation. The ANSP clears Sunset 42 to conduct the STAR and approach. The Sunset 42 flight crew initiates the OPD 4DT and begins the descent at the selected TOD following FMS speed guidance.

During the arrival and approach, the Sunset 42 FMS monitors the speed and position of Winds Air 134, and periodically recalculates the timing along its 4DT to achieve the proper final spacing, making slight speed adjustments as necessary. Headwinds are stronger than expected, and the flight crew makes a four knot speed adjustment, but there is no problem meeting the spacing criteria or need for notifying the ANSP.

During the arrival phase, Winds Air 134 is arriving from a different Arrival Meter Point and is traveling at a significantly higher speed than Sunset 42, but the FMS has compensated for the speed differential in calculating the OPD 4DT, and Sunset 42 seamlessly merges into the stream behind Winds Air 134.

Throughout all this maneuvering, the ANSP TBO automation is performing conformance monitoring to assure compliance with the arrival and approach segments. Progress is noted and if an aircraft falls behind on its intended performance, the controller will receive an alert. Conformance monitoring functions also support TBO automation functions that can provide options to the controller to adjust a trajectory if needed.

At 30 nm from the airport, the ANSP issues Winds Air 134 approach clearance for the GLS approach to RWY 9. Since Winds Air 134 is heavily loaded and will require a longer distance to slow down, the ANSP assigns Winds Air 134 a taxiway at the far end of the runway.

At 10 nm from the runway, the ANSP gives landing clearance and advises Sunset 42 to plan to turn off at an assigned taxiway and uplinks taxi instructions to the aircraft. The taxi instructions are automatically loaded into the onboard EFB. The ANSP notifies Sunset 42 that Winds Air 134 will be using a taxiway at end of runway and that Sunset 42 is cleared to land on RWY 9 before Winds Air 134 departs the runway. Sunset 42 is using onboard CDTI and decision support tools to determine that Winds Air 134 is braking effectively and predicted to make its turn off. The Sunset 42 crew acknowledges the landing clearance and their own taxiway turnoff. Winds Air 134 is still on the runway, but close to turning off on its taxiway when Sunset 42 touches down. Upon clearing the runway, the crew of Sunset 42 pulls up the data linked taxi instructions and follows them, monitoring the EFB moving map display to comply with the taxi instructions.

13.5 Surface Movement – Taxi In

Upon completion of its PHX-MIA leg, the last revision of the taxi plan is uplinked to Sunset 42 just before touchdown. Northeast 416 touches down on RWY 9 and then Winds Air 134 touches down. Both aircraft elect to use their onboard automatic braking systems. Each aircraft slows and takes its assigned high-speed runway exit. At touchdown, the navigation display for both Northeast 416 and Winds Air 134 automatically changes to a taxi-map surface display, showing the assigned runway exit. Sunset 42 then touches down on RWY 9 and follows surface guidance to the gate. The TBO surface movement system updates the taxi route on exit for Sunset 42.

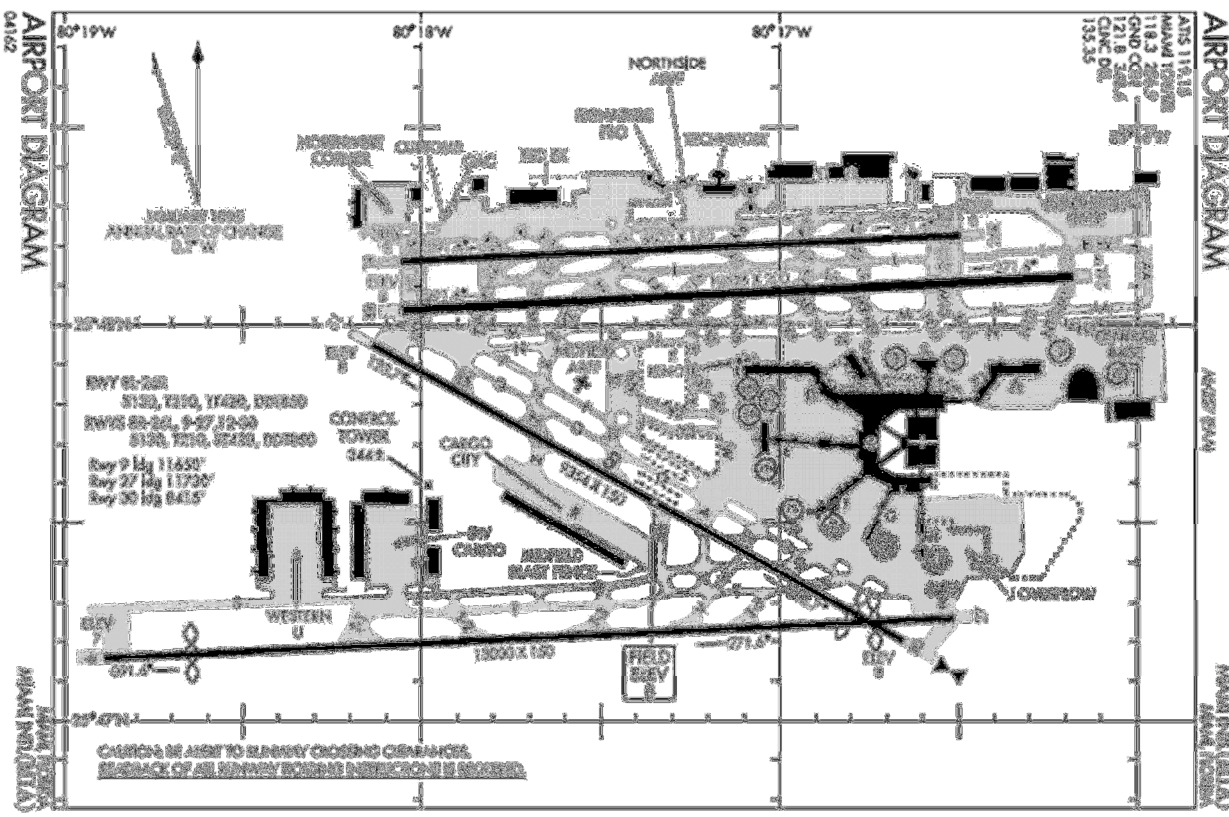


Figure 8. MIA Surface Layout

14.0 Detroit To Dulles Scenario

14.1 Surface Movement

The Surface Automation monitors and updates schedules as events occur, including late or missed events[18]. The Flight Data (FD) and Clearance Delivery (CD) function then sends the departure

---

[18] The sequence of departure is continuously updated as information becomes available on the readiness of aircraft to leave the gate, any delays being experienced in taxi, and special handling and priority information. In the far-term, surface radar will be replaced at ASDE sites with a multilateration/ADS-B system referred to as the Airport Surface Surveillance Capability (ASSC) and will be renamed the Terminal Surface Multilateration System (TSMS).

clearance. Meanwhile, the Transcon 1324 pilot logs in to the network with auto-load of the flight object and 4DT to the FMS (security feature). The pilot receives the DCL. At the prescribed time, Ramp Control issues pushback to Transcon 1324 who then requests taxi instructions.

In preparation for issuing a clearance, the ground controller uses automation and determines the taxi route with time constraints to RWY 3L. The ANSP surface movement actions are motivated to meet deicing time requirements as part of the overall safety process. The taxi route to deicing also takes account of environmental effects and their impact on TBO. This requires balancing flow constraints with deicing performance requirements to takeoff since the aircraft must start its takeoff roll within a window of the effectiveness of deicing. The taxi route is ultimately constrained based on automated taxi recommendations that include sequencing information based on the departure schedule slot for Transcon 1324 and any downstream traffic management initiatives.

In the 2025 time frame, TFDM (the FAA far-term integration of surface TBO capabilities containing the ANSP Surface Movement Management automation module) implements complete 3D taxi routing. This includes automated generation of optimized 3D surface taxi route with times at surface waypoints and any hold-short point. The controller can modify the 3D taxi route provided by automation. The TFDM also includes revision of a conflict-free (with respect to other aircraft) taxi plan when conflict and conformance monitoring indicates a problem. The TFDM also generates a route that is conflict-free with all surface vehicles. The TFDM integrates surface and airborne 4D trajectories to achieve one seamless TBO trajectory. The TFDM then executes taxi conformance monitoring of the 4DT to ensure adherence to the conflict free-taxi route. Once calculated, the TFDM sends the 3D taxi route to the flight crew, other NAS stakeholders, and TBO surface movement automation. This results in implementation of integrated (surface and airborne) 4DT-based taxi route generation, where the 3D portion can be handed off to the takeoff/climb segment of TBO automation.

TFDM implements runway assignments by using optimization criteria (e.g., arrival spacing) to assign the departure runway in the far-term. TFDM enhances scheduling and sequencing in the far-term to enable proactive automation assistance for deicing planning and execution. The TFDM also implements scheduling for fully integrated airborne and surface trajectory operations. The combination of surface surveillance and TFDM allows the TFDM to learn from previous taxi performance, from parked position to runway entry, to improve predictive capabilities and remove variability. TFDM knows the representative taxi time for the aircraft operator, aircraft type, route selected, and environmental conditions (day/night, wet/dry, deicing performance requirements, etc.). TFDM implements departure routing to evaluate acceptability of alternate departure routes and provide for route change. The TFDM then shares route viability assessment with the aircraft.

In the far-term, TFDM adds snow-impact planning capabilities under Airport Planning.

The ground control position provides taxi instructions to the pilot via data communications. Network-centric operations may also carry information that is pre-decisional in nature, i.e., not involved with navigating the aircraft. Surface movement taxi guidance arrives via data link and is either presented on the CDTI or hosted on class III EFB, depending on the forward field of view accessibility[19].

The pilot of Transcon 1324 acknowledges taxi instructions and coordinates pushback with ramp control. The ground controller issues further taxi instructions based on changes. The ground controller and the pilot monitor taxi conformance. The primary responsibility for separation and safety during taxi operations rests with the pilot, who follows the assigned taxi route and provides an extra layer of protection for blunders by others, including runway incursions and unforeseen weather conditions.

Time performance is presented to the pilot as part of the surface movement map. At selected points along the taxi route, the pilot can see the time progression with an RTP tolerance of +/- one minute. If another aircraft delays progress in the queue, this one-minute performance is modified based on actual conditions, and the expected 4DT is also modified.

In the far-term, surface radar will be replaced with a multilateration/ ADS-B system referred to as the ASSC. The ASSC includes equipment operating as Mode S on 1090 MHz and UAT on 978 MHz. The ASSC will use multilateration and receipt of ADS-B information to determine location of vehicles and aircraft. It will interrogate transponders on 1030 MHz to support multilateration as needed. The ASSC must have a GPS independent time reference for multilateration calculations. The ASSC will fuse multilateration sensor data with ADS-B aircraft information for display on an FAA certified airport tower controller display that is part of the ASSC configuration. ASSC shall have the capability of providing data to other external FAA systems (e.g., TFDM, Surveillance Broadcast Services [SBS], Runway Status Lights [RWSL], and network-enabled communications).

ASSC will track surface vehicles/aircraft, providing information for ATC services. It will also provide pilots and vehicle operators with improved situational awareness through ADS-B TIS-B services. Using the TIS-B data, pilots and vehicle operators with ADS-B-equipped receivers will be able to locate the position of other faulty or non- ADS-B equipped aircraft or vehicles. In the far-term, there is a requirement for transponder equipage of all surface vehicles.

At the busiest airports, it may be important to continue surface primary surveillance radar in consideration of unequipped intrusions on the surface, faulty avionics or vehicle equipment, or surface security, such as perimeter intrusion.

The CDTI is planned as a mid-term enabler. It is used to present taxi diagram information with the taxi route provided by ground automation. The CDTI is then used to significantly improve aircraft crew situational awareness on the relative position of their aircraft with regard to the airport infrastructure (runways, taxiways, aprons) layout and as an aid to conformance to the taxi route.

Enhanced vision equipment can be used for surface operations in low visibility down to below 300 feet Runway Visual Range (RVR). This is an additional capability that allows the aircraft crew to expedite its taxiing in low visibility conditions with fewer interpretation errors as to which taxiway to take, and the holding points for hold shorts. Typically, steering directions with possibly lateral path

---

[19] The location of presentation of taxi route information is both a research and policy issue that requires resolution before commitment to data link delivery of taxi route information graphically.

deviation indications are provided. This will converge towards a better predictability of the aircraft movement on the airport surface. Such guidance capability requires the use of a HUD display. The HUD presentation can contain the taxi diagram and can be used for taxiing on the assigned route in low visibility.

Surface TBO in the far-term is implemented as automated taxi guidance**,** according to a prescribed clearance, that allows the aircraft crew to expedite the execution of surface movement. Such automated guidance may even lead to interfacing with flight controls and auto-throttle functions.

Surface TBO thus eliminates many of the possibilities for runway incursions, as the TBO conformance and conformance monitoring provide more robust safety assurance than exists today. Runway incursion- alerting software then works similarly to Traffic Collision Avoidance System's (TCAS) role in aircraft separation as a safety net, in addition to the nominal ATC traffic surveillance to alleviate potential collision with other aircraft maneuvering on the airport surface.

In the scenario, ground control from the ANSP updates the taxi instruction, corrective action, or new clearance taxi route to RWY 3L. But then RWY 3L becomes blocked due to snow removal activities. The integrated arrival/departure/surface scheduling from TFDM re-computes a new solution. Transcon 1324 is changed to RWY 4R for departure. The new pushback time is assigned based on predicted taxi time between the gate and RWY 4R plus runway wait time, since additional movement time must be factored in due to snow/ice-covered surfaces. The predicted takeoff time accommodates a merging slot in the departure stream. Transcon 1324 acknowledges updates to the clearance. The new taxi route and schedule is depicted on the CDTI and accepted by the crew.

Ground control then coordinates runway crossing for Transcon 1324 with the local controller for crossing RWY 27R. The Ground control then issues handoff to local controller. The local controller issues clearance for the RNAV/RNP Standard Instrument Departure (SID). There is an RNAV-0.3 requirement for the initial segment of the departure for noise abatement and Transcon 1324 is operationally approved for the SID.

At this point, it should be noted that in the flight planning for Transcon 1324, the dispatcher had prepared multiple options for surface movement, knowing that the major constraint was to get through the deicing operation and meet the time interval that the treatment allows. The pilot can select the change in departure runways from a series of pages in the FMS and select that option.

The pilot of Transcon 1324 monitors EFVS to maintain centerline. Own-ship surface movement alerting is also employed for indication of the correct runway identifier and insufficient runway length alerting. The pilot of Transcon 1324 takes off to slot into a departure stream to join the overhead flow. The takeoff event is distributed within the NAS through network-centric operations. The TBO strategic evaluation service re-computes downstream flows and conformance monitoring in the airspace begins.

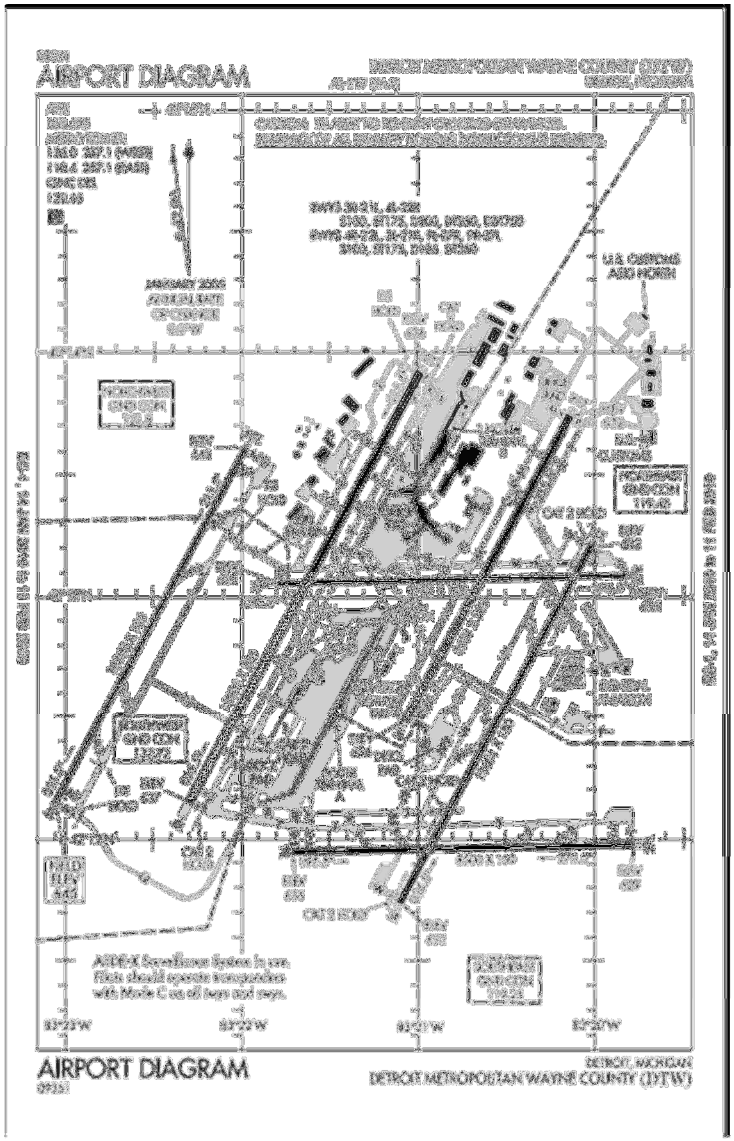


Figure 9. DTW Surface Layout

14.2 Detroit Takeoff and Climb

Transcon 1324 is departing on RWY 4R and will be conducting an RNP 0.3 dynamic OPC. This will be negotiated between DTW Departure and Transcon dispatch after pushback, when the aircraft's actual takeoff weight (final PAX and fuel on board) and performance is confirmed. Departure/Arrival TBO automation provides OPCs that are separated from arrival and other departure flows, and provides an efficient climb for Transcon directed towards its destination. Most importantly, knowledge of the actual aircraft weight and climb trajectory allows the time-to-climb to be calculated so the takeoff time can be set to allow the aircraft entry into congested en route flow towards IAD. Since DTW's airspace is very congested at peak times of day, climb and descent profiles for even the most equipped aircraft remain within the airspace reserved for one of the published procedures, and tailored procedures outside the boundaries of a published procedure are permitted only during off-peak times. However, Transcon's dispatch has requested priority handling at DTW to meet "turn" requirements at IAD for a continuing flight on to Europe, and has agreed to perform an in-trail following application behind a WestAir Boeing 767, which will depart the same runway bound for BWI prior to them. The agreed-upon OPC is data linked to Transcon 1324, acknowledged, reviewed, accepted, and auto-loaded by the flight crew. At execution, a confirming data link message is automatically sent to the ANSP for conformance monitoring. The procedure requires Transcon to follow Westair at 130 to 150 seconds in-trail from initiation at about 5,000 feet AGL until the initial cruise altitude, but both aircraft have flexibility in the vertical plane to optimize their climbs.

The OPC represents the most likely and most preferred rate to climb. From a vertical airspace perspective, the lower limit of the vertical variability is the engine-out obstacle clearance performance or a similar terrain or obstacle clearance climb gradient. Once this hurdle is passed along the flight track, the ground automation uses a range of climb performance values based on takeoff gross weight. The range of OPC calculations bounds the amount of variability accepted in the climb by automation to create airspace windows and the need to hit certain airspace altitudes for crossing traffic. Winds play a significant role in climb performance, but the vertical boundary around and in front of the aircraft can be estimated by ADS-B position reports and used to tailor the conformance monitoring parameters.

Once a positive rate of climb is established, Transcon 1324's flight crew retracts the landing gear and executes the prescribed sequence of climb speeds and flap retractions.

As the aircraft climbs through 2,000 ft AGL, the aircraft control is transferred within the ANSP. A chime reminds the flight crew they are no longer in contact with tower voice communications and can expect routine communications with ATC through data link. A "channel open" light on the data link control panel indicates data link is online with the ANSP for departure and a voice channel is available if needed. Transfer of control, for both voice and data arrives by data link and frequencies are changed automatically, or can be set manually by the flight crew. If notified of a change, the flight crew receives a chime. There is an assumption that "cleared for takeoff," "cleared to land," "go-around," and emergency messages would be delivered by voice.

At about 2,500 feet AGL, they engage LNAV/VNAV and begin the AKRON NINE OPC.

At 5,000 feet AGL, the ANSP's Departure Control confirms the instruction to Transcon by data link to maintain 130 to150 seconds in trail behind the WestAir. Transcon's flight crew identifies WestAir ahead of them at 140 seconds spacing on the CDTI display. The spacing closure tool of the merging and spacing automation on the aircraft indicates that the present speed will maintain WestAir within the 130 to 150 second window ahead, and the pilot not flying configures her CDTI display to monitor the spacing. Transcon 1324 confirms the in-trail following requirements by data link with the ANSP. A minor speed change is executed at FL 190 to maintain Transcon in the time window for the spacing maneuver.

The ANSP manages traffic by voice and data link to maintain an uninterrupted climb for Transcon so that it will complete its OPC within the expected time window for entry into the initial cruise portion of flight.

An Antonov an25 cargo plane that departed Chicago O'Hare (ORD) at maximum gross weight bound for Madrid has experienced lower than expected climb performance due to unexpected atmospheric conditions, and is now nearly 2,000 feet lower than its earlier 4DT projection for this location. Its current trajectory may pose a wake hazard to Transcon, which will pass only a thousand feet below its path unless its trajectory is modified. Normally, Transcon would have priority in this situation, and the Antonov an25 should be maneuvered. However, the tactical controller monitoring this airspace believes that, for safety reasons, Transcon should level off until clear of the Antonov an25's potential wake. He can see on his screen that a short duration level-off will not cause a conflict with any other aircraft for Transcon. He contacts Transcon by voice and instructs a one-minute level off, together with termination of the in-trail following task. Transcon responds by voice and adjusts the mode control panel to maintain level flight. Knowing that they are now on an open trajectory, the Transcon flight crew attentively monitors their CDTI for nearby traffic, especially the Antonov an25 climbing above them. This capability provides a helpful safety backup while the controller makes adjustments to the parameters for conformance monitoring. The tactical controller creates a new closed trajectory for Transcon and waits a few seconds while the strategic TBO evaluation automation updates. He checks this trajectory for conflicts, and, when the automation has verified the new trajectory, he sends it to Transcon. Transcon's flight crew receives, reviews, and accepts the new trajectory, and executes the change. A confirming data link message is sent to the ANSP. The crew maintains level flight for one minute before climbing to the initial cruise altitude. The tactical controller continues to monitor the Antonov an25 until the aircraft has climbed to its cruise altitude, and there is no discrepancy between its projected and actual 4DT.

Transcon 1324 reaches the initial cruise altitude further downstream than planned, but is still able to join the flow of traffic towards IAD as intended to meet their "turn" requirement for a flight to Europe because the unplanned level off has not caused a significant delay in their overall flight plan.

On this departure, the aircraft started with a closed trajectory, for which the ground and airborne automation were in sync. This makes conformance monitoring possible by the automation and reduces controller workload. Controllers need to manage strategically or provide tactical intervention for non-conforming aircraft. As soon as the controller identified the potential wake conflict (or was alerted by the ground automation) and gave Transcon an intermediate level-off and discontinued the flight crew-timed climb following another aircraft, the trajectory became open. The effect is to expand the area of variability or to impose a restriction in the 4DT. This change is counter to the downstream planning for the aircraft, and requires a recomputed 4DT to return the aircraft to a closed trajectory.[20]

14.3 Detroit to Dulles Cruise Segment

This describes negotiated changes to the cruise segment that alters arrival ETAs and the flight profile. In the cruise phase, aircraft intent is being downlinked to the ANSP from the aircraft, and the ANSP makes the information available to the AOC and others via network-centric operations. ATC is checking to assure the trajectory "fits" with others in the airspace/routing. Exceptions and changes can be "what-ifed" and accepted or not using the ANSP's strategic TBO evaluation automation.

During climb out, the ANSP had verified that the aircraft ETA at the arrival meter point fit with all other traffic and cleared the profile. Cruise altitude is FL 300 initially, the best altitude for the aircraft initial cruise weight.

---

[20] The relationship between open and closed trajectories and conformance monitoring in ground automation must be explored through research. As the aircraft enters an open trajectory, the conformance parameters need to change if alerting is to continue.

Merging into an overhead stream of traffic is dependent on time performance, arriving at the right time to allow the merge and sustain separation. This merge will happen as the aircraft climbs above FL 300. Once established in cruise at FL 300, the aircraft intent downlink information shows the ETA at the arrival meter still acceptable to the ANSP, resulting in no action. The flight crew reviews FMS pages and concludes that a cruise climb to FL 370 would be very beneficial for fuel burn. This is discussed with airline operations, which agrees to request a cruise climb from the ANSP. The ANSP needs to know if the merge time is still on target relative to other traffic. Negotiation completed, the ANSP sends a change in the 4DT to the aircraft, who accepts, loads, and executes the change. At execution, a data link message confirms the action and closes the trajectory for conformance monitoring. After the cruise climb has begun, the flight crew uses “what if” capabilities in the FMS using a secondary route capability. The ETA has moved far enough that the ANSP cannot now accept, so they request a CTA at the arrival meter point that meets the ANSP’s needs. The crew verifies that they can comply and are cleared to initiate the cruise climb with the addition of the CTA at the arrival meter point, which reduces the benefit of the cruise climb and trades efficiency for conformance with the time requirement. The cruise climb function in the FMS produces locations and times at which the aircraft will reach each higher flight level as it climbs toward its final cruise altitude, so that ATC can verify that no conflicts arise with overhead routes/traffic. It is unlikely that the cruise climb would match the altitude of overhead crossing traffic at the exact location of the overhead route, but that needs verification. As the flight progresses, after the merge point to join the traffic stream, weather necessitates a re-routing of the profile, along with a necessary compression of the flows. The ANSP uplinks a change to the lateral route with tighter RNP values (moving from RNP 2 to RNP 1) on the segments of the reroute to allow for closer parallel route spacing for other aircraft. The flight crew accepts the change and a new profile (4DT) is downlinked with revisions to TOD and OPD (OI-0309) due to both the reroute and the higher final altitude from cruise climb. The ANSP verifies that the planned route does not conflict with others in the same destination.

As TOD nears, the ANSP’s traffic flow management unit determines and publishes that demand at IAD exceeds a given threshold, indicating that VCSPR operations will be invoked at the 750-feet parallel runway spacing over a given time window. Sunset 123, originating from MIA, is arriving from the south, as is Transcon 1324. Sunset 123 and Transcon 1324 are both equipped for VCSPR operations.

Thirty minutes prior to Transcon 1324 and Sunset 123 arriving at their arrival meter points (just prior to TOD), IAD terminal TBO arrival management automation determines that if Transcon 1324 arrives later, both aircraft will arrive within an acceptable one-minute window and their FAS have enough similarity for VCSPR pairing. The ANSP uplinks a 4DT flight object request to Transcon 1324. Transcon 1324 cannot slow far enough to make that late of an arrival, and downlinks UNABLE RTA (early), so the ANSP opens the trajectory lateral window to allow Transcon 1324 to do a lateral offset maneuver to consume time. The Transcon 1324 crew selects an offset within the window that will allow them to lose enough time through the lateral path stretching (extra time to reach the offset and equal extra time to return to parent path) to make the requested arrival meter point CTA.

IAD is currently controlling Sunset 123, and uplinks a 4DT request to the flight crew that consists of similar information as Transcon but assigns Sunset as VCSPR leader, who review and downlink acceptance of VCSPR operation. The 4DT may contain more than one CTA (i.e., at arrival metering

point, at approach metering point, at runway threshold, etc.), but most FMSs are only able to execute one RTA a time, updating to the next after passing the previous.
As TOD nears, AOC uplinks descent wind forecasts, which fortunately do not affect the ability to hit the RTA. These winds contain corrections received from winds aloft calculations from other aircraft that improve the precision of the descent wind profiles.

14.4 Detroit to Dulles Arrival/Approach and Landing

Transcon 1324 and Sunset 123 arrive at their respective arrival meter points within the CTA/RTP performance threshold. Just prior to arriving at the arrival meter point, both aircraft receive their runway assignment, arrival/approach route, sequencing, and parallel runway pairing assignments. Transcon 1324 and Sunset 123 are each transmitting their planned final approach speeds via data link. The ANSP determines that although Transcon 1324 will have a final approach speed that is 10 knots faster than Sunset 123, the speed differential is acceptable for the two aircraft to be paired together for VCSPR approaches. Transcon 1324 has a faster final approach speed, so Transcon 1324 will be positioned behind Sunset 123 at the coupling point.

As shown in Figure 10, Ariba 121 and Ariba 122 will be arriving at IAD on staggered approaches ahead of Transcon 1324 and Sunset 123. Ariba 121 and Ariba 122, which are NextGen Classic equipped, are not equipped for airborne merging and spacing, and are conducting time-based approaches with the 4DT, generated by ground-based automation data linked to the aircraft. They will be conducting staggered runway operations rather than VCSPR operations. The two Ariba aircraft have arrived during a lull in traffic just before a high-density arrival push. If they had arrived during high-density operations, they would have had to wait in a queue to land on a runway designated for handling classic-equipped aircraft.

A 4DT OPD is generated for each Ariba aircraft by ground-based automation, which is then transmitted to each aircraft in the form of speed and altitude profile constraints along the arrival and approach routes. Transcon 1324 will be landing behind Ariba 121, and Sunset 123 will be landing behind Ariba 122.

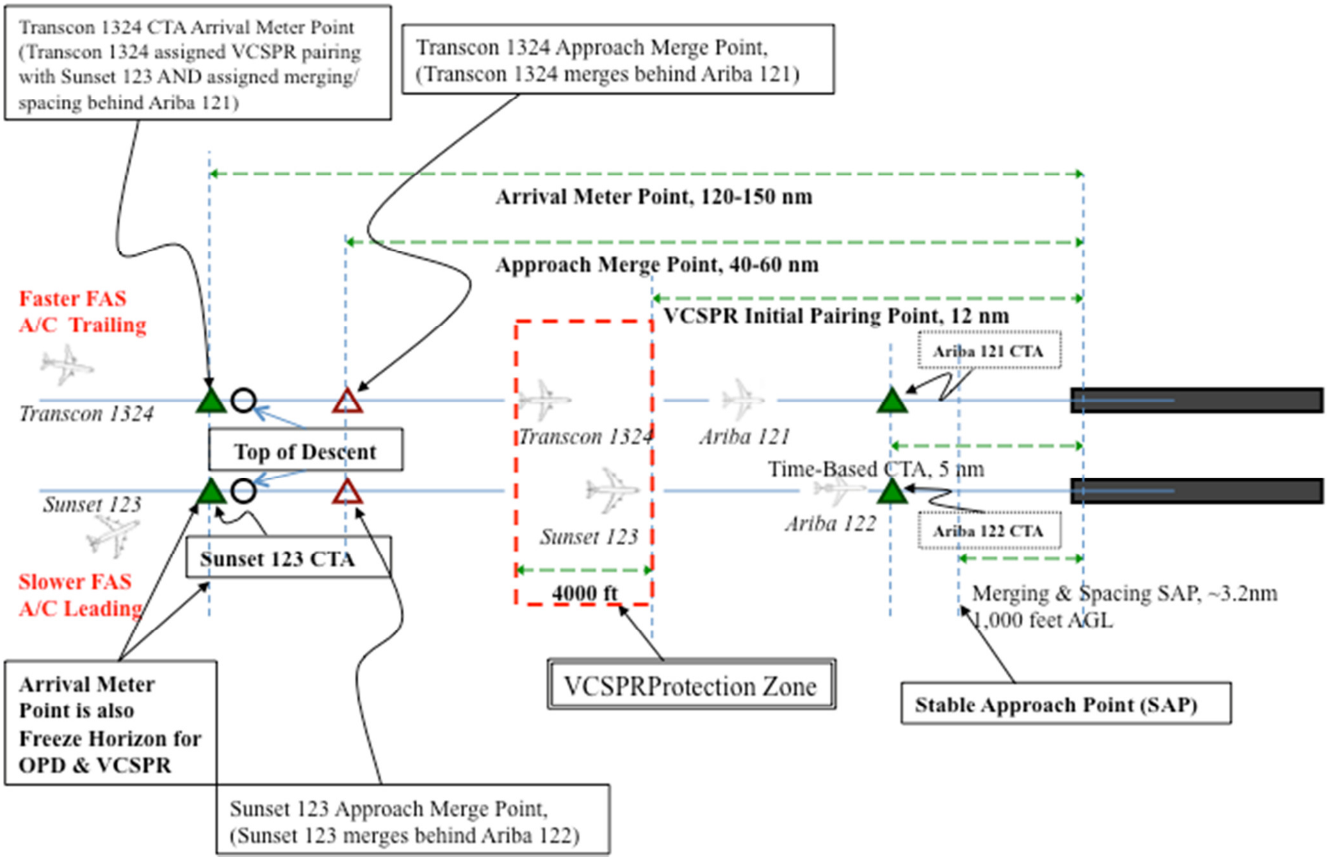


Figure 10: IAD Arrivals

As Sunset 123 approaches the arrival meter point, the ANSP assigns airborne merging and spacing responsibility behind Ariba 122. Transcon 1324 is assigned responsibility for airborne merging and spacing with respect to Sunset 123 to arrive with appropriate spacing at the initial coupling point for the VCSPR operation.

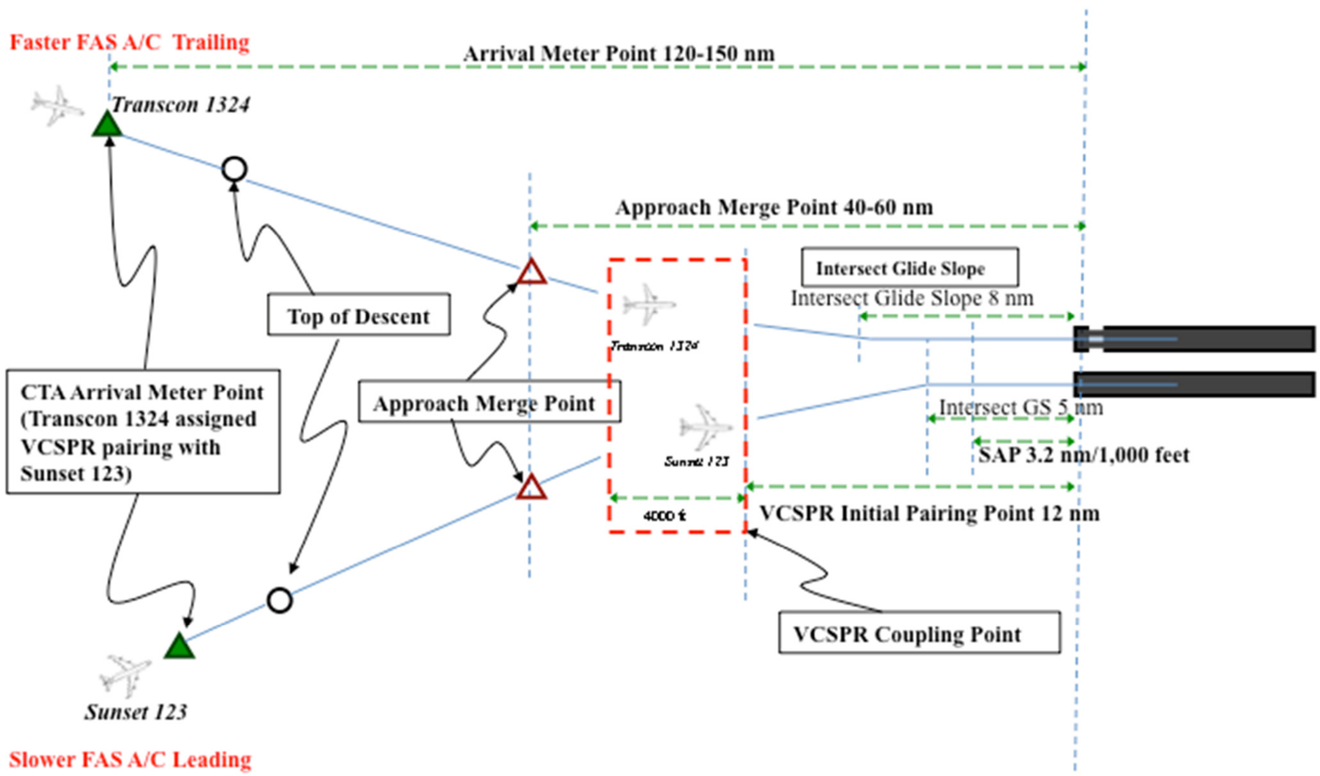


Figure 11. VCSPR Pairing Detail

Because high-density operations are in effect, all four aircraft are transmitting additional ADS-B intent information (such as planned final approach speed) to aid ground-based and onboard decision support tools in calculating efficient spacing trajectories. Before TOD, the pilot of Transcon 1324 will use available airborne equipage to calculate an initial 4DT for airborne merging and spacing with OPD using RNAV/RNP route assignments. The FMS selects a desired TOD point and 4DT within the constraints of the given speed and vertical flight-path waypoint crossing restrictions to arrive at the VCSPR coupling point with the appropriate pair positioning behind Sunset 123. During the arrival and approach segments, the Transcon 1324 onboard decision support tools (elements of conflict detection and resolution functions) will continually monitor the speed and position of Sunset 123 and provide speed guidance cues to the flight crew. Sunset 123 will likewise calculate and downlink a 4DT for airborne merging and spacing with OPD to arrive with the designated spacing behind Ariba 121, and will conduct the spacing/OPD procedure supported by onboard tools.

Some small pop-up convective weather cells are beginning to appear along the arrival route. The ANSP, using the TBO arrival decision support tools with integrated weather information, plans a temporary modification to the initial segment of the arrival route to avoid the weather cells by adding two new waypoints. Both Transcon 1324 and Sunset 123 receive arrival route modifications, which they load into their FMSs. Since they are still more than 60 nm from the airport, they have sufficient time to rejoin the original route and make up lost time for efficient final spacing. Both aircraft have the same highly accurate terminal area wind profile data as the ground automation, facilitating accurate trajectory prediction and efficient OPDs. By using ADS-B and data link access to network-centric operations, the aircraft receive information on terminal area conditions and all approaching traffic. The flight object also includes a pre-clearance taxi plan for post-landing surface operations generated by surface movement TBO automation systems, and based on predicted touchdown time generated by IAD TBO arrival management automation. This may be updated as situations change.

Approach:
As Transcon 1324 and Sunset 123 conduct their respective approaches, the ANSP monitors conformance for each aircraft. The assigned routes are configured such that 23 nm from the runway, Transcon 1324 levels off at 2,500 feet altitude and Sunset levels off at 1,500 feet altitude, so they are on parallel courses 750 feet apart laterally, but separated vertically by 1,000 feet. Since Transcon 1324 has been assigned to be the initial follower in the VCSPR pairing, it is responsible for positioning the aircraft with the appropriate longitudinal spacing with respect to Sunset 123 before reaching the coupling point 12 nm from the runway. This is accomplished using speed guidance provided by onboard spacing tools. Both aircraft are cleared for the VCSPR operation before either aircraft intercepts the three-degree glide slope.

If Transcon 1324 had not achieved the required spacing by the coupling point, it would have been required to conduct a missed approach at that point. During the VCSPR operation, both Transcon 1324 and Sunset 123 are flying coupled-autopilot approaches with highly precise lateral navigation. Both aircraft are using onboard alerting algorithms to monitor the other aircraft for indication of a possible blunder, which would necessitate a breakout maneuver. The alerting algorithms are using application-specific information transmitted via the ADS-B intent message, such as position, bank angle, and autopilot and navigation status information.

As each aircraft intercepts the glide slope, Transcon 1324 continues to actively space off of Sunset 123, staying towards the back of the conformance zone. After the FAF, the two aircraft slow to their respective FASs and are in their landing configurations by the SAP three nm from threshold. At the three nm point, active spacing ends and each flight crew maintains their respective FAS and focuses on safe landing. Since Transcon 1324 has FAS that is 10 knots faster, Transcon 1324 passes and touches down ahead of Sunset 123.

Before touchdown, the ANSP clears both aircraft for Segment 1 (through runway exit) of the taxi plan (the ANSP can cancel green status and issue a missed approach if necessary.) The flight crews acknowledge the clearance via voice and visually inspect the runway as the aircraft approaches for touchdown. Under instrument conditions or at night, a glance at the CDTI will show aircraft that may be on the runway. Onboard alerting exists for runway incursion prevention.

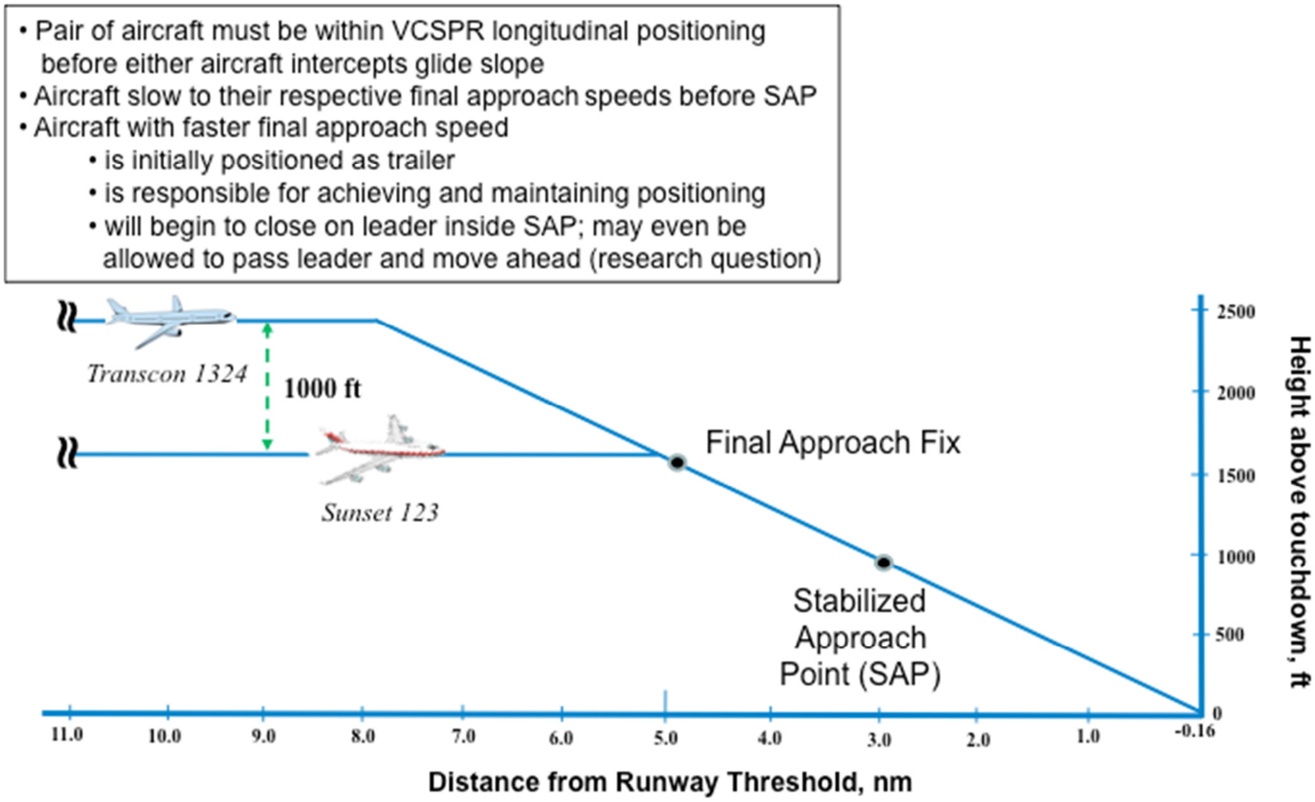


Figure 12. VCSPR Glideslopes

Landing:
The last revision of the taxi plan is uplinked to aircraft just before touchdown by the TBO surface movement automation. A combination of ground-based and airborne runway incursion detection and alerting tools monitors the runway status. Ariba 122 has already touched down, but missed its assigned exit and is still taxiing down the runway when Sunset 123 crosses the threshold. Since Ariba 122 is very near the next exit and is expected to depart the runway very soon, Sunset 123 is allowed to land, using CDTI and onboard decision support tools to monitor the status of Ariba in case aggressive breaking may be required (OI-0341).

Transcon 1324 touches down and then Sunset 123 touches down on the adjacent runway. Both aircraft elect to use their onboard automatic braking systems. Each aircraft slows and takes its assigned high-speed runway exit.

At touchdown, the navigation display for both Sunset 123 and Transcon 1324 automatically changes to a taxi-map surface display, showing the assigned runway exit and taxi route. Both the HUD and the EFB show the assigned taxi route as green, meaning the aircraft is expected to be able to take the assigned exit, and the exit is clear of traffic.

As Sunset 123 touches down, information appears on the HUD showing the location of the assigned high-speed runway exit, the distance to that exit, and information on the braking and thrust-reverser performance of the aircraft.

At some point after touchdown, the avionics from both aircraft automatically send braking action reports to the ground-based automation system, which are used to update the runway condition status used in calculating spacing intervals for future arriving aircraft.

14.5 Surface Movement – Taxi-in

Upon completion of its DTW-IAD leg, the last revision of the taxi plan is uplinked to Transcon 1324 just before touchdown.

A combination of ground-based and airborne runway incursion detection and alerting tools monitor the runway status. Own-ship surface movement alerting will significantly help in reducing runway excursions of its own-ship aircraft, by providing timely alerting to the aircraft crew of unsafe situations. For example, when approaching a runway (flying an approach), it provides an indication of the runway identifier of the runway towards which the aircraft is approaching, and runway overrun indication and alerting. Next, when landing on a runway, it provides runway exit indication and runway overrun alerting.

Ariba 122 has already touched down, but missed its assigned exit and is still taxiing down the RWY 12/30 when Sunset 123 crosses the threshold at IAD. Since Ariba 122 is very near the next exit and is expected to depart the runway very soon, Sunset 123 is allowed to land, using CDTI and onboard decision support tools to monitor the status of Ariba in case a go-around may be required (OI-0341).

Transcon 1324 touches down on RWY 12/30 and then Sunset 123 touches down. Both aircraft elect to use their onboard automatic braking systems. Each aircraft slows and takes its assigned high-speed runway exit. Braking assistance significantly minimizes the time passed on a runway after a landing. Such braking assistance will provide indications of where the aircraft will stop on a runway, or have a controlled airspeed depending on the actual usage of braking.

At touchdown, the navigation displays for both Sunset 123 and Transcon 1324 automatically change to a taxi-map surface display, showing the assigned runway exit.

The taxi-map surface display is provided via data communication from ANSP automation. This is enabled by TFDM far-term capabilities in the areas of airport planning, taxi routing, runway assignment, and scheduling and sequencing. This results in automated generation of optimized 4-D surface taxi route with times (at surface waypoints and hold shorts).

Transcon 1324 follows surface guidance to the gate. On-board runway incursion alerting is provided when taxiing on the airport surface in terms of approaching runway indication and alerting, as well as approaching runway alerting without line-up clearance. This involves on-board correlation of the 4DT taxi clearance with the route as actually executed. In the far-term, this is all automated guidance, and will require interfacing with flight controls and auto-throttle.

The TBO surface movement system updates the taxi route on exit of Transcon 1324.

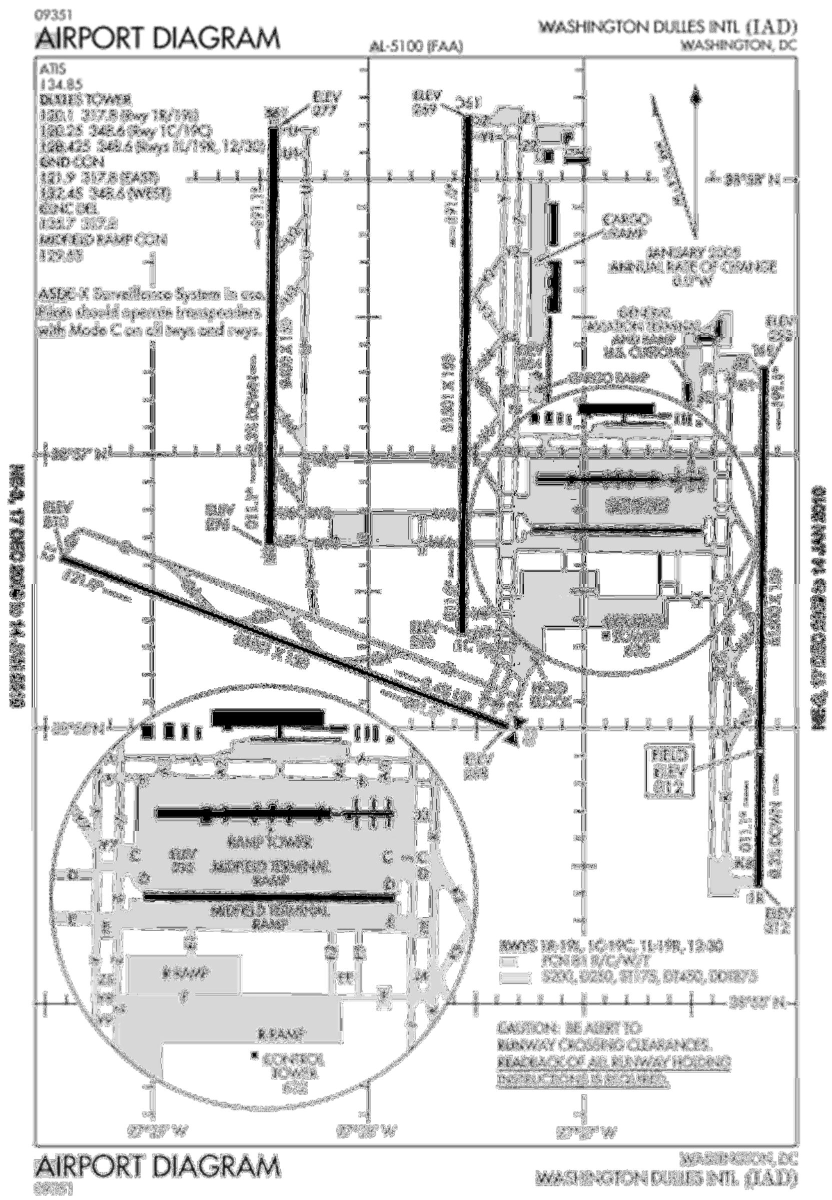


Figure 13. IAD Surface Layout

15.0 Phoenix To Bozeman Scenario

15.1 N72MD General Aviation Flight Planning

The pilot uses her laptop PC to access network-enabled operations to obtain forecast weather and airspace restrictions (OI-0306). A network-centric function similar to today's Direct User Access Terminal Service (DUATS) allows the pilot to submit trial plans and obtain various alternatives to constraints along her route of flight. For example, the pilot uses FL210 for the initial altitude departing the Phoenix area. Based on the rate of climb the pilot enters, network-centric operations tools determine that the aircraft will climb through an arrival corridor into PHX, and provide the appropriate lateral route offset that will take the pilot further east out of the way and stay below this PHX arrival route. The tools offer other alternatives, as well. One alternative is a more direct route if remaining below FL190 until past the arrival route. The pilot selects that alternative. She also determines that once at FL210, she will potentially have to contend with arrivals and departures in and out of Salt Lake City (SLC) to the east.

Once the pilot is finished with trial planning and settles on a route and altitude, she downloads the information to the external physical EFB device that she can carry anywhere and use with an Internet connection. The EFB contains identical planning software as the base unit in the aircraft, but has a smaller screen and controls. Trial planning is easier on the device. The pilot has configured the EFB software to interface with the network-centric operations to access airspace constraints, update weather information, and file flight plans. The EFB can use Wi-Fi, Ethernet or a mobile wireless connection to communicate with network-centric operations via the Internet.

Initially, there is a +/- 15-minute window assigned to the destination arrival time for this flight plan due to the lack of VNAV and 4DT autopilot equipment, as identified by the flight plan equipment code. Consequently, the ANSP will initially de-conflict N72MD using vertical/altitude separation. Once in steady state flight, the ANSP will be able to calculate, as well as use ADS-B intent information for short-term intent and narrow the performance time (e.g., +/- one minute). This in turn permits separation using time to the degree accuracy allows. The ANSP's TBO evaluation service will use the 15-minute separation window for planning and examining downstream conflicts and then shift to one-minute intervals once airborne.

The pilot will make a final check of the weather and airspace constraints the morning of the flight and will file the flight plan, populated with information used by the flight object for this flight. The clearance will be sent back to her and accepted in the EFB via mobile wireless. Once in the aircraft, the pilot will plug her portable device into the aircraft's EFB and synchronize the EFB with the aircraft navigation system, so that the EFB and navigation system utilize the same flight plan information, which alleviates the need to program the navigation system by hand. The pilot must still review and confirm that the flight plan is correct in the navigation system before it is executed.

The pilot is delayed 20 minutes. She updates the flight plan Expected Departure Time (EDT) via cell phone by calling an 800 number that links her into the network-centric operations system. The ANSP takes this information and updates the predicted 4DT route that will be the basis for the clearance.

Upon reaching the airport, the pilot uses the portable EFB to connect to network-centric operations via the Internet to download any final changes to the clearance. The ANSP added two waypoints to the flight plan that coincide with waypoints on the PHX and SLC arrivals that N72MD will cross. Including these waypoints in the navigation unit's flight plan means that the pilot will see an ETA to these waypoints when navigating, and the ADS-B message will include these points as intent information to support sequencing and separation. The ADS-B intent information is used by the ANSP because this aircraft does not have data link or a FMS.

Once the pilot has powered up the aircraft and its avionics, she uses the navigation system menu to import the flight plan from the EFB. The navigation system performs a logic check on the flight plan, confirms its integrity, and prompts the pilot to review and accept the flight plan for importation. The pilot reviews and accepts the flight plan.

N72MD's departure clearance releases the aircraft at 28 minutes past the hour. REESE is the first waypoint in the flight plan. Traffic in the PHX area is heavy, and N72MD will be cleared to remain at or below 6,000 feet until passing REESE to remain under an arrival stream. This altitude is made possible by PHX using continuous descent arrivals resulting in steeper, more fuel efficient vertical profiles thereby freeing up more low altitude airspace. The route then continues over Scottsdale, and then direct to a waypoint in the Salt Lake City area.

15.2 Surface Movement

The EFB indicates 10 minutes until planned departure time and the pilot radios ground control to taxi for takeoff. The pilot completes the preflight system checks, activates the flight plan in the navigation system and notifies the tower she is ready to depart. The tower has the clearance and required time of departure that is in three minutes. At one minute from departure time, the tower asks an aircraft in the traffic pattern to extend its downwind to allow N72MD to depart at its assigned time. N72MD is cleared into position for takeoff and released at the assigned departure time.

15.3 Phoenix Takeoff and Climb

N72MD departs RWY 26R with a right turn upon reaching 1,000 feet AGL and contacts PHX departure. Although PHX departure is separating N72MD from other traffic, the pilot monitors the CDTI for numerous VFR traffic during the climb, and correlates electronic targets with out-the-window visual contacts. The pilot maintains out-the-window vigilance for VFR traffic that may not have ADS-B out or an operating transponder (for traffic detection and broadcast to the aircraft on TIS-B) and is thus not depicted on her NAV/CDTI display. Climbing through 4,000 feet and approaching REESE waypoint, N72MD slows her climb rate to remain below 6,000 feet passing REESE, as instructed, in the departure clearance. Once two nm past REESE, N72MD is cleared to climb to planned cruise altitude of FL210 on course.

15.4 Phoenix to Bozeman Cruise Segment

Fifty nautical miles south of SLC, N72MD begins to experience turbulence. Pilot reports (PIREPS) provided via satellite broadcast weather show reports of moderate turbulence below FL250 in the eastern half of the SLC area. The pilot requests an altitude change to FL250 (OI-0303, OI-2010, OI-2020, OI-2021, OI-2022, OI-2023, OI-2024). The ANSP approves and instructs the pilot to navigate via VERNL, slightly east of the aircraft's current track. VERNL is a waypoint in an SLC arrival at which aircraft on arrival to SLC are near the same altitude.

N72MD climbs to FL250, and in doing so must slow to 160-knot climb speed. Until N72MD reaches FL250 and once again stabilizes at cruise speed, the ETA being transmitted as part of the ADS-B near-term intent message will continue to change and be inaccurate. The ATM system anticipates this and opens the TBO conformance window to allow the associated uncertainty in time of arrival at VERNL. This addition of uncertainty relative to time is then used by the ANSP TBO evaluation service to scan for any downstream conflicts.

Twenty nm prior to reaching VERNL, the ANSP detects a conflict that indicates that N72MD will conflict with a Sunset Boeing 737 going into SLC. The ANSP's TBO evaluation offers the controller a few options, one of which is to slow N72MD to 200 knots until passing VERNL at 17 minutes past the hour. That will put N72MD behind the Sunset Boeing 737, and in front of the next aircraft 15 miles away and inbound to VERNAL, providing sufficient separation. The flight object information for N72MD tells the controller that the aircraft is equipped with appropriate capability from the navigation system, but without auto-throttles. Consequently, the controller can only expect +/- one minute of conformance performance from the pilot. The controller asks the N72MD pilot if she can slow to and maintain 200 knots ground speed, and pilot answers in the affirmative. The pilot slows to a 200 knot ground speed on her navigation display and then holds the airspeed that represents the ground speed. The controller issues a clearance to do so and pilot adjusts speed until the GPS navigation unit is showing 200 knots ground speed. The controller informs the pilot that she needs to cross VERNL at 17 minutes past the hour. Because the pilot must manually fly the time, the pilot programs this time into the EFB for VERNL. The EFB provides a "how-am-I-doing" status indicator, showing the current ETA to VERNL at present speed, and an indication of target speed and ETA the pilot needs to fly to comply with the ETA. The pilot adjusts speed to match it with the desired speed and time at VERNL. Had the controller requested an increase in speed in excess of five knots, the pilot would have known she could not comply and would have notified the controller. The controller would have then chosen another option and negotiated that with the pilot via voice communications. This is an example where the pilot is able to meet the RTP through the use of simple aids in the cockpit, not requiring a FMS. Voice is used because of the lack of data link.

Passing VERNL, the satellite weather display shows that the storm system is moving faster than forecast and there will be heavy snow and moderate turbulence west of BZN at the time of arrival. The arrival for the RWY 12 ILS approach goes through this area. The pilot requests the RNP 0.3 GLS approach to RWY 30, an overlay approach, and the ANSP approves. This will keep the pilot out of the weather during approach and missed approach if necessary. The pilot selects this approach in the navigation system avionics.

Twenty miles prior to N72MD reaching the RWY 30 RNP feeder fix, the ANSP automation determines that a regional carrier flight to BZN will be in conflict, and the controller verbally instructs N72MD to slow to 160 knots and to descend to 14,000 feet. The pilot reduces power to comply.

15.5 Bozeman Arrival/Approach and Landing

The pilot obtains the latest weather and airport information. Weather at the destination ETA is forecast to be 3,000-foot overcast and three miles visibility in blowing snow. Wind is 300^{o} at 15 knots, gusts reported as high as 35 knots. Pilot reports indicate moderate turbulence from 10,000 feet all the way to the surface. Runway braking action is reported as fair by a Sunset Air 737-900. The pilot selects the airport arrival page on the multifunction display and reviews the arrival procedures for the approach. N72MD changes from an RNP 0.3 overlay approach and will use a new[21] RNP AR (RNP 0.1) approach to BZN RWY 30. Due to high terrain to the southeast of the airport, the RNP procedure approaches the airport from the west and uses a radius-to-fix (RF) curved segment to connect the downwind segment to the final approach segment. This RNP 0.1 approach procedure has several feeder fixes, including SLOAN to the southwest and LIVINGSTON to the east. The approach is made up of an initial approach fix (IAF) 10 nm to the southeast named EAGLE, a downwind that can be reached from SLOAN by a RF segment from STONY that terminates at BADGR abeam the approach end of RWY 30, a RF turn point (CYOTE) and the segment to the FAF, named WOLFE, and then the three nm final approach segment. This path provides a normal vertical descent profile into the airport area, remains within the terrain "bowl," and permits the use of a precision GNSS throughout the RF turn and final approach segments. This allows aircraft to land on RWY 30 using Localizer Performance Vertical Guidance (LPV) minima when the wind conditions favor that runway. Normally an RF turn would be a function of an FMS, but in this case, the navigation system presents the turn on the synthetic vision capability on the multi-function display. The pilot needs to fly the Highway-in-the-Sky (HITS) depiction for guidance around the turn to the FAF.

Bozeman has a staffed virtual tower, meaning that tower services are handled remotely at another ANSP location, and ADS-B, cameras, and other sensors monitor the surface situation. Data link and voice communications coverage is provided both in the terminal area and on the ground. The airport itself maintains a wireless Internet capability for use by pilots for flight planning. The ANSP uses the virtual tower capability and the benefits of ADS-B surveillance to eliminate the one-in-one-out procedures used at non-towered airports for IFR operations. Under one-in-one-out, aircraft would need to hold at the initial approach point pending confirmation through the ANSP that the preceding aircraft has taken off or completed a landing and the runway is clear. ADS-B allows the ANSP to see this information electronically. The net effect is an increase in effective capacity from four operations per hour to 12 during instrument meteorological conditions.

The virtual tower automation module within the TBO arrival, approach and landing automation, has recommended to the ANSP that the arrival sequence into BZN will be a Moon Air regional carrier flight, followed by N72MD, followed by N43P. Both Moon Air and N43P are arriving via LIVINGSTON, while N72MD is arriving from the southwest via SLOAN. Five miles prior to N72MD reaching the SLOANE feeder fix, the en route ANSP TBO strategic evaluation service determines that the Moon Air flight to BZN will be in conflict, and the ANSP receives options for resolving the conflict and verbally instructs N72MD to slow to 160 knots and to descend to 9,000 feet. The pilot reduces power to comply.

[21] This hypothetical procedure is intended to illustrate the possible use of RNP and LPV procedures and the navigation capabilities envisaged in NextGen. It is a rough estimate of a procedure and has not been reviewed for TERPS criteria or other FAA policy guidance.

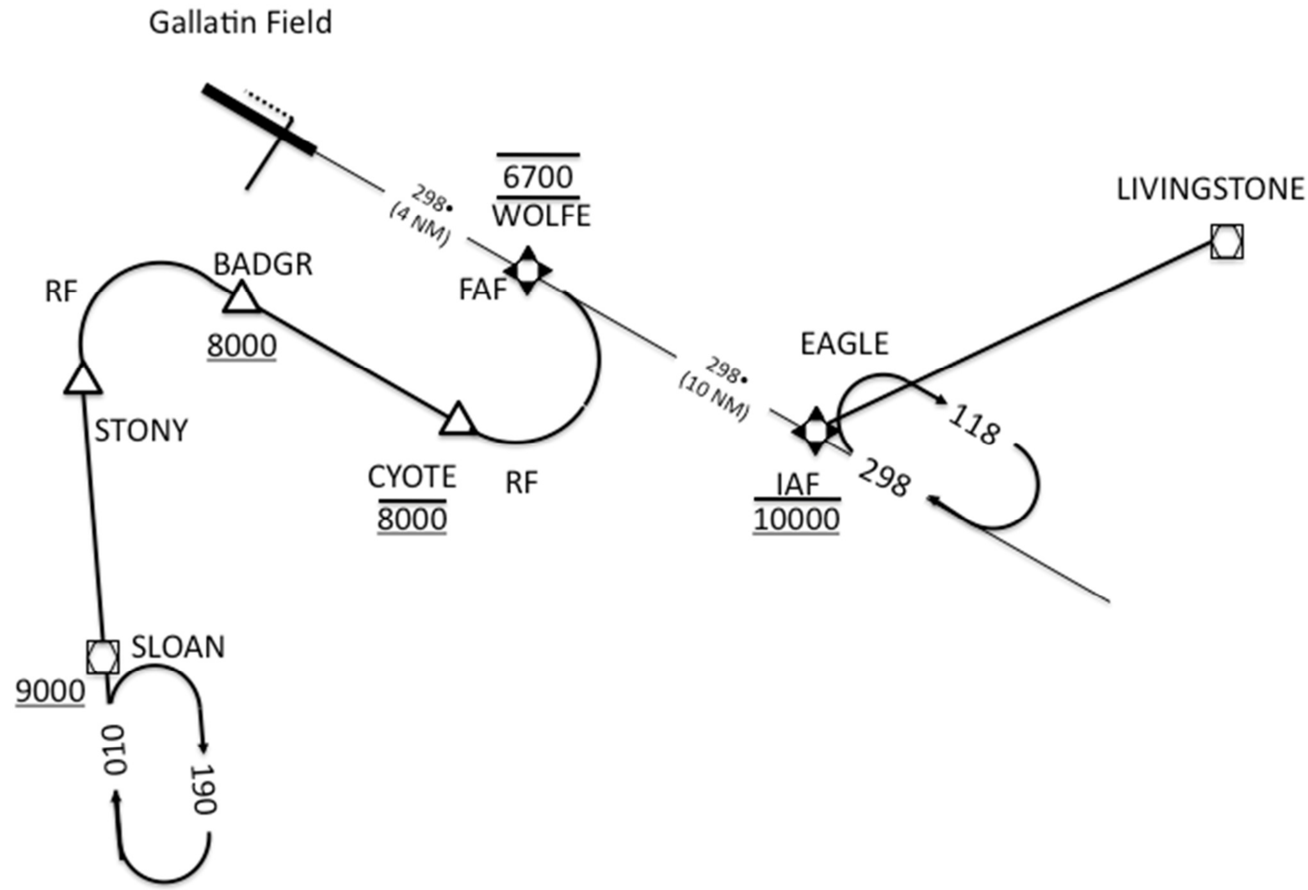


Figure 14. BZN Arrival

The ANSP verbally clears N72MD for the approach to RWY 30 behind the Moon Air flight, but instructs it to hold at the feeder fix until the regional carrier flight passes the initial approach fix on an RNP approach 13 nm ahead. Then, N72MD is to maintain five nm or greater separation behind Moon Air (OI-0362). The pilot uses the CDTI display to determine that the Moon Air aircraft has just passed the LIVINGSTON feeder fix. N72MD estimates that the Moon Air is probably travelling fast enough to reach the IAF at approximately the same time that N72MD will reach SLOAN, but without onboard spacing capability to calculate the closure rate, she isn't sure if the current speeds will provide adequate spacing. N72MD further reduces speed by an additional five knots to be sure not to have to conduct a short hold at the feeder fix.

N72MD reaches SLOAN just as Moon Air passes the EAGLE IAF, so N72MD continues without holding and begins a descent to 8,000 feet, which is the minimum altitude at BADGR. The Moon Air aircraft is traveling faster than N72MD, so spacing is not a problem. The N72MD pilot increases speed back to 160 knots. N72MD is instructed to contact the virtual tower via voice radio. The pilot contacts the virtual tower. The tower acknowledges and verifies the Moon Air flight ahead is at WOLFE FAF, which is mirrored on N72MD's CDTI display. Upon reaching BADGR on downwind, N72MD is level at 8,000 feet (2,500 feet AGL). She lowers the landing gear and continues slowly while crossing CYOTE at 8,000 feet. The virtual tower controller advises N72MD that the Moon Air aircraft ahead has reported deteriorating visibility at the runway.

When aircraft N43P is five nm east of the LIVINGSTON feeder fix, a data link message is received from the BZN virtual tower sequencing N43P to conduct the RNAV (RNP) RWY 30 Approach with five nm spacing behind aircraft N72MD. The pilot of N43P pushes a virtual button on his glass cockpit display to accept the clearance (WILCO). He sees on the CDTI display that aircraft N72MD has already started to RF leg from CYOTE to WOLFE. N43P's onboard spacing tool determines a relative 4DT for the approach to maintain adequate spacing behind the slower aircraft throughout the approach and landing. Upon reaching the EAGLE IAF, the pilot of N43P is instructed to contact the virtual tower via voice radio. The virtual tower ANSP clears N43P by voice for the approach and landing with delegated separation authority to conduct spacing behind N72MD. The pilot accepts the clearance via voice. This represents the first voice communication the pilot has had with a controller since leaving Cincinnati airspace. The assigned clearance means the controller intervenes by exception and only does so by voice when data communications are inadequate or the aircraft is not suitably equipped. N43P continues the approach, with onboard spacing tools continuously monitoring the progress of N72MD ahead and periodically updating the speed guidance for spacing.

The pilot of N72MD begins to roll out of the RF turn to the final approach with situational awareness of the surrounding terrain and flight path via the SVS terrain and Highway-In-The-Sky (HITS) displays. Pathway deviation indicators provide the guidance necessary to accomplish the RF turn and the RNP 0.1 approach. The pathway deviation indicators compensate adequately for the winds, and the pilot is able to maintain the course within RNP 0.1.

The navigation display shows WOLFE (FAF) at rollout of the turn four nm from the RWY 30 threshold with an altitude of 6,700 feet mean sea level (MSL). Upon reaching WOLFE, the virtual tower ANSP gives N72MD landing clearance via voice and instructs the pilot to report clear of the runway. Due to the high winds, the pilot will maintain an approach speed of Vref+20 until approximately one half mile from the runway threshold then slow to Vref+10 for landing. The aircraft is established on the straight-in segment of the final approach course at three nm from the runway.

At approximately one mile from the runway, the snow increases in intensity. The virtual tower ANSP reports that the visibility is now down to less than a quarter mile in blowing snow. The pilot is able to use the SVS to maintain runway alignment and vertical profile, but has not visually acquired the runway before reaching decision height, and is forced to conduct a missed approach. The virtual tower ANSP provides vectors for N72MD to leave the BZN vicinity with a left turn to cross over SLOAN at 10,000 feet. While in the turn, N72MD advises that she will proceed to her alternate and receives another vector from the ADS-B surveillance on course to successfully land at an alternate airport with better current weather. At handoff from the virtual tower to the en route tactical controller, a new 4DT to the alternate has been determined, and will be provided to the pilot to go from an open to a closed trajectory in TBO.

Aircraft N43P also encounters the higher intensity snow at one mile from the runway. However, N43P is equipped with an EVS in addition to its SVS. The N43P EVS provides the pilot with current runway environment information, including a depiction of the runway plus any obstacles present, obtained from an infrared sensor and displayed as a fused image with the SVS information on a head-up display. Using the EVS information, the pilot of N43P is able to "visually" acquire the runway environment and safely conduct a low-visibility landing.

15.6 Bozeman Surface Movement – Taxi-in

After N43P touches down, the virtual tower ANSP advises that he is unable to see the aircraft. The virtual tower ANSP can view live feeds from multiple cameras on the airport surface, but BZN airport is not equipped with any advanced cameras that can penetrate weather. The pilot extends his landing roll because he misses the first available turnoff.

The pilot exits the runway near the end and is able to visually maneuver the aircraft onto the parallel taxiway, using visual cues and SVS for situation awareness. The virtual tower determines N43P is on the ground and leaving the runway based on its ADS-B information, and automatically closes its flight plan. The virtual tower advises the pilot to use caution because an airport vehicle is moving out to perform a braking action report on the runway. The pilot cannot acquire the vehicle visually but observes it on his EFB surface situational awareness moving map and stops as the vehicle passes directly in front of him. The pilot then taxis to the terminal, secures the aircraft, and proceeds to the FBO where he will meet his ground transportation.

16.0 Off Nominal Operations

Before discussing variants on TBO in the context of NextGen, it is important to discuss what is nominal (usual) and off nominal (unusual). In this report, several off-nominal operations (e.g. a security incident and loss of GNSS) are featured. In addition, weather today is characterized as off nominal. With the advent of NextGen weather capabilities, this categorization should be reconsidered.

In today's NAS, most weather events such as convection (i.e., thunderstorms), which often cause flight delays and cancellations, are considered off nominal both strategically and tactically. This will change with NextGen. Within NextGen, weather information (i.e., forecasts, observations, and volumetric characterizations of potential weather constraints) are integrated directly into decision making. This means that, from a strategic perspective, SAS weather information and potential convective weather constraints are provided to the strategic TBO evaluation service. It is then used along with predictions of other non-weather constraints to routinely determine the operational impact on requested trajectories. Using this information, decision-support automation determines the impact on flows, and whether there may be a need to restrain demand in certain airspace. Aircraft in flight will have their trajectories modified against downstream flow contingencies developed to deal with weather and other constraints. All of these actions are considered strategic changes, those known in advance.

NextGen weather forecasts will be more probabilistic. This means that the exact time at which an airport must close a runway for snow removal, or when a thunderstorm is about to impact operations at an airport, may not be known with absolute certainty hours in advance. However, there is a tactical ability within NextGen to incrementally shutoff designated arrivals, begin moving trajectories to other paths, and refine the 4DT of some inbound aircraft accordingly.

Snow or a line of thunderstorms affecting a major airport like ORD are capable of being modeled operationally, so that scenarios can be developed and traffic demand tested against the scenarios. This means that while the exact time when the airport must close a runway for plowing, or when the thunderstorm is about to pass the airport may not be known with certainty, there is the ability to more precisely plan how flight paths will be modified to sustain the highest possible throughput.

Off-nominal operations are tactical in nature, reflecting a time horizon of the next 20 to 30 minutes of a given flight. This includes:

- Sudden closing of a runway or airport for safety or security reasons
- A security incident involving an airborne threat
- Change of runway landing direction as winds or weather shifts
- Sudden activation of special use airspace or similar restrictions to use of or access to the airspace
- System failures in automation, communications, navigation, and/or surveillance
- Decisions by other nations to restrict access to airspace
- Control by exception, where the flight has failed to meet or is unable to meet its 4DT and must be directed by the controller
- Military need for use of airspace for national security
- A flight-crew-declared emergency

These examples are not all-inclusive. But the general concept is that, if known at least 30 minutes or more in advance, such an event would not be considered an off-nominal. Rather, it is a planned change to a trajectory/flight path/timing to reflect newly identified flow contingencies. In general, NextGen would address most events and their resulting impact strategically. Off nominal would involve an event that still remains somewhat uncertain in a more tactical timeframe (i.e., less than 30 minutes) and is dealt with incrementally as the timing and impact of the event become better defined.

Four examples are provided to illustrate how TBO would handle off-nominal events. Each discussion covers the nominal portion of the event, as well as the off-nominal portion:

- A severe convective weather event at a high-density airport
- A runway closing at a high-density airport
- A loss of GNSS due to interference impacting a high-density airport
- A security incident (non-conforming and non-responsive air carrier aircraft)

16.1 Convective Weather

A front is moving west to east with thunderstorms expected with tops to FL410 and a band of intense weather stretching from north of Minneapolis to St. Louis. The front is kicking off tornados toward the south and severe thunderstorms on its northern end. This front is expected to cross Minneapolis at 2000 UTC and Chicago at 2130 UTC. Kansas City has a tornado watch out for 2000 to 2300 UTC, and St. Louis is expecting severe thunderstorms starting at 2100 UTC. The line of thunderstorms is expected to top out at FL410, but there are areas of lower tops expected north of Minneapolis and just south of Chicago. After crossing over Chicago, the front and storms are expected to continue their easterly track before thinning and finally dissipating around 0100 UTC.

In today's NAS, decision makers independently and cognitively determine how the weather would impact operations. In NextGen, the 4D Weather Data Cube provides a common weather source of observations and forecasts to all stakeholders, and this information is translated into volumetric characterizations of potential operational constraints (e.g., where aircraft will and will not fly) to better enable decision making.

Determining the exact time of storm passage at each airport is not possible hours in advance. But what is possible is to work the number of arrivals and departures and begin to model the operational impacts of just such a storm. For example, a reduction of capacity while the storm is in the vicinity of the airport, or a projected wind shift with the frontal passage that would result in a potential reconfiguration of the airport and airspace. Rather than wait until the storm arrives at Minneapolis or Chicago and reactively put ground stops into effect, flights are proactively offered different 4DT opportunities to change routing, climb higher, or change their timing throughout the day. Through net-centric operations and common situational awareness, flights tracks are adjusted before departing for the destination. Airports east of the storm are impacted as the front approaches. Some airlines may elect to fly a more circuitous route around or over the weather constraint, while others arriving and departing from an impacted airport must look to other options.

Weather forecasts from the SAS and potential constraint information are disseminated to the ANSP strategic TBO evaluation service, providing the opportunity to examine multiple time slices, both current and future. By examining 2100 to 2200 UTC ORD arrivals and departures, a projection is made for demand. An estimated airspace constraint due to severe weather is obtained from the weather translation capability that changes weather to airspace for modeling, and the TBO evaluation service, using probabilistic metrics, determines a range of possible impacts on approved 4DTs. This range of possible impacts will be continuously refined as updated weather forecasts are received and weather constraints become better understood.

Those Chicago-area arrivals within the one-hour window of the expected front arrival and passage that are not airborne yet will receive new 4DTs to delay their arrival. Those already airborne may receive a new routing, a slowdown, a change in the location of TOD, or an arrival path based on the expected arrival time of the storm. There is an exchange going on between the ANSP strategic TBO evaluation service and both the ANSP surface movement management and departure/arrival TBO management automation modules. The strategic TBO evaluation service is provided the best estimate of frontal arrival and passage. The surface movement management module is receiving SAS information along with local winds. The surface movement management module is examining the local departure hold lists and those aircraft that are released for departures. It is receiving arrival information over the short-term from the departure/arrival TBO management module, and building a picture of when the best time to change landing direction. This is fed back to both the departure/arrival TBO management module and the ANSP strategic TBO evaluation service, and widely distributed through network-centric operations.

Anticipating an airport and airspace reconfiguration, an aircraft is designated as the first to land from the new direction and its 4DT. Aircraft that will subsequently land are modified to use the new landing-flow direction. For some aircraft already on the arrival, they may receive a new 4DT that will place them on an extended downwind for a RF turn to final in the new landing direction. Other aircraft may be brought in over the top of the weather and assigned a new arrival path segment. Weather avoidance may also include a flow corridor where aircraft are routed because of gaps in the convective weather, or because of areas reported or detected on radar as having passable conditions.

The bottom line is to handle weather strategically, based on airspace that is potentially constrained during the development and transport of the storm. This still leaves aircraft that are scheduled to depart or committed to land during the window of worse weather.

For runway changes, aircraft are held at the gate and given a start taxi time so they can load passengers accordingly. Once off the gate, they are sequenced to expedite their flow to the runway end, such that there are minimal or no queues that would either be trapped by the weather or require redirection during runway swaps. Aircraft with taxi-out times close to the change in runways would be directed to the new runway. The concept of managing departures off the gate is done using the functions of the ANSP's surface movement management module. This module knows the taxi-out time by aircraft type, operator and gate, scheduling accordingly to avoid long queue formation during the worst part of the weather. This feature also deals with the deicing requirements for each aircraft type to get airborne within a specified interval.

Aircraft on arrivals and in the weather are avoiding intense storm areas using voice requests, and are traveling in open trajectories under the direction of ATC through control by exception. The cockpit workload is too great to accept constant changes to the 4DT during this phase of flight, and turbulence may require speed and direction changes. Aircraft on RNAV/RNP arrivals can expect to fly the arrival, but then receive vectors to downwind as the runway directions change. Those that arrive at the height of the weather constraint may receive holding instructions as necessary to balance demand. Coming out of holding, aircraft can expect a new 4DT provided by the TBO strategic evaluation service. The demand cannot exceed what the controller can handle in control by exception.

Controllers are aided by automation to maintain a demand that can support the higher volume of open trajectories that will be needed. Once the controller believes that the aircraft is capable of returning to 4DT, a clearance is issued to close the trajectory, and automation resumes separation responsibilities.

Deviations for weather are handled first under TBO as a strategic change through issuance of a new 4DT that considers weather, then as an open trajectory 4DT for maneuvering, then as an open trajectory, with vectors as control by exception. Once established on an approach path, the trajectory is again closed.

16.2 Runway Closing

A disabled aircraft on the runway creates this off-nominal event. The commuter aircraft had a right main gear collapse during landing rollout, and the aircraft veered off to the right and is sitting partially on the runway and partially on the grassy area. At the time of the event, two aircraft on final for the same runway were sent around and re-sequenced. A third was sequenced into a gap in the arrival stream for the parallel runway. Landing operations were shifted to the parallel runway that was in the middle of a departure push and departures were held. Emergency vehicles are responding and those aircraft taxiing are told to hold their current position.

Within minutes, the surface movement management module has begun to recalculate departure times and off-gate taxi-out times for all aircraft based on reduced throughput and the number of arrivals in the area. A flash message has been sent notifying all elements of automation of the change in acceptance rates at the airport, the time expected to be operating at this new rate set by past experience for runway closures across the nation, and information for network-centric common situational awareness.
Aircraft on TBO arrivals will continue, but those further out on the arrival will be slowed to create gaps so as to handle departures on the same runway. To create these gaps, some trajectories will need path stretching. The departure/arrival TBO management automation module calculates an integrated arrival and departure queue and timing for single-runway operations. The information is provided to the ANSP strategic TBO evaluation service, which begins to re-compute 4DTs for the arrivals and departures. New 4DTs are issued to aircraft on arrivals to change their destination runway.

As the emergency unfolds, aircraft on a hold for taxiing are allowed to continue, and aircraft holding for departure on the inner runway are now advanced to the outer, open runway. Queue length is reduced from this point by holding aircraft that have yet to push back at the gate. A new 4DT takeoff time is calculated for each aircraft by the ANSP strategic TBO evaluation service who has already considered the best mix of single-runway arrivals and departures based on what is in the air and yet to leave the airport. This information is transferred to the ANSP surface movement management module that is managing the departure queues and times off the gates.

The departure/arrival TBO management module now has the surface flows and recommended departure times. It has the new arrival sequence for both the tactical and strategic time horizons, and gaps can be efficiently created to manage departures. After reaching steady state, delays are accumulating to arrivals and departures spread over the duration of the incident that has closed the runway.

On the recovery side, a significant loss of capacity occurs in today's NAS when the runway is re-opened and the ANSP waits for arrivals to show up. Under TBO and net-centric operations, aircraft scheduled to depart and fly to the airport with the closed runway can be released based on their expected travel time and real-time updates on the status of the runway opening. Airlines can be given options to set their preferred sequence of release based on their priorities.

16.3 Loss of GNSS

The loss of positioning, navigation and timing (PNT), either through system failure or interference, becomes a significant complication for TBO. Individual aircraft system failures would be handled through control by exception. However, if every aircraft within a specified were impacted, this could not be handled and still sustain TBO. Since the traffic volume is depending on the TBO automation for separation, and is above the level at which the controller can just step in and manage all aircraft in the airspace, the problem is in transitioning from precision TBO to a TBO with larger separation distances and times. By 2020, the ANSP is increasingly dependent on GNSS for not only navigation, but for surveillance as well. In the absence of an alternative PNT capability, the following impacts would be felt:

- Limitations in RNAV/RNP performance through use of inertial navigation systems and DME/DME that degrade in precision over time (not carried by all aircraft)

- Loss of three-mile separation using ADS-B, since the GNSS is the source of broadcast surveillance, requiring reversion to the equivalent of radar separation
- Loss of functions enabled by TBO, like self separation, paired approaches, and airborne merging and spacing, since aircraft could not "see" each other
- Loss of VCSPR operations
- Loss of low-visibility surface operations between 300 and 1,200 RVR
- Degradation of oceanic and off-shore separation as inertial systems begin to lose precision, requiring procedural measures to begin diverging aircraft and using vertical separation and speed control in the interference area
- Oceanic and off-shore operations by aircraft not carrying an inertial system where dual GNSS without inertial is an accepted equipment installation for oceanic and remote areas (FAA Order 8400.12A and 8400.33)
- Diversity of departure paths dependent on lower RNP values would be reduced to support larger separations
- Some aircraft lose conflict-free 4DT because they lack a source of position and navigation capable of supporting RNAV

The duration and size of the interference area determines the impact of an interference event. The time to replace the signal in space dictates a large-scale system failure impact. As an example, it is reasonable to assume a 300 nm radius area of interference in oceanic airspace (the point source may be a ship on the surface)[22]. Flying through the widest part of the interference would take approximately 100 minutes before GNSS coverage would be restored. In that same 100 minutes, the inertial reference unit will have lost 13 nm of precision.[23] If the aircraft takes its output for ADS-B from the navigation bus, then other aircraft that had ADS-B In would still be able to see the aircraft. However, if GNSS were the only source of ADS-B, the aircraft would now only be seen on TCAS. Likewise, the worst case is for those aircraft flying with dual GNSS receivers and no inertial that would now be without navigation signals and have to rely on dead reckoning, especially in airspace that has no surveillance coverage from radar.

Within TBO airspace, quick identification by the ANSP of the extent of the interference area by mapping ADS-B position reports (there before, not there now) will provide a plot that can then be used to re-route traffic. Once mapped, the area becomes the equivalent of a weather event and aircraft are handled accordingly to route around the interference. Those that are trapped in the interference are now dependent on a backup. Most air carrier aircraft will still have DME-DME updates supporting the FMS, and will continue under TBO with some separation changes needed. Those aircraft not able to derive their own position will require vectoring until clear of the interference area. While this approach will work in the case of interference, it is of little use with a system failure of GNSS itself, where the coverage area could be quite large.

A likely scenario for disruption of flight operations is a localized intermittent, mobile interference source. The scenario is based on the greatest possible disruption in a major metropolitan area, and

[22] 300 nm diameter distance is used here based on DOD point interference experience for testing interference.

[23] AC 90-100A U.S. Terminal and En Route Area Navigation (RNAV) Operations specifies no greater than two nm/15 minute interval of no update to the IRU.

relies on disruption of operations to gain publicity. Most air carrier and large business aircraft could continue to dispatch using inertial navigation and flying out of the interference area. No very-light jets and smaller business aircraft carry inertial systems and would be dependent on a VFR departure only. Most arrivals would continue, but the question is whether or not the vectoring workload would be too great. Today, radar vectors manage the majority of arriving traffic at a major airport. In 2025, traffic densities would nearly double, making radar vectors a fallback in the absence of any other alternative PNT questionable because of controller workload. It is likely that demand would need to be cut back to approximately half for air traffic controllers to handle a busy airport. The continuing intermittent disruption of PNT raises the need to identify the maximum traffic density that could be handled by radar vectors as a backup to GNSS and whether there is an alternative PNT strategy that could continue to support TBO in the presence of GNSS interference or system failure.

16.4 Security Incident

An aircraft is deviating from its 4DT and not responding to communications. Alerts from conformance monitoring have already sounded and the aircraft is being tracked with ADS-B, secondary, and primary radar. Its destination and intentions are a mystery for the Department of Defense (DOD) and the Department of Homeland Security (DHS). The ANSP's job is to clear out airspace by modifying the 4DTs of other aircraft. Some of this will be through the use of closed trajectories; others will be open trajectory vectoring as control by exception. The situation is quite fluid, but simulations and drills have established the boundaries of a new flight corridor for our deviating aircraft. As its flight track changes, a buffer is established that will be treated by the ANSP TBO evaluation service and distributed through network-centric operations.

While the concept of clearing the airspace is likely, the threat scenarios are highly variable. This aircraft could have been in en route cruise, or could have just taken off. Time and location of detection of the deviation plays a central role in the ANSP-required actions. What TBO brings to the table is the continuous nature of conformance monitoring. Parameters can be built into the conformance monitoring module to detect more than just a deviation from flight track. Speed changes, altitude deviations, missed turn points, and erratic changes within the boundary of RNP performance can all be detected and used as an early indicator of problems.

Time is lost in assuming that the aircraft has some other reason for deviating. By setting performance parameters on conformance and linking this action to net-centric operations, common situational awareness allows for earlier detection of rogue action.

AOCs are alerted to the event and the nature of incident. The AOC can verify intent and provide necessary information to DHS and DOD. The ANSP's TBO evaluation service begins to build a moving temporary flight restriction (TFR) around the deviating aircraft against criteria that are pre-established and based on speed and altitude.

16.5 Regulating Demand

Off-nominal operations require balancing demand with the capacity for conditions. The challenge is to regulate demand only to the extent that it is needed to manage the throughput. A significant increase in capacity (less demand constraint) will be realized just by shared situational awareness and the use of network-centric operations to exchange information and strategically manage an event. This transparency of actions helps to make control measures more realistic for the situation and removes restrictions on demand earlier as conditions improve. What TBO does is provide the choices in strategically managing demand.

The NextGen ConOps, built on TBO, requires automation to manage separation, spacing, sequencing, and related relationships between aircraft. By 2025, the traffic volume will exceed what ATC can safely manage by stepping in and assuming responsibility for separation for all aircraft. The basis of control by exception is built on a few, not all. The expectation is that the controller will only need to handle a small sub-set of the population of flights, not every aircraft. This means that TBO must remain functional during off-nominal operations, both for strategic and tactical situations. As such, the amount of demand that must be regulated is less than would be required in today's NAS. Throttling back demand is more surgical, impacting only those flights needed to sustain a pre-defined throughput. This says that TBO must have a learning component that can set this pre-defined throughput based on the demand, capacity, and the off-nominal condition. By continually refining the mitigation choices, the NextGen system learns from prior experiences.

TBO choices first appear in options for flight planning. Flow contingencies are developed and shared. Users of the airspace also offer their priorities that can be mapped to the options. "What if" scenarios can be run for expected off nominal events. Once airborne, the choices are limited to what the aircraft is capable of doing, based on information contained in the flight object. The ANSP TBO evaluation service should not return choices that the aircraft cannot perform. When the controller receives options for dealing with off-nominal situations, the controller needs the ability to tailor the query. Likewise, the ANSP TBO evaluation service must be able to produce the plan used in shared situational awareness. The plan must be tailored with the amount of time to go before the event actually happens. An early version of the plan is available for flight planning. More refined versions emerge as more information becomes available.

This plan must be scored against a common set of metrics. Post analysis tells how well the plan worked, what the delay impact was, and where the delays were taken. It is the open, transparent nature of post analysis that refines the ANSP TBO evaluation process—separating aircraft from each other and the off-nominal conditions based on where the aircraft will be at a time in the future.

17.0 Summary of Automation Interactions

The TBO automation is a complex set of tools that support flight planning and execution. Throughout this report, many current and planned automation elements have been mentioned. However, there is clearly a lack of integration of functions or information. Therefore, this summary provides automation functions that follow a flight from a higher level of function. This summary would be a starting point for developing a functional decomposition and the necessary linkages to domains of flight operations.

TBO is integral to flight planning and execution. NextGen is expected to link the ANSP and the operators together with unprecedented connectivity through network-enabled operations, delivering and exchanging information in near- to real-time. For TBO, this exchange includes the flight plan and the flight object that carries the necessary 4DT information required by automation. It is likely that only changes would be sent to and from the aircraft as part of data link communications. The elements of this information exchange are designed to provide common situational awareness, knowledge of preferences for the flight, position information, and intent. Under TBO, aircraft are managed, separated, sequenced, merged, and spaced by their future position (intent) and monitored by their current location (position). Separation requirements are met by a combination of intent and current position. Progress along a flight track considers lateral, longitudinal, vertical, and time progression along an agreed-upon path and is monitored for conformance.

The common element for use in automation is the flight object. The flight object is a file of information passed from one automation application to another and represents the flight plan, user preferences, user aircraft performance, user aircraft capabilities (equipage, crew qualifications), positioning information, intent, and other information as needed to seamlessly move needed information between applications. The TBO Study Team is recommending work to lay out the structure and content of the flight object early in development of TBO.

The flight object also contains the 4DT information needed in the cockpit. It represents the negotiated agreement between the aircraft operator and the ANSP relating to execution of the flight. Likewise, changes from either the aircraft or the ground automation or controller instructions result in modification of the flight object. The flight object on the aircraft and the flight object within automation on the ground must be synchronized so that 4DTs can be safely and efficiently executed. Both the aircraft operator and the ANSP must be executing the same plan to realize benefits from TBO.

It is this synchrony that forms the basis for safe separation, supports security, and makes it possible to use automation in separation to increase capacity, gain efficiencies, and make environmental improvements. Separation becomes much more strategic, looking ahead to eliminate potential conflicts. The flight object, when synchronized, forms a contract between the ground and the air for execution of flight. It is the essence of the operational concept for conformance monitoring, alerting, and control by exception when a 4DT contract cannot be met or must be modified.

17.1 Strategic Resource Planning

TBO starts well before any flight. There is a strategic horizon (months, weeks, days in advance) that helps the ANSP, operators, and airports plan for the future and allocate staffing and other resources against workload and demand. While the flight object is not used, information on scheduling, fleet changes, route changes, requirements for airspace, airport changes, etc. are submitted to the ANSP for trial planning purposes. The ANSP can evaluate flight day system performance to determine what worked and what didn't, as well as identify opportunities for improvements (e.g., staffing, resources, demand management programs, etc.). This set of automation tools is focused on planning for a future, well before receipt of flight objects for any given day or time segment of that day.

Applications within the automation identify trends, expected shifts in demand, past performance, and longer-term constraints that may impact flows. Strategic resource planning outputs become available for trial planning for a flight or group of flights. Not all information is available to all users. Proprietary competitive information is protected by the ANSP. An example of proprietary information may be a future airline schedule to start service or expand services at an airport.

OI-0406 NAS Wide Sector Demand Prediction and Resource Planning
OI-0305 Continuous Flight Day Evaluation

17.2 Trial Planning and Optimization

Through continuous flight day evaluations, NAS status information, expected actions relating to weather, known or planned flow contingencies, dynamic special use airspace, and other information, the ANSP has assembled a set of information that is essential to flight planning: the ability to evaluate options well before negotiating a flight plan. Trial planning allows the pilot/operator to make planning decisions based on a common knowledge of forecasted NextGen performance, constraints, preferred flows and availability of airspace, airports, and services. The planning horizon is typically a weekly, next day of flight, and day of flight activity. Airlines would typically plan for next day and day of flight. General aviation would likely use the weekly, next day, and day of flight capability.

Trial planning may be a commercial capability or it may be provided by the ANSP. Trial planning may have value-added features that use ANSP-aggregated information. It is a subset of a flight planning capability that leads to a flight plan. Dispatch functions may have additional tools for flight planning, but the output of trial planning and optimization is a set of 4DT options to choose from that have passed an initial screening based on shared common information.

For general aviation, this application (likely Web-based) would accept an origin, destination, desired departure or landing time, pre-defined or modified user preferences, pre-defined or modified aircraft performance parameters, etc. Trial planning returns multiple flight objects to choose from, ranked in a user-defined order like most direct, lowest fuel, lowest flight time, greatest probability of acceptance, lowest weather risk, most comfortable ride, etc. The options can be stored and used later for pre-negotiation and negotiation of a 4DT.

An airline dispatch function may elect to use the ANSP-assembled set of information within the company's own automated planning toolsets. The airline could evaluate multiple legs of an aircraft or group of aircraft and optimize their schedules. The airline uses trial planning to review impacts of flow contingencies that are known in advance of the flight day.

Military operators can review expected demand and commercial constraints, and minimize their impact on civil operations when scheduling dynamic SUA. Minor adjustments in ETAs near dynamic SUA by civil users can result in access, and likewise, adjustments by the military in scheduling use of the airspace can provide the necessary safety and access opportunities. By using trial planning, common situational awareness exists in the planning horizon, where small adjustments can make a significant difference in access.

Built into trial planning are equipage and automation requirements for the airspace or the procedure. This may include where a GNSS backup capability is required, RNP values, requirements for data link, minimum climb performance, RTP, etc. This will be an important aspect for dynamic airspace, where performance requirements in that airspace have a temporal constraint. What is returned in trial planning is a good filter on initial choices that reduces downstream constraints. This information can be dynamic and have different constraints at different times.

OI-0360 Automation-Assisted Trajectory Negotiation and Conflict Resolution
OI-0306 Provide Interactive Flight Planning from Anywhere
OI-0346 Improved Management of Airspace for Special Use

OI-0366 Dynamic Airspace Performance Designation
OI-0382 Strategic User Requests
OI-0406 NAS Wide Sector Demand Prediction and Resource Planning
OI-2021 Net-Enabled Common Weather Information - Level 2 Adaptive Control/Enhanced Forecast

17.3 Pre-flight Planning

This is the phase where the flight object is built for negotiation with the ANSP. During pre-negotiation, next-day or same-day information is available in multiple planning horizons (time-based information is available). In pre-negotiation, the objective is to compare user preferences to constraints, flow contingencies, airspace changes, etc., to generate 4DT choices. These choices become the basis of building the flight object that now contains the flight plan, preferences, aircraft performance, constraints to the business trajectory, and a rank ordering of these choices.

This automation can be either ANSP provided or commercially provided. The output is a set of flight objects acceptable to the pilot/operator for each flight segment that can be submitted to the ANSP for negotiation.

OI-0306 Provide Interactive Flight Planning from Anywhere
OI-0346 Improved Management of Airspace for Special Use
OI-0360 Automation-Assisted Trajectory Negotiation and Conflict Resolution OI-0366 Dynamic Airspace Performance Designation
OI-0382 Strategic User Requests
OI-0406 NAS Wide Sector Demand Prediction and Resource Planning
OI-0408 Provide Full Flight Plan Constraint Evaluation with Feedback
OI-2021 Net-Enabled Common Weather Information - Level 2 Adaptive Control/Enhanced Forecast

17.4 ANSP Strategic TBO Evaluation

Once choices are submitted to the ANSP, each choice must be compared to all other choices for flights and constraints the ANSP has identified. The ANSP must first examine downstream conflicts, where one or more choices overlap with each other, where merges would be difficult, or where demand exceeds capacity. Choices are in priority for the individual flight and in priority for a group of flights from a specific airline. Priorities are set up by the airline for that day’s operations and aspects of each operation. The ANSP is looking for a clear path amongst the choices submitted. In absence of a clear path, recommendations come back to the pilot/operator as to the constraints and alternatives.

In the comparison of priorities within an airline for multiple aircraft, the first priority aircraft would be expected to get its first choice. When there is a conflict with another airline’s first priority, the ANSP applies an equity algorithm to distribute selections against multiple sets of priorities.

Priorities can change as the day progresses, so there is always a need for multiple evaluations as the day progresses, but once the aircraft pushes back, fuel loading precludes wholesale changes between desired business trajectories.

At this point in the evaluation the ANSP has weather forecasts, taxi-out and taxi-in times from previous days of flight for selected large airports. Additionally, it uses winds aloft and aircraft climb and descent preferences to model each individual flight and multiple choices for that flight. Conflicts are identified and the evaluation application suggests alternatives. This may be the selection of a choice provided by the pilot/operator or a recommendation for a change in the 4DT. If the conflict can be removed by offering one of the pilot/operator's choices within a flight object, this choice is provided by the ANSP. If there is a need for a modification, alternatives are provided so that the pilot/operator can make the choice. Once the choice is made, that flight object becomes the starting 4DT contract. If an alternative is provided that cannot be accepted by the pilot/operator, then it is up to the pilot/operator to provide additional options for evaluation. In every case where alternatives are provided by the ANSP, these alternatives carry the rationale for the recommended changes so that the pilot/operator knows what is needed to reach a successful, executable flight object.

Once accepted by the pilot/operator, the negotiated flight object becomes the basis for agreement between the pilot/operator and the ANSP. This is now the "contract" that all other automated tools work toward, whether these tools be on the flight deck or in ground automation. The agreed-upon flight object now contains the information necessary for conformance monitoring and keeping the airborne and ground automation in sync.

The ANSP strategic evaluation system is centrally managed with distributed access. Only authorized data stewards have the authority to provide changes, and access is controlled. Other ANSP automation pulls trajectories from the strategic evaluation service for local use, and trajectories are available through network-centric operations on an approved access basis. Whenever and wherever there is a need for a trajectory update, the strategic evaluation system provides the analysis, alternatives, and choices that lead to an agreed-upon trajectory.

OI-0360 Automation-Assisted Trajectory Negotiation and Conflict Resolution
OI-0306 Provide Interactive Flight Planning from Anywhere
OI-0346 Improved Management of Airspace for Special Use
OI-0366 Dynamic Airspace Performance Designation
OI-0382 Strategic User Requests
OI-0406 NAS Wide Sector Demand Prediction and Resource Planning
OI-0408 Provide Full Flight Plan Constraint Evaluation with Feedback
OI-2021 Net-Enabled Common Weather Information - Level 2 Adaptive Control/Enhanced Forecast

17.5 Ramp Control

Ramp control automation contains commercial applications for the management of preparing the aircraft for flight and handling arrivals. It is the next stop for the flight object. Takeoff gross weight is an important piece in the flight object, calculated from the fuel load, passengers, baggage and freight. The dispatcher provides this information for the airlines. For GA, the pilot will have already figured takeoff gross weight and it will be contained in the negotiated flight object. The addition of takeoff gross weight is important because it will be used by the ANSP to calculate a representative climb performance to be used for vertical separation along the climb path.

Since the airline, ramp control, and the ANSP want to make a pre-determined takeoff time, ramp control automation has historical information on taxi-out times, and uses this to calculate a pushback time that will be part of the flight object. Any delays—loading, maintenance, deicing, etc.—to the takeoff time are added to the flight object and passed to the ANSP's strategic evaluation service, and the surface movement automation is also updated through the flight object change passed from the strategic evaluation service.

OI-5006 Coordinated Ramp Operations Management
OI-5008 Advanced Weather Capability for Airside Facilities
OI-5009 Improved Tactical Management of Airport Operations
OI-0406 NAS Wide Sector Demand Prediction and Resource Planning
OI-0408 Provide Full Flight Plan Constraint Evaluation with Feedback

17.6 FBO Flight Management

At many airports that do not have a control tower, there is a FBO that generally provides services for aircraft. These services include fueling, access to flight plan filing, aircraft maintenance and handling, and similar support. The FBO is linked to the ANSP through network-centric operations, and can provide connectivity as a value-added service to pilots, whether in the FBO's facility or out on the ramp. The pilot can connect either by cellular phone technology or WiMAX covering the ramp area. FBO flight management can provide many of the same capabilities as ramp control, allowing the pilot to connect with changes to their trajectory that then flows to the ANSP's strategic evaluation capabilities. Delays can be noted, takeoff times updated, and ETAs changed.

OI-0306 Provide Interactive Flight Planning from Anywhere
OI-5006 Coordinated Ramp Operations Management
OI-5009 Improved Tactical Management of Airport Operations
OI-0406 NAS Wide Sector Demand Prediction and Resource Planning
OI-0408 Provide Full Flight Plan Constraint Evaluation with Feedback

17.7 ANSP Surface Movement Management

Surface movement management is the automation that moves the aircraft from the gate or ramp space to takeoff within the context of a 3DT (vertical component is not used since all aircraft are on the surface for this segment of TBO). The surface management function's purpose is to gain efficiencies in surface movement and deliver aircraft in the right sequence as close to their planned 4DT takeoff time as is possible.

Surface movement management is a learning system. Using surveillance from multilateration and ultimately ADS-B, it remembers throughput, from gate to takeoff and from touchdown to the gate. It can calculate a nominal taxi time that considers gate, airline, aircraft, time of day, weather conditions, and other airport operational parameters that affect time (e.g., passing through deicing). The system learns queue length, throughput, and travel times for combinations of taxi routes that may be assigned to the aircraft from its gate or runway exit positions. This accumulated information is used to modify the takeoff times based on expected taxi times for all aircraft.

Surface movement management includes the following functions:

- Departures are sequenced and staged to maintain throughput
- Lists, by departure and arrival runways, are maintained, and delays tabulated for departure and arrival flows
- Integrated information about weather, departure queues, aircraft flight plan information, runway configurations, expected departure times, gate assignments, and flow information shared with ramp control and airport operations
- Transmission of automated terminal information, departure clearances and amendments, taxi route instructions (including hold-short restrictions for runway crossings) and leads to data link and graphical transmission of taxi routes
- Conformance monitoring is provided while taxiing, continuously comparing the route clearance with surveillance information and alerting to non-conformance
- Predict demand and plan/manage surface movement and arrival/departure flows
- Updates the estimated departure clearance times to renegotiate the 4DT
- Factors in airport operational conditions such as snow removal, aircraft deicing, changes in runway configuration, and effective capacity for the landing and takeoff direction
- Factors in wake vortex separation for both departures and arrivals in managing takeoffs
- Identifies slot opportunities for arrivals when the takeoff sequence has holes
- Integrates advanced arrival and departure flow management functions to allow ANSP flow managers to work collaboratively with flight operators to manage high demand situations that consider various weather and airport conditions
- Integrates information from other metroplex airports for time-based departures based on efficient merging and spacing in complex airspace
- Surface movement automation performs runway safety functions supported by surveillance that enables limited simultaneous runway occupancy for landing aircraft, defining the safe distance by review of prior aircraft performance for wet, dry, day and night conditions
- Integrates surface movement information to improve controller situational awareness
- Provides a limited capability for surface management at secondary, non-towered airports based on ADS-B use on the surface
- Provides dynamic, pair-wise longitudinal and vertical information for wake turbulence separation by sequencing aircraft for takeoff
- Supports low-visibility takeoff and landing operations for appropriately equipped aircraft
- Provides a reduced set of functions for remotely staffed tower services and automated virtual towers to sustain the start of a TBO for takeoff and terminate a TBO with landing
- Information shared from surface movement management, including archived information, is available for improved strategic management of airside airport infrastructure
- Supports surface movement green operations, limiting noise and emissions, and gaining taxi-out efficiencies to reduce the environmental footprint of the airport

Throughout surface operations, TBO surface movement automation is working to update the 3DT and provide to the ANSP strategic evaluation service the necessary updates that coincide with a narrow takeoff window for the aircraft. Aircraft that must merge with planned overhead traffic have the tightest window of time. Those departures going to a secondary airport have time measured as an ETA, and do not require tight control. Once the departure sequence is set, progress in terms of time is being continuously monitored with the aid of surveillance. If an aircraft is going to be delayed, the first test is to determine if a new 4DT is required. If so, the strategic evaluation system provides that update. This may require a modification of the taxi route to add time or change the departure sequence. Inserting a new 4DT for one aircraft shall not impact the schedule of other aircraft unless they are trapped in a queue with no ability to move around the aircraft that needs a new 4DT.

If the flight object does not contain the takeoff gross weight for the aircraft during taxi-out or the landing gate/ramp designation for landing aircraft, the departure/arrival services automation is notified, since the vertical climb profile is predicated on knowing the takeoff gross weight to calculate a climb gradient that can be used to protect airspace for the climb. Through network-centric operations, the dispatch function is notified and requested to provide the update to the flight object.

At liftoff on the takeoff roll, the surface movement management function posts the takeoff time to the departure/arrival services and to the ANSP TBO strategic evaluation service. This actual takeoff time becomes the basis for the start of the 4DT TBO. Other authorized users of takeoff time can receive the information through network-centric operations.

OI-0320 Initial Surface Traffic Management
OI-0321 Enhanced Surface Traffic Operations
OI-0327 Full Surface Traffic Management with Conformance Monitoring
OI-0331 Improved Management of Arrival/Surface/Departure Flow Operations
OI-0339 Integrated Arrival/Departure and Surface Traffic Management for Metroplex
OI-0340 Provide Surface Situation to Pilots, Service Providers and Vehicle Operators for Near-Zero-Visibility Surface Operations
OI-0341 Limited Simultaneous Runway Occupancy
OI-0370 Trajectory-Based Management - Gate-To-Gate
OI-0383 Improved Runway Safety Situational Awareness for Controllers
OI-0386 Expanded Radar-like Services to Secondary Airports
OI-0387 Dynamic, Pair-wise Wake Turbulence Separation
OI-0409 Remotely Staffed Tower Services
OI-0410 Automated Virtual Towers
OI-5002 Improved Strategic Management of Existing Infrastructure (Airside)
OI-5010 Advanced Winter Weather Operations - Level 1
OI-5110 Advanced Winter Weather Operations - Level 2
OI-6021 Environmentally and Energy Favorable Terminal Operations - Level 2

17.8 Departure/Arrival TBO Automation

We will revisit most of this automation function when arrivals are covered. Arrival information is provided to surface movement, and surface movement feeds the departure portion for departure functions. For now, this discussion focuses on the segment from takeoff to initial level off at cruise.

Departure TBO automation has access to all 4DTs for known flights in the dynamically assigned airspace. The volume of airspace for departures can be different than the airspace for arrivals. In addition to the 4DT information from the ANSP strategic evaluation service and information from all surface movement management capabilities, there is surveillance information that is fused from ADS-B, multilateration, secondary, and primary radar. Any aircraft with a flight plan, whether under IFR or

VFR operations, are tracked. In addition, all pop-up targets from primary radar that do not have correlated surveillance information are called out. These may be VFR sport aircraft or other unknown users of the airspace. Since automation is providing the separation assurance and conformance monitoring, the departure TBO automation must deal with all detected aircraft to assure separation, as well as project forward for conflicts downstream, based on the provided future position from intent information delivered by data link from the aircraft.

The greatest variable in 4DT for the climb portion is the vertical dimension. Aircraft position uncertainty over time is governed by the aircraft's gross weight at takeoff, the consistency of the climb gradient, and the winds. The goal is to avoid intermediate level offs during climb. Automation calculates climb performance from the aircraft's performance charts and takeoff gross weight, and then applies surveillance information from previous climbing aircraft to estimate the wind corrections. Another option is for the flight object to provide the vertical climb rate in feet per nautical mile, but again having the automation compensate for the winds based on observation of all climbing aircraft.

At takeoff, the floor of the vertical dimension is set at the engine-out climb performance, and the ceiling is set at any cross-below altitude restrictions. As the aircraft is cleaned up, the calculated climb performance narrows vertical uncertainty, and information from surveillance and data linked intent information compares the calculated performance with the actual performance and makes adjustments.

Once the aircraft is cleaned up and stabilized on the climb, there is no better source for climb information than the aircraft itself. The aircraft will send an intent message that updates the climb profile that can then be used to further narrow this window of uncertainty in the vertical dimension.

Downstream tracking and time are monitored as the climb progresses and the automation calculates how well the aircraft is performing with time. Longitudinal separation from other aircraft is time-based.

Lateral variability is controlled by procedures that favor RNAV and RNAV/RNP to realize necessary capacity. At super-density and metroplex airports multiple paths are defined based on RNP 0.3 during the initial climb, and as aircraft begin to fan out and turn on course, RNP 1.0 precision is used. This can shift to RNP 2.0 in less dense airspace.

The calculated and observed variability become the basis of setting the conformance monitoring parameters in the automation. The tightness of the horn of uncertainty that projects forward from the aircraft is dependent on a combination of aircraft performance and traffic density. An aircraft climbing to join an overhead stream of traffic would have a tighter conformance monitoring than one who is traveling toward a secondary airport at an altitude that has no other traffic. The purpose of conformance monitoring is to assist in meeting the 4DT "contract," and alerting the air traffic controller and pilot when projected conformance falls outside the 4DT requirements.

This continual monitoring for conformance is being accomplished for every other aircraft in the airspace. Under 4DT, it is the current and future separation that is being controlled, with intent being the future element of separation. Aircraft that are climbing may require limits on the floor and ceiling of their vertical profiles. This is not unlike what happens on arrivals. Crossing altitudes must still be met. However, now the crossing altitude restrictions are based on actual and projected 4DT traffic flows, not the design of the airspace, and takes into consideration planned aircraft performance.

As aircraft continue their climb, the 4DT is the method of determining merging and spacing with other aircraft. The departure automation has a module designed to support merging and spacing, with requisite controller tools for establishing the merge, setting the spacing, and establishing the separation. The approach for the merging and spacing is similar to the methods available on some aircraft. Those aircraft that are equipped can do their own merging and spacing, or the ANSP can use the departure automation to set up the maneuvers through updates to the 4DT.

No distinction is made here as to terminal and en route automation functions. The objective is to have the automation deliver the aircraft to the cruise phase of flight. With transfer of control from one ANSP element to another, the same automation functions exist and from the flight perspective, transition to another control element of the ANSP is transparent, including the communications between air and ground.

In the case where the aircraft is not meeting its 4DT performance, the departure automation can request trial planning from the ANSP strategic TBO evaluation system and receive back options that the strategic or tactical controller can consider. Typically, options would include giving a momentary level off, changing the position in space the aircraft is heading to, or recommending modified multiple aircraft trajectories. If an option is selected, the 4DT is automatically updated for conformance monitoring and sent to the aircraft. Options may also be provided to the pilot as a negotiated change. Where time allows this type of transaction, either by the controller or the pilot selecting from options, the closed trajectory is preserved because the 4DT is changed.

The other off-nominal condition is where the conformance monitoring function of the departure TBO automation alerts, and a more tactical measure must be taken, as in giving a level-off clearance or providing a vector for separation. This places the aircraft on an open trajectory that now must be closed through the selection of options generated by the ANSP TBO evaluation system. The controller has the ability to open up or narrow the conformance parameters for future monitor alerting. For example, if there is a need to use an altitude level-off, the controller can set the altitude value on the conformance monitor.

The departure automation functions include:

- A capability for scheduling and staging arrivals and departures based on airport demand, aircraft capabilities, and gate assignments. This information is handed off to surface movement automation to provide a seamless transition in automation functionality
- Supporting GA access to traverse terminal airspace, including both IFR and VFR traffic
- Supporting requests for IFR handling from aircraft departing surrounding GA airports
- Providing time-based metering into en route traffic streams and flight corridors
- Using time-based metering tools for assigning RNAV and RNAV/RNP routes
- 4DT arrival and departure tools for scheduling the flow of traffic at high-density airports, which includes information on TMIs, current conditions, airport configuration, gate assignments, and aircraft wake characteristics for departure and arrival, and flight performance by aircraft

- Merging and spacing tools
- Variable separation standards support that is both time and distance-based and supports less than three-miles separation
- Provides wake turbulence separation
- A subset of departure TBO automation provides similar capabilities for remotely staffed tower services
- Integrates departure weather information into decision making for management of departure paths
- Supports optimized climb performance by aircraft type and takeoff weight to meet environmental objectives and deliver fuel efficiency through use of OPCs (similar to OPDs)

OI-0307 Integrated Arrival/Departure Airspace Management
OI-0310 Improved GA Access to Traverse Terminal Areas
OI-0319 Time-Based Metering into En Route Streams
OI-0331 Improved Management of Arrival/Surface/Departure Flow Operations
OI-0338 Efficient Metroplex Merging and Spacing
OI-0339 Integrated Arrival/Departure and Surface Traffic Management for Metroplex
OI-0348 Reduce Separation - High-Density Terminal, Less Than 3-miles
OI-0351 Flexible Airspace Management
OI-0370 Trajectory-Based Management - Gate-To-Gate
OI-0387 Dynamic, Pair-wise Wake Turbulence Separation
OI-0400 Wake Turbulence Mitigation: Departures - Wind-Based Wake Procedures
OI-0409 Remotely Staffed Tower Services
OI-2023 Initial Integration of Weather Information into NAS Automation and Decision Making
OI-6008 Environmentally and Energy Favorable Terminal Operations - Level 1
OI-6021 Environmentally and Energy Favorable Terminal Operations - Level 2

17.9 En Route TBO Automation

At the initial level-off, or at any position in the airspace, a transition is made to the en route cruise phase. Because the line between departure, en route, and arrival is now set by resource allocation, including dynamic airspace, the automation used in the classical en route operations also has elements of departure and arrival. The en route TBO automation provides the bridge between departures and arrivals, receiving aircraft and scheduling the descent into the arrival phase of flight. En route controllers may select specific modules of functionality, including certain arrival and departure functions.

Many of the same functions used in departure TBO are replicated in en route. Some of these functions can be turned on and turned off depending on the airspace configuration and the need to support airports without terminal services. Likewise, en route modules can be found in terminal TBO automation, supporting tower en route and other low altitude flight processes.

Conformance monitoring for the 4DT supports a much smaller horn of uncertainty,[24] in that most of the variability is now longitudinal in terms of time. Winds aloft will require frequent updates of the 4DT. En route TBO automation will use conformance monitoring, flight object, aircraft position, intent, and similar information from all other aircraft to look for downstream conflicts. It will do so by using the ANSP strategic TBO evaluation services.

When a downstream flow contingency like weather must be considered, trajectories are reworked for aircraft using the airspace, all the way back to the departures and forward to the landings. This reworking is a continuous process that produces options that can be strategic (greater than 20 to 30 minutes in the future) or tactical (within 20 to 30 minutes). Strategic options can be shared with airline operations/dispatch, since there is time to provide options for negotiation. Within the 20 minute horizon, the controller shares options with the flight crew who can select their preferences. Once an option is selected, the en route TBO automation uses this information to update the 4DT and, with new intent information, receives intent verification from the aircraft through data link that the changes on the flight deck have been implemented. The ANSP TBO evaluation service receives information on the selected choice and updates the aircraft's flight object for use in continuous 4DT and flow evaluations. In some cases, the changes must be more tactical—a heading, speed, or altitude change. The aircraft, when given this new clearance, is on an open trajectory. The open trajectory continues until a new point in space and time is defined and the 4DT is updated.

The advantage goes to the equipped aircraft. The more capable the aircraft is, the more likely the desired choices are known to the ANSP, and the easier it is for the ANSP to manage the aircraft. An aircraft that is less equipped and in the airspace will require more work to implement a change in trajectory.

Conformance monitoring parameters include the altitude, lateral displacement, longitudinal flight track, and separation based on time, and time to the next point reported in intent. All monitoring parameters can be adjusted based on traffic density and the need to meet downstream commitments for separation, sequencing, and merging. The parameters are derived from a combination of the performance requirements from the ANSP strategic TBO evaluation services and operator/pilot capabilities and preferences. A business aircraft at FL 450 will have a different set of conformance constraints than an air carrier aircraft at FL280 waiting to merge into an overhead stream at FL320. An aircraft heading to a tightly controlled merge point or metering point may have a very tight time performance, whereas another aircraft may have flexibility in time of many minutes. The parameter tolerances for each aircraft are bounded by the performance capabilities of the aircraft, its crew and the needs of the ANSP.

En route TBO automation supports:

- Considerable merging and sequencing
- Information on gaps in overhead streams to the ANSP strategic TBO evaluation service and to counterpart departure and arrival TBO automation
- Blocks of vertical airspace for military special use and aircraft cruise climb maneuvers

[24] The horn of uncertainty is a 3D representation of windows of reserved airspace in vertical, lateral, and longitudinal axes requiring reservation for the aircraft based on its performance.

In merging and sequencing, the arrivals using OPDs are set up in the cruise segment of flight well before TOD. The sequence is continually refined and exchanged with the arrival TBO automation.

En route TBO automation:

- Supports arrival and departure airspace management integration, with sharing of flight object and intent
- Supports en route access for GA through terminal airspace
- Supports time-based metering into en route traffic streams
- Receives departure-metered flights on RNAV and RNAV/RNP routes
- Supports definition of, and operations within, flow corridors for high-density traffic
- Supports a variety of separation standards, including three miles en route
- Provides ability to request modifications of trajectories and support trajectory negotiation and conflict resolution
- Provides procedures and safety algorithms for delegation of separation to the aircraft
- Manages aircraft access to SUA and provides the military with boundaries and operating times for dynamically created SUA
- Coordinates 4DT information with ANSP TBO evaluation services so that individual 4DT trajectories are synchronized
- Provides tactical and strategic separation management
- Provides wake turbulence separation performance in sequencing, as well as merging and spacing
- Provides the means to meet en route environmental objectives, including supersonic boom management, emissions, fuel efficiency through cruise climb and best cruise speeds, and overflight of environmentally sensitive areas.

OI-0307 Integrated Arrival/Departure Airspace Management
OI-0309 Use Optimized Profile Descent
OI-0310 Improved GA Access to Traverse Terminal Areas
OI-0325 Time-Based Metering Using RNAV and RNP Route Assignments
OI-0337 Flow Corridors - Level 1 Static
OI-0343 Reduced Horizontal Separation Standards, En Route - 3 Miles
OI-0360 Automation-Assisted Trajectory Negotiation and Conflict Resolution
OI-0363 Delegated Separation - Complex Procedures
OI-0365 Advanced Management of Airspace for Special Use
OI-0368 Flow Corridors - Level 2 Dynamic
OI-0369 Automated Negotiation/Separation Management
OI-0370 Trajectory-Based Management - Gate-To-Gate
OI-0387 Dynamic, Pair-wise Wake Turbulence Separation
OI-6005 Environmentally and Energy Favorable En Route Operations - Level 1
OI-6022 Environmentally and Energy Favorable En Route Operations - Level 2

17.10 Arrival/Approach and Landing TBO Automation

This automation replicates all the functions first described for departures, and integrates the exchange of information relating to arrivals to the surface movement TBO automation. The capabilities are highly coupled with en route TBO automation.

The big difference between the arrival/approach and landing TBO automation and en route TBO automation is the number of tools available to manage sequencing, and merging and spacing for OPDs, closely spaced parallel runway operations, wake turbulence spacing, and mixed equipage in the arrival streams. The information exchange between en route TBO automation and arrival/approach and landing TBO automation is essential for setting TOD due to the fact that this sequencing happens well into the cruise phase of flight, and is updated as aircraft get closer to their TOD position and time. There is a limited amount of time that can be gained or lost from TOD to touchdown.[25]

Arrival/approach and landing TBO automation is continuously updating the landing sequence based on the flight object, current position, and intent for all aircraft being handled. The automation also identifies potential gaps in the arrival stream to handle aircraft being vectored that are not capable of TBO operations. Best-equipped aircraft get the benefits of TBO and less equipped aircraft must accept gaps in the arrival streams for high-density airports and metroplex terminal operations. Such gaps are allocated in planning stages and adjusted to account for uncertainty. The automation injects new gaps when needed and, to the extent practical, may delay non-equipped aircraft for which the gap is being created.

Arrival/approach and landing TBO automation uses a combination of published arrival paths that are connected to approaches, metering fixes, dynamic merge points, and variable descent points at TOD to set the landing sequence and merge aircraft. Some aircraft are capable of doing their own merge and many aircraft are capable of sustaining spacing through the use of ADS-B and cockpit display of traffic information.

The arrival/approach and landing TBO automation also has conformance monitoring that relies on the same parameters as used in climb, but with different, lower acceptable variability. To help manage the variability, the arrival/approach and landing TBO automation uses learning capabilities from the tracking and intent of previous flights, then leverages surveillance information to refine winds and compression on arrival. By using surveillance and knowledge of aircraft performance, winds can be estimated and corrections applied. In addition, using archived same day and same hour flight path information, algorithms can apply corrections in near-real time to refine to seconds of performance.

---

[25] This is a rich area of research to identify the timing spread (+/-) for TOD and various other merge or metering points along the path from cruise to touchdown.

The arrival/approach and landing TBO automation functions include:

- The scheduling and staging of arrivals based on airport demand, aircraft capabilities, and gate assignments
- Extending the terminal separation standards farther from the airport(s)
- Supporting the use of OPDs that deliver the aircraft from TOD to the approach
- Spacing guidance based on aircraft weight and winds, along with speed commands, used to maintain the 4DT during the OPD
- Supporting GA access along predefined flight corridors to traverse terminal areas that include conformance monitoring for both IFR and VFR aircraft
- Time-based metering advisories for controllers to manage compression and lost landing opportunities, and related support to reduce uncertainty and increase predictability of sequencing and merging and spacing of operations
- Merging and spacing setup tools for delegation of merging and spacing to the cockpit
- Sequencing and scheduling tools, and 4DT agreements for management of flows, including knowledge and implementation strategies for TMIs, current weather conditions, airport configuration, arriving aircraft gate assignments, wake characteristics, and separation flight performance profiles for the arrival weight
- Support tools for managing merging and spacing to closely spaced parallel runways and converging approaches (includes wake vortex safety requirements)
- Providing the tools for modification of the 4DT for tactical changes
- Providing an interface to the ANSP TBO evaluation services to update arrival/approach and landing TBO automation information on the flight object, trajectories, and intent
- Providing controllers with spacing requirements for limited simultaneous runway occupancy
- Providing the tools necessary to authorize delegated responsibility for horizontal separation (lateral and longitudinal), including entry to and exiting from delegated separation to ANSP-controlled separation
- Supporting merging for pair-wise maneuvering and other delegated separation for complex procedures, especially in transition airspace
- Providing automation-assisted 4DT negotiation and conflict resolution in airspace managed for arrivals and departures
- Providing tools for mitigating wake vortices on arrivals
- Providing a subset of the arrival/approach and landing TBO automation in support of remotely staffed tower services
- Delivering environmental objectives through the use of environmental parameters and archiving environmental benefits

OI-0307 Integrated Arrival/Departure Airspace Management
OI-0309 Use Optimized Profile Descent
OI-0310 Improved GA Access to Traverse Terminal Areas
OI-0318 Arrival Time-Based Metering - Controller Advisories
OI-0325 Time-Based Metering Using RNAV and RNP Route Assignments
OI-0326 Airborne Merging and Spacing - Single Runway
OI-0329 Airborne Merging and Spacing with OPD
OI-0330 Time-Based and Metered Routes with OPD
OI-0331 Improved Management of Arrival/Surface/Departure Flow Operations
OI-0333 Improved Parallel Runway Operations
OI-0334 Independent Converging Approaches in IMC
OI-0335 Closely-Spaced Parallel Runway Operations in IMC
OI-0338 Efficient Metroplex Merging and Spacing
OI-0339 Integrated Arrival/Departure and Surface Traffic Management for Metroplex
OI-0341 Limited Simultaneous Runway Occupancy
OI-0348 Reduce Separation - High-Density Terminal, Less Than 3-miles
OI-0349 Automation Support for Mixed Environments
OI-0355 Delegated Responsibility for Horizontal Separation (Lateral and Longitudinal): Terminal
OI-0356 Delegated Separation - Pair-Wise Maneuvers
OI-0360 Automation-Assisted Trajectory Negotiation and Conflict Resolution
OI-0363 Delegated Separation - Complex Procedures
OI-0370 Trajectory-Based Management - Gate-To-Gate
OI-0386 Expanded Radar-like Services to Secondary Airports
OI-0387 Dynamic, Pair-wise Wake Turbulence Separation
OI-0401 Wake Turbulence Mitigation for Arrivals: CSPRs
OI-0403 Single Runway Arrival Wake Mitigation
OI-0409 Remotely Staffed Tower Services
OI-2020 Net-Enabled Common Weather Information - Level 1 Initial Capability
OI-2021 Net-Enabled Common Weather Information - Level 2 Adaptive Control/Enhanced Forecast
OI-2022 Net-Enabled Common Weather Information - Level 3 Full NextGen
OI-2023 Initial Integration of Weather Information into NAS Automation and Decision Making
OI-2024 Full Integration of Weather Information into NAS Automation and Decision Making
OI-6008 Environmentally and Energy Favorable Terminal Operations - Level 1
OI-6021 Environmentally and Energy Favorable Terminal Operations - Level 2

18.0 Findings and Recommendations

TBO is a cornerstone of the NextGen ConOps. The concept of TBO is based on the following:

- Aircraft will be separated, sequenced, and spaced based on a combination of their current position and future positions where the aircraft is expected at a prescribed time and position in the airspace
- Aircraft will be provided a closed trajectory to the maximum extent possible
- Automation will provide the separation function to handle the traffic volume in the airspace
- Automation will perform conformance monitoring, both in the cockpit and on the ground against a 4DT clearance, continuously monitoring progress and precision toward the future position
- Pilots will fly their contracted and approved 4DT, and failure to meet the performance required will be detected through conformance monitoring and may lead to control by exception, meaning that the controller would intercede and re-route or otherwise change the trajectory to the advantage of aircraft that can meet their 4DT
- Controllers will manage flows, provide choices for changes in 4DT, perform control by exception, and optimize sequencing using automation tools and a combination of voice and data link communications
- TBO starts with flight planning and includes all phases of operations, including surface operations

Central to TBO is the recognition that this is a major operational transformation for aviation, basing safe separation on not only the current aircraft position, but also its future position in time. Further, most of the separation duties will be performed by a combination of airborne and ground-based automation, where ambiguity in intent will not be acceptable. The challenges from a safety perspective are significant, but the benefits to handling an increasing number of aircraft, adding efficiency and capacity, and integrating environmental and security needs are worth the challenge.

The TBO Study Team was asked to add content to the concept of TBO. We have done so using operational scenarios to develop details of how TBO might work. In addition, chronological use cases that describe the exchange of information at each step along the scenario were identified as a first step in defining a basic TBO architecture. TBO will start in a mixed equipage environment and be a full element of NextGen after 2025.

Along the way, our deliberations produced a set of findings and recommendations that require further investigation through research and engineering, development of policies and procedures, and a deep dive into intent and its exchange between the air and the ground. This section contains findings and recommendations for consideration by the JPDO in preparing the transition to TBO by 2025.

18.1 Governance of the Pieces of TBO

For years, the National Aeronautics and Space Administration (NASA), MITRE Corporation's Center for Advanced Aviation System Development (CAASD), and the European research community have been working on pieces of TBO. Manufacturers are offering airborne capabilities for merging and spacing, conflict detection and resolution, tailored arrivals, CDAs, and other flavors of OPDs.

Automated assistance on braking action on landing and new flight planning tools have been recently introduced to save fuel. The aircraft is being transformed faster than the ground elements of TBO.

The FAA is just getting started on using some of the trajectory management concepts called Trajectory Operations (TOps) in order to gain early benefits for those aircraft equipped with newer avionics. When the concepts of TOps and TBO are combined, a logical transformation must be developed that integrates research, defines functional requirements, accomplishes the necessary trade studies allocating requirements to air and ground, and conducts the necessary safety studies. This work leads to operational performance standards for avionics and requirements for ANSP automation.

Recommendation TBO-1

Establish an FAA TBO point of accountability and responsibility that manages budgets, schedules, and transitions, and develops the necessary requirements for the integration of air and ground elements of TBO, including the operational procedures required to manage the transformation from TOps to TBO.

18.2 Avionics – Toward Sameness in Flight Performance

Today's avionics were not built for TBO. Avionics are evolving based on guessing what the requirements will be, but traditionally have been built to consensus minimum performance standards. The manufacturer interprets these standards to create competitive advantage in the market. Different algorithms produce different performance. The objective here is to not stifle innovation in implementation and marketing of new avionics, but to assure that certain common functions are performed the same way across the fleet. Examples include trajectory management of the aircraft, communication exchanges using data link, fly-by and fly-over of points in space, monitoring of performance in navigation, execution of a change in trajectory generating a data link message, how required time of arrival works, and conflict detection and resolution. In addition, there needs to be a common standard for delivery of safety-critical information to the pilot.

Realizing the same flight performance from the avionics automation necessitates a set of requirements tied to the trajectory of the aircraft. This is much different than minimum operational performance requirements that are normally developed by RTCA. This set of requirements must consider the tradeoff between what is accomplished through ground automation and what must be resident on the aircraft.

There can be no ambiguity between the air and the ground relative to the execution of a 4DT if the expectation is that automation is going to be performing the majority of the separation responsibilities. There must be an agreed-upon set of requirements that both avionics manufacturers and ATM automation manufacturers can use in their product development. These same requirements must then be tested as part of approval for both avionics and ground automation. From start to finish, the avionics invention-to-approval cycle is approximately 16 years. Twenty twenty-five is outside that window now, so there is some urgency in defining requirements for TBO.

Recommendation TBO-2

Set a higher level of performance and common algorithms that support TBO requirements for the 4DT. The RTCA Integration and Coordination Council needs to set a new level of "minimum" performance, so that operationally the aircraft provide the same performance in terms of precision and processes for TBO activities.

18.3 TBO Starts with the Business Trajectory

The cornerstone of TBO is that every operator/user defines their trajectory—how they want to fly the mission. The ANSP is either able to accept the choice of the operator/user, or provide constraints to the operator/user and begin a negotiation process to reach agreement. Once agreed to, the expectation is that the operator/user and the ANSP will have a contract for the flight, both sides fulfilling their parts of the mission. When changes are needed, whether in preflight or flight, options will be provided to the operator/user to help the ANSP with flows.

Recommendation TBO-3

Throughout the concept of operations, there needs to be greater emphasis on developing and offering trajectory options and flexibility from the ANSP to the operator/user, whether in flight planning or while in flight. These choices must each be executable, consistent with the aircraft's performance, ANSP capabilities, and the need to separate, sequence, and space with other aircraft.

Recommendation TBO-4

Expand the discussion of the role of automation in managing TBO to emphasize the business trajectory and the role trajectory options and operator/user flexibility play in negotiation and reaching agreement. Conduct research on the balance between aircraft and ground-derived options for executing a 4DT.

18.4 TBO is a Closed-Loop System

Once agreement is reached on a trajectory, a clearance is delivered to the aircraft as a 4DT. The flight crew accepts the clearance and enters the information into onboard automation. In order to close the loop, when executed by the pilot, a message needs to travel back to the ANSP that confirms the action taken and the planned execution that will follow. ANSP automation then compares what was sent as a clearance and what the flight crew is executing. This comparison starts conformance monitoring and represents the closure of the information loop.

Recommendation TBO-5

Define the agreement message that makes up the 4DT clearance and acceptance by the flight crew, and the message layout and performance for confirmation of execution by the aircraft's automation.

Recommendation TBO-6

Messages to and from the aircraft representing changes in the 4DT must have higher integrity than messages used for negotiating such a change. This is because the 4DT changes the flight path of the aircraft. However, because this messaging in support of the 4DT clearance is principally a strategic operation well in advance of execution, the data link need not be an instantaneous communication. The message could be sent multiple times before acknowledgement of receipt. The required communication performance (RCP) needs to be defined for TBO 4DT negotiation and delivery.

Recommendation TBO-7

Negotiation may be supported on different communication links. In a tactical situation, this negotiation will likely be accomplished by voice. In order to close the loop, a change to the 4DT should be sent using a path that allows for automatic loading from data link communications to the FMS, eliminating manual entry of information.

Recommendation TBO-8

The closed-loop approach to TBO is predicated on messaging between air and ground. Information in these messages needs to be defined. The TBO Study Team recommends that the record layout for the flight object and the 4DT transmittal, acknowledgement, input, execution, and transmittal of that execution be defined in terms of information needed for automation, not just a replacement for a voice clearance. The message length, bit content, update cycles, and authentication overhead for security must be defined, so as to properly size the data link. As stated previously, the exchange of information must have the same structure for all aircraft participating in TBO.

18.5 Flight Planning Needs Strengthening in the ConOps

The existing NextGen ConOps needs additional concepts explaining future flight planning activities in NextGen. TBO starts with a desired business trajectory. It may require trial planning that leads to negotiation between the operator/user and the ANSP over system constraints and preferences. The JPDO recognizes that a gap exists and that there is a need to add greater definition of the relationship between flight planning and the ANSP. While research and development will define most of the new concepts in flight planning, a starting point is needed that describes the relationship between the operator/user and the ANSP.

Recommendation TBO-9

Create a new operational improvement and supporting enablers around flight planning activities that leverage network-centric operations and provide the foundation for laying out the exchange of information between the operator/user and the ANSP, negotiation of the trajectory, and the enabling services required to be developed so that TBO can proceed. The following is recommended:

> The airlines can provide improvements to CATM and related processes through improved flight planning systems and communications. The results of these changes can reduce costs to all operators and provide greater efficiency. The key enablers are with operators, aircraft, and the ANSP, including flight-planning systems, data communications, and enhanced weather sensors. Weather forecast tools, combined with enhanced decision support tools, will provide upgrades in aircraft, ANSP and AOC information exchange, access, and throughput. These capabilities provide direct and indirect benefits to all operators with improved overall efficiency. This solution set covers strategic and tactical flow management, with continuous flight-day evaluations including routine and critical interactions with operators, specifically AOC, to mitigate situations when the optimum desired use of capacity cannot be accommodated. CATM solution set reviews current and future capacity, flow, and weather to make capacity adjustments to shift demand to alternate resources—routings, altitudes, times, and/or demand.
>
> Performance analysis, where throughput is constrained, is the basis for strategic user requests and operations resource planning. Continuous real-time flight day evaluations of constraints are provided to ANSP traffic management decision-support tools and users such as the AOC. Flight day evaluation metrics are complementary and consistent with collateral sets of metrics for airspace, airport, and flight operations to meet stakeholder demand while ensuring the highest level of safety, throughput, and regulatory compliance.

With flexible airspace management, ANSP automation supports re-allocation of trajectory information, surveillance, communications, and display information to different positions or different facilities, and working with the AOC allows maximum airspace utilization while maintaining the highest level of safety from gate to gate. These automation enhancements enable increased flexibility to change sector boundaries and airspace volume definitions in accordance with pre-defined configurations.

Future flight planning systems will utilize advancements in communications to make best use of all available routes, fully employing network-centric operations and implementation of tools and capabilities towards a true real-time CATM system. This active collaboration facilitates operators/users in maximizing negotiation and mitigating delays present and future, while still maintaining regulations.

Recommendation TBO-10

A future AOC/FOC Study Team should be formed to add flight-planning and flight following content to the NextGen ConOps.

Recommendation TBO-11

The basis of a flight's performance in TBO is a combination of what the desired trajectory is **and** the aircraft's performance. Information is needed from flight planning on aircraft gross takeoff weight, preferred climb profiles, and any limitations that may affect TBO choices, such as equipment or crew limitations. This information would be contained in the flight object provided with the flight plan and updated at or just after start of taxi for air carriers. The TBO segment of the flight object needs to be defined so that information is available to ground automation in calculating climb-protected airspace for departures and descents for arrivals and in defining executable choices with changes in the 4DT. Ground automation tools are needed for aircraft that lack the ability to calculate climb and descent profiles when not provided in the flight object.

Recommendation TBO-12

While Recommendation TBO-11 sets the initial boundaries for airspace based on flight planning, once the aircraft is airborne it is the most capable source of setting the boundaries for protected airspace. By using intent messages from the aircraft, the ANSP can modify the parameters in conformance monitoring to change the airspace uncertainty boundaries.

18.6 Airline Operations Center/Flight Operations Center (AOC/FOC) Operational Incentives

It is necessary to incentivize airline performance against goals and objectives in NextGen. It is not just about the costs of avionics that must be offset, but behaviors as well. The ANSP can develop rewards for participating effectively in dealing with flow contingencies and constraints. Credit needs to be given for equipage, but credit is also needed for making the supportive decisions from a business perspective. If CATM is to work, the incentives need to be defined and put in place.

Recommendation TBO-13

There needs to be active collaboration for NAS operators/users to maximize negotiated routes and mitigate both present and future delays. Regulatory standards constrain choices and these standards must be maintained through the choices offered for TBO. The TBO Study Team recommends that the following OIs and enablers be linked under the enterprise architecture and designated as AOC/FOC functions to identify the planning and flight-following elements for each OI and enabler. Then a more detailed segment architecture should be conducted.

Near Term – Mid Term:

AOC-001	Communication - Data Link (FANS I)
OI-0352	Automatic Clearance Delivery / Frequency Change
SAFE-002	Weather Avoidance
EN-1231	NextGen Enterprise Network - FAA
OI-2010	Net-Enabled Common Weather information Infrastructure
EN-2020	NextGen 4D Weather Cube Information Level 2
OI-2021	Level I, Net-Enabled Weather
OI-2023	Initial Integration Weather Information NAS Automation and Decision Making
EN-0004/05	4D Flight Plan Automation – ANSP / Operator
OI-0303	Traffic Management Initiatives with Specific Flight Trajectories
OI-0408	Provide Full Flight Plan Constraint Evaluation and Resource Planning
EN-0210	Flexible Routing Flight Plan Automation
OI-0306	Provide Interactive Flight Planning from Anywhere
OI-0382	Strategic User Request
EN-0033	Airspace/Capacity/Flow Management Decision Support Level 1
OI-0331	Improved Management of Arrival/Surface/Departure Flow Operations
EN0214	Flight Data Management Systems
OI-0305	Continuous Flight Day Evaluation
OI-0361	Resource Planning
OI-3004	Improved Operational Processes Using the Safety Management System (SMS)
AOC-002	Communication - Data Link Pre-departure Clearance Revisions (FANS II)
OI-0352	Automatic Clearance Delivery/Frequency Change
AOC-003	Communication - Data Link Clearance Delivery / Freq Changes (FANS II/VDLF)
OI-0339	Integrated Arrival/Departure and Surface Traffic Management for Metroplex
AOC-004	Communication - Data Link NAS Information and Advisory's AOC-ANSP-Aircraft
OI-0406	NAS Wide Sector Demand Prediction and Resource Planning
OI-0349	Automation Support for Mixed Environments

Far Term:

AOC-005	Communication (Data Communications) and Negotiation – among AOC, ANSP and Aircraft
OI-3101	Improved Safety of Operational Decision Making
OI-0350	Flexible Routing
OI-0360	Automation-Assisted Trajectory Negotiation and Conflict Resolution
OI-0385	Full Collaborative Decision Making
OI-0370	Trajectory Base Management Gate to Gate
OI-0327	Surface Management Level 3 Full NextGen
OI-4502	Integrated Flight Risk Management and Risk Mitigation Level 2 Dynamic
AOC-006	Manage Weather Resources
OI-2022	Net Enabled Weather Level 3 Full NextGen
OI-2024	Full Integration in NAS Automation

18.7 Operational Improvements on TBO

Throughout this report, the Study Team has identified applicable OIs that contribute to an integrated application of TBO.

Recommendation TBO-14

These OIs need to be linked together in the Enterprise Architecture showing their interdependencies with supporting TBO. There is no overall operational improvement on TBO that emphasizes the use of 4DT for flight planning, separation, sequencing, and spacing.

Recommendation TBO-15

Collapse OIs such as OI-0369 and OI-0370 into an new umbrella OI that replaces trajectory management with TBO. For OI-0369, rewrite to achieve balance between pre-flight and in-flight planning. Modify OI-0306, Provide Interactive Flight Planning from Anywhere, to include pre-negotiation and negotiation activities for TBO (changes in red text). Use OI-0370 as the umbrella TBO OI.

> (OI-0369) Flight planning activities are accomplished from the flight deck as readily as any location on the ground. Pre-negotiations and negotiations in flight planning are attained through the connectivity provided. Airborne and ground automation provide the capability to exchange flight-planning information and negotiate flight trajectory contracts, 4DT contracts, and amendments in near real-time. The key change is that the ANSP's automation allows the user to enter the flight plan incrementally through network-centric operations and receive feedback on conditions for each segment. Rather than testing full trajectories by submitting and waiting for full route evaluations, the system can test each segment as entered and provide feedback. Through this process, the user will work with the system to quickly reach a flight plan agreement. Any subsequent change, constraint, preference, or intent triggers a full flight plan review with feedback to the filer. The filer can develop preferred trajectories that may include an identified constraint that the automation system maintains in case subsequent changes to conditions will allow its promotion to agreement. Automation thus maintains multiple flight plans for an individual flight and allows the user to set preferences, make choices, and develop flight segments (or the full plan) for use in negotiation and agreement from anywhere, whether in the air or on the ground.

> (OI-0370) All aircraft operating in managed airspace will rely on TBO. The performance requirements are dependent on the density of the airspace. In high-density airspace, aircraft are managed by 4DT in en route climb, cruise, descent, and airport surface phases of flight to dramatically reduce the uncertainty of an aircraft's future flight path in terms of predicted spatial position (latitude, longitude, and altitude) and times along points in its path. Integrating separation assurance and traffic management time constraints such as runway times of arrival and gate times of arrival, this end state of TBO calculates and negotiates 4DTs, allows tactical adjustment of individual aircraft trajectories within a flow, resolves conflicts, and performs conformance monitoring by ANSPs to more efficiently manage complexity, ensure separation assurance, and enhance capacity and throughput of high-density airspace to accommodate increased levels of demand. This

will be enabled by the trajectory exchange through data communications, as well as many new surface automation and 3DT (x, y, and time) operations.

Recommendation TBO-16

Emphasis should be on developing and providing to the operator/user constraints and options that can be accepted and executed. Further, the TBO operational improvements should ensure access to all operator/user classes from AOCs to the single pilot general aviation operator. Many of the OIs as currently written have the ANSP telling the operator/user some action as opposed to giving choices. Under CATM, and in the context of the business trajectory, strategic choices should be presented from the ANSP to the operator/user.

18.8 TBO Provides Opportunities for Improved Climb Performance

TBO can be used to create OPC. What is needed is information on aircraft performance and desired climb rates to gain fuel efficiency and reduce the positional uncertainty in the vertical component of the 4DT. Information would include expected takeoff weight and then use aircraft performance tables to help define climb. If the aircraft calculates its own climb performance, the climb rate is given in the flight object, and the ANSP could issue altitude margins to meet. This is similar to altitude restrictions on arrival and approach, providing the pilot with minimum, maximum, and cross at altitudes. The objective is to eliminate intermediate level offs and set the climb gradient for the best performance for the aircraft.

Recommendation TBO-17

Create an OI on OPC and Tailored Departures. Aircraft reduce fuel consumption on departure through climbing optimally, without intermediate level segments, from takeoff until reaching their initial cruise altitude. Published departure procedures include vertical windows sufficient for aircraft to maintain their preferred vertical profile. These windows represent altitude boundaries at prescribed locations along the flight path. Equipped aircraft may negotiate a Tailored Departure with the ANSP when conditions permit. A Tailored Departure allows an aircraft to depart the airport towards its destination, as well as optimize its vertical profile once it has climbed above any noise or other obstruction restrictions. A Tailored Departure would normally be agreed on with the ANSP prior to departure, and might require data link capability to permit the ANSP to modify the trajectory as needed. A Tailored Departure could follow the published procedure up to some altitude, then be tailored to the individual aircraft's preferred direction once there is airspace available. When entry into a congested en route stream of traffic is the major goal, an OPC or Tailored Departure with timing constraints may be used to enable the aircraft to meet a time window matching a slot in the en route stream.

Recommendation TBO-18

Initiate research to do the following:

Define the detailed concept, analyze environmental and fuel savings benefits, define the level of specificity needed for the trajectory to realize these benefits aircraft performance information needed for ground automation, model expected profiles and compare to actual performance, and develop the automation module needed to approve an OPC for departure.

18.9 TBO Safety

One objective of TBO is to increase safety to meet the increase in traffic, reduction in separation, and greater use of automation to manage the traffic. The safe separation of aircraft from each other and from obstacles is a paramount consideration for NextGen operations, including TBO/4DT. Along with capacity and environmental benefits, NextGen is intended to create an even safer NAS by fundamentally changing the way the safety of the system is managed. NextGen's Safety Management Systems will evolve from today's post-accident data analysis to integrated historical and prognostic evaluations and management of hazard and their potential safety risk to prevent future accidents[26]. As NextGen technologies and procedures are developed, safety risk assessments are performed at every step in the planning and implementation process. Safe implementation and operation of TBO/4DT may require enhanced FAA capabilities for safety risk management and safety assurance, where safety assurance, as the regulatory authority, would continuously measure and assess the effectiveness of stakeholder safety management systems through joint audits and trend analysis[27]. To support development of these enhanced capabilities, the FAA is revising pre-implementation safety assessment requirements and has published a preliminary safety roadmap as part of its Enterprise Architecture, detailing ongoing FAA activities in the areas of SMS implementation and Aviation Safety Information Analysis and Sharing (ASIAS).

OI-3102[28] supports the safe evolution to NextGen by providing enhanced safety assessment and assurance methods for airborne and ground systems, as well as procedures. Advanced, integrated, and predictive safety assessment capabilities will accelerate the detection of previously unrecognized safety risks and thus contribute to safer operational practices. Improved Verification and Validation (V&V) processes will ensure that systems are certified to be reliable enough to perform automated operations, including recovery from critical failures without compromising safe operations. Advanced training concepts will help maintain proficiency for humans to safely conduct operation in instances when automation degrades or fails. A suite of tools that extracts relevant knowledge from data sources throughout the NAS will enable the FAA and aviation community partners to monitor the effectiveness of the enhancements to the NAS. These enhancements to the NAS will ensure that the operational capabilities that increase capacity, efficiency, and environmental benefits do not introduce additional risks to the system, and that safety issues are properly identified and managed. Ultimately, improved system-wide risk identification, integrated risk analysis and modeling, analytical processes that link together existing databases, shared expert knowledge, results of research, and experimentation and modeling capabilities will continually assess the safety performance of the NAS. The end result will ensure an increase in safety to match the increase in traffic, reduction in separation, and greater use of automation for NAS operations, benefiting all stakeholders and the traveling public.

TBO is a significant change in operations that affects the trajectory of aircraft and introduces a new way of separating aircraft based on their future position against a contracted flight path at a future time. There will be significant policy issues relating to implementation that require disciplined safety analysis. Some of the key safety issues include:

---

[26] Joint Planning and Development Office Concept of Operations for the Next Generation Air Transportation System, v 2.0, 13 June 2007, Chapter 9, section 8-1.
[27] Joint Planning and Development Office Concept of Operations for the Next Generation Air Transportation System, v 2.0, 13 June 2007, Chapter 9, table 8-4.
[28] JPE IWP FY12 Operational Improvement

- Certification of ANSP automation hardware and software to accomplish separation responsibilities
- Aircraft automation performance to meet the contracted 4DT
- Conformance monitoring system requirements and performance
- Use of TBO for very closely spaced parallel runways
- Use of TBO in self-separation
- Safety certification of the messaging that delivers and confirms execution of the 4DT
- Role of the controller in control by exception
- TBO under off-nominal conditions

Recommendation TBO-19
The policy of having aircraft separated by automation instead of controllers as a matter of routine needs to be defined, so as to set the functional requirements for such automation. This is particularly important for early research and development of the ANSP TBO evaluation service that compares all proposed and ongoing 4DTs in the system, identifies and resolves downstream conflicts, and deals with flow contingencies. A structured policy decision is required to flesh out the issues around the performance and acceptability of separation by automation through the use of TBO trajectory prediction for separation, conflict detection, and resolution.

Start now with TBO by using the FAA's SMS requirements and processes to define the TBO separation management safety case, define how good the automation needs to be, and identify ways to assess acceptability of automated safety separation using the safety case. The TBO Study Team's concern is that if the safety case cannot be made and deemed acceptable, the fundamental concept of operations for NextGen would need to change.

18.10 Time Window for De-Confliction
The team recognizes that to retain flexibility in the use of airspace, it is not possible to de-conflict hours in advance and hold an optimal profile for multiple flights. There is a tradeoff between system-wide optimization and providing flexibility in the use of the airspace. Aircraft will need to launch with an acceptable amount of uncertainty relative to a "clear path" 4DT that is subsequently modified during flight. The flight starts in a probabilistic construct that becomes much more deterministic when a 4DT must be met for merging, spacing, and separation. As an example, an aircraft departing DTW to merge into an overhead en route stream would depart with a general window of opportunity to merge. During climb, the aircraft 4DT would be modified once the placement of the aircraft into the overhead flow sequence is known.

Recommendation TBO-20
Research is needed to define the time window for look-ahead for conflict detection and resolution of the conflict that is balanced between system optimization for separation and flexibility in the use of the airspace. This time window must consider the aircraft performance limits for the phase of flight. The results of the research will provide the basis for understanding how refined the 4DT needs to be, the lead time to modify the 4DT, and the methods to be used in issuing a new 4DT for de-confliction with downstream flows.

18.11 Use of Data Link From the Aircraft for Conflict Detection

There are two classes of data link messages supporting 4DT and TBO, and the ADS-B Out link. The first class of 4DT and TBO confirms the execution of the 4DT clearance, and is accurate in the 3D with a broader time window representing time as estimated by the FMS. The second class of TBO data link message also originates from the aircraft, and are supplemental downlink messages that are consistent with the clearance, but provide more refined current information as executed by the aircraft. The first confirms that the 4DT clearance has been executed in the aircraft automation and the second provides updates that support conformance monitoring and 4DT de-confliction. This second message is sent automatically when performance information is refined and updated for the pilot by the avionics. This message class only contains changes in the 4DT as identified by the aircraft's automation. The use of supplemental information derived by the aircraft builds on OPD experiences where the aircraft calculates its performance in the airspace and sends information to the ANSP. These two classes of messaging, the initial confirmation of execution of a clearance, and supplemental information as refined, represent the intent used by the ANSP in TBO.

The ADS-B Out message is used by the ANSP for current position information for surveillance, but is not used for TBO intent. However, the ADS-B Out message is used for air-to-air limited intent capabilities and for air-to-air conflict detection and resolution. Additionally, the ADS-B Out message may be used to derive other performance information used by the ANSP, such as speed and winds aloft.

Recommendation TBO-21

Define the message content and layout for exchange of the 4DT and the subsequent updates of aircraft information for use in conformance monitoring.

Recommendation TBO-22

Conduct research on the use of the ADS-B messaging for airborne conflict detection and resolution and conformance monitoring.

18.12 Conformance Monitoring

Conformance monitoring exists both on the flight deck and within the ANSP's automation. The aircraft's avionics support altitude alerting to preset values and precision of navigation (measured as an RNP value), and will ultimately have longitudinal separation performance provided by conflict detection and resolution and/or merging and spacing tools. The ANSP's capability to monitor conformance and progress toward meeting the 4DT serves to alert the controller when conformance is not being met. The aircraft's inputs to conformance monitoring also provide the basis for comparing one aircraft's future position to all other aircraft future positions in the airspace. The information is vital to TBO separation.

Recommendation TBO-23

Create a new enabler for trajectory management services that defines conformance monitoring as opposed to a broad category called trajectory management.

Recommendation TBO-24

Conformance monitoring requires research on how good is good enough. In order to define the time precision requirements, the current variability in operations is needed. Using ASDE-X information at major airports, define current variability on arrival and approach to set the baseline for operational improvements.

Recommendation TBO-25

Develop more detailed scenarios for dealing with conformance monitoring when the aircraft's 4DT is changed to an open trajectory from a closed trajectory.

18.13 Trial Planning

Trial planning must consider the larger picture of the flows, not just the flight itself. As a dispatcher or individual pilot planning a flight, the acceptable profile that best meets the business trajectory must consider what the ANSP is planning. As an example, the ANSP may be planning to restrict certain airspace for weather. Dispatchers who are either flight planning or flight following can use access to this type of information to trial plan options. If the SAS for weather also contained information on flow constraints and flow strategies, then flight routes could be modified for airborne aircraft consistent with fuel loads. Aircraft that are yet to depart can provide the ANSP with additional options to reduce congestion and meet flow objectives. Common situational awareness on the ANSP's intent in dealing with flows needs to support trial planning opportunities in order for the operator/user to realize the best trajectory for the situation.

Recommendation TBO-26

Modify OI-0306 to provide opportunities to flight plan, and re-plan if airborne, around flows and possible flow contingencies and restrictions that are provided by the ANSP. The airlines would receive credit for changing their flights to reduce demand in exchange for handling their higher priority flights as incentives to helping the ANSP build the flows.

18.14 Adequacy of Data Link for Negotiation – Aircraft to AOC
Adequacy of Data Link for Negotiation – Aircraft to ANSP
Adequacy of Net-centric Connectivity for Negotiation – AOC to ANSP – UAS Operator to ANSP

TBO is based on pre-negotiation, negotiation, agreement, and execution. The questions are whether or not these negotiations between the parties should travel via the Internet, ground-ground connectivity, data link, or by voice, as in air-ground communications. AOC/FOC activities are very tactical in dealing with airborne assets. There are multiple communication paths that are possible between the AOC/FOC and the aircraft, including airborne Internet access. The UAS operator must also have connectivity with the ANSP. Negotiation is a strategic activity that will happen 20 minutes or more in advance of a change in the 4DT, and where the aircraft is offered choices to consider. In the interval of 20 minutes to the current time, changes are more likely to be transferred from the ANSP to the aircraft or operator accompanied by a voice transmission. The tactical changes will likely be more directive and less about choices. In a high workload environment at the AOC, at the ANSP or in the cockpit, what are the limits to using one method of communications over another?

Recommendation TBO-27

Research using simulation of negotiations in high workload environment can assess the adequacy of data exchanges only, data and voice, or voice only for negotiation on changes to the 4DT through ground-ground and air-ground communications.

18.15 Benefit of Imposing a 4DT Gate-to-Gate

The surface aspects of TBO assume that time is important and can be met with sufficient precision as to increase airport throughput. The challenges may outweigh the benefits, and surface TBO raises some research and performance issues:

- Surface TBO is primarily an issue over the precision of timing. Is this a flow issue or a separation issue?
- How good does the takeoff time have to be and what factors are driving the precision?
- Should the focus be on preferred performances in surface movement and leveraging surface movement learning[29] to make surface movement more predictable?
- Is it necessary to use TBO for runway exit and taxi-in, especially after using surface movement learning to help reduce runway occupancy times?
- How should surface TBO be used for intersection de-confliction and runway crossings?
- What human-machine interface (HMI) is needed to provide guidance cues on progress toward meeting takeoff time and expediting runway exiting for both the pilot and the ANSP?
- What HMI is needed to support sequencing and de-confliction of surface movement traffic for the ANSP?

The benefits of the surface segment of gate-to-gate are less queue delay, sequencing of departures for optimal throughput, environmental gains by reducing emissions at the airport, fuel savings for the users, improvements in deicing, and prioritizing flights for the airspace requirements.

Recommendation TBO-28

The TBO Study Team recommends a more detailed analysis of precision time performance on the airport surface in terms of safety, efficiency, capacity, and environmental benefits.

18.16 HMI Considerations for Surface Movement

The TBO Study Team recognizes that surface movement is a visual activity, even in low visibility. The mix of electronic information on displays and out-the-window current operations can lead to heads-down time that may not be appropriate for surface movement. The current implementation of electronic flight bags in various positions and configurations for surface moving maps is starting down the path of more heads-down time. Will surface TBO drive a forward field of view requirement? What credit will be given for equipage for forward view?

Recommendation TBO-29

Research on the concept of surface TBO needs to address the interface between the pilot and the automation in terms of placement, content, visual cues, techniques for identifying time progress, braking to exit, and other techniques to reduce runway occupancy times.

---

[29] Surface movement learning refers to the process of using surface surveillance to learn aircraft behaviors like taxi time by operator, aircraft type, and gate, as well as preferred exits (wet, dry, day, night) from the runway, queue length optimization, taxi-out variability, etc. This information is then applied in surface movement automation.

18.17 Staffed and Remote NextGen Towers

TBO is highly dependent on communications, navigation, and surveillance on the surface and in the equivalent of terminal airspace. Staffed and remote towers are alternatives to providing ANSP services at lower-activity airports. TBO is built on a concept that is flexible in providing RCP, Required Surveillance Performance (RSP), RNP, and now RTP. It can be adjusted for traffic density or airport/airspace complexity. The question is, how good does TBO have to be to support staffed and remote NextGen towers? The scenarios identified use of merging and spacing for arrivals and the possible use of departure times to meet merging into en route flows. TBO has benefits in eliminating the one-in-one-out operations in areas without surveillance coverage and for sequencing arrivals. However, these benefits may be small due to the density of traffic when compared with equipping staffed and remote towers with the necessary automation tools.

Recommendation TBO-30

The TBO Study Team recommends creating a baseline staffed and baseline remote tower traffic model that can be used for answering operational questions at the lower traffic densities expected. These models can then be used to help define procedures, identify benefits, and integrate GA traffic more fully into TBO.

18.18 Time-Based RTA vs. Merging and Spacing

The TBO Study Team began their deliberations with the understanding that there would be one RTA set in the FMS, consistent with today's FMS capabilities. In RTP, the objective is to meet the required time with a precision consistent with the density of traffic. The key advantage throughout the concept is that the more precise the time performance the more precise the separation. In high-density airspace, another advantage is the reduction in variability on arrival and approach to actually produce additional arrivals per hour for the same runway.

However, there is a balance between actual time performance and RTP. RTP occurs in merging and spacing. An RTA may only be valid at TOD for the case where the ANSP then asks the aircraft to merge, space, and follow another aircraft. At that point, the following aircraft shifts from absolute to relative time. As the sequence is developed for arrivals, and these arrival streams merged for the approach, an RTA to the initial approach fix becomes immaterial. In this case, the pilot is managing the interval between herself and the aircraft being followed.

Recommendation TBO-31

Technology needs to be matured to integrate aircraft capabilities and controller practices relating to airborne merging and spacing. Interleaving of capable and not capable aircraft is an issue that requires procedural and decision support automation development, so that during the transition, TBO benefits can be realized on arrivals and approach. The capable aircraft will be able to merge and space on any aircraft, however, procedural research and development is required to understand how merging and spacing will work in both mixed equipage and high-density operations.

18.19 OI for Closely Spaced Runways

Existing OIs on closely spaced runways fail to identify the targeted runway separation distances and do not cover the benefits of TBO in terms of getting aircraft aligned and sustaining separation during the maneuvers.

Recommendation TBO-32
Modify OI-0333 and OI-0335 to add TBO content and set the targeted distances for 2025 that are identified down to 750 feet. Add information on how spacing between aircraft is set up by TBO and how TBO is used to maintain separation on dependent parallels. Independent parallel runway operations are aided by merging and spacing from TOD to roll out onto the independent approach. Missing are the dimensions for VCSPR, establishing goals for the operations. There should be an incremental activity to first reach 2,500 feet, then 1,200 feet, and finally 750 feet of runway separation distances.

OI-0333 recommended changes would read:

> The improvement will explore concepts to recover lost capacity through reduced separation standards, increased applications of dependent and independent operations, enabled operations in lower visibility conditions, and changes in separation responsibility between the ATC and the flight deck. This OI sets a goal of achieving independent parallel arrivals down to 2,500 feet separation and dependent parallel arrivals to 750 feet. This improvement will develop improved procedures that enable operations for closely spaced parallel runways (runways spaced less than 4,300 feet laterally) in lower visibility conditions. This operational improvement promotes a coordinated implementation of policies, technologies, standards, and procedures to meet the requirement for increased capacity while meeting safety, security, and environmental goals. Intermediate concepts for maintaining access to parallel runways continue to be explored (e.g., use of RNP approaches to define parallel approaches with adequate spacing, RNP transition to an ILS final approach course, RNP/LAAS/WAAS, Wake Program Office initiatives). Research will be initiated to support far-term capacity requirements. Research will be focused on finding ways to recover lost capacity due to IMC events by providing a monitoring capability that mimics or replaces visual separation. VMC-like capacity may be achieved by integrating new aircraft technologies such as ADS-B In, precision navigation, data link and cockpit displays within the TBO capabilities.
>
> This OI seeks VMC arrival and departure rates in IMC through use of onboard displays and alerting for independent parallel runways. Using precision navigation, cooperative surveillance, and onboard algorithms and displays allows the reduction of lateral separation requirements for parallel runway operations in IMC and limited by wake vortex separation distances. This OI includes independent approaches to parallel runways with centerline distances as low as 2,500 feet. The implementation of this OI is strongly dependent on when an airline decides this is important and steps forward to advocate for it.

18.20 Connecting Top of Descent to STARs and Connecting STARs to Approaches
During the transition to TBO (between TOps and TBO), there is a need to build closed trajectories. To calculate an OPD, the aircraft needs to know how long its path is from TOD to the runway threshold. This path is then converted to a profile that represents what the aircraft will fly. Connecting STARs to approaches eliminates vectoring into an open trajectory. Since the aircraft will know where its TOD is likely to be, a closed trajectory to the start of a STAR can be provided to the aircraft in advance of the TOD, and the aircraft can then provide its flight profile.

When arriving from a direction opposite the landing runway, either new STARs can be developed or a waypoint can be established to travel to that is on the radar downwind for the landing runway. This radar downwind can also have waypoints describing a radius to fix turn to final at different points along the radar downwind. This closes a trajectory that would normally be handled by radar vectors.

Recommendation TBO-33
Develop the necessary policies and procedures to connect STARs to the approach to begin closing trajectories through published procedures.

18.21 Weather Ships and Calculating Winds Aloft

Time precision and the ability to predict position at a future time are dependent on good wind information. Current winds aloft is a forecasted value, but actual winds aloft and vertical wind profiles can be derived from information from the aircraft and calculated on the ground to feed back to the aircraft for use in refining conformance monitoring. All the elements are on the aircraft—outside air temperature, true airspeed, ground speed, heading, and course. Sampling during an en route and during OPDs can provide wind information for general use by other pilots and the ANSP.

In 2009, RTCA SC186 was asked to develop consensus standards and lay the groundwork for international agreement on the use of ADS-B as a vehicle for broadcasting a limited set of meteorological data. This action is to develop informative appendices for DO-260B (ADS-B MOPS)/ED-102A and DO-282B (UAT MOPS). These informative appendices provide justification for introducing broadcast data requirements into future MOPS and also provide initial estimates of desired data elements, update rates, and signal provisioning. It is now time to accelerate the winds aloft portions of this messaging to create information that can be used today to improve arrival performance.

Recommendation TBO-34
Initiate a review and provide further policy guidance from the JPDO to FAA and the National Oceanic and Atmospheric Administration (NOAA) on developing winds aloft and vertical wind profile information for use in trajectory operations derived from information coming from the aircraft, including ADS-B messages. This information can then be used to provide vertical profile information in real time for climbs and descents.

18.22 Merging Into Overhead Flows

The TBO Study Team explored two approaches for use of TBO to join an overhead flow. The first was to create a gap in the flow that would be filled by the merging aircraft based on comparison of all 4DTs in the flow (sequencing) and the second was to use an RTA to get the aircraft close to the opportunity to merge, and then use merging and spacing tools on the aircraft to join the overhead flow. The first approach is an absolute time; the second is a relative time. In the first case, the slot is known and maintained for the aircraft to a given precision that the aircraft must meet during climb. The other is to get the aircraft close to where a merge is possible and then let on-board automation space the aircraft behind a lead aircraft. The penalty for not meeting the merging and spacing time is to be held at lower altitudes, burning more fuel. While this difference may appear to be small, it goes to the issue of when TBO shifts from absolute RTP to a relative timing position behind a leader aircraft.

Recommendation TBO-35

Through modeling and simulation, evaluate the pros and cons of absolute (creating and sustaining a slot) and relative (merging and spacing) timing for merging into flows. Develop procedures for both and evaluate what changes would be needed in merging and spacing capabilities, and how conflict detection and resolution would take part in joining an overhead stream of traffic.

18.23 Sharing Intent Between Self-separating and ANSP Controlled Traffic

As part of the TBO closed-loop system approach (which provides information to the ANSP on aircraft 4DT changes through confirmation of execution of a change in 4DT and supplemental information derived by the aircraft), it becomes possible to have mixed operations in the airspace. The controller knows the intent of the self-separating aircraft, and the self-separating aircraft can yield to those aircraft being controlled by the ANSP. The problem is that the ANSP's intent in directing controlled aircraft is not known to the self-separating aircraft, and the intent of the self-separating aircraft is not known to the other controlled aircraft in the airspace because the data link message is addressed and not broadcast. While this lack of exchange of information can be accommodated by a combination of ADS-B intent information and rules of the road, this issue may be mitigated.

The question then becomes, what is the relationship between the intent message for TBO that is feeding conformance monitoring for the ANSP and the ADS-B Out intent information used by other aircraft in the vicinity? To what degree can we use ADS-B intent information to close the information loop and produce true situational awareness?

Short-term target state intent is available from ADS-B. Self-separation requires ADS-B In for conflict detection and resolution for use in self-separation.

Recommendation TBO-36

Create a study team to define air-to-air and air-to-ground intent, and how the information is used. Define the extent to which rules of the road can be used in a mixed equipage situation where some aircraft are self-separating and others are being managed by the ANSP.

18.24 Arrival Meter Point Becomes the Gate in Off-nominal Operations

TBO becomes the mechanism for a new acceptance rate in the presence of off-nominal operations. As demand must be adjusted downward, aircraft en route to the arrival meter point can be managed to realize demand in a 30 to 45 minute time window. Realizing that international arrivals have priority due to fuel reserve requirements, and diversions take priority over those arriving that are new to the airspace, queuing tools can be developed that match TBO information on all flights to a demand level and recommend courses of action to aircraft already in the air. Aircraft can be slowed, held, and given a different TOD and arrival path to slow them down to balance demand, along with other measures consistent with their preferences, fuel loads, and alternates.

Recommendation TBO-37

Develop alternatives for managing demand during off-nominal operations using the arrival metering point for aircraft that are airborne at the time of the need to regulate demand that can leverage TBO. Evaluate these alternatives in terms of efficiency in delay management.

18.25 TBO Policy Recommendations

There are some overarching policy recommendations being made that support a better definition of the operational aspects of TBO.

Recommendation TBO-38

The TBO Study Team recommends resolution of Best-Equipped, Best-Served (also known as performance-based operations) as an operational incentive for equipage, and that it should be applied relative to TBO. Collaboration with the operator community—airlines, GA, military—is required if support for TBO operations is to be realized. (IWP Policy references: PI-0014 – Aircraft Equipage, PI-0007 – Rules of the Road)

Recommendation TBO-39

TBO offers the opportunity to use computer automation to separate aircraft. Doing so may increase the cost of aircraft equipage and ANSP infrastructure due to stricter certification standards. Decisions are needed that involve human factors and labor issues, as well as technical and cost issues. Additional research is needed before policy decisions can be made to determine what the human does, including what is done by the automation, and what the role of the human is in off-nominal conditions so that requirements can be allocated for TBO. (IWP Policy references: PI-0006 – Balance of Human vs. Automation)

Recommendation TBO-40

The TBO concept requires two-way data communications and associated automation in order to exchange and negotiate full 4DTs and flight plans. Although air transport aircraft already carry data communications radios, proposed FAA requirements would require equipage with new radios at a significant cost. The TBO Study Team recommends a performance-based solution, including definition of the functional requirements for TBO and other communications uses, setting the performance requirements (e.g. availability, latency, message integrity), and resolving the data communications bandwidth and spectrum. Operators could be allowed to equip with any compliant system; this would increase flexibility, avoid rapid obsolescence, and likely reduce overall direct equipage costs. This may also permit the DOD to utilize Joint Tactical Information Distribution System (JTIDS) through software upgrades, thereby lowering equipage costs, reducing special mixed-equipage procedures, and streamlining TBO implementation. (IWP Policy references: PI-0017 – Data Communications Architecture Strategy, PI-0014 – Aircraft Equipage)

Additionally, there is a high likelihood that a significant percentage of GA aircraft will not be able to justify the expense of data communications avionics. However, trajectory intent information transmitted as part of an ADS-B message would provide limited TBO capabilities and may be all that is needed for these aircraft to operate outside of high-density flows in a TBO environment. Research is needed to define the adequacy of ADS-B Out messaging for TBO. (IWP Policy references: PI-0014 – Aircraft Equipage, PI-0008 – GA Benefits)

Recommendation TBO-41

Flight planning systems used by airline and flight operations centers (AOC/FOC) need to be able to communicate with ANSP systems and possess the necessary automation capability to carry out negotiations. Best-Equipped, Best-Served policy should be applied as an operational incentive for AOC/FOC equipage for flight planning. Operators that do not use AOC/FOC services, GA, for example, should be able to handle such communication and negotiation through other systems such as a Flight Service Station or online resources. However, allowances need to be made for aircraft that do not have access to such resources, at remote airports, for example. When, where, and the degree to which these policies are applied must be a conscious decision and accounted for in automation logic and TBO planning. Collaboration with the operator community—airlines, GA, military—is required if support for TBO operations is to be realized. (IWP Policy references: PI-0001 – AOC/FOC Equipage)

The TBO Study Team recommends that a well-equipped AOC/FOC will provide better 4DTs with finer granularity to reduce uncertainties that must be compensated for by the ANSP. This frees up airspace for increased efficiency. Incentives are needed for investment by the AOC/FOC, most of which can be delivered through competitive advantage.

Recommendation TBO-42

There will be times when similarly equipped aircraft will compete for access to airspace and airports. Policy guidance is needed to help manage these situations. Those policies will be augmented with collaborative decision-making, but the underlying policy must be there for it to work effectively. Although TBO allows most prioritization decisions to be made during the flight planning stage, there will be times that such situations will occur in the air. For example, international flights have lower reserve fuel requirements. If capacity is curtailed at the destination airport, international operators get priority. The same is true for aircraft that have diverted to another airport; they are given priority. Consequently, policies must be defined and incorporated into the ATM automation and ATC procedures. (IWP Policy references: PI-0077 – High-Density Operations – Flight Prioritization)

The TBO Study Team recommends research to develop equity algorithms that could be built into the TBO evaluation services. The TBO Study Team further recommends transparency in defining equity and system efficiency policies, in collaboration with the users, so that users retain flexibility in applying the results of these policies. The flight prioritization policies must then be defined for TBO and converted into automation executable rules.

Recommendation TBO-43

Performance requirements must be defined for position and timing accuracy, and integrity levels relative to TBO operations. These requirements include those applied in off-nominal operations when there is an interruption in primary PNT services and an expected corresponding degradation in performance. Additionally, define operational policies on the degree of acceptable degradation, the duration of degraded operations, and the acceptable number of mitigating performance levels used. (IWP Policy references: PI-0120 – PNT Performance Requirements)

The JPDO is in a position to resolve, across its partner agencies, the question of whether a backup to GNSS is needed and under what conditions. The JPDO should work toward ending the debate so that the FAA can move forward on solutions to providing the backup.

Recommendation TBO-44

The competitive economic environment drives airline scheduling and non-safety operational decisions. It is not always in an airline's best economic interest to make decisions that favor overall system capacity or efficiency. Policies that incentivize operator behavior, helping manage system demand and capacity, are needed to extract the maximum overall benefit of NextGen. For example, today if an operator cancels a flight during a GDP, that operator is given credit and permitted to substitute another flight. However, if that operator cancels a flight in anticipation of expected delays, but prior to a GDP going into effect, that operator is given no credit for that cancellation, even though such cancellations may help reduce or avoid implementation of a GDP. Enacting policies that encourage operator behavior that leverages NextGen operations will help increase system capacity and efficiency, as well as reduce automation complexity and cost. The TBO Study Team recommends that the JPDO define what operational behaviors are needed from the airlines, and then develop incentives that encourage those behaviors.

Recommendation TBO-45
Based on the experience of transitioning to RNAV and RNAV/RNP, there is a considerable educational effort associated with TBO, bringing dispatchers, controllers, pilots and system developers into the transition in using trajectories for both strategic and tactical use. This educational effort needs to start as early as 2012, building first on TBO-101, the terms and concepts of TBO. The TBO Study Team recommends that a TBO educational plan be developed to support the NextGen Concept of Operations.

Recommendation TBO-46
The NextGen Concept of Operations uses TBO as a significant pillar supporting aviation in the future. The TBO Study Team found it necessary to define new terms just to explain the concepts. Whether it be “closed trajectory,” “RTP,” or “freeze point” there is a need for defining the nomenclature of TBO and reaching consensus on what terms are to be used. RTP represents an example. It was used by the Study Team to reflect the general concepts found in RNP, only for the fourth dimension, time. Time is treated differently between the cockpit and ground automation. There are EDCT, ETA, RTA, CTA, TOAC (time of arrival control) and probably others. In developing these terms, they are unique to the origin, some having their origin in avionics standards, some in ATC procedural development. The Study Team recommends a glossary of terms and definitions be developed that spans TOPs and TBO.

19.0 Transition from Trajectory Operations to TBO

At the time of preparation of this report of Trajectory Based Operations, the RTCA has experienced delays in delivering the concepts for trajectory operations. TOps is the near- and mid-term elements of the transition to using trajectories. The RTCA report is now limited to an assessment of a series of concepts and scenarios for TOps with emphasis on CATM and improved flight planning, followed by limited use of new flight procedures. The emphasis on CATM provides the foundation for a transition to TBO. After the next few years of using trajectory information in collaboration, the transformational steps to using trajectories for separation becomes more visible to the users.

Critical to TBO’s success is early resolution of the issues identified in the recommendations. The next task is to develop the transition work between TOps and TBO and develop a TBO time line for research, demonstrations, and trials. The transformation to 4DT from a collaborative use under TOps to use for separation, sequencing and spacing under TBO needs to be identified so that development and implementation can occur in a manner that at least matches the growth in air traffic operations.

CATM represents improvements that can occur without avionics investments. However, improvements in flight planning, definition of the flight object, and building the connectivity between the operators and the ANSP should be based on net-centric operations. Airlines are coming off of years of losses and lack of investment in planning tools. With capacity reduced, every flight's performance becomes more critical. As the economy improves, airlines will begin to reinvest to attain shared common situational awareness. The ANSP needs to be prepared to conclude tool development and join in a joint effort to improve flight planning. This is one of the reasons the TBO Study Team has recommended expanding flight planning in the ConOps.

TBO has some challenges ahead that can be mitigated by TOps. Among these are resolving the intent message format and determining how ADS-B Out could be used to aid in intent and in providing more accurate wind information. Under TOps, early implementation of conformance monitoring will help to transform to TBO. Conformance monitoring provides a means of measuring flight progress based on surveillance and intent.

20.0 Conclusion

The TBO Study Team has provided just a glimpse into the world of TBO. TBO is a very significant and transforming change on the path to NextGen. The approach has been to expand the value of flight planning, recognize that the traffic volume will exceed what the air traffic controller can handle today, and rely on automation to perform separation based on a combination of present aircraft position and a future position in time. There is conformance monitoring both in the cockpit and with the ANSP, and conformance to a negotiated and agreed-upon trajectory forms a contract between the operator/user and the ANSP.

The separation automation must always work. Airborne and ground elements of automation must be certified to provide separation assurance. While separation represents a significant shift, increased collaboration through network-centric operations to improve common situational awareness will provide significant improvements in efficiency and capacity. It is important to emphasize that TBO is about choices. Once received, choices are negotiated, accepted, and then executed with precision. The higher the airspace traffic density, the greater will be the need for precision performance. But TBO can operate at any level of precision. It is the execution of the agreement that assures separation.

Strategically, automation must provide choices to the operator/user that resolve downstream conflicts and address flows. Weather is integrated into the decisions that must be made both strategically and tactically. As the number of strategic decisions rise, the number of tactical interventions will diminish, balancing workload both in the air and on the ground.

At this point in the discussion of TBO, the level of precision requires research. While the RNP values used in this report are likely to be very close to what is needed, it is because RNP is maturing at a fast pace. The same cannot be said for separation distances. While the targeted goal is three miles everywhere in domestic airspace, we will not see it until the surveillance data network is providing fused information and the population of ADS-B equipped aircraft has been reached to support it. Likewise, the TBO Study Team has used notional time performance under the concept of RTP that requires development.

In communications, TBO is highly dependent on ground-ground connectivity for network-centric operations and data link for negotiations, agreement, and validation of execution of any given 4DT. But one data link pipe does not represent a single solution. Because TBO communications are mostly in a strategic time frame, the urgency of connectivity is unnecessary for a majority of the transactions. The team has made several recommendations on developing the messaging content and requirements for TBO because of the urgency in getting to a set of requirements. The requirements are more about the information flows between systems than about the performance of the link.

With respect to aviation security, TBO represents one of the layers of adaptive security. Intent is a powerful tool in monitoring conformance. Likewise, in flight planning there are opportunities to build in authentication, from submittal of a plan to starting the aircraft. In-flight performance puts bounds around the aircraft, and deviations from these bounds have separation consequences that must be addressed.

Environmentally, TBO provides an opportunity to meet improved noise performance by more closely defining flight tracks. TBO offers savings in fuel burn, on the airport, during climb, through the use of cruise climb, and the optimized arrivals to an airport. Noise, emissions and fuel savings translate into tangible environmental benefits.

Finally, The TBO Study Team recognizes that this is the start of a greater debate on the details of TBO. Our approach was to provide information on how TBO would work in the context of operational scenarios. Much work must follow. Critical in this work is the beginning of a safety case and the necessary analyses to reach decisions on fundamentally changing how aircraft are separated. This safety case is followed by the functional requirements for TBO and a significant discussion on definition of requirements for automation’s performance.

Appendix A
Directory of Aircraft Used In Scenarios

The following aircraft are involved in the scenarios described in the body of the report. Additional aircraft and UAS vehicles have been used as traffic but are not identified by call sign. Three classes of performance are used: fully NextGen Capable, meaning that they can do all maneuvers with required performance for the airspace and are capable of self-separation; NextGen Enabled, meaning that they can do all maneuvers except self-separation (lack Conflict Detection and Resolution capability; and NextGen Classic, meaning that they can perform most elements of NextGen but lack certain capabilities that require additional ANSP support.

Sunset Air 42 (Fully NextGen Capable)
Type: Boeing 737-1000
Manufacture: 2019
Avionics:

- Dual Analog Voice
- Dual Digital Data Links
- FMS – NextGen capable with 4DT and Single RTA
- Dual Inertial Reference Unit
- Auto-throttles and auto-land
- Conflict Detection and Resolution package capable of self-separation
- Merging and spacing
- ILS (Cat II/III)
- VOR
- DME-DME
- GNSS with SBAS and GBAS,
- Dual Transponder
- Dual TCAS
- Electronic Flight Bag and field of view Guidance Display with surface moving maps
- 1090 ADS-B In
- RNAV RNP 0.11 capable
- Dual Enhanced Vision with Heads Up Displays
- Weather Radar

Westair 351 (Fully NextGen Capable)
Type: Airbus A330
Manufacture: 2014
Avionics:

- Dual Analog Voice
- Dual Digital Data Links
- FMS – NextGen capable with 4DT and Single RTA
- Dual Inertial Reference Unit
- Auto-throttles and auto-land
- Conflict Detection and Resolution package capable of self-separation

Merging and spacing
ILS (Cat II/III
VOR
DME-DME
GNSS with SBAS and GBAS,
Dual Transponder
Dual TCAS
Electronic Flight Bag and field of view Guidance Display with surface moving maps
1090 ADS-B In
RNAV RNP 0.11 capable
Weather Radar

Northeast 416 (NextGen Classic)
Type: Airbus A-320
Manufacture: 2007
Avionics:
Dual Analog Voice
Dual Digital Data Link
FMS – NextGen capable with 4DT and Single RTA
Dual Inertial Reference Unit
Autopilot with Auto-throttles and Auto-land
ILS (Cat II/III)
VOR
DME-DME
GNSS with SBAS and GBAS
Dual Transponder
Dual TCAS
Electronic Flight Bag with surface moving maps
1090 ADS-B Out
RNAV RNP 0.11 capable
Weather Radar

Winds Air 134 (Fully NextGen Capable)
Type: Boeing 737-900
Manufacture: 2015
Avionics:
Dual Analog Voice
Dual Digital Data Links
FMS – NextGen capable with 4DT and Single RTA
Dual Inertial Reference Unit
Auto-throttles and auto-land
Conflict Detection and Resolution package capable of self-separation
Merging and Spacing
ILS (Cat II/III)

VOR
DME-DME
GNSS with SBAS and GBAS
Dual Transponder
Dual TCAS
Electronic Flight Bag and field of view Guidance Display with surface moving maps
1090 ADS-B In
RNAV RNP 0.11 capable
Dual Enhanced Vision with Heads Up displays
Weather Radar

Sunset 123 (Fully NextGen Capable)
Type: Boeing 737-1000
Manufacture: 2018
Avionics:

Dual Analog Voice
Dual Digital Data Links
FMS – NextGen capable with 4DT and Single RTA
Dual Inertial Reference Unit
Auto-throttles and auto-land
Conflict Detection and Resolution package capable of self-separation
Merging and spacing
ILS (Cat II/III)
VOR
DME-DME
GNSS with SBAS and GBAS,
Dual Transponder
Dual TCAS
Electronic Flight Bag and field of view Guidance Display with surface moving maps
1090 ADS-B In
RNAV RNP 0.11 capable
Dual Enhanced Vision with Heads Up Displays
Weather Radar

Transcon 1324 (Fully NextGen Capable)
Type: Airbus A-330
Manufacture: 2013
Avionics:

Dual Analog Voice
Dual Digital Data Links
FMS – NextGen capable with 4DT and Single RTA
Dual Inertial Reference Unit
Auto-throttles and auto-land
Conflict Detection and Resolution package capable of self-separation
Merging and spacing

ILS (Cat II/III)
VOR
DME-DME
GNSS with SBAS and GBAS,
Dual Transponder
Dual TCAS
Electronic Flight Bag and field of view Guidance Display with surface moving maps
1090 ADS-B In
RNAV RNP 0.11 capable
Dual Enhanced Vision with Heads Up Displays
Weather Radar

Ariba 151 (NextGen Enabled – not capable of self separation)
Type: Airbus A-320
Manufacture: 2008
Avionics:
Dual Analog Voice
Dual Digital Data Link
FMS – NextGen capable with 4DT and Single RTA
Dual Inertial Reference Unit
Autopilot with Auto-throttles and Auto-land
ILS (Cat II/III)
VOR
DME-DME
GNSS with SBAS and GBAS
Dual Transponder
Dual TCAS
Electronic Flight Bag with surface moving maps
1090 ADS-B Out
RNAV RNP 0.11 capable

Ariba 121 and 122 (NextGen Classic)
Type: Airbus A-320
Manufacture: 2002
Avionics:
Dual Analog Voice
Dual Digital Data Link
FMS
Inertial Reference Unit
Autopilot with Auto-throttles
ILS (Cat II/III)
VOR
DME-DME
GNSS with SBAS and GBAS
Dual 1090 Transponder

Dual TCAS
Electronic Flight Bag with surface moving maps
1090 ADS-B Out
RNAV RNP 0.11 capable

N72MD (NextGen Classic)
Type: Socata TBM 850 Turboprop
Manufacture: 2011
Avionics:
Dual Analog Voice
Mode S Transponder with TAS
Dual GNSS with SBAS
1090 ADS-B In with CDTI and TIS-B (no FIS-B)
Satellite delivered weather and flight information
Autopilot capable of 3D – no auto-throttle connectivity
Dual ILS (CAT I) with VOR
RNP 0.3 with radius to fix upgrade
Glass cockpit with Electronic Flight Bag functions including self-separation tools
Automated pilot assistant

Moon Air Regional Carrier (NextGen Classic)
Type: Bombardier Q400
Manufacture: 2013
Avionics:
Dual Analog Voice
Dual Digital Data Link
FMS
Inertial Reference Unit
ILS (Cat II/III)
VOR
DME-DME
GNSS with SBAS and GBAS
Dual Transponder
Dual TCAS
Electronic Flight Bag with surface moving maps
1090 ADS-B Out
RNAV RNP 0.11 capable

N34P (Full NextGen Capable)
Type: Cirrus Turbo SR22T
Manufacture: 2014
Avionics: Garmin G1000 suite
Dual Analog Voice
Dual Data Link
Mode S Transponder

Dual GNSS with SBAS
Enhanced and Synthetic Vision System with Highway-in-the-Sky presentation
UAT ADS-B In with TIS-B and FIS-B
Satellite delivered weather and flight information
Autopilot capable of altitude and airspeed control
Conflict Detection and Resolution Package
Dual ILS (CAT I) with VOR
RNP 0.3 with radius to fix upgrade
Glass Cockpit with Multifunction Display

Appendix B
Flight Planning Data Elements

Appendix B provides the data elements that are considered by Aircraft Dispatch in preparing a commercial flight for departure under FAR 121. While flight-planning requirements may change in 2025, these elements represent the content of current requirements to be considered in preparing the aircraft for flight.

Items Reviewed and Required for Commercial Flight Plan Releases

Applicable Paperwork and Manuals (FAR 121.133, 121.135, 121.137, 121.139, 121.141)

- Aircraft Operating Manual (AOM, Systems, Performance)
- Minimal Equipment List (MEL)
- Flight Manual Part One General Operation Manual
- Flight Manual Part Two - Approach Charts (Paper [government or private], electronic)
- In-flight Procedural Manual
- Approved Training Manual
- International Supplements (ETOPS)
- EWINS Manual (121.101, 121.133, 121.601)
- Station Operation Manual
- Operating [Airworthiness] Certificate (FAR 91.7)
- Aircraft Certificate (FAR 91.203)
- Aircraft Insurance
- Flight Plan Release (FAR 121.593, 121.595, 121.597, 121.631, 121.695, 121.687)
- Permits
    - Ferry Permit (FAR 21.197)
    - Special Ferry Permit [Maintenance] (FAR, 21.197, 21.199,)

Applicable Aircraft Planning Requirements (Applicable OIs: OI-3010, OI-0311, OI-0313, OI-0315, OI-0317, OI-0320, OI-0321, OI-0322, OI-0327, OI-0330, OI-0332, OI-0334, OI-0335, OI-0337, OI-0348, OI-0352, OI-0353, OI-0356, OI-0357, OI-0358, OI-0359, OI-0360, OI-0363, OI-0368, OI-0369, OI-0381, OI-2020, OI-2021, OI-2022)

- Aircraft Flight Manual (ensure compliance and knowledge)
    - Bulletins
    - Performance Charts
    - Limits and Specifications
    - Normal Operations
        - Takeoff/Landing limits
            - Runway limit
            - Structural limit (91.605)
                - Ramp weight
                - Takeoff weight (FAR 121.195)
                - Landing weight
                - Zero Fuel weight
            - Performance limit
                - Second segment climb limit
                - Min climb gradient limit
                - Go around limit

- En route limit
  - Obstacle Clearance Limit
  - Drift Down Terrain Clearance Limit
- Irregular/Emergency Operations
  - High
  - Hot
  - Failure of System or Component
- Major Systems and Components
  - Navigation, Communication, Electrical, Emergency Equipment-Fire protection, Engines/APU, Flight Controls, Hydraulics, Fuel, Pneumatics /Ice Protections, Landing Gear, Warning System / EICAS
- MEL / CDL Management (FAR 121.563, 121.701)
  - Aircraft Maintenance Status
  - Restrictions/Limitations
  - Configuration Considerations

Applicable Airport Information (Applicable OI's: OI-3109, OI-4101, OI-4102, OI-4105, OI-4106, OI-4107, OI-4204)

- Diagram (AC 120-74A)
- Terminal [regular scheduled or off-nominal i.e. diversion] (OI-OI,-0310, OI-5003, OI-5004, OI-5005, OI-5006, OI-5012, OI-5014, OI-5015, OI-6014)
  - Security (OI-4105, OI-4107, OI-4201, OI-4202, OI-4203, OI-4521))
  - Space (OI-5006, OI-5009)
    - Airport
    - Gate
    - Ramp
  - Personnel
  - Ground Based Transportation (OI-0321)
  - Environmental (OI-6014)
- Approved / On Line – Off Line (FAR 121.537, 121.631, 121.635) (OI-5004)
  - Scheduled/Regular/Alternate Airport
  - Fuel
    - Fuel Vender Approved (single point [truck, pit] over wing)
    - Fuel Approved (OI-6017)
  - Runway Analyses complete and current
  - Environmental Analyses complete and current (OI-6014)
  - Maintenance On Site (in house/contract)
- Dual Use
  - Civilian/Military (OI-5000)
    - Military Approvals for operation
- Charter Operations (FAR 121.117, and 121 Supplemental) (OI-5000)
- Control Tower (OI-4109, OI-4110)
  - Hours of Operation [onsite – remote] (OI-0409)
    - Pilot Controlled lighting after hours (virtual towers OI-0410)
    - Departure/Approach Minimums with/without tower

- PDC/Data Comm/Trajectory Negotiation (OI-0352, OI-0360)

- Instruments Operations (FAR 121.97) (OI-0317, OI-0384)
  - ASOS
  - Lights
  - Decibel meter operational
  - Braking Action Sensor
  - Wind Shear Sensors
  - GBAS (OI-0381)
  - Radar
  - SMS (OI-3004)
- Runway (OI-0381, OI0387, OI-4000, OI-4001, OI-4002, OI-4003, OI-5000)
  - Construction (OI-0316, OI-0321, OI-0331)
    - Direction – multiple directions – multiple same direction operations OI-0333, OI-0341, OI-0356)
      - Land And Hold Short Operations (LAHSO) (OI-0334)
      - Closely Spaced Parallel Operations (CSPO) (OI-0335)
      - Wake Turbulence operations (OI-0387, OI-4000 thru OI-4003)
      - Crosswinds Ops
      - High Speed Turn-offs
    - Length available
    - Width available
    - Space between runways
    - Weight Restrictions
    - Grooved
    - Lighting (OI-0322)
      - Approach
      - Centerline
      - Intensity
  - Instruments operational (OI-0305, OI-0320, OI-0321, OI-0322)
    - RVR
    - Ground surveillance (OI-0320, OI-0321, OI-0327)
    - ACARS, Data Comm Receiver/Transmitter
    - Approach
      - Precision
      - Non-Precision
  - No Obstructions permanent or temporary
    - Ground
      - Arresting Cable
      - Stanchions (around construction)
    - Air
      - Crane
      - Buildings/Mountains
- Facilities
  - Environmental/HASMAT (OI-4204)

        - Fuel Containment Disposal
    - CFR (OI-0420)
        - Fuel Capacity
        - Passenger Capacity
    - Deicing facility
        - Type of Fluid
        - Application of Fluid
            - Truck
            - Bay
            - Heated or not
        - Distance/Time to Departure
            - Collection/Retention capability
    - Special Events Features (OI-4600)
        - Air shows
        - Fly-ins
        - Store and/or restaurants

Navigation Flight Planning (Applicable OIs: OI-0303, OI-0339, OI-0381, OI-6005, OI-6006)

- Departure
    - SID
    - Take Off Minimums
        - Standard
        - Lower than Standard (OI-0388)
- En route (OI-0311, OI-0319, OI-0325)
    - RNAV/RNP (OI-0311)
        - Define, equipment requirements, routes
    - GPS FMS (OI-0303)
        - RNP (value) (OI-0311)
        - RAIM prediction
- SID/STAR (OI-0307, OI-0309)
    - Identify transitions and appropriate departure/arrival
    - GBAS (OI-0381)

Fuel (Applicable OIs: OI-6005, OI-6008, OI-6017)

- Requirements (FAR 121.639)
    - Domestic
        - IFR
        - IMC
    - International
        - IFR (Exemptions, Reserve, Special Reserve, Re-dispatch)
        - IMC
        - Oceanic (OI-0354)
    - Hold
        - Known and Forecasted Delays (FAR 121.647)
    - Limitations

            - Types (OI-0617)
                - JP4, JP4A, JP5, BIO/Alternative
                - Additives (i.e., anti-icing additive)
            - Freeze Limits (temperature)
    - Additional
        - Taxi (OI-0320, OI-0321, OI-0322)
            - Out
                - Operational
                    - Deicing
                    - Gate Space
                    - GDP/TMI
                - Airport Configuration
            - In
                - Airport Configuration
                - Operational
        - En route deviation
            - Route Deviation (nominal or off-nominal)
            - Altitude Deviation
        - Hold
            - Possible Delays (Operational, or possible Weather)

ATC Planning (Applicable OIs: OI-0303, OI-0305, OI-0346, OI-0361, OI-0366, OI-0382, OI-0385, OI-0406, OI-0408)

- Brief/Review ATC system constraints utilizing self and ATC Coordinator (representative)
    - ATCSCC OIS page
    - SIRD (SPO, VIP, DOT critical flight list)
    - GDPs
    - AFPs
    - Special routes
    - Ground Stops
    - ATC constraints
    - VIP movements
    - SUA (OI-0346)
- Filing/Amending/Canceling/Remarks/Radio Numbers/PDC (OI-0306)
- Type of Operation
    - Normal
    - Diversion Recovery
    - Civil Reserve Air Fleet
    - Lifeguard
    - Maintenance/Test Flight

Route Planning (Applicable OIs: OI-0331, OI-0382)

- Preferred Route
    - Best Time Route
    - Best Fuel Burn Route

        - Company Negotiated
            - Altitude, Speed, Time of Day specifics (LOA)
    - National Route Program (NRP)
    - ANSP Program
        - Playbook routes, Coded Departure Routes (CDR), Choke point routes
    - Airspace Considerations (OI-0366, OI-0368)
        - RVSM
        - Drift Down Requirements (FAR 121.191 exceeds FAR 91.177)
        - Restricted/Warning Areas, Special Use (OI-0346)
        - Over water
            - 50 nautical miles from shore
            - 162 nautical miles exemption
            - Over water equipped
            - ETOPS
            - Oceanic (OI-0304)
    - Environmental Considerations
        - Weather (i.e. wet-icy runway, air density)
        - Noise abatement
            - Continuous Climb/Step Climb/Circle Climb
        - Geography (i.e. terrain, temporary [crane] or permanent [mountain])
    - Performance Considerations
        - Weight (Continuous climb or Step climb)
        - Second stage climb limits
        - Accelerate stop performance
    - Weather Considerations
        - Partial Restrictions – minor deviation
        - Altitude, minor course correction
        - Custom routes

Weather Planning (Applicable OIs: OI-0388, OI-0389, OI-0390, OI-2010, OI-2020, OI-2021, OI-2022, OI-2023, OI-5110, OI-5111)

- All Weather tools (required for ops – textual and visual) Weather review is inclusive of departure, en route, destination, and required alternates (FAR 121.613, 121.617, 121.619, 121.625, 121.631)
    - Alternate Determination Requirements
        - Take Off Alternate (FAR 121.617)
        - Destination (FAR 121.619, 121.625, 121.635)
        - Additional [Second] Alternate {Domestic Flight Ops Only} (FAR 121.619)
        - Drift Down Alternate (FAR 121.191)
    - Area and En route Weather
    - METAR [current] and TAF [forecasted]
    - SIGMETS/AIRMETS (current and outlooks)
        - Icing
        - Turbulence
        - Convective SIGMETS

- Volcanic Ash Advisory
- Solar/Space WX activity
- Weather Warnings (WW) for area of operation and responsibility
- PIREPS
- Field Conditions
  - ATIS/ASOS
  - Station Reports
- Graphical charts
  - Surface, WX depiction both High and Low, Jet stream, winds, high and low Sig. etc) GWAS (seasonal), GWRW, Radar (NEXRAD/Visible/Infrared), and satellite imagery
- Notices to Airmen
  - FDC, Local, Area, En route, Chart, Company
- Winds
  - Surface, Aloft, EWINS
- Seasonal Considerations
  - Winds
  - Fog
  - Extreme Temperatures
  - Bird Migration

Crew Flight Planning

Airlines have negotiated contracts with cockpit and cabin crews and have enlisted entire departments to comply with crew contracts and federal regulations that ensure compliance and correct irregularities, but the dispatcher still has final overview.

- Authority PIC (FAR 91.3, 121.551, 121.553, 121.627))
- Qualification (FAR 61.3, 121.383, 121.433, 121.434)
  - Medical (Far 61.23, 61.53)
  - Training (FAR 121.439)
    - Initial / recurrent (FAR 121.409, 121.438, 121.441, 121.440)
    - Equipment (upgrade to FMS, RNP .3)
    - Safety (FAR 91.13, 121.535, 121.537)
    - Airport (FAR 121.445)
    - Route (FAR 121.445)
  - Pairing (FAR 121.385)
- Time (FAR 121.384, 121.471, 121.503, 121.505)
  - Flight time (today, month, year; scheduled -extended)
  - Duty time (today, past 24 hours, extended- from scheduled)
  - Rest time (regular, extended)
- Human Factors
  - Evaluate all relevant data and signs ensure safe/prudent operation ask questions and evaluate answer and situation.

Flight Following Activities (FAR 121.533) (Applicable OIs: OI-0303, OI-0306, OI-0350, OI-0382, OI-0385)

- Monitor
  - Flight progress
    - Ensure remain on flight path and altitude assigned
    - Watch traffic flows and possible constraints in delays
      - Miles In Trail (MIT)
      - Route Deviation (Re-route)
      - Holds
      - Nominal/Off-nominal dynamic route modification
  - Weather
    - Departure/Destination/Alternate change to METAR or TAF
      - Departure/approach routes
      - Required alternate change or addition
    - Storm systems forcing modification to route or approach
    - Fronts, winds, Significant WX causing modification to route

Dispatch Resource Management (DRM) (Applicable OIs OI-0303, OI-3120)

- Communication (FAR 121.147)
  - Exchange of ideas, information, and instruction in an effective and timely manner so messages are correctly received and clearly understood
  - Briefing/debriefing, inquiry, assertion and conflict resolution
  - Inclusive of flight crew briefings
- Situational Awareness (FAR 121.533)
  - Ongoing process of attentiveness and surveillance
    - Understanding current conditions
    - Anticipating outcomes of those factors
  - Maintain situational awareness, vigilance must be exercised at all times
- Decision Making
  - Determining and implementing a course of action and evaluating the outcome
  - Process includes;
    - Problem recognition
    - Information assessment
    - Identifying alternatives and a timely resolution
- Workload Management
  - Planning, prioritizing and recognizing situations where task saturation has occurred or is imminent
  - Ability to request or provide assistance and delegate as needed is essential

Flight Planning Reference Guide
Input Flight number, hold/extra fuel, MEL, alternate etc
Route Planning and Selection
Preferred Routes and National Route Program (NRP)

ATC Considerations (Playbook Routes, CDR's, Chokepoints, GDP/GS, FCA's, ICR's and Holding)

Review Alternate Routes

NOTAM Considerations (En route, Facility, Company)

Airspace Considerations (RVSM, Restricted/Warning Areas/Special Use)

Build Route, Restricted Area Building, Display Route function)

Special Considerations

Over Water (50 nm from shore, 162 nm Exemption, O/W Equipped)

Does aircraft have necessary equipment?

Fuel for greatest route provide fuel burns for alternate route selections

Meteorological Considerations (SVR WX, Turbulence, Icing, Solar, Ozone)

En route Time Management (On-Time D +14/Slow-Fast consideration, Speed Adjustment)

Volcanic Ash/Smoke (Avoidance and required reports)

Alternates

- **Destination requirement** (1,2,3 rule, exemption 3585)
- **Selection** (High/Low prob., Marginal requirements, Tower/No Tower Ops)
- **Take-off** (requirement for, parameters for selection)
- **En route** (Method I and II /Manipulation of Drift down Record)
- **Determining Minimums –** (correctly determine Alternate minima)

Fuel

- **Fuel Guidance** (FAR, Hold, Extra, Policy)
- **Taxi Fuel Considerations** (Manipulation/Max ramp weight)
- **Economic** Operational, Ferry Fuel
- **Density / Capacity** (Weight and Balance Fuel)
- **Abnormal Fuel** (Structural check fuel, Pay Load Fuel, Unusable Fuel)

ATC Flight Plan

- **Filing** (Service Provider, Lockheed Martin FSS)
- **Amend** (Timing for auto amendment)
- **Cancellation** (Timing for auto cancellation)
- **Remarks** (DVRSN, lifeguard, MAINT TEST FLT, etc)
- **Radio Numbers** (Purpose)
- **PDC**

Weight and Balance

- **Airport Analysis** (request for data run program)
- **DPWM** (taxi fuel, TOGW, security, MEL, CLP Phone)
- **Weights Call**
- **Weight Restricted** (En route Stop, Equipment Substitution)
- **Adjustments** (Max. fuel Tank Capacity, RWY Clutter, Method I or II)
- **Manual ATOG adjustment**

MEL / CDL Application

- **PLACARD** (MEL Reference)
- **Handle Manually MEL's** (MELC)

Output Flight Plan

Flight Planning Guide Shell

Flight/Tail Number	
Origin	
Intermediate Stop	
Destination	
Alternate Airport Required Including Take Off Drift Down and Destination	
Minimum Fuel Supply	
Any Exemptions Used (3585)	
Required Documentation	
Hold Fuel (minutes or pounds)	
Extra Fuel: for deviation, Operational	
MEL's and any associated restrictions	
Primary Route Planned	
Secondary Route Planned	
Third Route Planned	
Additional Route (s) Planned	
Fuel Consumption for Primary Route	
Fuel Consumption for Secondary Route	
Fuel Consumption for Third Route	
Fuel Consumption for Additional Route	
ATC Considerations/Constraints	
Alternate Route Planned (greatest dist)	
Fuel Consumption for that Constraint	
Weather Considerations/Constraints	
Fuel Consumption for WX Constraint	
Time Considerations (adjust speeds)	
Fuel Consumption for that Change	
Altitude Considerations (adjust altitude)	
Fuel Consumption for that Change	
Fuel for Longest Route / Constraint	
Add fuel for Taxi	
Calculations for Adjusted Routes	
File Agreed-upon Plan (multi routes)	

Flight Planning Guide for Transcon 1324

Flight / Tail Number	Transcon 1324
Origin	Detroit (KDTW)
Intermediate Stop	-------------------
Destination	Dulles (KIAD)
Alternate Airport Required Including Take Off Drift Down and Destination	Take- Off Alt. (KIAD) 333NM [assume 777; 370nm] Destination. Alternate (KJFK) 200NM
Minimum Fuel Supply	43,450 lbs wheels up
Any Exemptions Used (3585)	Not required
Required Documentation	Standard
Hold Fuel (minutes or pounds)	60 min – 10,000 lbs
Extra Fuel: for deviation, Operational	20 min deviation – 3300 lbs
MEL's and any associated restrictions	None
Primary Route Planned	NRP(DTW..ACO2..ACO-AIR.J34-ESL..SHNON2..IAD)
Secondary Route Planned	DTW-WINGS.V103-ACO-AIR.J162-MGM..JASEN4..IAD
Third Route Planned	DTW..MAARS1..ACO-AIR-MGM..JASEN4..IAD
Fuel Consumption for Primary Route	12650 lbs (79 min)
ATC Considerations/Constraints	ZOB / ZDC constrained 60 min max delay
Alternate Route Planned (greatest dist)	Closed trajectory 150 nm course correction
Fuel Consumption for that Constraint	5760 lbs (150 nm or .6 hour)
Weather Considerations/Constraints	30 min possible delay or reroute
Fuel Consumption for WX Constraint	4800 lbs
Time Considerations (adjust speeds)	-------------
Fuel Consumption for Speed Change	-------------
Altitude Considerations (adjust altitude)	-------------
Fuel Consumption for Altitude Change	------------
Fuel for Longest Route / Constraint	5760 lbs
Add fuel for Taxi	2000 lbs (15 min taxi burn dual engine weight restriction)
Calculations for Adjusted Routes	
File Agreed-upon Plan (multi routes)	Fueled for greatest route and longest delay
Fuel Summary	Destination 12650, Destination alternate 10000, hold 10000, reserve 7500, add 3300, taxi 2000; total release fuel 45,450 lbs
Additional Considerations and or Nominal / Off-Nominal Events	Midwest Airspace Enhancement (MASE) EA addressed specific runway configurations, fixes, aircraft type on predetermined (i.e., closed trajectory) routes; additionally in an earlier ATC call possible constraints identified

What follows is the ***Flight Planning Guide*** for the flight from Phoenix to Miami.

Flight / Tail Number	Sunset 42
Origin	Phoenix (KPHX)
Intermediate Stop	--------------------
Destination	Miami (KMIA)
Alternate Airport Required Including Take Off Drift Down and Destination	Destination Alternate KRSW
Minimum Fuel Supply	
Any Exemptions Used (3585)	Not Required
Required Documentation	Standard, Overwater Equipped
Hold Fuel (minutes or pounds)	45 Minutes (4200 lbs – below FL100)
Extra Fuel: for deviation, Operational	En route SUA pending activity 100 nm (1500 lbs)
Extra Fuel: for deviation, Operational	En route Volume Contraint 12 Minutes (1100 lbs)
MEL's and any associated restrictions	None noted
Primary Route Planned	PHX..TFD2..CIE.J2-JCT.J86-LEV.Q102-BAGGS..SSCOT1..MIA
Secondary Route Planned	PHX..TFD2..CIA.J2-JCT.J86-LEV.Q102-CYY..CYY5..MIA
Third Route Planned	PHX..TFD2..CIE.J2-ELP.J86-PUFER-LCH-HRV.Q105-BLVNS.Q102..SSCOT1..MIA
Additional 4TH Route Planned	PHX..SJN5..SJN.J74-TXO-FUZ.J58-HRV.Q105-BLVNS.Q102-BAGGS..SSCOT1..MIA
Additional 5TH Route Planned	PHX..TFD2..CIE.J2-FST.J138-CSI.J138-WEEVE.J86-LEV.Q102-BAGGS..SSCOT1..MIA
Additional 6TH Route Planned	PHX..MOBIE2..GBN.J2-ELP.J183-CLL-LFK.J50-CEW.J2-SZW..SSCOT2..MIA
Additional 7th Route Planned	PHX..MAXXO1..CNX.J74-TXO-FUZ.J58-AEX-MCB.J50-CEW.J2-SZW..SSCOT1..MIA
Fuel Consumption for Primary Route	21,310 lbs
Fuel Consumption for Secondary Route	21,415 lbs
Fuel Consumption for Third Route	22,275 lbs
Fuel Consumption for Additional Route	23,182 lbs
ATC Considerations/Constraints	15 en route 45 destination; 60 total (4,850 lbs)
Alternate Route Planned	1894 nm

(greatest distance)	
Fuel Consumption for that Constraint	23,882 lbs
Weather Considerations/Constraints	10 minutes

Fuel Consumption for WX Constraint	990 lbs (at altitude)
Time Considerations (adjust speeds)	10 minutes
Fuel Consumption for that Change	990 lbs (at altitude)
Altitude Considerations (adjust altitude)	2,000 ft
Fuel Consumption for that Change	1,200 lbs

Fuel for Longest Route / Constraint	28,882 lbs
Add fuel for Taxi	15 minutes 800 lbs (53 lbs min dual engine idol)
Calculations for Adjusted Routes	2,572 lbs difference
File Agreed-upon Plan (multi routes)	Fueled for greatest route
Fuel calculations	En route Destination 21,310; Taxi 800; Alternate 2,494; Reserve 3613; En route Hold 1,150; Destination Hold 3,700; Contingency: Weather 990, Speed 990, Altitude variation 1,200; NM difference between routes 2,372; Total release fuel 38,819
Additional Considerations	SWIM network data communication conference revealed several nominal and off-nominal considerations for constraints on routing, special use airspace, two areas of constraints for volume, and two weather constraints along with altitude/speed limitations en route.

Appendix C
Acronyms

The following is a list of acronyms used in the TBO Study Team Report:

3D	Three Dimensional
4D	Four Dimensional
4DT	Four Dimensional Trajectory
ACFT	Aircraft
ACO	Air Carrier Operator
ADS-B	Automated Dependent Surveillance Broadcast
ADS-C	Automated Dependent Surveillance – Contract
AFP	Airspace Flow Programs
AGL	Above Ground Level
AMASS	Airport Movement Area Safety System
ANSP	Air Navigation Service Provider
AOC	Airline Operations Center
AOM	Aircraft Operating Manual
APU	Auxiliary Power Unit
ASD	Aircraft Situation Display
ASDE-X	Airport Surface Detection Equipment, version X
ASOS	Automated Surface Observation System
ASSC	Airport Surface Surveillance Capability
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATIS	Automatic Terminal Information Service
BZN	Gallatin Field, serving Bozeman, MT
CATM	Collaborative Air Traffic Management
CDL	Configuration Deviation List
CDM	Collaborative Decision Making
CDR	Coded Departure Routes
CDTI	Cockpit Display of Traffic Information
CMU	Communication Management System
ConOps	Concept of Operations
CSPO	Closely Spaced Parallel Operations
CTA	Controlled Time of Arrival
DCL	Departure Clearance
DHS	Department of Homeland Security
DOD	Department of Defense
DRM	Dispatch Resource Management
DTW	Detroit Wayne County Metropolitan Airport
DUATS	Direct User Access Terminal Service
EDT	Expected Departure Time
EFB	Electronic Flight Bag
EFVS	Enhanced Flight Vision Systems

EICAS	Engine Indicating and Crew Alerting System
ETA	Estimated Time of Arrival
ETA	Estimated Time of Arrival
ETOPS	Extended-range Twin-engine Operational
EVS	Enhanced Vision System
EWINS	Enhanced Weather Information Systems
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FANS II	Future Air Navigation System model 2
FANS-I	Future Air Navigation System model 1
FAR	Federal Aviation Regulation
FAS	Final Approach Speed
FBO	Fixed-base Operator
FCA	Flow Constrained Area
FDC	Flight Data Center
FL250	Flight Level altitude of 25,000 feet
FMS	Flight Management System
FOC	Flight Operations Center
FSS	Flight Service Station
GBAS	Ground-based Augmentation System
GDP	Ground Delay Program
GLS	GPS Landing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GS	Ground Stop
HASMAT	Hazardous Materials
HITS	Highway-In-The-Sky System
HMI	Human-Machine Interface
HUD	Heads-up Display
IAD	Washington-Dulles International Airport
IAF	Initial Approach Fix
IAH	George Bush Houston Intercontinental Airport
ICR	Initial Collaborative Rerouting
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Condition
IWP	Integrated Work Plan
JPDO	Joint Planning and Development Office
JTIDS	Joint Tactical Information Distribution System
LAAS	Local Area Augmentation System
LAHSO	Land and Hold Short Operations
LNAV	Lateral Navigation
LOA	Letter of Agreement
LPV	Localizer Performance with Vertical Guidance
MEL	Minimum Equipment List

MIA	Miami International Airport
MIT	Miles in Trail
MLAT	Multilateration
MOPS	Minimum Operational Performance Standards
MSL	Mean Sea Level
NAS	National Airspace System
NEXRAD	Next Generation Radar
NextGen	Next Generation Air Transportation System
nm	Nautical Mile
NOTAM	Notices to Airmen
NRP	National Route Program
OI	Operational Improvement
OPC	Optimized Profile Climb
OPD	Optimized Profile Descent
PAX	Passenger
PDC	Pre-departure Clearance
PHX	Phoenix International Airport
PIC	Pilot in Command
PIREPS	Pilot Reports
PNT	Positioning, Navigation and Timing
RAIM	Receiver Autonomous Integrity Monitor
RCP	Required Communications Performance
RF	Radius to Fix
RNAV	Area Navigation
RNP	Required Navigation Performance
RSP	Required Surveillance Performance
RTA	Required Time of Arrival
RTP	Required Time Performance
RVR	Runway Visual Range
RVSM	Reduced Vertical Separation Minimum
RWSL	Runway Status Lights
RWY	Runway
SAP	Stable Approach Point (1,000 feet AGL)
SAS	Single Authoritative Source
SBAS	Satellite-based Augmentation System
SBS	Surveillance Broadcast Service
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
SLC	Salt Lake City
SLEP	Service Life Extension Program
SMS	Safety Management System
STAR	Standard Terminal Arrival Route
SUA	Special Use Airspace
SVR WX	Severe Weather
SVS	Synthetic Vision System

SWIM	System-wide Information Management
TBO	Trajectory-based Operation
TCAS	Traffic Collision Avoidance System
TDFM	Terminal Departure Flow Management
TERPS	Terminal Instrument Procedures Tools
TFDM	Tower Flight Data Manager
TFR	Temporary Flight Restriction
TIS-B	Traffic Information System – Broadcast
TMI	Traffic Management Initiative
TOD	Top of Descent
TOGW	Takeoff Gross Weight
TOps	Trajectory Operations
TRACON	Terminal Airspace Control facility
UAS	Unmanned Aerial System
UAT	Universal Access Transceiver
UTC	Coordinated Universal Time
V&V	Verification and Validation
VCSPR	Very Closely Spaced Parallel Runways
VDLF	VHF Data Link Frequency
VFR	Visual Flight Rules
VHF	Very-high Frequency
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
WAAS	Wide Area Augmentation System
WILCO	Will Comply
WX	Weather

Document Revision History

VERSION	DATE	DESCRIPTION
Draft Version 1.9	9/15/10	Agency coordination copy
Draft Version 1.9.1	9/20/10	Modification of appendices
Draft Version 1.9.2	4/14/11	Modified to reflect delays in RTCA TOps scheduled activities and changed title from "Operational Scenarios for 2025" to "Operational Scenarios for NextGen"
Draft Version 2.0	11/14/11	Coordination of final report with team members
Final Report	12/4/11	Delivery of final report to JPDO from team