

Air Traffic Management Technology Demonstration-1 Concept of Operations (ATD-1 ConOps), Version 2.0

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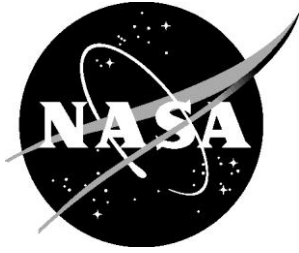
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NASA/TM-2013-218040



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National Aeronautics and
Space Administration

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Hampton, Virginia 23681-2199

September 2013

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
443-757-5802

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1.0 Introduction/Scope

This document updates the Concept of Operations (ConOps) for the Air Traffic Management (ATM) Technology Demonstration #1 (ATD-1) [ref 1]. It describes the goals, benefits, technologies, and procedures for ATD-1 operations, and is an update to the original version (Version 1.0) published in 2012. Significant changes between versions are highlighted in Appendix B.

ATD-1 is sponsored by the National Aeronautics and Space Administration (NASA) System Analysis, Integration, and Evaluation (SAIE) Project, part of NASA's NextGen Airspace System Program (ASP). The ATD-1 goal is to operationally demonstrate the capability of three integrated NASA research technologies, along with Automatic Dependent Surveillance – Broadcast (ADS-B) In technology, to achieve Trajectory-Based Operations from cruise to the runway threshold while maintaining high throughput in busy terminal airspace. The expected benefits of reduced fuel consumption and improved schedule integrity are intended to address the forecasted increase in aircraft operations and flight delay, as well as stimulate equipage with ADS-B In to achieve these benefits [ref 2, ref 3].

The technologies are:

- TMA-TM: “Traffic Management Advisor with Terminal Metering” (TMA-TM) for precise time-based schedules to the runway and meter points within terminal airspace
- CMS: “Controller-Managed Spacing” (CMS) decision support tools for terminal airspace controllers to better manage aircraft delay using speed control
- FIM: “Flight-deck Interval Management” (FIM) aircraft avionics and flight crew procedures to conduct airborne spacing operations

In the near future, NASA, the FAA, and industry partners will define the scope, location, and schedule of these demonstration activities. Results from the research into these technologies and the demonstration activities will be used for technology transfer to the operational systems employed by the FAA and industry partners. These technologies and their transfer are currently in the FAA roadmap and decision making documents for operational deployment.

The ATD-1 ConOps is an integrated system that could be deployed in the 2015-2020 timeframe, and aligns with the Federal Aviation Administration's (FAA) NextGen Mid-Term ConOps [ref 4], the Terminal Sequencing and Spacing (TSS) Concept of Operations [ref 5], the Time-Based Flow Management (TBFM) ConOps [ref 6], and is consistent with the FAA's expected National Airspace System Enterprise Architecture Operational Improvements (OI) in the 2015-2018 timeframe. In its NextGen Mid-Term Implementation Plan (NGIP) [ref 7], the FAA has accepted the Air Traffic Control Association (ATCA) NextGen Mid-term Task Force's Tier 1 recommendations, which included specific guidance that the FAA and the aviation industry should agree on the set of capabilities that warrant equipage incentives. The FAA has stated that it will establish priorities for incentivizing operator equipage for Performance-Based Navigation (PBN), Automatic Dependent Surveillance–Broadcast (ADS-B) and Data Communications (DataComm).

The ATD-1 ConOps also closely aligns with the FAA Surveillance Broadcast Services (SBS) Program's Interval Management – Spacing (IM-S) ConOps [ref 8]. In addition to these ConOps, the ATD-1 ConOps also supports NASA's Integrated Arrival, Departure, and Surface (IADS) concept for the Mid-Term [ref 9], and takes advantage of PBN specifications and requirements [ref 10]. Related ATM research and concepts are described in Appendix C.

This document is consistent with FAA guidance for ConOps development [ref 11], and provides concept-level requirements for supporting services, systems, technologies, tools, procedures, and airspace changes. This document focuses on the arrival scenarios and procedures to be used during the ATD-1 operational evaluation of TMA-TM and CMS (planned for 2015-2016), and flight test of FIM avionics with TMA-TM and CMS (planned for 2016). Aircraft data transmitted via ADS-B will be used by air traffic ground tools and by aircraft equipped to receive that data. The end-state operational concept of these capabilities include other flight phases (e.g., departure operations), incorporate other technologies (e.g., DataComm.), and incorporate more sophisticated controller decision support tools; however only the ATD-1 operations and procedures that are enabled by technology expected to be fielded by the demonstration timeframe are discussed in this document.

1.1 Background

To prepare the National Airspace System (NAS) for the traffic volume increases predicted by 2025 and to improve the efficiency of the air transportation system, Congress enacted the Vision 100 – Century of Aviation Reauthorization Act and created the Joint Planning and Development Office (JPDO) in 2003. The JPDO – composed of representatives from the FAA, NASA, the aviation industry, the Departments of Transportation, Defense, Homeland Security, and Commerce, and the White House Office of Science and Technology Policy – was tasked to develop a vision of the NAS in the year 2025 that promotes scalability of air traffic operations. The JPDO published a Concept of Operations for NextGen that describes a high-level vision for the air transportation system for the year 2025 and includes a description of the roles for the various operating elements within the air transportation system [ref 12]. The ATD-1 ConOps is thematically consistent with this JPDO NextGen ConOps.

Increasing the capacity and efficiency of the NAS are primary goals of the JPDO NextGen ConOps and ATD-1 ConOps. Achieving these goals requires that the throughput to the high-density airports and the efficiency of arrival operations be simultaneously optimized. The FAA's NextGen Operational Improvements (grouped by Solution Set) associated with ATD-1 and the capabilities that enable them are:

- Initiate Trajectory Based Operations (TBO)
 - 102137 Automation Support for Separation Management (2014-2018)
 - 104120 Point-in-Space Metering (2014-2018)
 - 108209 Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigation Performance (RNP) (2010-2014)
- Increase Arrival/Departure at High Density Airports (HD)
 - 104123 Time-Based Metering Using RNAV/RNP Route Assignments (2012-2016)
 - 104128 Time-Based Metering in the Terminal Environment (2015-2018)
- Increase Flexibility in the Terminal Environment (FLEX)
 - 104124 Use of Optimized Profile Descents (2010-2017)

- Increase Safety, Security, and Environmental Performance (SSE)
 - 109319 Environmentally and Energy Favorable ATM Concepts, Phase I (2011-2015)

1.2 Problem Statement

The 2013-2033 FAA Aerospace Forecast predicts U.S. commercial aviation revenue passenger miles will grow on average 2.9% annually throughout these twenty years. By 2033, U.S. commercial air carriers are projected to fly 1.74 trillion available seat-miles – approximately 175% the seat-miles flown in 2012 [ref 13]. Arrivals into high-density airports, especially during peak traffic periods and inclement weather, experience significant inefficiencies due to the use of miles-in-trail procedures and step-down descents. These procedures contribute to not achieving the airport’s maximum capacity, increase controller workload, increase arrival delay, and increase aircraft fuel burn, emissions and noise. While advanced PBN procedures exist at a limited number of sites (e.g., RNAV arrivals and optimized profile descents), they are not well utilized due to the lack of supporting scheduling and spacing tools and the lack of ATC awareness of aircraft capability (flight crew training and aircraft equipage) early in the arrival sequencing process.

1.3 Identification

Figure 1 shows the position of the ATD-1 ConOps within the FAA’s structure of Concept Levels (Level 1: Enterprise; Level 2: Service; Level 3: Sub-service; Level 4: Solution). While the ATD-1 ConOps was developed to directly support the Mid-Term Concept of Operations for the NAS [ref 4], the Level 2 and Level 3 ConOps are examples closely related to ATD-1, but not formally guiding the development of the ATD-1 ConOps.

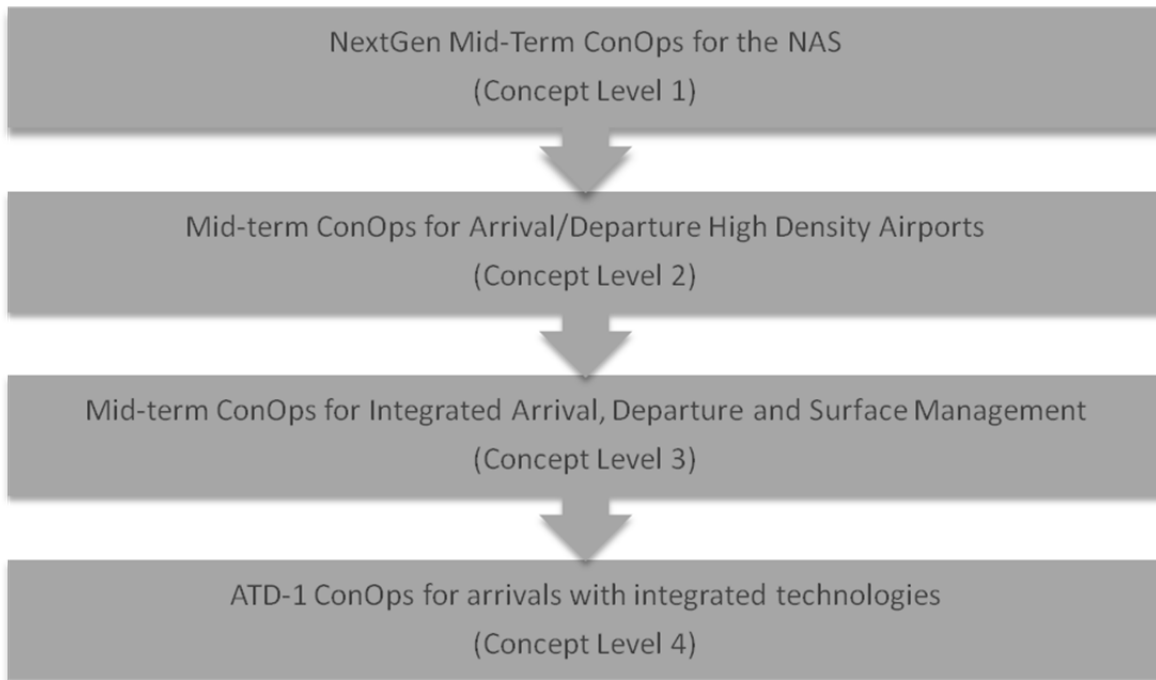


Figure 1. Position of ATD-1 within FAA operational concept hierarchy.

1.4 Operational Need

The operational need for the capabilities represented in the ATD-1 ConOps is driven by present day shortfalls in the air traffic management areas of capacity, flexibility, efficiency, safety, and environment [ref 4].

1.4.1 Capacity

For domestic flights in 2008, there was a total of approximately 3.2 million hours of delay according to the FAA's Aviation System Performance Metrics (ASPM) system [ref 4]. Approximately 20% of these hours were airborne delays (much more costly to airlines than ground delays), and these delays are expected to more than double in the next ten years without NextGen improvements [ref 14]. Throughput in high-density airspace, particularly around major metropolitan airports, is reaching its limit using current technology and procedures, in part due to ground automation lacking the means to identify areas of unused capacity in busy overhead and arrival/departure streams. Current automation lacks the means to not only identify areas of unused capacity, but to also forecast these areas.

1.4.2 Flexibility

Constraints in the infrastructure of today's NAS impart a limited flexibility on the Air Navigation Service Provider (ANSP) workforce. From the perspective of the ANSP, facilities offer limited flexibility in their ATM operations, in particular, their ability to respond to changes in traffic demand, weather, Special Activity Airspace, and other events. Challenges also exist for delegating tasks to flight crews, and for supporting operations other than first-come/first-served schedules (e.g., best-equipped/best-served).

1.4.3 Efficiency

Minimizing the cost of flight operations and the disruptions to the flying public require more efficient and predictable operations. The cost to operators is exacerbated by limitations on operating practices and routing options, while the flying public contends with an increase in flight delays and cancellations. This is especially true during inclement weather. Rather than allowing more efficient and direct routing to destination airports, flight plans are constrained by airspace design limitations, fixed airways, and inefficient arrival and departure procedures. Ground and airborne operations, particularly those in high-density airspace, are not integrated to maximize operational efficiency and capacity during peak demand. Aircraft navigation performance capabilities are not fully considered when providing separation management services or solving traffic flow management problems. Altitude, heading, and speed changes issued verbally by ATC are not entered into controller automation, which reduce the accuracy of conflict predictions generated by this automation, and reduce the fuel-efficiency of the aircraft's flight path. Furthermore, efficiencies gained in the en route airspace through advanced scheduling automation are often lost in terminal airspace due to that information not being shared with terminal airspace controllers. Finally, the inability of controller automation and cockpit automation to directly communicate with each other causes a loss of throughput during all phases of flight and across all operational conditions.

1.4.4 Safety

A primary goal of aviation is to continue to improve safety in all phases of flight, and secondarily to accommodate increased traffic growth and new types of aircraft in the years to

come. The need to improve safety is particularly important for those areas in which accidents and incidents have historically been more likely to occur, such as taxi operations, during convective weather events or periods of low visibility, and in operations in areas without surveillance services. The approach to aviation safety must evolve into one in which safety information and lessons learned are shared more freely, and combined with a cultural transformation for users and service providers from a reactive to a proactive approach to safety improvements.

1.4.5 Environment

Environmental concerns have become a global issue to which the aviation community must respond. The current airspace design and route structure typically requires aircraft to plan and to fly to waypoints that create inefficient horizontal routes and altitude profiles, in turn consuming additional fuel and time while contributing to greenhouse gas emissions. Current arrival and departure procedures often include incremental climbs and descents that are undesirable both from a fuel consumption and flight time perspective, and generate an undesirable noise footprint around airports. The more frequent use of complete PBN procedures increases the aircraft arrival time accuracy, which in turn reduces delay and increases throughput efficiency, which in turn reduces engine emissions, noise, and fuel consumption.

1.5 ATD-1 ConOps Overview

The ATD-1 ConOps combines advanced arrival scheduling, controller decision support tools, and aircraft avionics to enable de-conflicted and multiple efficient arrival streams in high-density terminal airspace (Figure 2). To achieve increased fuel efficiency during periods of high traffic demand, aircraft will use PBN procedures that include a transition from the arrival procedure to the instrument approach procedure of the assigned runway.

When the aircraft crosses the Freeze Horizon (see section 4.4.1), the TMA-TM tool assigns the most suitable runway and freezes the Scheduled Time of Arrival (STA) for the Meter Fix, terminal Meter Points, and runway threshold. The relevant schedule information is shown to en route and terminal controllers. The same route and schedule information is used by the software that calculates the data displayed to controllers (CMS) and flight crew (FIM).

En route controllers will issue the arrival procedure and expected runway to all aircraft, and use their current displays and GIM-S software to achieve the time calculated at the Meter Fix by TMA-TM. When the required delay is predicted to exceed the capability of speed-only operations, the en route controller will use path stretching (vectors) or step down the aircraft to lower altitudes to absorb the delay, and then revert to speed-only control when feasible. At that point, the controller will issue the flight crew the clearance to descend via the arrival procedure, and for equipped aircraft, issue a FIM clearance. If the delay isn't absorbed as expected, the controller interrupts the descend-via arrival procedure (and suspends the FIM operation if appropriate), then reverts to traditional separation strategies such as speed control, vectoring, and altitude assignments (step-downs) until the delay has been reduced.

Terminal controllers receive aircraft data and STA information, graphical information (spacing circles), as well as CMS advisories on their controller display to correct the remaining spacing error. Terminal controllers will use this information and the CMS advisories when speed control is sufficient to absorb the remaining delay.

All flight crew fly the appropriate speed (in prioritized order: controller assigned, FIM [if so equipped], published, company assigned) during the arrival and approach. Flight crews of FIM equipped aircraft will be issued a FIM clearance after the Freeze Horizon and after vectors (to absorb required delay) are no longer expected. The FIM clearance consists of the Target (or lead) aircraft, the Target's route of flight, and the Assigned Spacing Goal (ASG) between the two aircraft. FIM operations may use Target aircraft on the same or different arrival procedure as the FIM aircraft. Controllers will “suspend” FIM operations if the need exists to momentarily vector either the FIM aircraft or Target aircraft, and any controller issued vector or speed instruction takes priority of published procedures or FIM guidance.

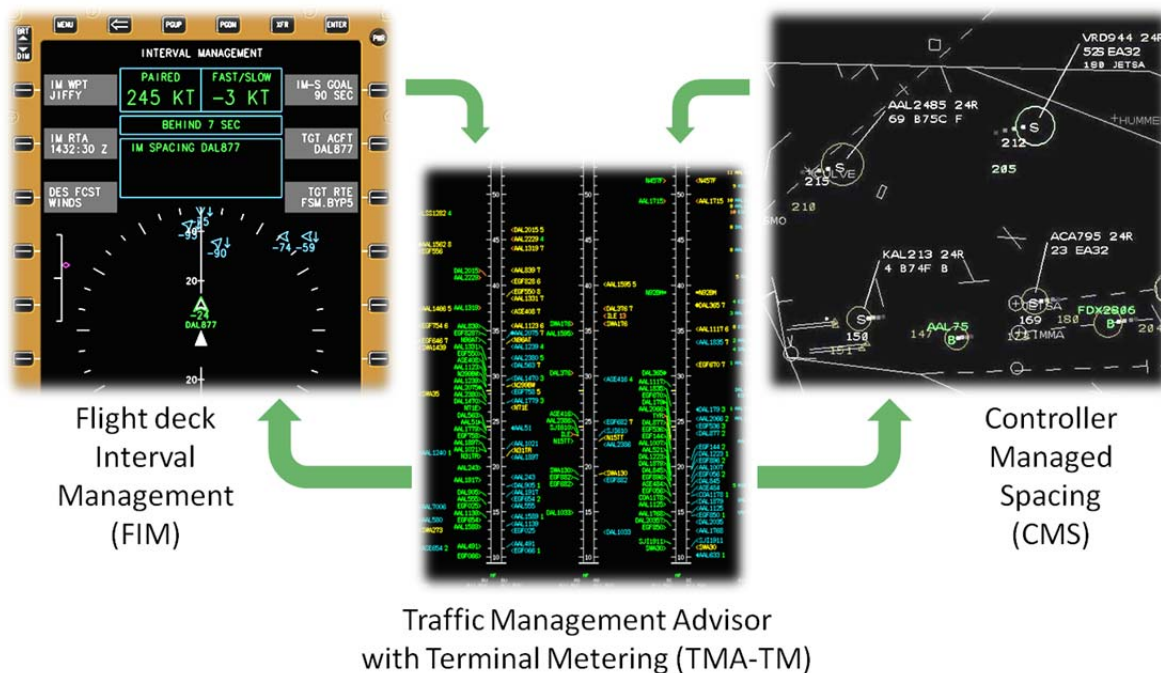


Figure 2. Integrated NASA technologies in the ATD-1 ConOps.

1.6 Integration with ANSP Ground Systems and Aircraft Systems

The ATD-1 ConOps and operations require the ATD-1 ground side technologies to be integrated with the Time-Based Flow Management system (TBFM), the En Route Automation Modernization system (ERAM), and the Standard Terminal Automation Replacement System (STARS). Interoperability with the FAA's soon-to-be-fielded Ground-based Interval Management – Spacing (GIM-S) capabilities is also required.

On the flight deck, the FIM technology required for aircraft systems may be installed either “forward-fit” for advanced aircraft (in particular, integrated with the autoflight system), or “retro-fit” for aircraft currently in operational use (such as one or more auxiliary displays, to include one in the primary field of view). The “retro-fit” option is considered the most likely airborne integration option to meet the planned ATD-1 demonstration time frame.

2.0 Operations and Capabilities

This section provides a description of the present-day operational elements supporting arrivals into high-density airports, with emphasis on aspects that the ATD-1 ConOps proposes to change.

2.1 Description of Users in Current Operation

An aircraft landing at a high-density airport traditionally executes a series of step-down descents starting at its cruise altitude, flies along a published airway, transitions to a Standard Terminal Arrival Route (STAR), and enters terminal airspace at a metering fix or corner-post. The aircraft is then handed off by the Air Route Traffic Control Center (ARTCC) to the Terminal Radar Approach Control (TRACON). The STAR simplifies issuing the arrival procedure but frequently does not connect to the instrument approach procedure, particularly when the aircraft is approaching the runway from opposite the direction of landing traffic (i.e., downwind routes). When the STAR and instrument approach procedure do not connect, those aircraft must be given radar vectors to the final approach course by the terminal controllers.

During current arrival operations, aircraft may conduct an Optimized Profile Descent (OPD), or fuel-efficient profile descent from cruise to the runway in light to moderate traffic. The vertical profile of the OPD trajectory can vary based on several factors (aircraft type and weight, terminal area winds, etc.), and can be unpredictable for controllers. This variability and unpredictability make it difficult for the ANSP to maintain aircraft separation without controller intervention, particularly at merge points, making it difficult to maintain the OPDs during periods of high throughput. Recently, some newly certified RNAV STARs have been designed to achieve OPD benefits by reducing or eliminating level segments on the procedure. They include vertical and speed constraints to make the procedures more predictable; however, challenges still exist that require controller intervention, especially when managing the separation of aircraft at merge points within TRACON airspace.

The stakeholders supporting arrival operations into high-density airports include:

2.1.1 Traffic Flow Management (TFM) Traffic Management Coordinators (TMCs)

For airports with sufficient levels of traffic demand to necessitate arrival metering operations, Traffic Flow Management TMCs use TMA to perform metering by assigning arrival metering point time (MPT) constraints. TMA uses these arrival MPT constraints to determine the time for each aircraft to cross into TRACON airspace, and uses en route MPT constraints for aircraft upstream from the arrival sector. By assigning arrival MPT constraints, TMCs plan aircraft sequences and spacing (in time) across each arrival meter point to help ensure that the airport will receive arrival demand that matches its prescribed arrival capacity. TMCs also maintain the airport configuration and decide when a reschedule of a single aircraft or a global reschedule of all aircraft is needed.

2.1.2 En Route (ARTCC) Sector Controllers

En route controllers monitor flight progress and maintain separation in en route airspace, issue descent clearances, merge arrival streams prior to the TRACON boundary, and ensure that Traffic Management Initiatives (TMIs), including specifications for sequencing and spacing, are

maintained. When an aircraft has been assigned an MPT by TMA, the en route controller manages the aircraft, as necessary, to ensure that the aircraft meets its assigned MPT and maintains separation with other aircraft. Maneuvers used to meet the MPT constraints could include a lateral maneuver (vector to a heading and then back direct to a fix on the route), an altitude adjustment (such as a step descent), or a speed adjustment. Current practice is to adjust speed first to achieve the required meter time, and then if needed, step the aircraft down in altitude to lower the ground speed, or issue a vector to path-stretch the route. Controllers also have the option of altering the TMA-calculated sequence of arriving aircraft (known as “swapping”) when they find it operationally advantageous.

2.1.3 Terminal (TRACON) Controllers

Terminal controllers monitor flight progress, separate departure and arrival flows using altitude limits for departure and arrival aircraft, maintain separation among aircraft within each specific flow, merge arrival streams in TRACON airspace, and make runway assignments. After aircraft enter TRACON airspace, arrival controllers monitor their descent, maneuvering them as necessary to maintain required separation. When the STAR connects to the approach procedure, controllers are frequently able to use primarily speed control to maintain the required separation. When the STAR does not connect to the approach procedure, TRACON controllers assign a number of heading, speed, and altitude changes to establish the aircraft onto the final approach course of its assigned runway. The terminal controllers have no information from the TMA system to aid in these tasks. The controllers use their experience and standard operating procedures to select a landing runway and to guide the aircraft from the entrance of the TRACON to the runway threshold.

2.1.4 Flight Crews

The flight crew is able to plan and execute a vertical profile (altitude and speed) along a lateral path that is optimized for their specific aircraft make and model, using its Flight Management System (FMS) and autoflight system. The FMS has data on the detailed performance specifications of the aircraft (desired performance requirements, engine model, fuel onboard, cargo weight, etc.), state information (present location, altitude, current winds, forecast winds, etc.), and other data (altitude constraints, noise abatement procedures, etc.) to optimize the vertical profile within the constraints of the assigned arrival procedure. Since the vertical profile is based on the aircraft’s energy state, the trajectory generated by the Flight Management System, and airframe-specific data, each aircraft will have a different vertical profile. The vertical profile differences between aircraft, particularly between different airframe types, can be significant. Most current generation FMSs only calculate the vertical profile prior to the aircraft reaching its top-of-descent point, and do not recalculate the vertical profile after the aircraft has started its descent. If the planned vertical profile is interrupted (i.e., the aircraft is temporarily held at an intermediate altitude or vectored off the expected lateral path), the vertical profile is not automatically recalculated.

Throughout the flight, crews adhere to ATC instructions such as altitude changes, vectors, and speed adjustments to achieve the appropriate sequence and required spacing interval. Since most arrivals into busy terminal areas are interrupted by controller instructions, flight crews are seldom able to fly the FMS-calculated lateral and vertical path all the way to final approach. The non-FMS guidance modes routinely used by flight crews and the additional distance in both

lateral and vertical flight path in busy terminal areas result in increased fuel consumption, aircraft noise, and engine emissions.

Flight crews of aircraft equipped with cockpit display of traffic information may monitor the position of other aircraft. Regardless of aircraft equipage, en route and terminal controllers have the responsibility of maintaining separation between aircraft. This is particularly challenging, especially during periods of high traffic demand, which results in nearly all OPDs being interrupted to maintain the desired separation between aircraft.

2.1.5 Airline Operations Center (AOC)

During the mid-term ATD-1 demonstration, connectivity between the ATD-1 technologies and the AOC will not exist. However, in the long-term vision of the ATD-1 ConOps, the Airline Operations Center (AOC) will have all current-day operational capabilities and responsibilities, as well as those presently being developed outside of the ATD-1 effort. It is postulated that the better arrival predictability could improve ground-handling functions conducted by the AOC, and potentially allow for the reduction in block times at the airport.

2.2 Supporting Capabilities

2.2.1 Current FAA Automation

During periods of congestion, arrival operations are characterized by significant interactions between the controller and pilots for the issuance of heading vectors, descent clearances, and speed changes to moderate the demand during the arrival process. The identification of congested periods is often accomplished using controller experience-based judgment, augmented by a number of tools (Flight Schedule Monitor, Flow Evaluation Area, Monitor Alert, etc.), as well as interactions between the TRACON and ARTCC. Whether it is the ad hoc experience or the TMA automation, decisions are made to apply delay such that the demand is safely moderated to the arrival capacity. Using ad hoc experience, the identification of congestion is done by observing how the final approach courses to the runways are being extended from the nominal (i.e., uncongested) procedures as well as utilizing the tools mentioned earlier. Upon observation that controllers need to continually extend the final approach segment to maintain aircraft separation minima (frequently referred to as “tromboning”), the TRACON Traffic Management Unit (TMU) may issue a miles-in-trail restriction to the ARTCC to moderate the controller workload and traffic flow. These restrictions are again ad hoc and experience-based, and they often cause excessive delay in the ARTCC. Miles-in-trail restrictions between the ARTCC and the TRACON may be generated by either the TRACON or ARTCC or in collaboration to meet an airport acceptance rate.

Proactive use of the TMA automation identifies periods of traffic congestion, and distributes delay between the ARTCC and TRACON using meter fix crossing times, known as scheduled time-of-arrivals (STAs). Though the TMA predicts congestion at the runway and moderates the flow at the meter fixes of the ARTCC/TRACON boundary, the TRACON does not have the ability to follow the TMA runway schedules due to a lack of controller interfaces and limited TMA modeling of merging procedures within the TRACON. To maintain the integrity of the schedule, TMA currently adds a buffer to the required separation to allow the TRACON to safely

moderate the congestion. This means the maximum runway capacity (based on the minimum separation requirements) is not realized. Even with this limitation, the TMA's proactive congestion identification and the arrival metering at the meter fixes has been shown to efficiently distribute arrival delay and controller workload between the ARTCC and TRACON while maintaining the runway throughput at the desired airport arrival rate. During periods of congestion, enroute controllers manage aircraft to the TMA generated meter times by issuing speed instructions, and if additional delay is required, they may descend the aircraft early or vector it off its route. Within the TRACON, terminal controllers manage the separation of aircraft by speed instructions and vectoring, as well as tromboning the turn to final.

2.2.2 FAA Automation to be Fielded for ATD-1

Ground Based Interval Management for Spacing (GIM-S) is part of the FAA's work to support Extended Metering. GIM-S adds additional meter points, called constraint satisfaction points (CSP), upstream from the arrival airport, and speed advisories to these points should mitigate or eliminate the dependency on miles-in-trail constraints. By conditioning the arrival flow, GIM-S is intended to reduce the number of interventions required by the controller, thereby reducing controller workload in busy arrival sectors. An aircraft's arrival time at the runway during the ATD-1 demonstration will be calculated by TMA-TM (see section 4.1.1), then coordinated with the FAA's GIM-S software to provide ARTCC controllers speed advisories for aircraft not conducting FIM operations. The GIM-S display and speed information will be used during the ATD-1 demonstration in ARTCC airspace by center controllers, since their software update cycle will not include CMS displays by the 2015-2020 timeframe. Center controllers will use the GIM-S speed for any aircraft not conducting a FIM operation.

Notional depictions of the GIM-S tool and aircraft full data block are shown in Figure 3. From left to right in the left panel, the columns represent the aircraft identification, STA at the respective waypoint, minutes early or late, and the GIM-S speed advisory (in Mach or Calibrated Airspeed). In the right panel, the full data block adds a fourth (bottom) row to show the controller assigned heading and Mach or calibrated airspeed.

| MRP | | | |
|---------------|------|--------|-----------|
| DCA NORTH 076 | | | |
| FAK | | | |
| <N50001 | 0127 | 1 | NO ADVSRY |
| <AWE302 | 0119 | 2 | M62/270 |
| <AWE303 | 0116 | - 1 | M73 |
| <AWE301 | 0113 | - 1:30 | M65 |
| OTT | | | |
| <COA207 | 0153 | 2 | |
| <COA206 | 0149 | - 1 | |
| <AWE304 | 0143 | 0 | 280 |
| <COA205 | 0118 | 3 | |
| <SWA403 | 0116 | 3 | 250 |
| <COA204 | 0114 | - 1 | 250 |
| <COA203 | 0113 | 0 | M58/230 |

| I | | | |
|---------|-----|------|-----|
| UAL1123 | 330 | 1290 | |
| 292 | 300 | 1 | |
| H250 | | | M78 |

Figure 3. Notional GIM-S displays and aircraft full data block.

2.2.3 Aircraft Avionics

The aircraft's avionics systems have limited information on surrounding traffic. The use of the Traffic Alert and Collision Avoidance System (TCAS) gives the flight crew an approximate picture of the immediate surrounding traffic, but it does not provide enough information to allow maneuvering in a manner integrated with ground control to achieve the overall air traffic management goals.

This limitation applies to the typical current minimum equipage for air transport aircraft. Certain aircraft are also equipped with Cockpit Display of Traffic Information (CDTI) devices, for example, some aircraft flying oceanic routes and participating in the In-Trail Procedures evaluation. These aircraft receive additional traffic information from Traffic Information Service - Broadcast (TIS-B). This additional equipage allows crews to conduct certain procedures, or make more informed requests, which enables more efficient operation of the aircraft.

3.0 Description and Justification of Changes

The ATD-1 ConOps addresses essential elements of NextGen by integrating several important ground-based and flight deck technologies to achieve efficient trajectory-based operations into a high-density airport during peak traffic periods. This section outlines changes to the current air traffic system in the NextGen mid-term (described in Section 2) and the justification for them. The benefits for NAS stakeholders that are expected from these changes are discussed in Section 4.5.

The following capabilities will be used during the ATD-1 operational evaluation and flight test activities:

- The use of a comprehensive, accurate, time-deconflicted schedule for all aircraft, to include runway assignment and adjustment for the forecasted terminal area winds
 - Enables the required delay to be distributed more efficiently
 - Allows schedule integrity to be maintained between en route and terminal airspace, creating fewer sequence swaps or changes to the assigned runway.
- Controller automation support to provide the schedule, assigned runway, waypoint meter times, and speed advisories to meet them, in both en route and terminal airspace
 - Reduces controller workload since using GIM-S or CMS speed advisories which should result in fewer events that require a vector from the controller
 - Reduces size of additional spacing buffer to aircraft separation requirements, in turn reducing total delay or increasing throughput.
- Extensive use of PBN procedures from the en route cruise altitude to the runway during periods of high-density traffic
 - Reduces controller workload due to fewer instructions required to issue the arrival procedure
 - Reduces flight crew workload due to less data entry into the FMS
 - Increases use of the aircraft auto-flight system to fly the PBN procedure, in particular using the FMS-calculated trajectory and TOD, will improve aircraft fuel efficiency, as well as reduce engine noise and emissions
 - Reduces the amount of airspace used for arrivals and increase the amount of airspace available for other procedures, such as arrivals to secondary airports.
- Increased use of advanced flight deck capabilities, to include ADS-B In and FIM technologies, displays, and procedures
 - Provides additional improvements in aircraft fuel efficiency, and reduction in noise and emissions
 - Enables the flight crew to predictably and accurately achieve the assigned spacing interval established by the schedule
 - Reduces controller workload due to fewer vectors and speed instructions required.

4.0 ATD-1 Concept of Operations

4.1 Concept Goal

The operational goal of the ATD-1 ConOps is to enable aircraft, using their onboard autoflight systems, to plan for and fly PBN procedures to the maximum extent possible, from cruise to the runway at a high-density airport, during peak traffic demand, using primarily speed control to maintain in-trail spacing and the arrival schedule. The three technologies in the ATD-1 ConOps achieve this by calculating a precise arrival schedule, using decision support tools to provide terminal controllers with speeds for aircraft to fly to meet times at particular meter points, and using onboard software providing flight crews with speeds for the aircraft to fly to achieve a particular spacing behind the preceding aircraft. Small increases or decreases in the speed flown by the aircraft during the arrival procedure (to retain aircraft fuel efficiency) will be calculated by the CMS or FIM software to achieve the schedule and thus the desired throughput.

By integrating time-deconflicted arrival scheduling with CMS tools and FIM capabilities in the terminal environment of high-density airports, the ATD-1 ConOps enables several important capabilities in the mid-term:

- **Mixed Equipage Operations** – A combination of ground-based and flight-deck-based Interval Management tools can help achieve sustained fuel-efficient operations during periods of high throughput while an aircraft fleet mix containing both less capable avionics and more advanced avionics.
- **Terminal Metering** – Advanced arrival scheduling enables flow conditioning throughout the entire arrival phase of flight to ensure efficiency gains achieved by advanced automation in en route airspace are not lost in terminal airspace.
- **Trajectory-Based Operations** – Integration of the arrival scheduling and Interval Management capabilities enables trajectory-based operations to be continued in terminal airspace during periods of high throughput when these fuel-efficient operations would otherwise be interrupted to maintain aircraft separation.

4.2 Concept Description

The ATD-1 ConOps provides de-conflicted and efficient operations of multiple arrival streams of aircraft, passing through multiple merge points, from top-of-descent to touchdown (see Figure 4). PBN arrival procedures, such as RNAV OPDs, are combined with advanced arrival scheduling through TMA-TM, CMS speed advisories and displays, and FIM capabilities (for those aircraft equipped) in the terminal environment of a high-density airport. These RNAV OPDs provide a lateral path from the en route jet route structure to the runway threshold (including transitions that connect the STAR to the instrument approach procedure), and specify vertical constraints, as required, and a speed for most segments of the arrival procedure. This enables the TMA-TM software to create a more accurate schedule, and allows flight crews to use their onboard autoflight systems to fly from en route cruise altitude to landing while requiring fewer controller interventions and fly fewer level flight segments [ref 15]. (RNAV OPDs are developed by the FAA and are independent from the ATD-1 project; however, the ATD-1 ConOps intends to enable aircraft to remain on PBN procedures more often, thus improving aircraft efficiency and airspace throughput.)

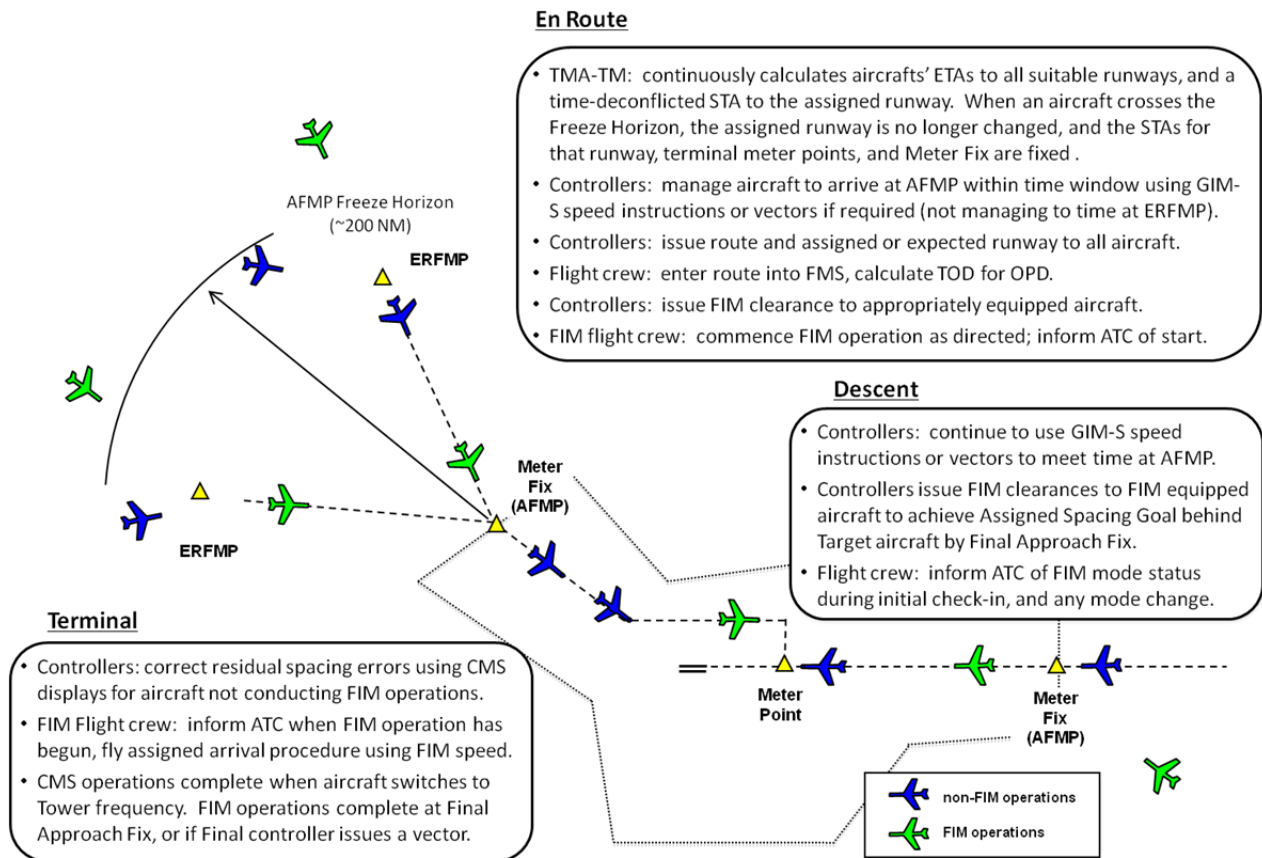


Figure 4. Nominal ATD-1 operation.

Where continuous RNAV OPD procedures do not exist from the enroute environment to the runway, TMA-TM uses supplemental information from the facilities standard operating procedures to calculate the arrival schedule. The same route and supplemental information is used by the CMS and FIM software to calculate the data provided by those displays, however, the CMS and FIM operation itself is terminated if the terminal controller must issue the flight crew a vector to intercept the final approach course (occurs when the STAR and instrument approach are not connected).

During ATD-1 operations, it is expected upstream flow conditioning will, in most situations, allow speed control alone to be sufficient to achieve the arrival schedule. The TMA-TM scheduling software continuously calculates ETAs and STAs for aircraft to all eligible active runways. The trajectories associated with these ETAs incorporate the aircraft's route-of-flight, top of descent, its intended speed profile, and the forecasted winds. When the aircraft crosses the Freeze Horizon (the goal is for this to occur prior to the aircraft's TOD), the TMA-TM tool assigns the most suitable runway and freezes the STAs for the runway threshold, Final Approach Fix, terminal meter points, and meter fix. The schedule information at each meter point is presented to the appropriate en route and terminal controllers (display of the information is contingent on the FAA's plan to implement updated software). (Note: the En Route Flow Meter

Point (ERFMP) shown in Figure 4 illustrates the potential interaction between ATD-1 and other concepts in the future, however an ERFMP will not be used by the ground scheduler or controllers during the ATD-1 demonstration.)

En route controllers will issue the arrival procedure and expected runway to all aircraft. They will also use their current DSR displays and GIM-S software to achieve the time calculated at en route meter points by TMA-TM when speed control is sufficient to absorb the remaining meter fix or en route meter point delays. When the delay is predicted to exceed the capability of speed-only operations, the en route controller will use path stretching (vectors) or lower altitudes to incur the required delay, and then revert to speed-only control when feasible. At that point, the controller will issue the flight crew a clearance to descend via the arrival procedure, then a FIM clearance to the flight crew of FIM-equipped aircraft.

Traffic permitting, flight crews will normally be given discretion to initiate descent from cruise altitude in order to utilize the FMS calculated trajectory and their onboard autoflight system to fly the RNAV OPD. If the delay isn't absorbed as expected, the controller will interrupt the descend-via arrival procedure, suspend FIM operations, and revert to traditional separation strategies such as speed control, vectoring, and altitude assignments (step-downs) until the delay has been reduced. At that time, the controller instructs the crew to resume the arrival procedure and FIM operation.

Terminal controllers receive aircraft data and STA information, graphical information (spacing circles), as well as CMS advisories on their STARS display to correct the remaining spacing error. Terminal controllers will use CMS advisories when speed control is sufficient to absorb the remaining runway or terminal meter point delays. However, the CMS spacing circles can still be displayed to facilitate the aircraft being returned to the PBN procedure after vectoring to achieve more delay than speed control affords. If the situation permits, terminal controllers can use CMS once the aircraft is able to resume its PBN procedure and speed control is sufficient.

FIM clearances will be issued as soon as possible after the schedule freeze and once vectoring is no longer expected; however, they may be issued after TOD to reduce the number of required voice instructions. FIM clearances may use Target aircraft on the same arrival as the FIM aircraft, or on a different arrival and crossing a different meter point to enter the TRACON. FIM clearances may be amended by ATC issuing a change to the ASG; however, controllers will "suspend" FIM operations if the need exists to momentarily vector either the FIM aircraft or Target aircraft. Changes to the arrival sequence, route of flight, or assigned runway require the FIM operation be terminated and a new FIM clearance issued if desired.

FIM operations normally terminate at the Achieve By Point (the Final Approach Fix for ATD-1). When ATC terminates a FIM operation prior to that point, the flight crew maintains the current or assigned speed, removes all FIM indications from cockpit displays, and deletes FIM clearance information from the avionics. When the STAR and instrument approach procedure do not connect, the FIM operation is also terminated when the controller issues the flight crew a vector to intercept the final approach course.

4.3 Assumptions and Requirements

Programmatic assumptions and requirements to accomplish ATD-1 include:

- NASA develops and the FAA implements TMA-TM at the ATD-1 demonstration site to support integrated scheduling and spacing within the TRACON (i.e., terminal metering).
- FAA implements ERAM changes to support display of the TMA-TM runway assignment for every aircraft, and to support use of GIM-S speed advisories by en route controllers.
 - Controller procedures and ERAM automation changes needed for FIM initiation and monitoring may not be available by the ATD-1 demonstration timeframe, and remains an area of on-going discussion with the FAA.
- NASA develops and the FAA implements CMS automation and displays within STARS at the ATD-1 demonstration site.
 - Controller procedures and STARS automation changes needed for CMS may not be available by the ATD-1 demonstration timeframe, and remains an area of on-going discussion with the FAA.
- The FAA develops and implements PBN procedures from the en route environment to the runway at the ATD-1 demonstration site.
 - Where PBN procedures are not available, ATD-1 technologies and operations will use adapted standard operating procedures (for example, a Letter of Agreement).
- Most aircraft scheduled to land at the high-density airport during peak traffic periods are equipped for RNAV operations.
- Some aircraft scheduled to land at the high-density airport during peak traffic periods are equipped for FIM operations (ADS-B In plus FIM displays and software).
- Controller-pilot communications will be by voice during the ATD-1 demonstration.

Technical assumptions and requirements are presented in Appendix E. Highlights include:

- ANSP retains responsibility for maintaining separation between all aircraft, and meeting the schedule for aircraft not conducting FIM operations.
- The TMA-TM schedule establishes the time-deconflicted arrival sequence of aircraft, and is available to all controllers.
- All controllers will actively manage to the schedule to the maximum extent possible, using published procedures and GIM-S or CMS advisories (when available).
- En route controllers will attempt to issue “Descend Via” clearances to flight crews, which authorizes them to meet fly the arrival procedure and meet the published altitude and speed constraints. The FMS may be utilized to maximize the aircraft’s efficiency while conforming to these constraints, thereby maximizing fuel efficiency as well as reducing noise and emissions.
- Flight crews retain responsibility for operating the aircraft in accordance with procedures and instructions (ATC instructions, FIM software speed guidance, etc.).
- The FIM clearance may be issued to any suitably equipped aircraft. The Target aircraft must be transmitting ADS-B and be assigned to the same runway as the FIM aircraft. However, it is not required that the Target aircraft to be in the same sector or to be on the same arrival procedure as the FIM aircraft, and it is not required that the FIM clearance be issued only after the Target aircraft is within ADS-B range of the FIM aircraft.

4.4 Operational Environment

The operational environment targeted for the ATD-1 ConOps is the latter part of NextGen Mid-Term (2015-2020). The ConOps will optimize the efficiency of arrival operations into high-density airports as well as the throughput of the airport. This ConOps will work with current and future ATC programs, and will subscribe to FAA, Aeronautical Information Conceptual Model (AICM), Aeronautical Information Exchange Model (AIXM) 5.0, the Flight Information Exchange Model (FIXM), the Weather Information Exchange Model (WXXM), and International Civil Aviation Organization (ICAO) data standards. Key related programs include TBFM, Terminal Automation Modernization and Replacement (TAMR) and its Standard Terminal Automation Replacement System (STARS) equipment, and developments in PBN such as RNAV STARs and RNP approach procedures. The controller procedure and automation changes needed for FIM initiation and monitoring may not be available by the ATD-1 demonstration timeframe on the En Route Automation Modernization (ERAM) platform for ARTCC, and this remains an area of on-going discussion with the FAA. The ATD-1 ConOps also relies on the FAA requirements for GIM-S capabilities to be added to ERAM. All of the required capabilities outlined in the requirements and operational environment are elements of the NextGen mid-term plan, and are expected to be available for the ATD-1 operational evaluation and flight test activities.

Within this operational environment, the three NASA technologies required to implement the NextGen mid-term ATD-1 ConOps are:

- An advanced version of TMA incorporating Terminal Metering (TMA-TM) [ref 16-19]
- Controller Managed Spacing (CMS) decision support software and displays [ref 20-21]
- Flight-deck Interval Management (FIM) spacing software and displays [ref 22-24]

A high-level description of each technology is provided in Appendix F.

The ATD-1 ConOps users and their notional relationship to each other during the mid-term are shown below in Figure 5. The final location of the NASA technologies will be determined by the FAA, and may vary based on the specific site. Not shown are other expected users and their interactions in the long-term version of ATD-1 operations, such as the AOC and Tower.

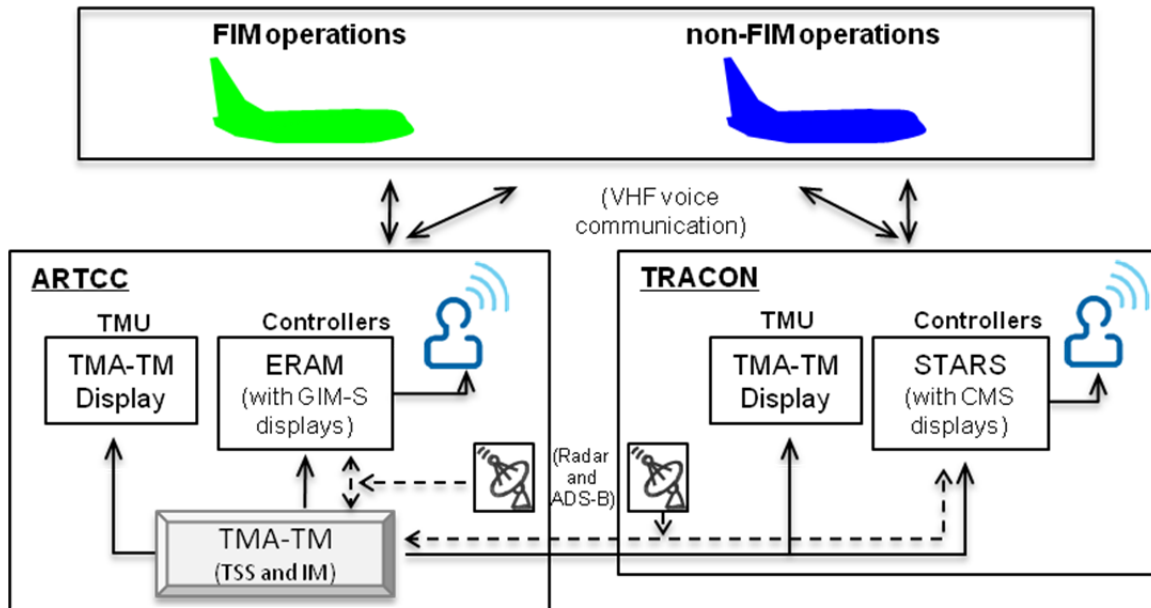


Figure 5. Block diagram of ATD-1 ConOps users.

4.5 Operations by ATD-1 Technology

4.5.1 TMA with Terminal Metering (TMA-TM)

A key element of the ATD-1 project is an advanced ground tool for ATM that determines an appropriate arrival schedule and the landing time intervals between aircraft, and then computes the appropriate speed required to space aircraft close to the minimum time or distance allowed for the runway conditions and meter points. TMA as presently deployed by the FAA in ARTCCs and some TRACONS, assists controllers and traffic managers in meeting STAs to closely match the desired separations, Airport Arrival Rate, as well as other constraints. The FAA also has systems and procedures being developed for extended metering and coupled scheduling (an enhancement to TBFM that allows for meter points and times to be defined well prior to the TRACON boundary) to precondition traffic flows further upstream.

While TMA and other decision support tools provide ancillary environmental benefits, their primary objective has been to reduce delay and increase throughput. Recent NASA research has focused on enhancing TMA and controller advisory tools to enable OPDs for the specific purpose of reducing fuel burn, emissions and noise impact. The TMA-TM system is a trajectory-based strategic planning and tactical control tool that consists of trajectory prediction, constraint scheduling and runway balancing, controller advisories, and flow visualization. The trajectory prediction, constraint scheduling, and runway balancing functions are built on the existing TMA. The controller spacing and metering advisories are built upon the research of the Controller Managed Spacing (CMS) and Efficient Descent Advisor (EDA) technologies. NASA simulations have shown that TMA-TM is beneficial in the development of a fully integrated trajectory-based automation that enables both more efficient utilization of the airport's capacity, and more fuel and emission-efficient operations from cruise to touchdown for NextGen.

TMA-TM extends the basic TBFM scheduling capability by including merge fixes inside TRACON airspace, and optimizes the flow of multiple arrival stream merges into an airport. The terminal delay model is enhanced to be more compatible with PBN procedures, and to enforce separation constraints at merges within the terminal area. The TMA-TM constraint scheduling, runway balancing logic, and algorithms necessary for the diverse operational requirements of ATC are beyond the scope of this paper, however the basic functional logic is a first-come-first-served algorithm that is then modified for separation requirements (radar and wake vortex). This logic is also coupled with a runway balancing algorithm that uses available runway capacity and a delay distribution in the terminal and en route airspace to create the aircraft specific STA. This creates conflict-free schedules simultaneously at the Center meter-fixes, terminal meter points, and the runway threshold. Additional details include:

- Freeze Horizon: a prescribed point at which (1) the aircraft's landing runway is calculated, (2) deconflicted STAs to the Meter Fix (TRACON boundary), terminal Meter Points, and runway are calculated, and (3) the runway STA is "frozen" (no longer updated automatically).
- Meter Fix Constraints: multi-step schedule process based on earliest ETA to the Meter Fix, with the first aircraft in the sequence STA equal to its earliest ETA, and subsequent aircraft STA set to ensure in-trail separation constraints are met.
- Runway Constraints: ensure required runway threshold separation is met (wake-vortex standards based on aircraft weight class, runway dependencies, etc.). Controllers may increase these values due to weather or other significant events.
- Delay Distribution Function: the delay distribution function sets the amount of delay that can be absorbed within the TRACON airspace when runway demand exceeds capacity, using only speed control.
- Meter Point Constraints: the STAs at TRACON meter points are evaluated simultaneously with the evaluation of STAs for the Meter Fix and runway to ensure that separation constraints are not violated. This is repeated until all aircraft have been scheduled without violating separation constraints at any merge-point.
- Runway Allocation: an event-driven algorithm that occurs periodically up until the aircraft crosses the freeze horizon, at which point the runway allocated to that aircraft is fixed. The algorithm considers the active flight plan, aircraft position, and total system time delay for all aircraft. Flight time for each aircraft is evaluated for the scheduled and alternate runways, and the runway allocated to the aircraft is based on the least total system time delay. Future versions of the runway allocation algorithm could include other factors, such as preferential scheduling of FIM-equipped aircraft.

Though TMA-TM creates an aircraft arrival sequence, it does not consider controller technique or workload. To reduce workload, controllers may re-sequence from one to five aircraft in one entry. Some events require a complete recalculation of the schedule (sequence, deconflicted STAs) for all aircraft inside the freeze horizon (airport configuration change, acceptance rate change, etc). This procedure is done by the controlling TMU. Controller displays (meter lists, speed advisors, and slot markers) are updated for both events.

The TMA-TM schedule and meter list has also been expanded to support en route controllers issuing GIM-S speed advisories and FIM clearances. Figure 6 displays the aircraft identification for NASA1 and NASA2, two aircraft proceeding to the waypoint SQUEZ. From left to right, the

asterisk indicates the aircraft's runway and STA is frozen, followed by the STA at SQUEZ and the amount of delay required to achieve it. Directly below the "T" is the GIM-S speed advisory (in Mach and Airspeed) calculated to achieve the STA at SQUEZ. SCADE is the Achieve By Point for the FIM aircraft, 124 the Assigned Spacing Goal in seconds, and the data on the right is the Target aircraft identification and the Target aircraft's route. (Note: to mitigate the expected lack of datalink communications in the ATD-1 Demo timeframe, the Achieve By Point has been removed from the FIM clearance to reduce controller and flight crew workload and voice transmissions, and will be removed from the meter list shown below.)

| T | | | | | |
|-----------------|------|--------|---------|-------|------------------------|
| METERLIST SQUEZ | | | | | |
| NASA2 * | 0253 | +00:00 | M85/340 | SCADE | 124 NASA1 SSO .KOOLY 4 |
| NASA1 * | 0251 | +00:00 | M84/340 | SCADE | |

Figure 6. TMA-TM meter list.

The TMA-TM schedule itself does not identify which aircraft are FIM capable, rather the “problem resolver” function within ERAM will identify those aircraft to enable generation of the FIM clearance. This function will also update the FIM status indicator when events occur that changes the FIM clearance. (Not updating or terminating a FIM clearance when these events occur could result in the FIM aircraft attempting to achieve the assigned spacing interval behind an aircraft no longer its lead.) TBFM is expected to calculate the GIM-S speeds, and ERAM will manage the display and advisory information.

4.5.2 Controller-Managed Spacing (CMS)

Controller-Managed Spacing (CMS) tools assist terminal controllers in achieving their goal of maximizing throughput on capacity-constrained runways. They ensure that the terminal controllers have knowledge of, and follow, the same arrival schedule that en route controllers use to manage the flows of traffic into the terminal airspace. The CMS tools provide the information necessary to more accurately achieve arrival schedule conformance using speed commands. This information is expected to allow terminal controllers to reduce the use of tactical vectoring, thereby minimizing interruptions to fuel-efficient PBN arrival procedures [ref 20-21].

The CMS tools consist of schedule timelines, slot markers (or ‘slot marker circles’), early/late indicators, and speed advisories shown in Figure 7. These tools function as follows:

- **Schedule Timeline (left panel):**
The schedule timeline displays the TMA-TM-computed schedule at the scheduling point relevant for a particular controller position. Entries for each aircraft show the aircraft identification code and a symbol that identifies the aircraft's weight class. Estimated time-of-arrival (ETA) entries appear on the left side of the timeline (always shown in white); scheduled time-of-arrival (STA) entries appear on the right side. The STA is colored green for aircraft that have not initiated hand-off to the sector, bright white when the upstream controller initiates hand-off, and the same white as the ETA when the receiving controller accepts the hand-off.

- Slot markers (top right and bottom right panels)
Slot markers translate the temporal schedule information into a spatial target on a controller's display. The slot marker circles indicate where an aircraft should be at a given time if it were to fly the arrival and approach procedures, meeting all published speed and altitude restrictions, and arrive on schedule. The instantaneous indicated airspeed of the slot marker is also displayed adjacent to the slot marker circle. In the figure, the aircraft shown are travelling right to left. In the top right panel, an aircraft that is close to on-time appears inside the circle, while in the bottom right panel an aircraft that is slightly early appears ahead of the circle. Note that the slot markers are always positioned along the RNAV OPD used to schedule the aircraft, even if the associated aircraft has been temporarily vectored off the procedure.
- Early/Late Indicators (top right panel)
Early/late indicators in an aircraft's Full Data Block (FDB) enable controllers to quickly assess the schedule conformance of that aircraft, in a manner similar to the delay countdown timer (DCT) presently available to ARTCC controllers. An early/late indicator is displayed using three characters in the third line of the FDB. Early/late indicators display the required delay with one-second precision when the absolute delay is less than 100 seconds (e.g., -15 indicates an aircraft is fifteen seconds late); larger delay values are shown with one-minute precision (e.g., +2M indicates an aircraft is approximately two minutes early). Thus, SWA353 is currently estimated to be three seconds early.
- Speed advisories (bottom right panel)
Speed advisories display airspeeds computed to put the aircraft back on schedule. The advised airspeed is computed using information about the nominal speed profile along the assigned RNAV OPD, and are displayed in ten-knot increments. If an aircraft is late, a speed increase may be advised. The speed advisories appear in the same three-character field on the third line of the FDB that is used to display the early/late indicator. Thus, the speed advisory for SWA1184 is 190 knots, which is slower than the nominal speed of 210 knots for that segment, causing the aircraft to move towards the slot marker. If TMA-TM cannot compute a speed advisory different than the nominal speed, or the required speed is outside the available speed control margin, the early/late indicator is displayed instead. The CMS speed advisories are completely independent of the GIM-S speed advisories.

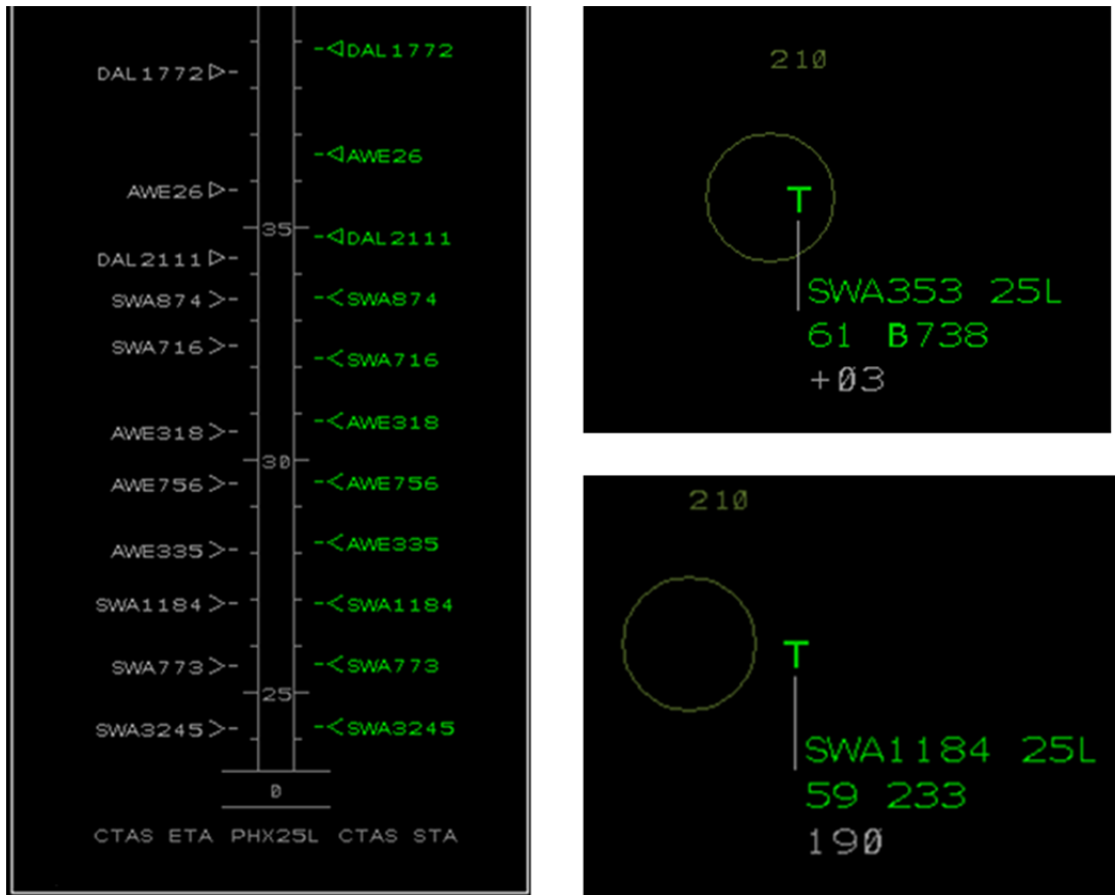


Figure 7. CMS tools and displays.

Controllers may configure which CMS tools are displayed, as well as specific CMS-tool properties. Three ‘overall’ modes are available:

1. No CMS displays shown
2. Early/late indicators and speed advisories shown in FDBs, and slot markers shown when the cursor dwells on the FDB
3. Early/late indicators and speed advisories shown in FDBs, and slot marker always shown for all tracks

In addition, when the slot marker is displayed, the size of the slot marker is configurable to represent a specified time in seconds (referenced to the aircraft’s instantaneous ground speed), a distance in tenths of nautical miles, or raw pixels. When the early/late indicators (absolute delay must exceed the specified value) and speed advisories (the aircraft’s instantaneous airspeed must differ from the computed advisory speed by at least the specified value) are displayed is also configurable, and can be set to met the requirements of a particular operation.

Additional display functionality beyond the basic CMS tools has also been developed to help controllers monitor the status of FIM operations, using either Display System Replacement (DSR) in ARTCCs (top row of Figure 8), or STARS in the TRACON (bottom row of Figure 8).

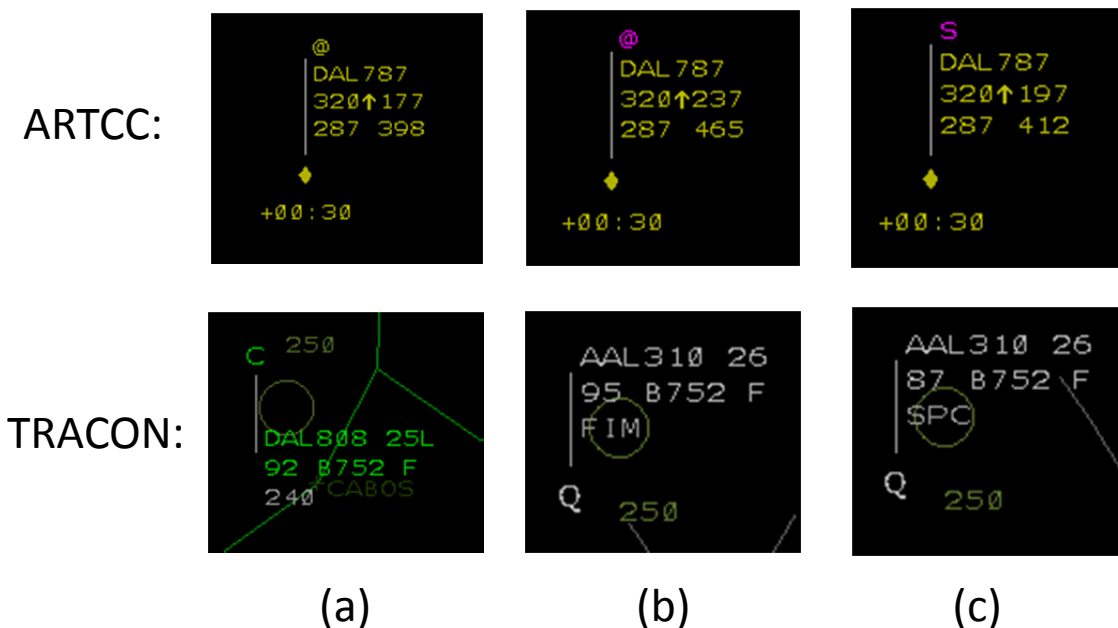


Figure 8. FIM status indications.

The top panel in Figure 8a illustrates how a FIM-equipped aircraft's FDB appears to a Center controller before the FIM clearance is issued. The DSR FDB includes a yellow "@" symbol that indicates the aircraft is FIM-equipped and can therefore accept a FIM clearance (no comparable equipage symbol is provided for TRACON controllers since they do not have FIM clearance information available). (Note: recent development work indicates it may be desirable to have the "@" symbol indicate FIM-available; that is, FIM-equipped and a FIM clearance is available.) The top panel in Figure 8b shows a magenta "@" symbol, which occurs when the ARTCC controller issues a FIM clearance. The top panel in Figure 8c shows the FDB has been updated to reflect that the flight crew reported commencing the FIM operation, and the controller updated the symbol to a magenta "S".

FIM status information entered in the ARTCC is transferred to the TRACON, and the bottom row of Figure 8 corresponds to the same sequence of FIM status as the top row. TRACON controllers also make entries to change the FIM status indications to match aircraft reports. Suspending a FIM operation requires the controller to return the indicator to the 'FIM issued' status (Figure 8b), and terminating a FIM operation requires updating the FDB to a FIM equipped status (Figure 8a).

4.5.3 Flight Deck Interval Management (FIM)

FIM enables the flight crew to actively assist both en route and terminal controllers in maximizing throughput while operating the aircraft in a fuel-efficient profile. It also enables the en route controller to issue a single strategic clearance to the flight crew to achieve the ASG behind a Target aircraft. This is accomplished by using the Target aircraft state data received via ADS-B In technology to calculate the necessary airspeed onboard the FIM aircraft that will meet the controller issued FIM clearance by the Achieve-By Point. For the ATD-1 demonstration, the Achieve-By Point will always be the Final Approach Fix (FAF).

Prior to issuing the FIM clearance, the en route controller issues the arrival procedure and expected runway to the flight crew. In addition to entering this data into the aircraft's FMS, the flight crew ensures that the current forecasted terminal area winds are entered into both the FMS and FIM equipment. The controller is expected to issue the FIM clearance shortly after the TMA-TM Freeze Horizon and prior to Top-of-Descent (TOD) if the difference between the aircraft's ETA and STA at the Meter Fix is manageable by speed control only, typically one to two minutes. When the difference between the ETA and STA at the Meter Fix is greater than that, controllers will first pre-condition the aircraft (vectors to path stretch or altitude step-down to reduce ground speed) until that difference is minimized, and then issue the FIM clearance. The FIM clearance includes the Target aircraft's identifier, the Target aircraft's arrival procedure, and the ASG. However, the use of voice communication between controllers and pilots during the ATD-1 demonstration may make issuing the FIM clearance after TOD more appropriate and procedurally simpler (see note in Appendix G).

The Target aircraft may not be in the same airspace sector as the FIM aircraft, and may be on a different arrival procedure as the FIM aircraft (and therefore cross the TRACON boundary at a different meter fix). To accommodate the limitations of voice communication, partial integration of the ATD-1 technologies into the ground air traffic software, and range of Target and FIM aircraft geometries that will occur during the ATD-1 demonstration, two different phraseologies are available for the controller to issue a FIM clearance (see Appendix G). The "WHEN ABLE" clearance is used to initiate FIM operations as soon as feasible, and would be used primarily when the Target and FIM aircraft are on the same arrival procedure, and the controller does not expect either aircraft to require vectors off their arrival procedures to absorb required delay. The "AFTER (waypoint name)" clearance is used allow the flight crew to enter the clearance as soon as feasible, but to not initiate FIM operations until the specified waypoint. This is expected to typically occur when the Target and FIM aircraft are on different arrival procedures or in different sectors, or if the controller anticipates the need for vectors for either the Target or FIM aircraft to absorb required delay.

During the ATD-1 demonstration, the FIM speed will be calculated and available to the flight crew after both the Target and FIM aircraft have passed the first waypoint on their respective arrival procedure that contains a speed constraint. Published arrival procedures that do not connect to an approach procedure to the assigned runway will be augmented by the standard operating procedures for that TRACON to define the FIM route to connect the arrival procedure to approach procedure. No changes to published procedures will occur for ATD-1, nor will the crew enter additional waypoints or constraints in the FMS unless instructed to do so by the controller.

The FIM airspeed calculated by the spacing tool is the airspeed required to achieve the ASG by the Achieve-By Point. The spacing tool does this by calculating the ETA at the Achieve-By Point of both the Target and FIM aircraft along their respective routes, then comparing the difference between those ETAs to the ASG. This difference between the ETAs and the ASG is the time error that must resolved by minor speed adjustments around the published or expected airspeed profile. Once the flight crew determines this FIM speed is feasible, they notify ATC

that the Interval Spacing operation is commencing, then set the speed value in the Mode Control Panel speed window to match the FIM speed advisory.

The flight crew manages the aircraft speed using the FIM software to achieve the inter-arrival spacing by the Achieve-By Point, while flying the FMS lateral and vertical path defined by the arrival and approach procedures. To provide predictability to controllers and flight crew, as well as stability to subsequent aircraft, the FIM speed calculated by the FIM equipment is limited to 15% faster or slower than the published or standard speed for that segment of the arrival or approach procedure. However, the FIM speed will always comply with operational speed restrictions (250 KIAS or less when at or below 10,000 feet Mean Sea Level, etc.).

After commencing the FIM operation, the flight crew will operate the aircraft in accordance with normal flight deck procedures, with the exception that the FIM speed supersedes any published speed (similar to a controller issued speed instruction). If the flight crew is not able to follow the FIM speed command or experiences a system error, they will notify the controller that they are unable to continue the FIM operation, and traditional air traffic control methods will be used (for example, published speed or instructions from the controller). The FIM operation is complete when the FIM aircraft crosses the Achieve-By Point, at which point all FIM displays are automatically cleared. If the arrival procedure does not connect with the approach procedure, the FIM operation is terminated when the controller issues a vector to intercept the final approach course, at which point the flight crew manually clears the FIM displays. When the FIM operation is terminated in this case, whether the controller states “Cancel Interval Spacing” or not, and the flight crew will depress the FIM “terminate” button to remove all FIM displays and fly the last assigned or standard operating airspeed.

Controllers always have sole responsibility for aircraft separation, and flight crews have responsibility for spacing; that is, to fly the FIM speed. At any time, the controller can intervene with a speed instruction or a vector, which takes precedence over a FIM generated speed and suspends the FIM operation. If the controller anticipates the speed instruction or vector will resolve the issue and the aircraft will return to the arrival procedure in a timely manner, the controller will suspend the FIM operation as part of the speed instruction or vector, and may resume the FIM operation after returning the aircraft to the arrival procedure. If the controller does not anticipate a timely return to the arrival procedure, or if the assigned runway for either the Target or FIM aircraft has changed, the controller will terminate the FIM operation. If desired, a new FIM clearance can be issued with the updated information (new Target aircraft, change to the Target route, or change to the assigned runway).

Cockpit displays for the flight crew to conduct FIM operations will be developed by the airline and avionic partners participating in the ATD-1 demonstration. Options investigated in previous research include displaying the FIM speed on an ADS-B Guidance Display (AGD) and auxiliary displays, or displaying the FIM speed on the Primary Flight Display (PFD). Figure 9 is an example of an AGD from previous development work, and Figure 10 depicts a possible auxiliary display for use during FIM operations.



Figure 9. ADS-B Guidance Display (AGD) with FIM speed.



Figure 10. Auxiliary display with FIM clearance and traffic.

4.6 Benefits to be Realized

4.6.1 Overall Benefits

PBN arrival procedures generally provide less flexibility for the controller to maintain aircraft separation using traditional tactical control techniques (i.e., moderate amounts of vectoring and step-down descents in terminal airspace), but they enable reduced track miles (benefit for the airline) and improved track predictability (a safety and capacity benefit). The integration of scheduling and spacing is needed to achieve the required arrival time accuracy and its associated inter-arrival spacing precision.

While TMA-TM, CMS, and FIM technologies each exhibit benefits individually, their impact when integrated will realize significantly more benefits, especially at high-density airports during peak traffic periods. Advanced scheduling allows better planning of arrival operations by considering separation at key terminal meter points. CMS tools help controllers achieve the arrival time accuracy required of non-FIM aircraft. FIM equipment and operations further increase the precision of inter-arrival spacing precision, and are intended to reduce controller workload as well. The benefits of the three technologies and their associated procedures when integrated can be realized at any airport during any traffic density, and the greatest benefits are provided for complex arrivals during peak traffic periods.

A summary overview of key features during ATD-1 operations and their intended benefits is listed below, with subsequent sections providing additional details of ATD-1 benefits that have been grouped by users of the ConOps.

- Consistent schedule-driven trajectory-based operations throughout entire arrival phase
 - Enables more frequent assignment of advanced arrival procedures
 - OPDs enable more fuel-efficient and reduced emissions vertical profiles
 - Enables required delay to be absorbed more efficiently
 - Absorbing required delay using speed control results in fewer vectors and less level distance flown in terminal area, thereby reducing fuel consumption
 - Better flow conditioning to the same schedule throughout the arrival phase of flight is expected to result in the aircraft requiring smaller deviations from the FMS optimized speed and vertical profile.
- Improvement of arrival time accuracy and in-trail spacing precision
 - Allows advanced arrival procedures to be maintained more often
 - Mitigates typical reduction in aircraft fuel-efficiency as traffic demand increases
 - Reduces excess spacing buffers needed to account for uncertainty
 - Fewer tactical interventions will reduce workload for controllers and flight crews
 - Increases effective airport throughput (at same delay per aircraft) or decreases system and aircraft delay (at same traffic throughput).
- Flight crew understands the entire arrival procedure earlier in the operation
 - Arrival plan (including expected runway assignment) communicated earlier, and flight crew enters information into FMS to calculate entire trajectory
 - Improve situational awareness for controller and flight crew
 - Typically reduces workload for controller and flight crew in en route environment.

- Use of FIM capability by ADS-B In equipped users
 - Situational awareness further improved, voice communication further reduced
 - Increased inter-arrival spacing precision enables improved throughput
 - Predictable behavior of aircraft while meeting overall air traffic goal results in less vectoring, thereby reducing fuel-consumption, noise and emissions in addition to those generated by the integrated schedule.

4.6.2 Benefits to ANSP

Increased arrival time accuracy allows arrival schedules to be planned earlier and followed throughout the entire arrival phase of flight. These schedules enable the use of strategic speed control to achieve and maintain the desired aircraft separation. Strategic use of speed control allows less delay to be taken in the form of path stretching in terminal airspace. Use of CMS tools increases the arrival time accuracy as compared to today's manual operations. Increased arrival time accuracy can reduce the size of the spacing buffer added to aircraft separation criteria, and reduces the frequency of controller intervention to maintain separation. Smaller spacing buffers also increase the achievable runway throughput at high-density airports. Use of a single and accurate schedule, coupled with displays and tools for the controllers and flight crew to achieve it, minimizes the need for radar vectoring of each and every flight by controllers. Radar vectoring is used less frequently and only when speed control is insufficient to maintain aircraft separation. Using ATD-1 technologies and procedures to conform to the same arrival schedule in terminal airspace that was used in en route airspace will reduce the frequency of aircraft being re-sequenced or rescheduled.

4.6.3 Benefits to Flight Crew

Use of advanced arrival procedures minimizes the need for radar vectoring of each flight by controllers. Instead, flight crews are able to use their onboard FMS and autoflight systems to efficiently navigate from cruise to landing. Radar vectoring is used less frequently and only when speed control is insufficient to maintain aircraft separation. The increased predictability of the arrival operation and reduction in required voice communications are expected to enhance the flight crew's situation awareness and reduce their workload.

Use of FIM capabilities allows the delegation of routine spacing to the flight deck. Spacing will be achieved and maintained using small speed corrections to the arrival procedure's nominal speed profile. These speed adjustments will be provided by onboard automation instead of by voice clearances from the controller. Use of ADS-B In and the corresponding FIM capabilities allows the flight crews to take a more active role in arrival spacing than is possible using current procedures and technology. Reduced voice communication and vectoring is expected to reduce the flight crew's workload.

4.6.4 Benefits to Airline

The synergy of precision scheduling (TMA-TM) and tools to achieve that schedule (CMS and FIM) can be used to not only increase throughput by reducing delay, but also reduce the cost of the delay taken. The ATD-1 procedures allow for much of the delay to be incurred more efficiently at higher altitudes or by small deviations from the aircraft's optimum descent speed, instead of within TRACON airspace by using vectors or path stretches. Operationally, this

means shorter and fewer fuel-inefficient level segments at lower altitudes, reducing fuel consumption as well as reducing noise and greenhouse gas emissions from aircraft.

Fuel economy will also be improved by PBN procedure clearances being issued more frequently, which includes the aircraft's FMS calculating the most efficient TOD for that arrival. The increased frequency is primarily enabled by the integrated schedule and pre-conditioning of the arrival flow prior to TOD. The use of the aircraft FMS calculated trajectory and TOD point is enabled by issuing a "Descend Via" clearance when traffic permits, which is expected to also occur more frequently due to the schedule and pre-conditioning.

Airline benefits from FIM equipage include increased flight crew awareness, reduction in controller – flight crew voice communication needed to maintain desired spacing, and increased probability of remaining on fuel-efficient PBN procedures (or decreased probability of being issued vectors). The long-term implementation of ATD-1 functionality could allow for the reduction in size of the buffers added to the separation criteria (not part of this demonstration), thereby further improving throughput or reducing delay.

4.6.5 Benefits to Airport

Use of CMS and FIM tools increases the arrival time accuracy as compared to today's operations. Increased arrival time accuracy should enable the reduction of additional spacing buffers above aircraft separation requirements, creating an effective increase in the achievable runway throughput at high-density airports.

The ATD-1 ConOps and procedures are expected to produce longer periods of sustained high-throughput at the airport runways, or be used to reduce delay at the same traffic density levels. Increasing the use of PBN procedures (such as environmentally efficient OPDs) during periods of high-density traffic will reduce noise and greenhouse gas emissions from aircraft, in turn reducing the number of noise complaints received by the airport. Furthermore, the precision of these PBN procedures results in less airspace required for arrival operations, in turn making more airspace available for other procedures (departures, arrivals to satellite airports, etc.).

5.0 Operational Scenarios

The procedures for a “nominal” (expected or typical) ATD-1 operation are described in section 5.1, with section 5.2 providing details for each phase of the operation. Section 5.3 describes events that may occur during an ATD-1 operation, and section 5.4 describes contingency ATD-1 operations. Limitations to the fully-implemented ATD-1 ConOps required during the 2015-2020 timeframe are outlined in Appendix D.

Most controller-pilot phraseology remains unchanged from what is used today (sector frequency check-in, initiation of descent, etc.), and phraseology to be used during ATD-1 operations is documented in Appendix G. This phraseology aligns to the maximum extent possible with the international standard for Interval Management procedures [ref 25], the proposed FIM Data Link messages [ref 26], and the FAA’s Air Traffic Control documentation [ref 27]. Modifications have been made to accommodate the mid-term voice communication environment expected during the ATD-1 demonstration, and feedback from research experiments conducted at NASA Ames and Langley Research Centers for ATD-1.

5.1 ATD-1 Scenario by Phase

A flowchart of controller-pilot procedures to be used during ATD-1 operations is shown in Figure 11. A numbering system is provided in the upper left of each box to assist in grouping and establishing relationships between various events. The schema is the first digit indicates the phase of the operation (0-schedule, 1-precondition, 2-initiation, 3-operation, 4-termination), the second digit indicates the user (0-schedule, 1-controller, 2-flight crew not equipped with FIM, 3-flight crew equipped with FIM), and the third digit is a sequential index for that user during that phase.

Figure 12 through Figure 16 present the ATD-1 ConOps described in Section 4.2 by phase, with each phase linked to the respective procedure shown in the procedure flowchart (Figure 11).

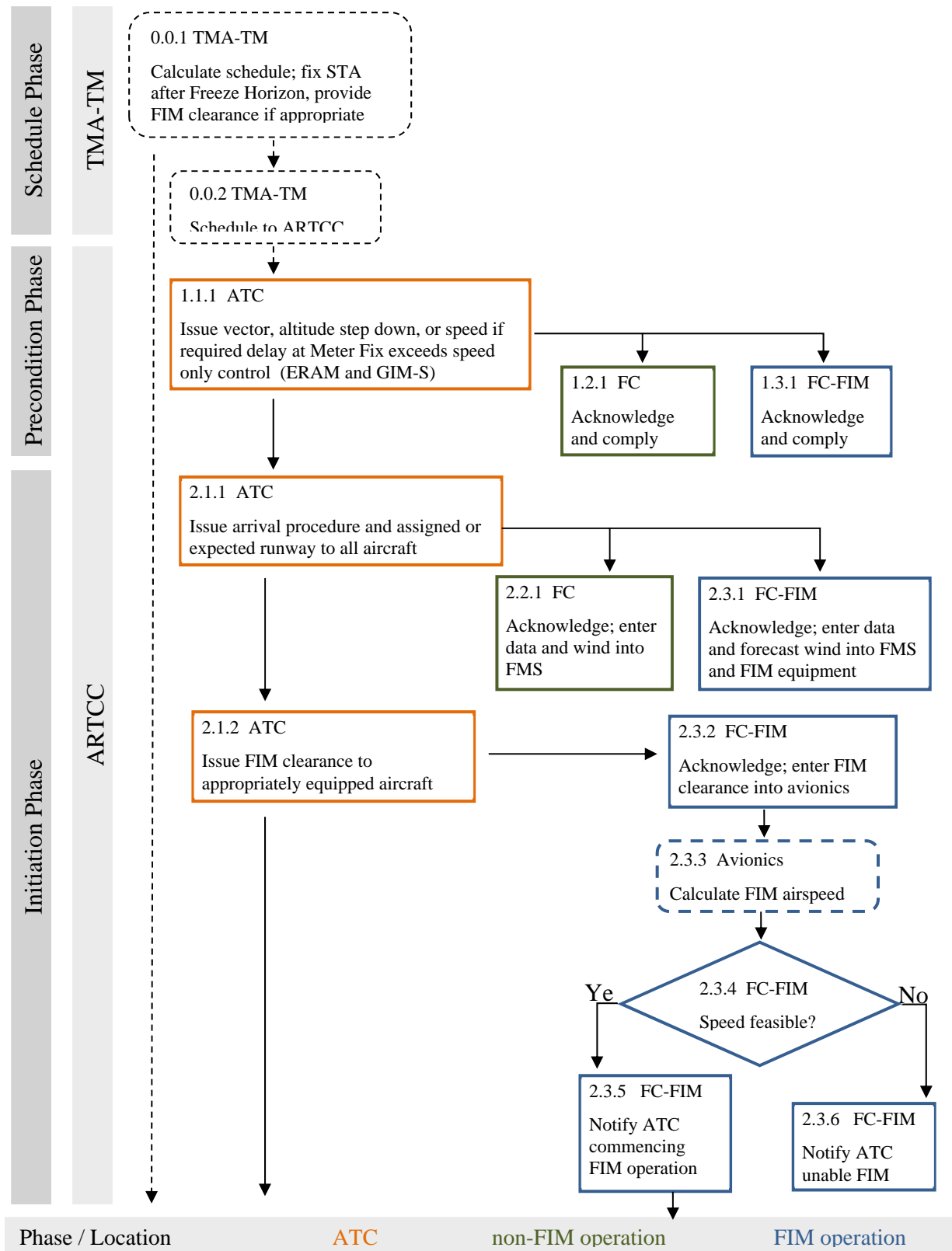


Figure 11. Operational procedure flowchart.

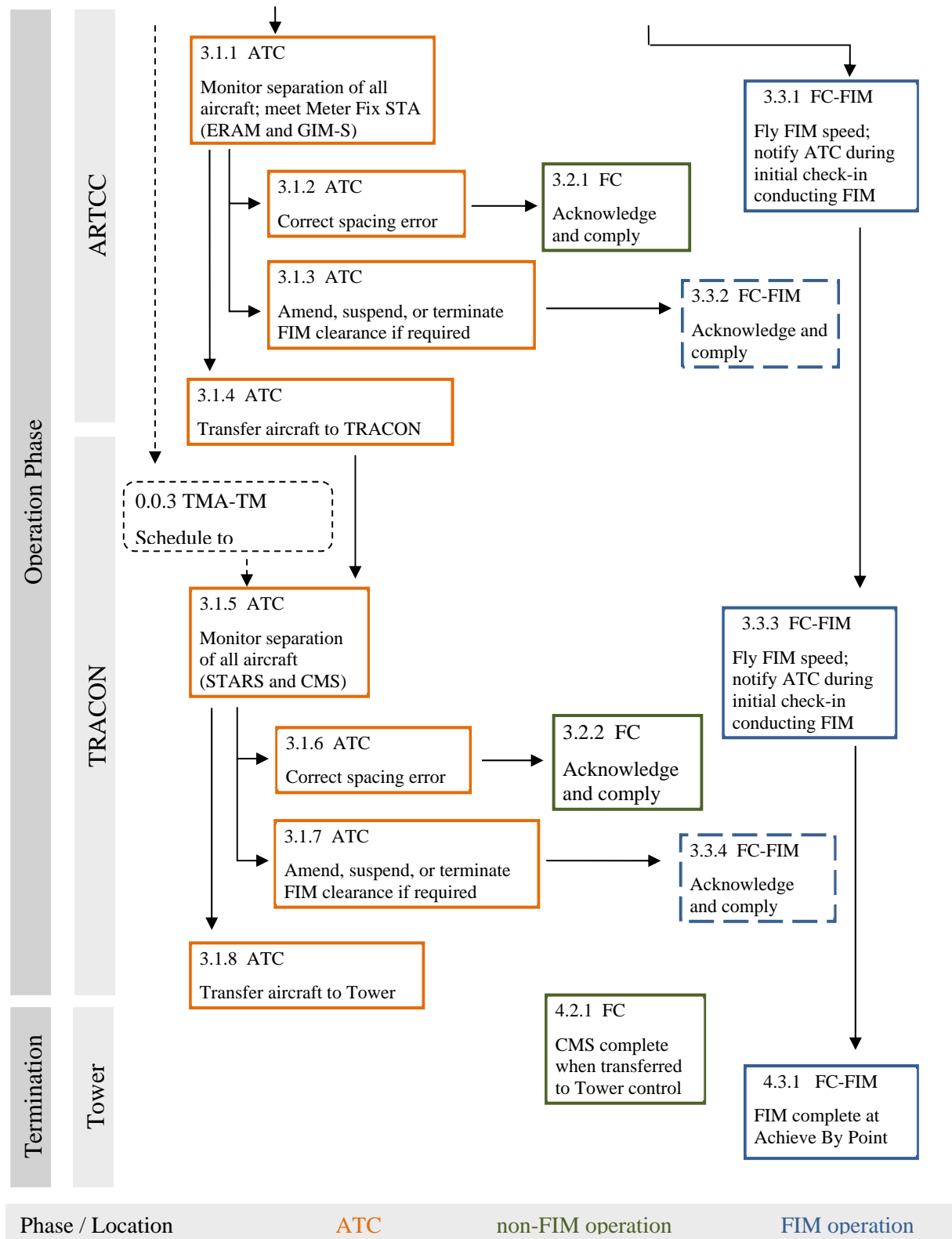


Figure 11. Operational procedure flowchart (concluded).

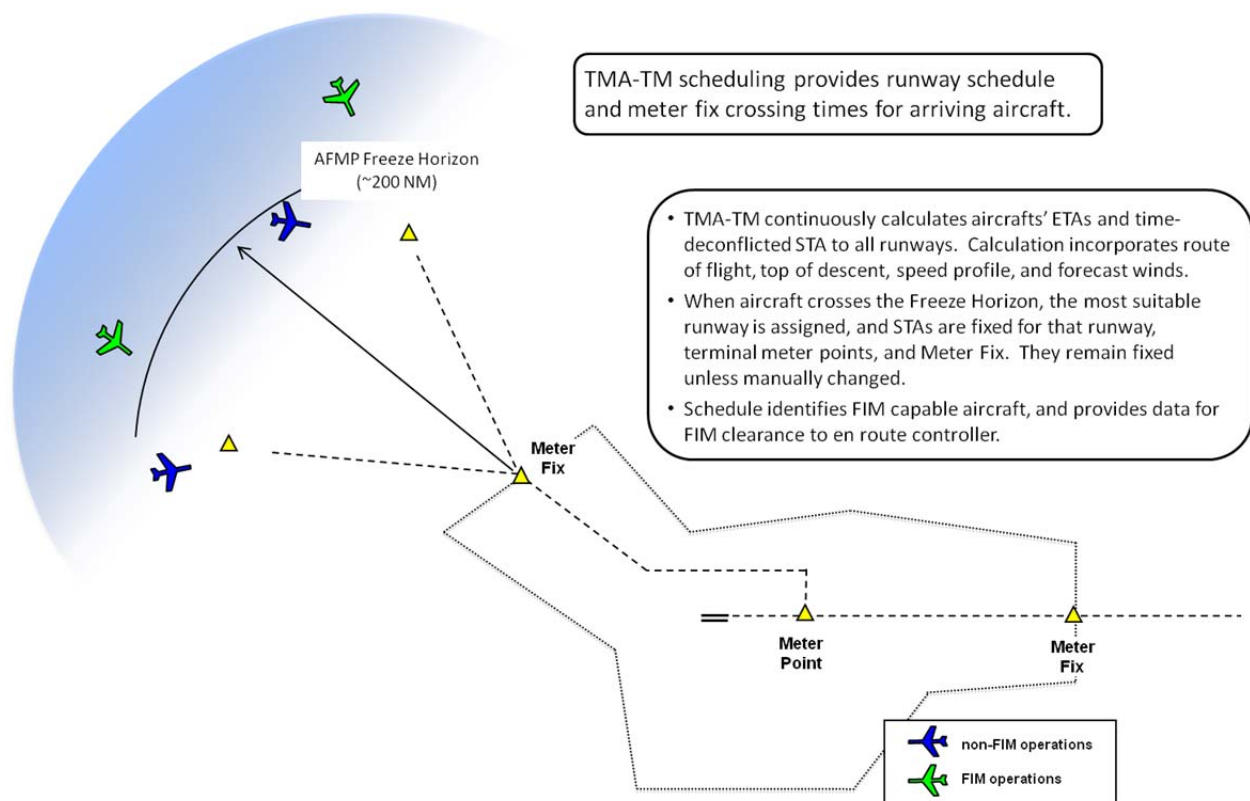


Figure 12. ATD-1 operation: Schedule Phase.

The blue area shown in Figure 12 highlights the airspace and subset of aircraft in the schedule phase of ATD-1 operations (that is, prior to the Freeze Horizon), and an overview of activities that occur during this phase are listed on the right. The numbers in the left column of the table below correspond to the operational procedures in Figure 11.

- 0.1 Prior to the aircraft crossing the Freeze Horizon, TMA-TM continuously calculates the ETA for that aircraft to all suitable runways, and updates the STA to all runways as well. At the Freeze Horizon, the TMA-TM software assigns the aircraft to a runway, and freezes the STA for that aircraft and runway. The TMA-TM ETA for each aircraft is used to update delay advisories, GIM-S speed advisories, and CMS advisories.
- 0.2 The TMA-TM information and GIM-S speed advisories are available to en route controllers on the DSR as part of the meter list and aircraft's full data block, and include arrival metering information, expected runway assignment for all aircraft, and FIM clearance information for those aircraft so equipped.
- 0.3 The TMA-TM information and CMS indications are available to terminal controllers on the STARS display, include arrival metering information and speed advisors for all aircraft.

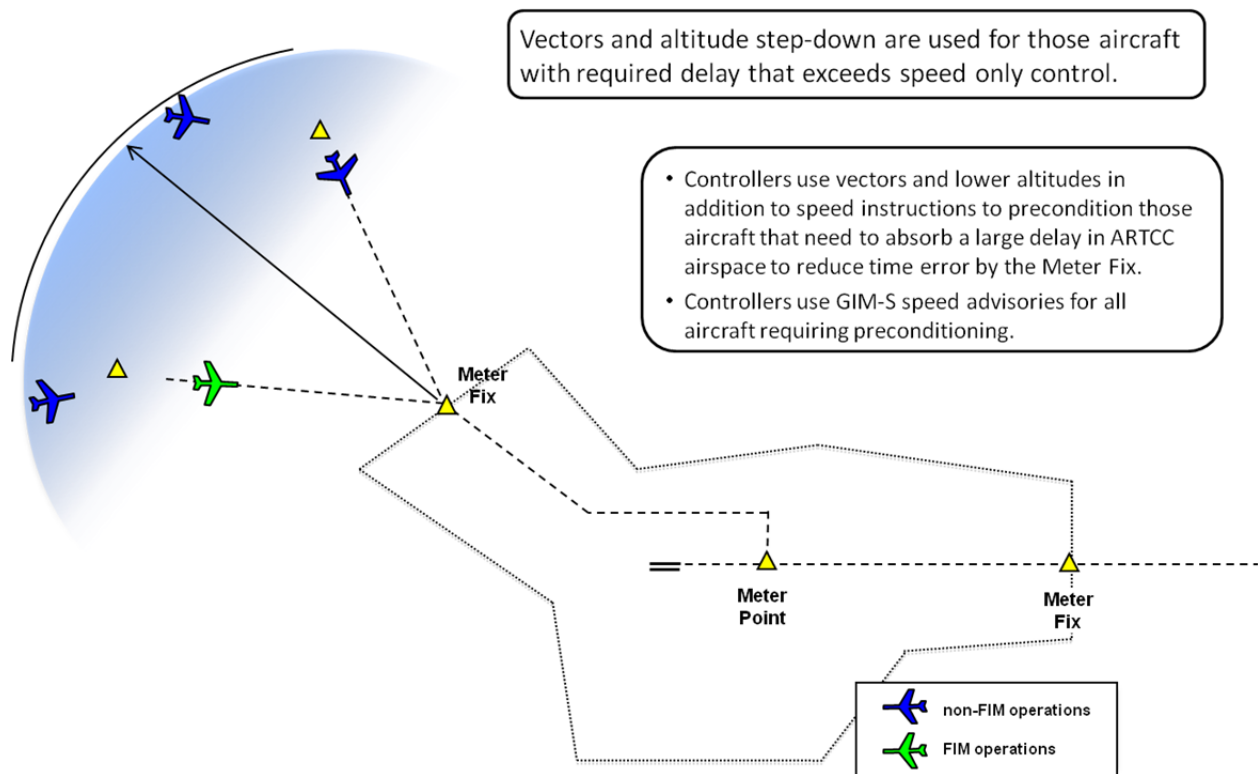


Figure 13. ATD-1 operation: Precondition Phase.

Figure 13 illustrates the aircraft and activities that occur during the precondition phase of ATD-1 operations, that is, what occurs when speed control alone is not sufficient to absorb the required delay assigned by TMA-TM. Based on demand and the effectiveness of up-stream flow control, aircraft may or may not require this phase. When aircraft cross the Freeze Horizon and do not require vectors or step-down in altitude to meet the Meter Fix (AFMP) time assigned by TMA-TM, the Initiation phase commences immediately after the Schedule phase. The numbers in the left column of the table below correspond to the operational procedures in Figure 11.

- 1.1.1 If required, en route controller issues vectors, altitude step-downs, or speed instructions to achieve desired time delay (TMA-TM schedule to interface with GIM-S, which provides display) to any aircraft not conducting FIM operations.

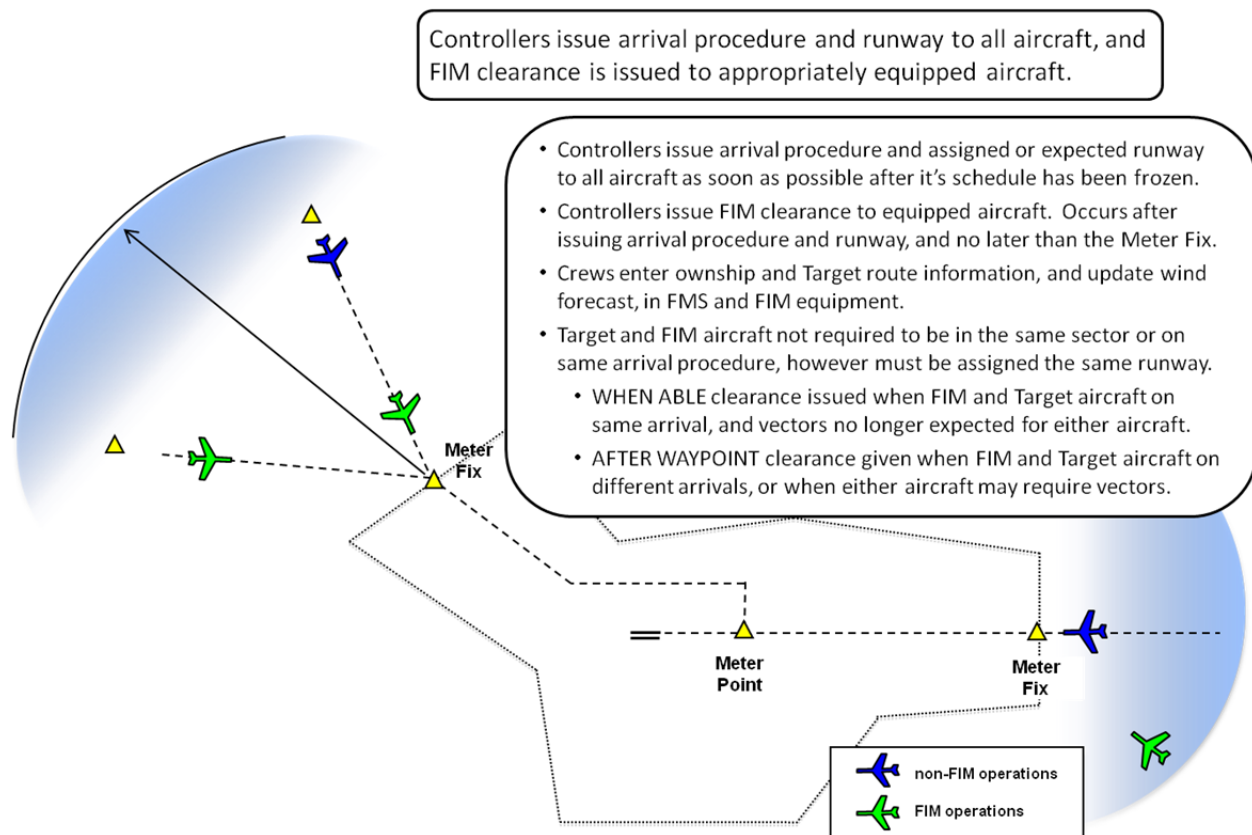


Figure 14. ATD-1 operation: Initiation Phase.

Figure 14 illustrates the aircraft and activities that occur during the initiation phase of ATD-1 operations, that is, when controllers issue a FIM clearance to suitably equipped aircraft, and the flight crews respond. During this phase, speed control alone is typically sufficient, however vectors may be required if the schedule changes or other operational considerations require controller intervention. The numbers in the left column of the table below correspond to the operational procedures in Figure 11.

- 2.1.1 The en route controller issues the arrival route and expected runway to all aircraft, the FIM clearance to those aircraft so equipped, and clears all aircraft for the arrival procedure.
- 2.2.1 The flight crew enters the arrival procedure, expected runway, and current terminal area forecasted winds into the aircraft's FMS and FIM equipment (if so equipped).
- 2.1.2 The en route controller issues a FIM clearance to the flight crew of FIM-equipped aircraft.
- 2.3.2 The FIM crew acknowledges ATC, and enters the FIM clearance into the aircraft avionics.
- 2.3.3 The FIM aircraft software calculates the Mach number or airspeed needed to achieve the Assigned Spacing Goal behind the Target aircraft by the Achieve-By Point.
- 2.3.4 The FIM flight crew determines if the speed is operationally feasible.
- 2.3.5 If the FIM speed is feasible, the flight crew notifies ATC they are commencing FIM operation.
- 2.3.6 If the FIM speed is not feasible, the FIM flight crew notifies ATC that they are unable to conduct the FIM operation.

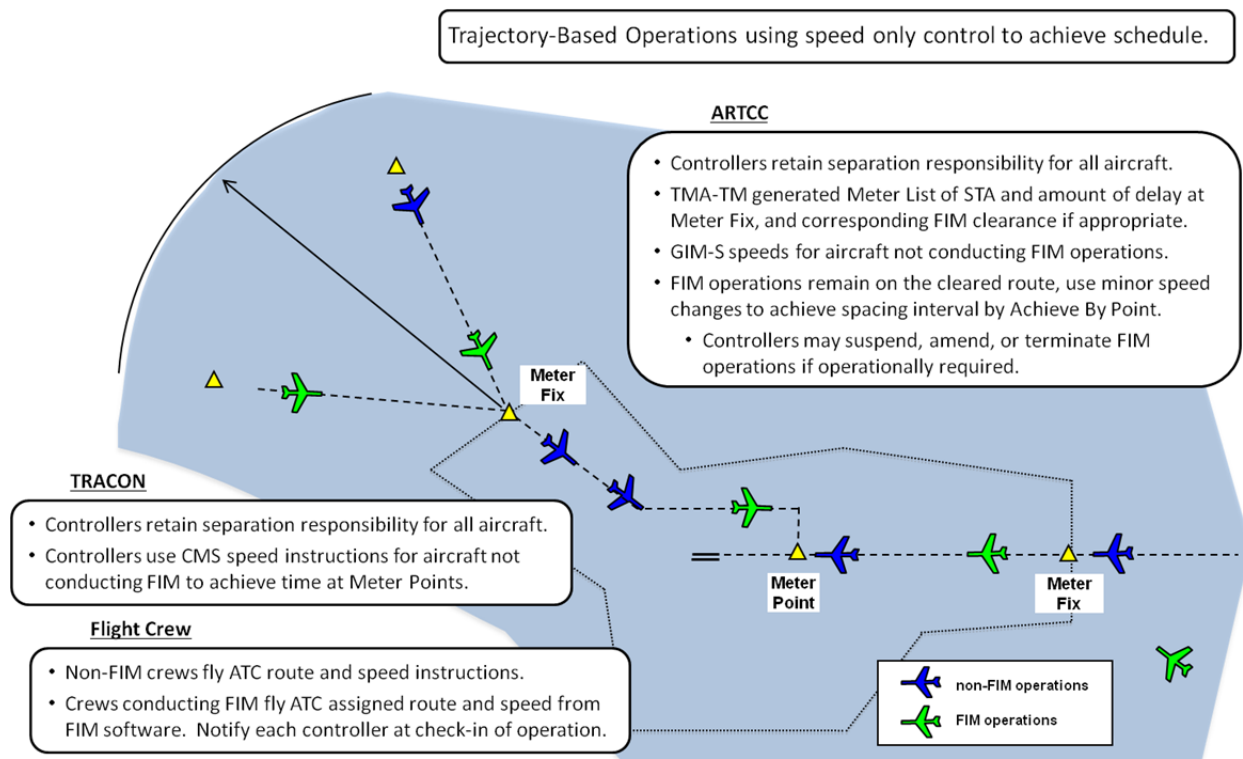


Figure 15. ATD-1 operation: Operation Phase.

Figure 15 illustrates the aircraft and activities that occur during the operation phase of ATD-1 operations, that is, controllers use primarily speed control to achieve TMA-TM scheduled times and crews fly FIM speed to achieve the assigned spacing interval. The numbers in the left column of the table below correspond to the operational procedures in Figure 11.

- 3.1.1 En route controllers retain safe separation responsibility for all aircraft within their sector.
- 3.1.2 En route controllers use GIM-S information to assign speeds to all aircraft not conducting FIM operations (non-FIM equipped, or FIM equipped aircraft prior to issuing FIM clearance).
- 3.3.1 Flight crews conducting FIM will notify ATC when commencing the operation, and fly the FIM calculated speed during the arrival and approach.
- 3.1.3 If needed, en route controllers may amend, suspend, or terminate FIM operations. Controller instructions always take precedence over the FIM speed calculated onboard the aircraft.
- 3.3.2 Flight crews will acknowledge ATC when the FIM clearance has been amended, suspended, or terminated.
- 3.1.5 Terminal controllers retain safe separation responsibility for all aircraft within their sector.
- 3.1.6 Terminal controllers use CMS information to assign speeds to crews of non-FIM aircraft. CMS speeds may also be used for FIM aircraft if necessary.
- 3.3.3 Crews conducting FIM operations will state so during initial check-in with each controller.
- 3.1.7 If needed, terminal controllers may amend, suspend, or terminate FIM operations. Controller instructions always take precedence over the FIM speed calculated onboard the aircraft.

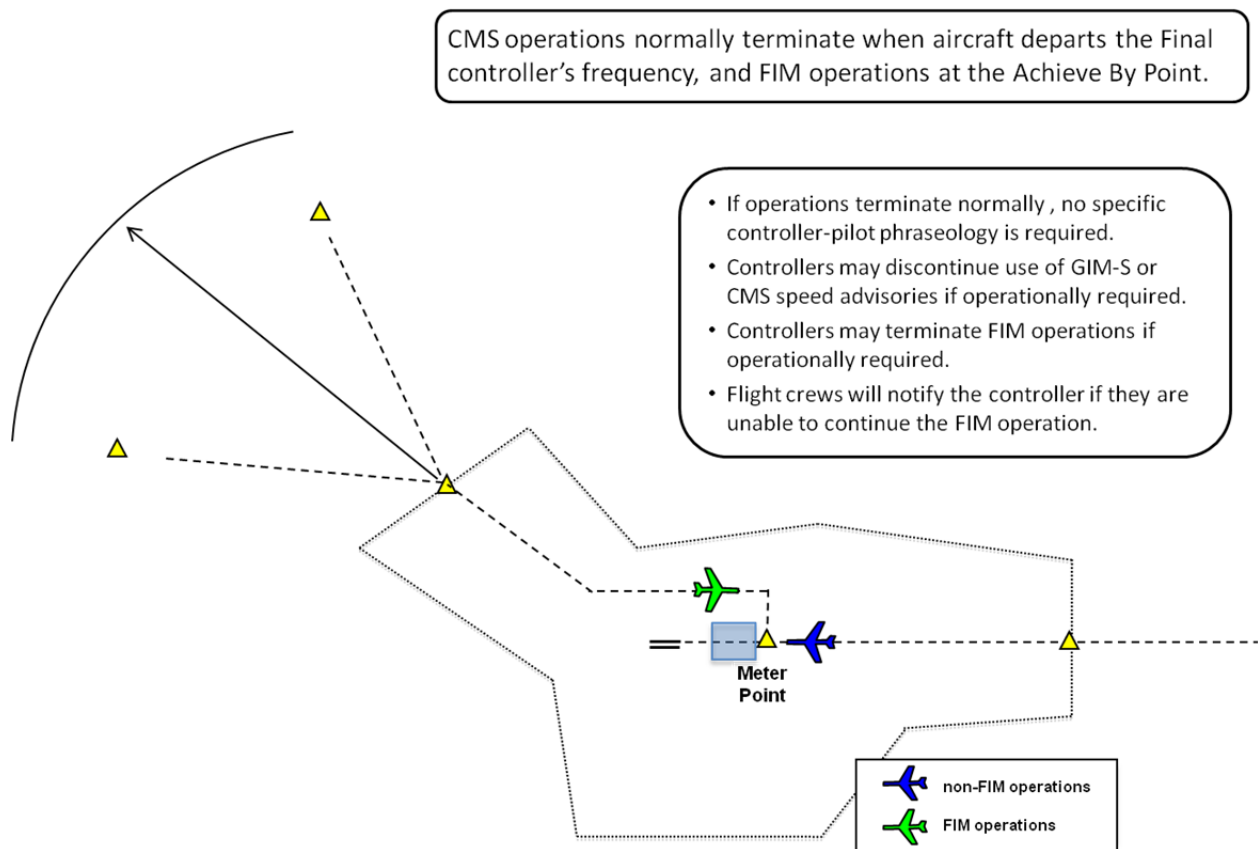


Figure 16. ATD-1 operation: Termination Phase.

Figure 16 shows the aircraft and activities that occur during the termination phase of ATD-1 operations. CMS operations cease when the flight crew changes to the Tower frequency, and FIM operations terminate at the Achieve-By Point or when the controller issues a vector to intercept the final approach. Operations may also be suspended or terminated if vectors or altitude step-downs are needed to absorb the required time delay. Crews may terminate FIM operations (no Target data, FIM equipment failure, etc.) by notifying the controller, who then issues a new FIM clearance or reverts to normal control procedures. The numbers in the left column of the table below correspond to the operational procedures in Figure 11.

- 4.2.1 CMS operations are complete when the flight crew switches from the Final controller to Tower frequency. No specific communication is required.
- 4.3.1 FIM operations are complete when the aircraft crosses the Achieve-By Point. No communication is required if FIM terminates at the Achieve-By Point. When the arrival and instrument procedure do not connect, the FIM operation is terminated when the controller issues a vector to the crew to intercept the final approach course.

5.2 Events and Procedures During ATD-1 Operations

This section addresses events and procedures that occur in response to common but unanticipated events during ATD-1 operations. These events may require a TMA-TM sequence swap, a TMA-TM reschedule, discontinue use the GIM-S or CMS speed advisory, or suspend or terminate FIM operations.

When events occur that affect the controllers' or flight crews' ability to conduct ATD-1 operations, the contingency plan is to revert to current day procedures. Examples of events that may trigger contingency procedures includes incorrect or undesirable information on controller decision support tools, incorrect or infeasible information on cockpit displays, failure of hardware or software, or changes to the goal of the air traffic plan. Use of current day operations as the contingency plan for when ATD-1 operations must be terminated has proven viable in NASA's concept development and testing phase since aircraft separation criteria, as well as the roles and responsibilities assigned to controllers and flight crew, are the same in both operations.

5.2.1 ATC changes arrival sequence

Controller may need to change arrival sequence. When this occurs, the CMS displays are automatically updated to reflect the new TMA-TM schedule. If the sequence swap affects either the Target or FIM aircraft of a FIM operation, the existing FIM clearance must be terminated by the controller, and a new one issued if desired. (The long-term vision for the ATD-1 ConOps has the ground automation providing the controller a message that the FIM clearance must be cancelled, and offer a new clearance. However, this functionality will not be available by the demonstration time-frame.)

5.2.2 ATC Display of CMS or FIM Information

Each controller will have the ability to individually turn off and back on CMS information (slot markers, speed advisors) and FIM information (aircraft status, FIM clearance). This is an optional technique available to the controller to mitigate an unexpected and rapidly occurring event that momentarily causes deviation from the TMA-TM generated schedule, resulting in outdated or incorrect CMS or FIM information. Once the schedule has been updated, the controller has the ability to turn back on the CMS or FIM information.

5.2.3 ATC Amends a FIM Clearance

A controller may amend the FIM clearance by changing the ASG to allow space for departing aircraft, etc. (Changing the Target aircraft, Target aircraft route, or FIM aircraft route require ATC to terminate the FIM clearance, then issue a new one if desired). Compared to terminating the current FIM clearance and entering a new one, amending a FIM clearance requires less workload for the flight crew.

5.2.4 ATC Suspends or Resumes a FIM Operation

When ATC temporarily suspends a FIM operation (expected to resume at a later time), the flight crew remove the FIM speed from cockpit displays with a single button push, but retain the FIM clearance information in the application. FIM operations are suspended whenever a controller issues a vector or speed instruction to the FIM aircraft, even if not explicitly stated so by the controller. Altitude change instructions to the FIM aircraft do not suspend FIM operations. Vectors or speed instructions to the Target aircraft should also cause the FIM

operation to be suspended, however the controller for the FIM aircraft may not be aware of those instructions to the Target aircraft. Therefore the logic in the FIM software will cause the FIM application to automatically switch to a suspend mode whenever it determines the Target aircraft is greater than 2.5 nmi off the arrival or approach procedure, or has a greater than 10% deviation from the expected airspeed. Altitude changes by the Target aircraft do not cause the FIM software to switch to a suspend mode. The resume procedure allows the crew to return the FIM speed for the previously issued FIM clearance to the cockpit displays with a single button push.

5.2.5 ATC Terminates a FIM Operation

FIM operations normally terminate at the Achieve By Point (the Final Approach Fix for ATD-1), and no controller or pilot communication is required. When ATC terminates a FIM operation prior to that point, the flight crew maintain the current or assigned airspeed, remove all FIM indications from cockpit displays, and delete the FIM clearance information from the avionics. Several operational events that may require ATC to terminate a FIM operation early include a change to the route or runway of either the Target or FIM aircraft, or a schedule re-sequence that impacts either the Target or FIM aircraft. The FIM operation is also terminated prior to the Achieve By Point when the STAR and instrument approach procedure do not connect, and the controller issues the flight crew a vector to intercept the final approach course.

If ATC does not terminate the FIM operation for the FIM aircraft when one of the events above occurs, the FIM flight crew will continue to fly speeds designed to achieve the Assigned Spacing Goal behind the Target aircraft. This may result in undesirable performance by the FIM aircraft. (The long-term ATD-1 ConOps envisions a change to either the Target or FIM aircraft's route results in an automatic update to the schedule and FIM clearances. The updated schedule will exist by the ATD-1 demonstration timeframe, however the capability to update the FIM clearance will not exist by then.)

5.2.6 ATC issues an infeasible FIM clearance

The FIM clearance issued by ATC may not be feasible for the flight crew. Examples of causes for this event include turbulence may require the flight crew to fly a slower speed than the commanded FIM speed, or the FIM clearance includes a Target route not known to the FIM aircraft. The flight crew procedure is to notify ATC that they are unable to conduct FIM.

5.2.7 Flight Crew Terminates a FIM Operation

Flight crews conducting FIM operations may need to terminate FIM operations for a variety of reasons. Examples include: the FIM speed becomes infeasible (for example, too fast or too slow), the ADS-B data from the Target aircraft is lost or no longer has sufficient quality, the ADS-B data from the Target is not received, or the FIM spacing tool has failed. The flight crew will state 'UNABLE INTERVAL SPACING', and if possible, include the reason for termination (considered likely only in low traffic density conditions). Controllers may use the provided GIM-S or CMS tools to complete the arrival operation.

5.3 Contingency ATD-1 Operations

Contingency ATD-1 operations typically require controllers and flight crews to revert to current day procedures. Examples of events that may trigger contingency procedures include incorrect or undesirable displays on controller decision support tools, incorrect or infeasible displays for flight crew, failure of hardware or software, or changes to the goal of the air traffic plan. Reversion to current day operations as the contingency plan when ATD-1 operations must be terminated has proven viable in NASA's concept development and testing phase since aircraft separation criteria, as well as the roles and responsibilities assigned to controllers and flight crew, are the same in both operations. An overview of some of these events and their impact by ATD-1 technology is provided in the Table below, with more detail in subsequent paragraphs.

Table 1. Contingency Operations Matrix

| Event | TMA-TM | CMS | FIM |
|--|---|--|--|
| User terminates the use of the ATD-1 technology | Revert to current day operations. ATC may use ground delay or miles-in-trail to reduce throughput. | Revert to current day operations. CMS displays turned off, controllers issue instructions. | Revert to current day operations. FIM operation cancelled, controllers issue vectors or speed instructions. |
| Significant weather event | Revert to current day operations. ATC may use ground delay or miles-in-trail to reduce throughput. | Revert to current day operations. ATC turns off CMS displays until TMA-TM reschedules, then resume ATD-1 operations. | Revert to current day operations. ATC issues vectors or speeds until TMA-TM reschedules, then resume ATD-1 operations. |
| Airport configuration change or runway not available | Revert to current day operations. ATC may use ground delay or miles-in-trail to reduce throughput. | Revert to current day operations. ATC turns off CMS displays until TMA-TM reschedules, then resume ATD-1 operations. | Revert to current day operations. ATC issues vectors or speeds until TMA-TM reschedules, then resume ATD-1 operations. |
| Aircraft emergency or priority handling | Current day procedures remain unchanged for priority aircraft; others use ATD-1 procedures. | Current day procedures remain unchanged for priority aircraft; all others operate using ATD-1 procedures. | Current day procedures remain unchanged for priority aircraft; all others operate using ATD-1 procedures. |
| Different levels of aircraft avionics equipage | ATD-1 operations not affected, if the technology has awareness of the aircraft's equipage and can assign the optimum procedure. | ATD-1 operations should not be affected. | ATD-1 operations should not be affected, unless the FIM aircraft's spacing software does not have the Target aircraft's procedure. |

5.3.1 User terminates the use of the ATD-1 technology

The three ATD-1 technologies are designed to be configurable by the user, and to be turned off or re-initialized if appropriate. Examples are given below.

- TMA-TM: TMA is currently operationally deployed in today's NAS, and no change is envisioned to controller procedures during schedule contingencies when TMA-TM is deployed. Two of many possible events and their outcome include:
 - The required delay reaches a level that controllers cannot achieve (due to runway closure, significant weather event, etc). In this case the use of metering is frequently, but not always, terminated.
 - The arrival sequence in the schedule becomes out of sequence or is not desired by the controller. In this case the TMC may recalculate the or ripple the list.
- CMS: CMS displays and information are calculated based on the TMA-TM schedule. Terminal controllers may turn off the CMS displays and information if the schedule is infeasible or undesirable, reverting the controller scope to current day standards.
- FIM: FIM speeds are calculated to achieve the spacing between aircraft set by the TMA-TM schedule. If the FIM speed becomes infeasible or undesirable (spacing error too great, environmental or airframe conditions require a different airspeed, etc.), the flight crew may suspend or terminate the FIM operation. Current day operations are used by the flight crew when this occurs.

The ATD-1 ConOps technologies have a one-way interaction with each other, in that changes to the TMA-TM schedule cause the CMS information to update, and a new FIM clearance must be issued (if appropriate). Although the CMS and FIM displays and information can be turned off, the CMS or FIM information itself cannot be modified by the user, and there is no feedback mechanism to the schedule.

5.3.2 Significant weather event

Weather events will have a range of impacts on ATD-1 operations based on condition type and location of the event. Generally, conditions such as fog, rain, low ceiling or visibility, and convective weather that prevent aircraft from flying through it, will reduce the airport's arrival throughput. However, low ceiling or low visibility weather typically causes a stable condition that can be managed with TMA-TM over long periods of time. Convective weather on the other hand, is more dynamic and makes strategic tools like TMA-TM more difficult to manage especially in cases where the growth, decay, and movement of weather is not easy to predict. The location of the weather is another major factor in determining the magnitude of the impact to ATD-1 operations. Weather requiring a re-routing of traffic in the enroute environment may have little impact on ATD-1 operations or airport throughput, while weather overhead the airport may require suspending all arrival and departure operations. This will require a varied response that allows some aircraft to deviate and rejoin their routes, possibly changing the arrival sequence or rippling the list, and some areas will be impacted to such a degree that ATD-1 operations and tools would not be usable.

5.3.3 Airport configuration change or runway closure

When the runway configuration changes (change in wind direction, noise abatement, etc.) or a runway is no longer available (aircraft disabled on the runway, etc.), some aircraft must be rerouted and a new arrival schedule calculated. Based on the timing and type of event, the impact to the arrival schedule may be minor or significant while TMA-TM is updated. Similar to the procedures for a significant weather event, controllers and flight crew have the ability to selectively turn off ATD-1 displays until the information presented has been updated to reflect the new runway status and condition.

5.3.4 Aircraft emergency or priority handling

An aircraft may unexpectedly require priority for landing (medical emergency, system malfunction, etc.), or unexpectedly require a slot in the arrival stream (go-around, tower arrival, etc.). These events may require some other aircraft to absorb delay to create the slot for the priority aircraft. When this occurs, vectors are normally required for the aircraft that must absorb delay, resulting in potentially incorrect controller and flight crew displays related to schedule information. Similar to the significant weather event, controllers and flight crew selectively turn off displays with incorrect information, and use current day non-Trajectory Based Operations and procedures.

5.3.5 Different levels of aircraft avionics equipage

Aircraft are equipped with a wide range of avionics that creates a broad spectrum of aircraft navigation capability. Mixed operations, or aircraft of widely varying navigation capability intermingled in the same arrival stream, can lead to certain inefficiencies or challenges. By the ATD-1 demonstration timeframe, it is possible that TMA-TM will not have access to complete and current information for all aircraft, such as RNP versus non-RNP equipped, or FIM versus non-FIM equipped. Should that occur, some of the benefits offered through ATD-1 operations will not be realized, or the aircraft will be manually updated outside of the normal data process. CMS operations should not be impacted by mixed operations, unless the aircraft is flying an arrival or approach procedure not assigned by TMA-TM (for example, a visual turn to final instead of the ground track anticipated by TMA-TM). FIM operations in a mixed equipage operation should not be impacted, unless the spacing software does not contain in its database the arrival or approach procedure of the Target aircraft.

6.0 Summary of Impacts

The anticipated impacts of the proposed ATD-1 ConOps on current operations are summarized in Table 2 below:

Table 2. Summary of Impacts

| User | Current Operational Use | Enhanced Use with ATD-1 ConOps |
|---------------------------------|--|---|
| Traffic Management Coordinators | Use the Traffic Flow Management System automation and TMA to establish the sequence and schedule for aircraft arriving at the high-density airport. | Use the Traffic Flow Management System automation and TMA-TM to establish a higher fidelity sequence and more precise schedule for aircraft arriving at the high-density airport. |
| En route Controller (ARTCC) | Comply with facility procedures for delivering aircraft to meet the TMA schedule. This includes issuing route clearances (such as “Descend Via”) and expected runway assignments using standard operating procedures. | Comply with facility procedures for delivering aircraft to meet the TMA-TM schedule. This includes issuing route clearances and the expected runway assignments using TMA-TM information. Controllers will also issue FIM clearances to those aircraft suitably equipped, issue speed instructions (based on GIM-S) to aircraft not conducting FIM operations, and monitor safe separation of all aircraft. |
| Terminal Controller (TRACON) | Comply with facility procedures for delivering aircraft to meet the posted airport acceptance rate. Maintain aircraft separation and deliver them to the runway. There is no access to the TMA runway assignments or schedule. | Comply with facility procedures for delivering aircraft to meet TMA-TM scheduled metering plans to the assigned runway. Use CMS automation to improve the delivery accuracy to the runway of aircraft not conducting FIM. Update or terminate FIM operations if required. Monitor safe separation of all aircraft. |
| Flight crew | Comply with all established procedures and controller instructions. | Comply with all established procedures and controller instructions. Crews conducting FIM operations will also enter FIM clearance and forecast winds into the spacing avionics, monitor the FIM status, notify ATC when that status changes, and fly the speed calculated by the FIM software. |

7.0 References

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Appendices

Appendix A: Glossary and Definitions

Table 3. Glossary and Definitions

| Acronym | Term | Definition |
|---------|--|---|
| -- | Four-dimensional trajectory | The centerline of a path formed by segments that link consecutive trajectory change points; each point defined by a longitude, latitude, altitude, however not every point will have a time. NOTE: some waypoints may have time, altitude, and/or speed constraints, and can be equality or inequality constraints. |
| | -- 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. (FAA APNT) |
| | -- 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. (FAA APNT) |
| -- | Airborne Metering | A form of time-based metering in which air traffic controllers issue clearances to active flights in their sectors that cause the flights to absorb arrival delays. |
| -- | Achieve-By Point | The point on the FIM Aircraft's flight path where the Assigned Spacing Goal behind the Target Aircraft is expected to be achieved. For ATD-1, this point is the Final Approach Fix. |
| ADS-B | Automatic Dependent Surveillance – Broadcast | ADS-B is a technology where aircraft avionics (or ground equipment) autonomously broadcasts the aircraft's (or ground vehicle's) position, altitude, velocity, and other parameters. "ADS-B Out" refers to the broadcast of ADS-B transmissions from an aircraft or vehicle, and "ADS-B In" refers to reception of ADS-B transmissions from other aircraft or vehicles. |
| AGD | ADS-B Guidance Display | A flight deck display that presents the airspeed calculated by the onboard spacing software to achieve the Assigned Spacing Goal behind the Target aircraft (based on the FIM clearance given by ATC and entered by the flight crew into the software). |
| AIXM | Aeronautical Information Exchange Model | An XML-based aeronautical data format developed jointly by the FAA and Eurocontrol. |
| ANSP | Air Navigation Service Provider | Government or private organizations that manage flight traffic on behalf of a company, region, or country. |
| AOC | Airline Operations Center | Responsible for decision-making and operational control of an airline's daily schedules and facilitating disruption recovery. |
| ARTCC | Air Route Traffic Control Center | A facility providing air traffic control service to aircraft operating on IFR flight plans within controlled airspace, principally during the en route phase of flight. |
| ASG | Assigned Spacing Goal | The inter-arrival time in seconds (may also be given as a distance) between the Target and the FIM Aircraft assigned by the controller as part of the FIM clearance. |

Table 2. Glossary and Definitions (continued)

| Acronym | Term | Definition |
|----------------|--|--|
| ASTAR | Airborne Spacing for Terminal Arrival Routes | Advanced flight deck-based automation that constantly calculates the airspeed required to position an aircraft at the Achieve By Point at the Assigned Spacing Goal behind the Target aircraft. |
| ATCA | Air Traffic Control Association | Independent, non-profit organization for promoting the air traffic control profession and the aviation community. |
| ATD-1 | Air Traffic Management Technology Demonstration #1 | The first of a planned series of NASA NextGen Airspace Systems Program technology demonstrations. This demonstration integrates three research efforts to achieve high throughput fuel-efficient arrival operations using precision time-based schedules, aircraft speed control, and controller display technologies. |
| CMS | Controller-Managed Spacing | Controller decision support tools and display symbology to assess an aircraft's conformance to the arrival schedule and desired in-trail spacing, and to provide speeds to resolve any errors. |
| ConOps | Concept of Operations | Document describing a proposed operation that utilizes new technologies or procedures. |
| CSP | Constraint Satisfaction Point | Meter points used by GIM-S in en route airspace. |
| DSR | Display System Replacement | Displays and equipment used by en route air traffic controllers. Flat screen displays replaced older en route equipment suite in 2000. |
| EDA | Efficient Descent Advisor | Decision-support tool for air-traffic controllers managing arrival airspace in enroute facilities. |
| ERAM | En Route Automation Modernization | FAA program that provides the platform for NextGen improvements, including System Wide Information Management, Data Communications, and Automatic Dependent Surveillance-Broadcast. |
| ERFMP | En Route Flow Management Point | Flow management point prior to Top-Of-Descent. Time assigned by TBFM. |
| ETA | Estimated Time-of-Arrival | The current estimate of the aircraft's time-of-arrival at a point along its flight path based on forecasted winds, aircraft performance and defined arrival procedures, but not adjusted to compensate for traffic separation or metering delays. The ETA is re-calculated on events and radar updates. |
| FAF | Final Approach Fix | The fix from which the final approach to an airport is executed and which identifies the beginning of the final approach segment. |
| FAS | Final Approach Speed | The speed flown by the aircraft from the Final Approach Fix to touchdown on the runway. There are flight crew and airline variances for when this speed is achieved. |
| FDB | Full Data Block | Lines of information next to aircraft icon containing pertinent data for the air traffic controller. |
| FIM | Flight deck Interval Management | Flight crew makes use of specialized avionics that provides speed commands for interval management. |
| -- | FIM aircraft | The aircraft receiving speed commands from the onboard FIM equipment to achieve the assigned spacing behind the Target aircraft. This aircraft must have ADS-B In equipment, and be equipped for FIM operations. |
| -- | FIM clearance | The FIM clearance during ATD-1 operations are the Target aircraft's identification (Target ID), Target's route of flight, and the Assigned Spacing Goal (ASG). The remaining data fields identified in Reference 25 are not included (accommodation for use of voice communication). |

Table 2. Glossary and Definitions (continued)

| Acronym | Term | Definition |
|---------|--|---|
| -- | FIM operations | Refers to one or more FIM aircraft actively spacing to achieve the ASG behind their Target aircraft. Responsibility for spacing (accomplished by flying the FIM speed) resides with the flight crew, aircraft separation responsibility remains with ATC. |
| -- | FIM speed | The speed calculated and provided by the aircraft FIM equipment during a FIM operation to achieve the Assigned Spacing Goal behind the Target by the Achieve-By Point. |
| FIXM | Flight Information Exchange Model | A data interchange format to share flight information. |
| FMS | Flight Management System | An FMS is a computerized avionics component found on most commercial and business aircraft to assist pilots in navigation, flight planning, and aircraft control functions. It is composed of: FMC (Flight Management Computer), AFS (Auto Flight System), Navigation System including IRS (Inertial Reference System) and GPS, and EFIS (Electronic Flight Instrument System). |
| -- | Freeze Horizon | After an aircraft crosses the Freeze Horizon for an En Route Flow Management Point (ERFMP) or Arrival Flow Management Point (AFMP), the Scheduled Time-of-Arrival (STA) for that aircraft to that waypoint is “frozen” (no longer updated). |
| GIM-S | Ground-based Interval Management - Spacing | Ground-based functions intended to support aircraft crossing the TRACON boundary along the route of flight at specific metered times or STAs, as well as stand-alone CSPs. Part of ERAM v4.1. |
| -- | GIM operations | Refers to one or more aircraft not conducting FIM operations that are spaced by ATC. This spacing can be aided by tools (GIM, 3D-PAM, CMS, etc) or unaided (manual operations). |
| ICAO | International Civil Aviation Organization | United Nations agency that codifies international air navigation standards and practices. |
| ID | Identification code | The alphanumeric code used to identify an aircraft. The aircraft ID is shown on controller and cockpit displays, and used to define the Target aircraft within a FIM clearance when using voice communication. The aircraft code is not always the same as the aircraft callsign. |
| MPT | Metering Point Time | Time calculated for an aircraft’s arrival at a given Meter Point. The Meter Point STA is an example of a Metering Point Time. |
| MF | Meter Fix | A Constraint Satisfaction Point (CSP) used for managing arriving aircraft; one of several points referred to as Arrival Flow Meter Points (ARFMP). This ATD-1 document uses Meter Fix as the transition from en route to terminal airspace. |
| MP | Meter Point | A Constraint Satisfaction Point (CSP) used for managing en route aircraft; one of several points referred to as En Route Flow Management Points (ERFMP). Examples include Airspace Meter Point (AMP), Extended Metering Point (XMP), and Coupled Metering Point (CMP). Meter Points in Terminal airspace (Terminal Meter Points) are a new functionality for ATD-1. |
| -- | Non-FIM aircraft | Aircraft receiving heading, speed, and altitude commands from ATC to manage the spacing behind the preceding aircraft. This aircraft may also be a Target aircraft for the subsequent aircraft. |

Table 2. Glossary and Definitions (continued)

| Acronym | Term | Definition |
|---------|---|---|
| OPD | Optimized Profile Descent | OPDs are designed to reduce fuel consumption, emissions, and noise during descent by allowing aircraft to fly an optimized descent during an arrival procedure (such as a STAR) with engines near idle. Ideally the OPD extends to the runway threshold, however, it may not include the instrument approach portion. OPD procedures specify the lateral path and vertical boundaries of the procedure, and some segments include a speed. Vertical boundaries are established to accommodate a wide range of descent profiles, and speeds are defined to enable the use of speed control only by controllers and flight crews. |
| PBN | Performance-Based Navigation | Area navigation based on performance requirements for aircraft on a route, approach procedure, or designated airspace. Navigation performance requirements are expressed in terms of accuracy, integrity, continuity, availability, and functionality needed for the proposed operation. [ref 10] |
| RNAV | Area Navigation | A method of navigation which permits aircraft operation on any desired flight path within the coverage of ground or space-based navigation aids, or within the limits of the capability of self-contained aids, or a combination of these two. |
| RNP | Required Navigation Performance | The navigation performance necessary for operation within defined airspace. (May be used but not a ATD-1 requirement.) |
| -- | Separation | The spacing of aircraft to achieve their safe and orderly movement in flight and while landing and taking off. (FAA Pilot/Controller Glossary) 1) Applicable separation minima remain unchanged by any ATD-1 operation. 2) During ATD-1 operations, the controller remains responsible for providing separation between aircraft. 3) Flight crew conducting FIM operations are responsible for achieving the assigned spacing from a designated (Target) aircraft as stipulated by the controller. |
| SI | Spacing Interval | The true horizontal along-path spacing (expressed in time) between the FIM and Target Aircraft. The SI should equal the ASG by the Achieve-By Point (the FAF in ATD-1). |
| STA | Scheduled Time-of-Arrival | Calculated by the ground scheduling software to meet all of the scheduling and sequence constraints, set at 'Freeze Horizon', and normally not changed. Changing a frozen STA is a 'reschedule', and is triggered manually by the Traffic Manager in response to a significant event (weather, runway change, etc.). |
| STAR | Standard Terminal Arrival Route | A pre-planned instrument arrival procedure published for pilot use in graphic and/or textual form. Provides transition from the en route structure to an instrument approach fix in the terminal area. |
| STARS | Standard Terminal Area Replacement System | Displays and equipment used by controllers in terminal radar approach control facilities and towers. |
| -- | Target Aircraft | The lead aircraft specified by ATC for the FIM aircraft. Must be equipped with ADS-B Out (transmit), but is not required to be ADS-B In (receive) equipped or capable of FIM operations. |
| TAMR | Terminal Automation Modernization and Replacement | FAA program designed to modernize the air traffic control system at all the major US airports. |

Table 2. Glossary and Definitions (concluded)

| | | |
|--------|---|---|
| TBFM | Time-Based Flow Management | An operational concept using time to more efficiently utilize available airport capacity without decreasing safety or increasing workload. |
| TCP | Trajectory Change Point | A full 4-D trajectory is defined by a series of trajectory change points (TCPs). Every point along the track where an altitude, heading, or speed transition occurs. |
| TMA | Traffic Management Advisor | A traffic flow management tool that calculates Estimated Times-of-Arrival (ETA) and corresponding Scheduled Times-of-Arrival (STA) at various points along the aircraft flight path to an airport to optimize the flow of aircraft into capacity-constrained areas. TMA also provides the STA and delay times to the respective En Route controller to maintain the optimum flow rates to runways from the ARTCC to the TRACON. |
| TMA-TM | Traffic Management Advisor with Terminal Metering | An enhancement to TMA that calculates precise time-based, conflict-free schedules to the runway and all meter points. This information is available to TRACON controllers. |
| TMU | Traffic Management Unit | Non-control, coordination positions in the ARTCC and the TRACON, connected to the central flow control function and responsible for dissemination of flow control information at the local level. |
| TOD | Top-Of-Descent | The computed transition from the cruise phase of flight to the descent phase, the point at which the descent to final approach altitude is initiated. |
| TRACON | Terminal Radar Approach Control Facility | Radar control facility associated with an airport. |
| WXXM | Weather Information Exchange Model | International standard weather model currently under development. |

Appendix B: Changes to ATD-1 ConOps

The initial ATD-1 ConOps document published in 2012 [ref 1] benefited greatly from an in-depth review by the FAA and industry partners that generated over 350 individual comments and numerous pages of feedback. Also contributing to the update were several experiments conducted at NASA Ames and Langley Research Centers specifically designed to test the ATD-1 ConOps. A partial list of changes made to the ATD-1 ConOps in Version 2 includes:

- Clarified ATD-1 demonstration goal and objectives
- Regrouped and clarified changes to the current air traffic system needed for ATD-1 operations, and the expected benefits for stakeholders
- Expanded explanation of three NASA technologies
- Added text and a graphic of CMS displays and FIM data block displays
- Provided updates to FIM operations, including:
 - the removal of Scheduled Time of Arrival (STA) functionality,
 - clarification of when FIM speed is first calculated,
 - ability to commence operations when not on a published route,
 - when FIM operations commence and terminate,
 - added detail to contingency operations
- Corrected errors and added detail to graphics and text that describe the phases of ATD-1 operations
- Clarified that flight crews are not expected to manually enter additional waypoints and constraints in the FMS to enable FIM operations
- Added text that flight crews conducting FIM operations will ensure the most current terminal area wind forecast is in both the FMS and FIM equipment
- Added Appendices to document changes from previous version of ConOps, and to highlight related concepts and work B
- Assumptions and requirements in body of text and Appendix E updated
- Added detail on TMA-TM algorithm and calculations in Appendix F
- Simplified phraseology, clarified some terminology, removed and added terminology in Appendix G

Appendix C: Related ATM Concepts and Research

This Appendix briefly describes related ATM concepts and research efforts, and how the ATD-1 ConOps compares to, supports, or benefits from them.

C.1 TBFM and TSS

Several planned TBFM enhancements have relevance to or can be supported by the long-term ATD-1 ConOps, in particular Terminal Sequencing and Spacing (TSS). The TBFM enhancements are not expected to occur in time to impact the mid-term ATD-1 demonstration; however the TSS enhancements are directly tied to NASA's TMA-TM development. The FAA TBFM and TSS documentation is paraphrased below.

C.1.1 Time-Based Flow Management (TBFM)

Path Stretch Controller Advisories. Provides controllers with tools to assist in absorbing delays during time-based metering operations. The enhancement is based on the mature TBFM trajectory modeler, which is used to compute the additional distance needed to absorb a flight's metering delay at an assigned airspeed. From the additional distance, it computes a closed-form lateral path stretch maneuver that is conflict free. It computes a change to the flight's trajectory that increases the distance flown and hence the flight time, but does not involve an altitude change.

Metering During Reroute Operations (MDRO). Four new capabilities that allow time-based metering to be continued during severe weather conditions in which today metering would be suspended.

- Predefined Meter Points (PDMP). When convective areas become sufficiently large and severe, normal traffic routes are closed, and one or more PDMPs will be activated where the merging of rerouted and normal traffic flow creates high traffic volumes. Metering to the PDMPs regulates traffic volume into the affected points and assists in merging the flows.
- Weather Avoidance Fields (WAF). These allow metering to continue when localized convective weather causes flights to deviate, but normal routes remain open and the deviations stay within the affected sectors.
- Data integration to improve metering. Data integration with other systems improves TBFM system capabilities to facilitate the continuation of metering in severe weather conditions.
- Cumulative metering delays. Tracking the cumulative delay flights have already received at upstream meter points will allow downstream meter points to schedule flights more equitably.

C.1.2 Terminal Sequencing and Spacing (TSS)

Terminal Sequencing and Spacing introduces three new TRACON Time-Based Metering capabilities. Much of the development comes directly from the NASA research and testing done to develop TMA-TM. These capabilities are:

- Terminal Runway Assignment (TRA). TRA will consider real-time operational air traffic conditions within terminal airspace along with operational objectives to determine appropriate runway assignments for aircraft arriving at airports within the terminal airspace.
- Terminal Arrival Runway Sequencing Assignment (TARSA). TARSA will consider real-time operational air traffic conditions within terminal airspace along with operational objectives to determine appropriate terminal arrival runway sequencing assignments for aircraft arriving at airports within the terminal.
- Terminal Merge Points (TMP). TMP will provide the TRACON controllers the ability to meet a metering constraint inside terminal airspace to support mixed equipage operations and also to allow continuous metering in TRACONs with expanded airspace.

C.2 Interval Management

The NASA FIM procedures used in ATD-1 are a subset of the Arrival Interval Management – Spacing (IM-S) concept and procedures developed by the FAA. The NASA research has been closely linked with the FAA’s development, and the ATD-1 demonstration is intended to support the FAA’s decision making process regarding NextGen decisions. The FAA IM-S ConOps documentation is paraphrased below.

The arrival IM-S concept employs a ground-based flow component to support the management of arrival streams for the setup and conduct of Optimized Profile Descents (OPDs) in en route airspace through the use of time-based flow management (TBFM) and speed advisory functionality. The IM ground-based flow component is intended to increase the opportunity to conduct OPD operations for medium levels of traffic. This concept also employs a flight deck-based component to support the conduct of OPDs. This component is expected to further increase the opportunities to conduct OPD operations during higher throughput rates.

The arrival IM-S concept utilizes Automatic Dependent Surveillance – Broadcast (ADS-B). The deployment of ADS-B will support increased accuracy in trajectory prediction for the ground-based flow component, and will also be a critical enabler for the flight deck-based spacing component. FIM-S is identified as the flight deck-based

spacing component for this concept. For the FIM-S descriptions in this document, the FIM-S aircraft is the “trailing” aircraft performing FIM-S operations and receiving speed guidance from onboard avionics to achieve the assigned spacing goal behind its “target” (or “leading”) aircraft, with this aircraft providing ADS-B Out surveillance information.

C.3 RNAV and RNP

The development of arrival and approach procedures to leverage new technologies and capabilities, such as RNAV/OPD STARs and RNAV/RNP approaches, directly impact the ATD-1 effort. ATD-1 depends on these base FAA programs, and these programs stand to benefit from ATD-1. Early trials and implementations of RNAV/OPD STARs have seen the need for ground and/or airborne tools to allow use of the procedures under high traffic density conditions. Trials of RNAV/RNP procedures that connect merging traffic streams to common or parallel approaches require new controller procedures and possibly tools like those designed for ATD-1. Coordination of FAA and industry efforts at RNAV/OPD and RNP procedure development with ATD-1 is critical to the success of both efforts.

One example of this coordination is the “Greener Skies” work at Seattle by the FAA, which is an effort to use RNP in lieu of the ILS for closely spaced runways. Airports throughout the United States are deploying Area Navigation/ Required Navigation Performance (RNAV/RNP) routing capabilities, yet full use of these capabilities is being inhibited by the lack of approved procedures and rule changes that incorporate the unique abilities of PBN-equipped aircraft. Research is needed to explore the operational limits associated with this technology and explore the potential changes to the relevant operational criteria and procedures to fully use the PBN technologies. The FAA, in partnership with the Port of Seattle, industry, and other local and state governments, is seeking to improve efficiency and minimize the environmental impact on the ground and in the air by reducing aircraft noise and emissions at Seattle-Tacoma International Airport through expanded use of RNP, RNAV, and OPDs.

A second example of this type of work is the RNP approaches in Atlanta being developed by Delta Airlines and the FAA. “Peachy Skies” is an effort to use the “Greener Skies” capabilities in visual meteorological conditions in lieu of changes to the FAA air traffic regulation. The current spacing requirements [ref 27, Chapter 5, Section 9] create large inefficiencies in the NAS when an airport conducts simultaneous operations. This work used RNAV and RNP to provide a means to reduce these inefficiencies through path keeping capability, monitoring, and alerting.

C.4 Tailored Arrivals

The development of Tailored Arrivals (TAs) has benefited the ATD-1 ConOps conceptually and by assisting in developing phraseology and procedures. The FAA Tailored Arrival ConOps is paraphrased below.

Tailored Arrival (TA) operations are a central component of the joint US and Europe Atlantic Interoperability Initiative to Reduce Emissions (AIRE) project and the Asian Pacific Initiative to Reduce Emissions (ASPIRE). Early development of this concept provides an arrival route that is “tailored” to account for individual aircraft performance, environmental factors, and other air traffic. The desired end state is a dynamic optimized trajectory that may be data-linked to the aircraft. Until then, the TA is composed of playbooks from which the controller will select the optimal arrival route.

The uplinked clearance contains speed and altitude constraints for points in the profile. These constraints can be assigned to either named points or specified by latitude and longitude. Using non-named points for clearance construction provides greater flexibility for controller manipulation and reduces the demands for navigational database storage by the FMS. The instrument approach and runway assignment are provided to allow a full 4D trajectory computation and control by the FMS. Clearance to fly the approach and actual runway assignment are provided by the TRACON or Tower as appropriate.

C.5 Time-Based Procedures

One of the Single European Sky ATM Research (SESAR) efforts was the Environmentally Responsible Air Transport (ERAT) project, which explored enhanced departure and arrival services into major airports. The concept of time-based continuous descent operations was developed and applied to the Stockholm Arlanda Airport and the surrounding airspace environment. The concept used Controlled Times-of-Arrival (CTA) as a constraint for inbound aircraft to achieve a more orderly and predictable arrival sequence. This CTA time constraint was applied to dedicated waypoints on the different arrival routes to the airport. Experience from previous projects indicated the most optimal CTA waypoint was located at a distance of 30NM to the runway with the present state of technology and procedures. This distance allowed good probability to execute successful CDA approaches, and still provide sufficient airspace after the CTA point for final corrections by the approach controllers, as necessary.

Appendix D: Limitations to the ConOps During the ATD-1 Demonstration

This Appendix contains a partial list of operational limitations that are expected to exist during the demonstration that precludes full implementation of the long-term ATD-1 ConOps and operations, and results in the mid-term ATD-1 ConOps and operations as described in the body of this document. Although these limitations to varying degrees are expected to impact the ATD-1 demonstration results, improvements in efficiency and workload should still be realized.

1. Only ATD-1 arrival operations to a single airport with independent runway operations will be demonstrated.
 - Some ATD-1 technologies are envisioned during departure, en route, and oceanic environments. ATD-1 concept and technology development could eventually support closely spaced parallel runway operations.
 - Impact when resolved: as ATD-1 procedures become prevalent in all operational environments and phases of flight,
 - ATD-1 operations provide greater benefit for the cost required to upgrade software and equipment, and
 - increased familiarity with procedures should reduce controller and flight crew workload.
2. Trajectory from aircraft's position to runway not known by all users and automation.
 - Some information required by the ground (ERAM, STARS, etc) and airborne (FMS, FIM, etc) systems to implement the long-term ATD-1 ConOps is not expected by the demonstration timeframe. Some of the data elements not universally available include:
 - aircraft's cruise airspeed and descent profile,
 - scheduler's plan for the aircraft's cruise speed and descent profile,
 - aircraft ETA at waypoints and the runway,
 - scheduler's STA at waypoints and the runway,
 - aircraft's intended trajectory, and
 - scheduler's intended trajectory for that aircraft.
 - Impact when resolved:
 - flight crew increase frequency using FMS calculated Top-Of-Descent,
 - fewer controller interventions (vectors, altitude step down) required,
 - CMS and FIM operations continue to Achieve By Point (the Final Approach Fix) instead of terminating early when the Final controller issues a vector to intercept final course (when the arrival procedure does not connect to the approach procedure), and
 - more correct and desirable FIM operations since Target aircraft's actual trajectory will be used to calculate FIM speed.
3. Ground automation systems (TMA-TM, ERAM, STARS) do not have capability to exchange all data between each other, and not all controller displays for that data will have been developed.
 - Impact when resolved:

- complete schedule, including FIM clearance, is known to all controllers (may be accomplished during the ATD-1 demonstration via direct coordination between the TMU and controller),
 - phraseology by flight crew stating FIM operation in effect may not be required during initial check-in, and
 - sequence swaps and reschedules trigger notification to the controller to terminate a FIM clearance if required.
4. Coupled scheduling between ARTCCs not in use (still in development).
 - Impact when resolved:
 - TMA-TM will be able to expand on coupled scheduling increased ETA accuracies, and
 - enhanced Arrival System scheduling accuracy.
 5. ATD-1 technologies not yet integrated with other emerging technologies, such as Efficient Descent Advisor.
 - Impact when resolved:
 - arrival accuracy of ATD-1 operations will be enhanced.
 6. Ground and airborne automation do not have Data Comm to send complete route, complex routes, or dynamically tailored routes.
 - Impact when resolved:
 - air traffic ground tools cognizant of aircraft's planned trajectory in sufficient detail to calculate and predict aircraft separation,
 - aircraft FIM software no longer limited to using published procedures for Target aircraft's route, and
 - FIM operation may not be terminated when the Final controller issues a vector to intercept the final approach course.
 7. FIM operations not fully implemented by the ATD-1 demonstration timeframe.
 - Impact when resolved:
 - any waypoint may be issued as the Achieve By Point and Terminate Point, and those two points may be different,
 - FIM Turn functionality available (as defined in reference 25),
 - FIM to Closely Spaced Parallel Runways functionality available, and
 - FIM operations continue unless specifically suspended or terminated by controller (for example, step down altitudes or vectors to final).
 8. The Airline Operations Center (AOC) is not expected to be part of the demonstration.
 - Impact when resolved:
 - AOC to have connectivity to TMA-TM as well as the flight crew, and
 - aircraft operations will be tailored inflight (for example, change of the cost index) to assist in achieving scheduled time of arrivals at particular points.

Appendix E: Assumptions and Requirements for ATD-1

This Appendix outlines the technical assumptions and requirements of the operating environment to successfully accomplish the ATD-1 demonstration.

E.1 Schedule Phase

- The arrival and approach procedures used by ATD-1 will support PBN from the current aircraft position to the assigned runway. These procedures will define a speed for each segment of the PBN procedure, and when required, altitude or speed constraints at some waypoints, if required. Examples are CROSS AT (altitude), CROSS AT OR ABOVE (altitude), and NO SLOWER THAN (speed).
 - Where PBN procedures are not published all the way to the runway (that is, the arrival does not connect to the approach or airspeed is not defined on a segment), the TMA-TM, CMS and GIM-S functions will use adapted standard operating procedures which describe the operation from cruise to touchdown.
 - The FIM software requires knowledge of the fully defined trajectory of both the Target and FIM aircraft. Therefore the software cannot produce a valid FIM airspeed until both aircraft are on a speed-constrained portion of their respective procedures. Prior to both aircraft being on a speed constrained portion of the arrival, the FIM software will indicate either the clearance has been loaded, or the clearance is loaded and valid ADS-B data from the Target is available but a speed cannot yet be calculated.
- The ground scheduler will determine a STA at the runway threshold and all upstream meter points for each aircraft within the scheduler's Freeze Horizon. These times create the intended aircraft arrival sequence. The associated spacing intervals between aircraft meet or exceed all air traffic separation requirements, including wake separation standards, safe separation practices, runway occupancy requirements, etc.
- The TMA-TM schedule will use the most detailed aircraft data available. This includes: aircraft identification code, state information (latitude, longitude, altitude, velocity), intent information (route of flight, runway assignment, etc.), and aircraft specific data (aircraft type, navigation equipment identifier, etc.).
- The TMA-TM schedule will only use aircraft transmitting ADS-B data as a valid Target aircraft for a FIM operation.
- The ground scheduler will derive FIM clearances for the controller to issue to FIM-equipped aircraft based on the arrival sequence, and the difference in runway STA for that pair of aircraft.
- The TMA-TM arrival schedule will be available to ARTCC controllers on the DSR displays. The types of information presented to the ARTCC controller will include metering information (aircraft identification code, time to the appropriate meter point, assigned runway) for all aircraft, and the FIM clearance information (Target identification code, Target route, and spacing interval) for suitably equipped aircraft.
- The TMA-TM arrival schedule will be available to TRACON controllers. The types of information presented to the TRACON controller include sequence and

meter point information for all aircraft, and FIM status via the data tag block for suitably equipped aircraft.

- Unique RNAV and RNP navigation capabilities are not required for ATD-1 operations, other than those required for the air traffic facility's arrival and approach procedures.
 - Although non-RNAV procedures and non-RNAV equipped aircraft can be utilized by ATD-1 technologies and procedures, the intended improvements in airport throughput and aircraft efficiency would not be fully realized without the use of RNAV or RNP.

E.2 Precondition Phase

- When significant metering delay must be absorbed, ARTCC controllers may use controller derived speed instructions, GIM-S speed advisories, vectors, or step down the aircraft's altitude to achieve the needed delay.
- When significant delay does not need to be absorbed, ATD-1 operations proceed from the Schedule Phase directly to the Initiation Phase.

E.3 Initiation Phase

- The en route controller will retain positive control over all aircraft in the sector, and retain responsibility for separation of all aircraft.
- All aircraft will have at least standard separation between aircraft for any ATD-1 operation.
- The en route controller will have the necessary information and displays to include Meter Fix ETA and STA for all aircraft, issue speed commands (using GIM-S displays), and issue FIM clearances.
- En route controllers will issue the arrival procedure and expected runway to all aircraft as soon as feasible after the Freeze Horizon. This is to enable the FMS to calculate the TOD and a fuel-efficient trajectory for that arrival based on aircraft weight and forecasted winds.
- En route controllers will attempt to issue "Descend Via" clearances to flight crews, enabling the flight crew to fly the arrival procedure and meet the published altitude and speed constraints. The FMS may be utilized to maximize the aircraft's efficiency while conforming to these constraints, thereby maximizing fuel efficiency as well as reducing noise and emissions.
- The FIM clearance will be issued as soon as feasible after the schedule is frozen. It is desired to be issued prior to the FIM aircraft's TOD, however should be issued after the Descend Via instruction.
- FIM clearances will be issued via voice from ATC to the flight crew.
- The flight crew will acknowledge the FIM clearance or amendment as expeditiously as possible, as other cockpit tasks allow.
- The Target aircraft and FIM aircraft may be in the same or different airspace sectors, and may be on the same or different arrival procedure (therefore cross the same or different TRACON Meter Fix).

- The Target aircraft and FIM aircraft of a FIM pair will be assigned to the same runway.
- The FIM aircraft must receive ADS-B data from the Target aircraft, but is not required to receive ADS-B data from any other aircraft.

E.4 Operation Phase

- The integrated ATD-1 technologies, procedures, and operations are designed to be used in any situation the current TMA is used.
- Controllers will attempt to avoid vectoring aircraft unless safety concerns or other operational considerations require they do. Vectoring reduces the accuracy of the CMS speed advisory and suspends the FIM operation.
- “Sequence swaps” or “rippling of the list” events that impact either the Target or FIM aircraft require the controller to terminate the existing FIM operation, and issue a new FIM clearance if still desired.
- Flight crew conducting FIM operations will update the terminal airspace wind forecast prior to TOD in both the FMS and FIM equipment.
- CMS tools and FIM operations can be used simultaneously, that is, aircraft receiving controller speed instructions can be on the same arrival procedure as aircraft conducting FIM.
- ATC speed instructions take precedence over published speeds and the FIM speed. ATC will suspend or terminate FIM operations prior to issuing vectors or speed instructions to the flight crew conducting FIM. If the controller omits the term suspend or terminate while issuing the instruction, the FIM operation is suspended and the flight crew will adhere to the ATC instruction.
- The terminal airspace controller will have the necessary information and displays to issue speed commands (using CMS displays).
- The FIM speed calculated by the spacing software is equivalent to a controller’s speed instruction, that is, the FIM speed supersedes the published speed on the arrival or approach procedure and must be flown unless the flight crew notifies ATC otherwise.
- The flight crew is expected to respond to a FIM speed change as expeditiously as possible.
- An aircraft flying a FIM operation will achieve the Assigned Spacing Goal behind the Target Aircraft by the Achieve-by Point (the Final Approach Fix).
- The FIM operation is “Suspended” if either the Target or FIM aircraft is vectored. If the controller is unaware that the Target aircraft has been vectored off the procedure, or the controller’s workload does not permit notifying the flight crew, the FIM software will transition to the “suspend” mode when the Target aircraft exceeds 2.5 nmi lateral deviation from the assigned Target route.
- The FIM operation is “Suspended” if the FIM aircraft is given a speed instruction. If the controller omits the term “suspend” in the instruction, the FIM operation is suspended and the flight crew will adhere to the ATC instruction.

E.5 Termination Phase

- CMS operations cease when the Final controller hands off the aircraft to the Tower controller.
- FIM operations cease at the Achieve-By Point when the published arrival and approach procedure connect. FIM is terminated by crew interaction.
- FIM operations cease when the Final controller issues the flight crew a vector to intercept the final course when the published arrival and approach procedure do not connect. FIM is terminated by crew interaction.
- After the Achieve-By Point, the FIM software provides no speed commands to correct spacing errors, and crew interaction is not required. The flight crew have no FIM related tasks or displays.
- When FIM terminates, the flight crew will maintain the last FIM speed unless the controller issues a speed instruction
- The FIM operation is terminated if either the Target or FIM aircraft is given a change to its route.
- If ATC suspends or terminates a FIM operation, the FIM equipment, via flight crew interaction, will inhibit the display of FIM speed guidance information.
- The flight crew will notify ATC if they terminate the FIM operation prior to the Achieve By Point.

Appendix F: Description of Algorithms

This Appendix defines how the algorithms used by the ground scheduling tool and airborne spacing tool produce values expected by the other components of the ATD-1 ConOps.

F.1 Ground-based Scheduling Algorithm

- The TMA-TM scheduling algorithm will use the published or standard operation arrival procedure to calculate the STA to the runway threshold for each aircraft.
- The runway STAs are assigned at the runway threshold to as a minimum comply with wake vortex separation criteria. The STA is derived from the aircraft's ETA calculated by TMA-TM.
- The runway STA is used to calculate deconflicted times at the Meter Fix and terminal airspace merge points based on the speeds and available time delay for each segment.

F.2 Controller Managed Spacing Algorithm

Information for early/late indicators comes directly from arrival schedules; thus, it is to be communicated to the TRACON controller workstations from TMA-TM. CMS advisories are not available to ARTCC controllers.

Slot marker circles are computed via the following process:

- Determine the meter point and runway schedules. The meter point and runway STAs are generated by TMA-TM. For each Meter Point, TMA-TM calculates the STAs and ETAs for all scheduled aircraft. The schedules are updated every six seconds and in response to reschedule events.
- Compute the aircraft's nominal trajectory. The nominal trajectory is the trajectory that the aircraft would fly if it did not receive any speed commands from ATC and met all speed and altitude restrictions that are specified in the nominal arrival procedure.
- The Meter Point Times (MPT) are based on adjustments made by the TMA-TM schedule to accommodate the required delay for that aircraft. Each trajectory point will have a nominal time-of-arrival that represents the time at which an aircraft would arrive at that position if it flew the nominal trajectory and arrived at the STA at the next meter point.
- Compute the nominal flight state. Given the trajectory and the adjusted times-of-arrival, use a trajectory-based interpolation algorithm to compute the aircraft's state at the point along the trajectory corresponding to the current time.
- Store the nominal flight state with the aircraft record. The slot marker circle is the graphical representation of the nominal flight state (i.e., spatial representation of the schedule).

Speed advisories are computed via the following process:

- Determine if speed control can be used to meet the scheduled times-of-arrival at each of the meter points. The speed advisory algorithm traverses the meter points between the aircraft's current position and the assigned runway and computes

whether the desired STA at each meter point lies within the aircraft's time-of-arrival window. The algorithm uses the fastest and slowest speeds for each trajectory segment to make this determination.

- Construct the speed advisory. For each meter point where a speed advisory is possible, iterate over the possible speed values, to change the speed restrictions between the current aircraft location and the meter point. For each test speed, compute the corresponding trajectory and evaluate the ETA at the meter point. If the absolute difference between the STA and the ETA is less than a preset threshold (e.g., 2 seconds), indicate success, and quantize (per adaptable parameters) the result for display to the controller.

F.3 Flight-deck Interval Management Algorithm

The FIM software tool provided by the ATD-1 avionics partner for the demonstration should be similar to the ASTAR algorithm [ref 28] used by the NASA research team. Behavior and design goals of the airborne spacing algorithm include:

- The speed control law is designed to reduce the inter-arrival spacing error gradually, but not uniformly, as the operation progresses. The error may temporarily increase if the forecasted winds are incorrect.
- The ASTAR spacing algorithm does not know, nor is it controlling to, the adjusted times calculated by TMA-TM for upstream meter points. If these adjustments are significant or non-uniform, the speeds flown by aircraft conducting FIM may not align with controller CMS displays for that aircraft. Therefore, the behavior of the FIM operation will not closely align with the behavior indicated by the CMS displays, especially when the Target aircraft is not maintaining the airspeed prescribed on a published procedure.
- FIM speeds greater than 250 KIAS will not be commanded after the aircraft has descended below 10,000 feet MSL.
- FIM speeds will not exceed 15% greater than or 15% less than the published speed restriction for any segment of the published route. This value was set to be less than observed controller speed instructions, and to provide arrival stream stability for subsequent aircraft.
- The FIM speed commanded by ASTAR is quantized to reduce the number of speed changes, and therefore the flight crew workload.
- The aircraft's sensed wind, and the forecast wind entered by the crew into the FIM application, are used by ASTAR to calculate the aircraft's trajectory. A gain factor is applied to the forecast wind values so that as an aircraft approaches a waypoint or altitude, the percentage of forecast wind used in the calculation is reduced to zero. The forecast wind values and gain schedule is also applied to the Target aircraft's trajectory calculation.

Appendix G: Controller-Pilot Phraseology

Current controller-pilot phraseology (initial check-in, issuing route instructions, ‘Descend Via’ clearances, etc.) remains unchanged during ATD-1 operations to the maximum extent possible, and no new phraseology has been identified for CMS operations. Phraseology in this Appendix unique to FIM operations has been derived from the FAA IM Working Group [ref 25-26] and current controller-pilot phraseology [ref 27], although several modifications were made to enable shorter transmissions for voice communication operations, and some words were changed for increased clarity (for example, “Paired” instead of “Interval Spacing” to report FIM engaged). Any FAA guidance or direction has precedence over phraseology described in this Appendix.

The validation of using voice communication to conduct FIM operations in a complex and busy terminal airspace is an important supporting objective of the ATD-1 demonstration. Phraseology in this section has not only been simplified from the proposed standards mentioned above (designed with data link capability), but portions of the FIM operation have also been procedurally limited and defined (the “Achieve-By Point” and “Termination Point” are both the Final Approach Fix, the Assigned Spacing Goal is always “precise” and defined in seconds, and the Target and FIM aircraft must land on the same runway). Validating this is important so aircraft operators can develop business cases for ADS-B In applications.

The normal procedure is for the en route controller to issue each aircraft their route of flight and expected runway assignment prior to Top Of Descent, or as part of the “Descend Via” clearance. For those aircraft equipped with FIM equipment, the en route controller subsequently issues the FIM clearance. The flight crew read back the FIM clearance, notify the controller when the FIM operation commences, and include a FIM status as part of the initial check-in on each subsequent frequency. Any controller may amend, suspend, or terminate the FIM clearance, and any ATC instruction takes precedence over the FIM speed.

NOTE: the use of voice communications during ATD-1 operations will likely cause the FIM clearance to be issued after the flight crew has been given their Descend Via arrival instruction. Subsequent air traffic control instructions supersede previous instructions, therefore the FIM clearance must be issued after the Descend Via instruction to enable the flight crew to fly the FIM speed and not the published arrival speed.

The terminal feeder controller issues the actual runway assignment to all crews (in some cases may be given by an en route controller), and the Final controller normally issues the approach clearance to all crews. If the arrival and approach connect via the published procedures, controllers are not expected to issue vectors and crews may use the auto-pilot system to fly the procedures. If the arrival and approach procedures do not connect, controllers issue vectors to place the aircraft on final.

The elements of a FIM clearance are:

- Assigned Spacing Goal [in seconds],
- Target (lead) aircraft identification [phonetic],

- Target aircraft route [STAR name, and approach if feasible].

Phraseology used with the FIM clearance adheres to the following guidance:

- “WHEN ABLE” is used to instruct the crew to enter the FIM clearance and initiate the FIM operation as soon as feasible (dependent on when the Target ADS-B data is first received, and the prioritization of other cockpit tasks).
- “AFTER (waypoint name)” is used to instruct the crew to enter the FIM clearance as soon as feasible, but to initiate the FIM operation after the specified waypoint (the TRACON Meter Fix during ATD-1).
- “PAIRED” is used by the flight crew to announce when the FIM operation has begun, and to clearly differentiate from the FIM clearance read-back phraseology.

When referring to the Target aircraft, normally the phonetic alphabet will be used. Based on proficiency, frequency congestion, and similarity between the flight identification and callsign, controllers may alternatively use letters or the callsign of the Target aircraft. In the example below, the aircraft callsign should not be used since it is not similar to the flight identification that is visible on controller and flight crew displays.

- Normal voice phraseology (phonetic) when referring to the Target aircraft identification within the FIM clearance:
 - Aircraft Identification Code (phonetically): *Romeo Papa Alpha One-Five*
- Alternatives:
 - Aircraft Identification Code (letters): *R P A One-Five*
 - Less desirable due to potential lack of clarity
 - Aircraft Callsign: *Brickyard One-Five*
 - Not desirable when callsign is dissimilar to data tag code

G.1 Route and runway assignment by en route controller

During ATD-1 operations, en route controllers will issue the route of flight and the expected runway to all aircraft after the Freeze Horizon and prior to Top-Of-Descent. The runway may be given as a separate instruction, or by appending it to the STAR or Descend Via clearance. Route and runway assignments should also be given prior to issuing a FIM clearance to suitably equipped aircraft. Traffic permitting, en route controllers will issue a “Descend Via” clearance to authorize the flight crew to descend at their discretion. Terminal feeder controllers will issue the actual runway and Final controllers the approach clearance.

There are several acceptable variations to this phraseology, and it is influenced by the specific facility procedures and Letters Of Agreement with neighboring facilities, controller experience and preference, as well as workload and frequency congestion. The first example below is intended to represent the situation when the en route controller assigns the arrival procedure and the expected runway, and the second example is intended to represent the situation when the en route controller clears the aircraft to begin the arrival procedure and issues the assigned runway.

The first example in this sub-section also depicts a STAR that does not connect to the approach procedure, and the second example is when they do connect. Whether or not the STAR and approach procedure connect is not linked to whether a route clearance or Descend Via instruction is given, nor is it linked to whether the runway is assigned or expected. Many combinations and variations are possible, however for brevity only two examples are given.

G.1.1 Route clearance and expected runway (Figure 17 and Figure 19).

ATC: (Callsign), CLEARED TO PHOENIX VIA BOULDER CITY, THEN THE (MAIER Five) ARRIVAL, EXPECT RUNWAY (two-six) TRANSITION.

Crew: (Callsign), CLEARED TO PHOENIX VIA BOULDER CITY, THEN THE (MAIER Five) ARRIVAL, EXPECT RUNWAY (two-six) TRANSITION.

G.1.2 Descend Via and assigned runway (Figure 18 and Figure 19).

ATC: (Callsign), PROCEED DIRECT (ZUNI), DESCEND VIA THE (EAGUL Five) ARRIVAL, RUNWAY (two-six) TRANSITION.

Crew: (Callsign), PROCEED DIRECT (ZUNI), DESCEND VIA THE (EAGUL Five) ARRIVAL, RUNWAY (two-six) TRANSITION.

G.2 FIM Clearance Issued by ATC

The FIM clearance will be given after the route and expected runway has been issued. This clearance only impacts the speed an aircraft maintains while flying the previously assigned arrival and approach. Any subsequent clearance or instruction from ATC, such as a speed instruction or Descend Via clearance, terminate the FIM clearance (whether the controller states “cancel interval spacing” or not).

G.2.1 Preparatory call for FIM clearance

A preparatory voice transmission should be made by ATC prior to issuing a FIM clearance similar to issuing any other clearance to flight crew.

ATC: (Callsign), CLEARANCE AVAILABLE, ADVISE WHEN READY TO COPY.

Crew: (Callsign) READY TO COPY.

G.2.2 FIM clearance to commence after a waypoint

The FIM clearance may be issued to begin FIM operations after a specific waypoint. During ATD-1, this point will be the AFMP on the FIM aircraft’s route. This is done if any of the following conditions are true:

- The Target and FIM aircraft are not on the same arrival,

- The controller is not aware of both aircraft (likely due to the Target on a different arrival),
- The controller believes vectors are still required for either aircraft.

In this case, after issuing the FIM clearance until the aircraft reaches the AFMP, the controller continues to issue speed instructions (if required) using the GIM-S tool to meet the assigned time at the AFMP.

ATC: (Callsign), AFTER (HOMRR), WHEN ABLE SPACE (niner-five) SECONDS BEHIND (Alpha Alpha Lima one-three-six) ON THE (KOOLY Four) ARRIVAL. REPORT PAIRED.

Crew: (Callsign), AFTER (HOMRR), WHEN ABLE SPACE (niner-five) SECONDS BEHIND (Alpha Alpha Lima one-three-six) ON THE (KOOLY Four) ARRIVAL. REPORT PAIRED.

G.2.3 FIM clearance to commence as soon as feasible

The FIM clearance may be issued to begin FIM operations as soon as feasible, however since the Target aircraft may not be within ADS-B reception range of the FIM aircraft, the precise location or time the FIM operation commences is not always known. This may be done when all of the following conditions are true:

- the Target and FIM aircraft are on the same arrival,
- the controller is aware of both aircraft, and
- the controller believes no further vectoring is required for either aircraft.

In this case, the controller should not have to issue further speed instructions after the crew reports having begun FIM operations.

ATC: (Callsign), WHEN ABLE, SPACE (eight-seven) SECONDS BEHIND (Uniform Alpha Lima two-five-four) ON THE (KOOLY Four) ARRIVAL. REPORT PAIRED.

Crew: (Callsign), WHEN ABLE, SPACE (eight-seven) SECONDS BEHIND (Uniform Alpha Lima two-five-four) ON THE (KOOLY Four) ARRIVAL. REPORT PAIRED.

G.3 Flight crew FIM status notification to ATC

Flight crews are required to notify ATC when FIM operations commence, and advise all subsequent controllers of the status of the FIM operation (during initial check in). The term “Interval Spacing” is used by the flight crew to indicate a FIM clearance has been received by the operation has not commenced, and “Paired Behind” to indicate the FIM operation has commenced (“Paired With” is also acceptable). See Termination section (G.6) when the flight crew cannot commence the FIM operation or needs to terminate it after it has begun.

Normal communication procedures apply during check-in with the receiving controller. For example, the flight crew's initial check-in with any new facility will include the altitude the aircraft is currently at or passing through to verify the transponder data, and the crew's initial check-in with the TRACON will include the ATIS code. When the crew has been assigned an altitude to descend to, that altitude is included in the initial check-in. When the flight crew has been cleared to Descend Via an arrival procedure, that procedure name without an altitude is used in the initial check-in.

For brevity, the communication for only three of many possible combinations is given.

G.3.1 FIM operation commencing, no frequency change

Crew: (Callsign) PAIRED BEHIND (Romeo Papa Alpha two-two-one).

ATC: (Callsign), ROGER.

G.3.2 Intra-facility check-in, FIM operation commenced, initiating descent

Crew: (Callsign) LEAVING (one-niner thousand), DESCENDING VIA THE (MAIER Five) ARRIVAL, PAIRED BEHIND (Delta Alpha Lima one-two-eight).

ATC: (Callsign), ROGER.

G.3.3 Initial TRACON check-in, FIM operation pending, in descent

Crew: (Callsign) PASSING (one-two thousand) DESCENDING VIA THE (MAIER Five) ARRIVAL WITH INFORMATION (Tango), WITH SPACING CLEARANCE BEHIND (Delta Alpha Lima one-two-eight-niner).

ATC: (Callsign), ROGER.

G.4 FIM Clearance Amended by ATC

The spacing interval of a FIM clearance may be modified by ATC as new information becomes available or operational goals change. The intended benefit of amending a FIM clearance versus canceling and issuing a new FIM clearance is to reduce both controller and pilot workload. Any other change to the FIM clearance (Target aircraft ID, Target route) or a change in the FIM aircraft's route requires the current FIM clearance to be terminated and a new FIM clearance issued (if desired).

Three different scenarios would create minor variations in the phraseology. They are: when the FIM operation has already commenced; a FIM clearance to commence after a waypoint (G.2.2); and a FIM clearance to commence as soon as feasible (G.2.3). For brevity only one example is shown for after the FIM operation has begun. The other two scenarios would use phraseology from the appropriate section.

ATC: (Callsign), AMEND CLEARANCE. WHEN ABLE SPACE (one-three-zero) SECONDS BEHIND (Delta Hotel Lima seven-eight-three).

Crew: (Callsign), AMEND CLEARANCE. WHEN ABLE SPACE (one-three-zero) SECONDS BEHIND (Delta Hotel Lima seven-eight-three).

G.5 Suspending and Resuming FIM Operation

The FIM operation may be suspended by any controller, and later resumed (by the same or a different controller) when needed to achieve other objectives over a short time period and FIM is desired to be continued at a later time. The FIM operation must be suspended when: ATC issues a speed instruction to the FIM aircraft, a heading change to the FIM aircraft, or a heading change to the Target aircraft.

G.5.1 ATC suspends the FIM operation

ATC: (Callsign), SUSPEND INTERVAL SPACING, SLOW TO (two-three-zero) KNOTS.

Crew: (Callsign), SUSPEND INTERVAL SPACING, SLOW TO (two-three-zero) KNOTS.

G.5.2 ATC resumes the FIM operation

The controller may include “WHEN ABLE” if appropriate. This example does not include that phraseology.

ATC: (Callsign), RESUME INTERVAL SPACING BEHIND (Delta six-two-two).

Crew: (Callsign), RESUME INTERVAL SPACING BEHIND (Delta six-two-two).

G.6 Termination of FIM Operation

FIM termination at the Achieve By Point (FAF in ATD-1) does not require communication. If ATC terminates the FIM operation prior to that point, the controller may use the phrase “cancel interval spacing”, and if not used, the FIM operation is implicitly canceled by the subsequent speed instruction, vector, or clearance. If the flight crew cannot adhere to the FIM speed or there is no valid FIM speed, the flight crew will state “unable interval spacing” and may include the reason and intentions (reason and intentions in a low-density traffic environment only).

Any speed instruction or route clearance issued to the FIM aircraft terminates the FIM operation, whether or not the controller states “cancel interval spacing” or not. In a low-density traffic environment the controller may state “cancel” or “terminate” prior to issuing instructions, however during periods of high-density operations it should be expected that the controller will only issue the new instruction.

For brevity only two examples are given: ATC initiated termination during high-density operations, and flight crew initiated termination during low-density operations.

G.6.1 ATC initiated FIM termination during high-density operations

An example of ATC terminating FIM operation and instructing the aircraft to fly a specific speed, and not stating “cancel interval spacing” due to frequency congestion:

ATC: (Callsign), MAINTAIN (two one zero) KNOTS.

Crew: MAINTAIN (two one zero) KNOTS, (Callsign).

G.6.2 Flight crew initiated termination of FIM operation during low-density

An example of a FIM speed being operationally undesirable is:

Crew: (Callsign) UNABLE TO CONTINUE INTERVAL SPACING, (speed too fast).

ATC: (Callsign), CANCEL INTERVAL SPACING, MAINTAIN (two hundred) KNOTS.

Crew: (Callsign), CANCEL INTERVAL SPACING, MAINTAIN (two hundred) KNOTS.

G.7 ATC Requests FIM Operation Report

ATC may request the flight crew to state their FIM clearance, which may occur when the flight crew does not state the information during initial check-in or the original transmission was not heard. This request would not be expected when TRACON automation fully supports FIM operations. It is not necessary to include the Target route since the controller does have that information.

ATC: (Callsign), VERIFY INTERVAL SPACING CLEARANCE.

Crew: (Callsign), INTERVAL SPACING CLEARANCE IS (one-zero-five) SECONDS BEHIND (Uniform Papa Sierra five-niner-eight).

Appendix H: Example of ATD-1 Arrival and Approach Procedures

Shown are: 1) the MAIER FIVE arrival procedure with altitude and speed restrictions but not connecting to an approach procedure; 2) the EAGUL FIVE arrival procedure with altitude and speed restrictions that does connect to an approach procedure; and 3) the ILS instrument approach to Runway 26.

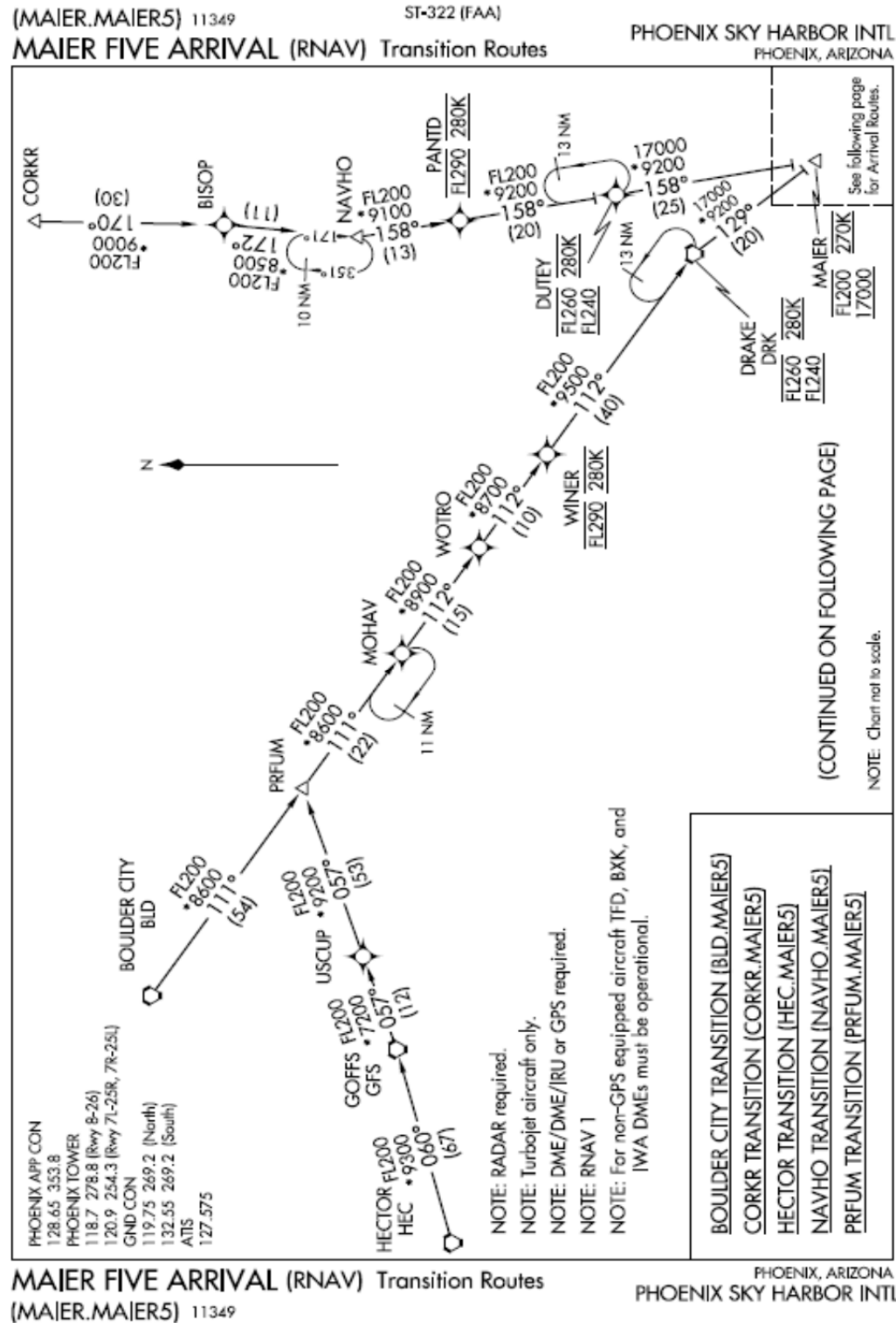


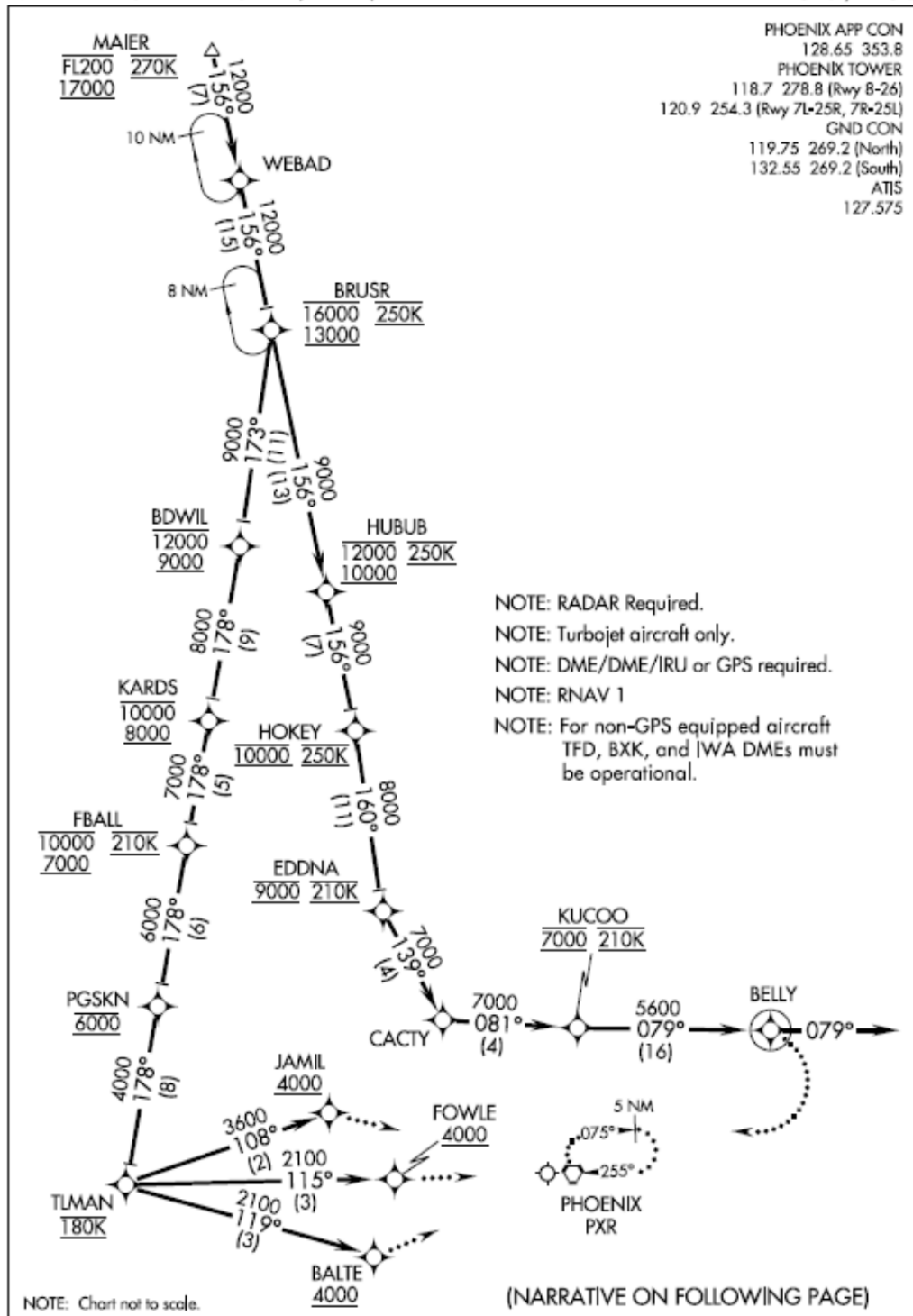
Figure 17. Arrival does not connect to the Approach.

(MAIER.MAIER5) 11349

ST-322 (FAA)

MAIER FIVE ARRIVAL (RNAV) Arrival Routes

PHOENIX SKY HARBOR INTL
PHOENIX, ARIZONA



MAIER FIVE ARRIVAL (RNAV) Arrival Routes

PHOENIX, ARIZONA
PHOENIX SKY HARBOR INTL

(MAIER.MAIER5) 11349

Figure 17. Arrival does not connect to the Approach (concluded).

EAGUL FIVE ARRIVAL (RNAV) Transition Routes

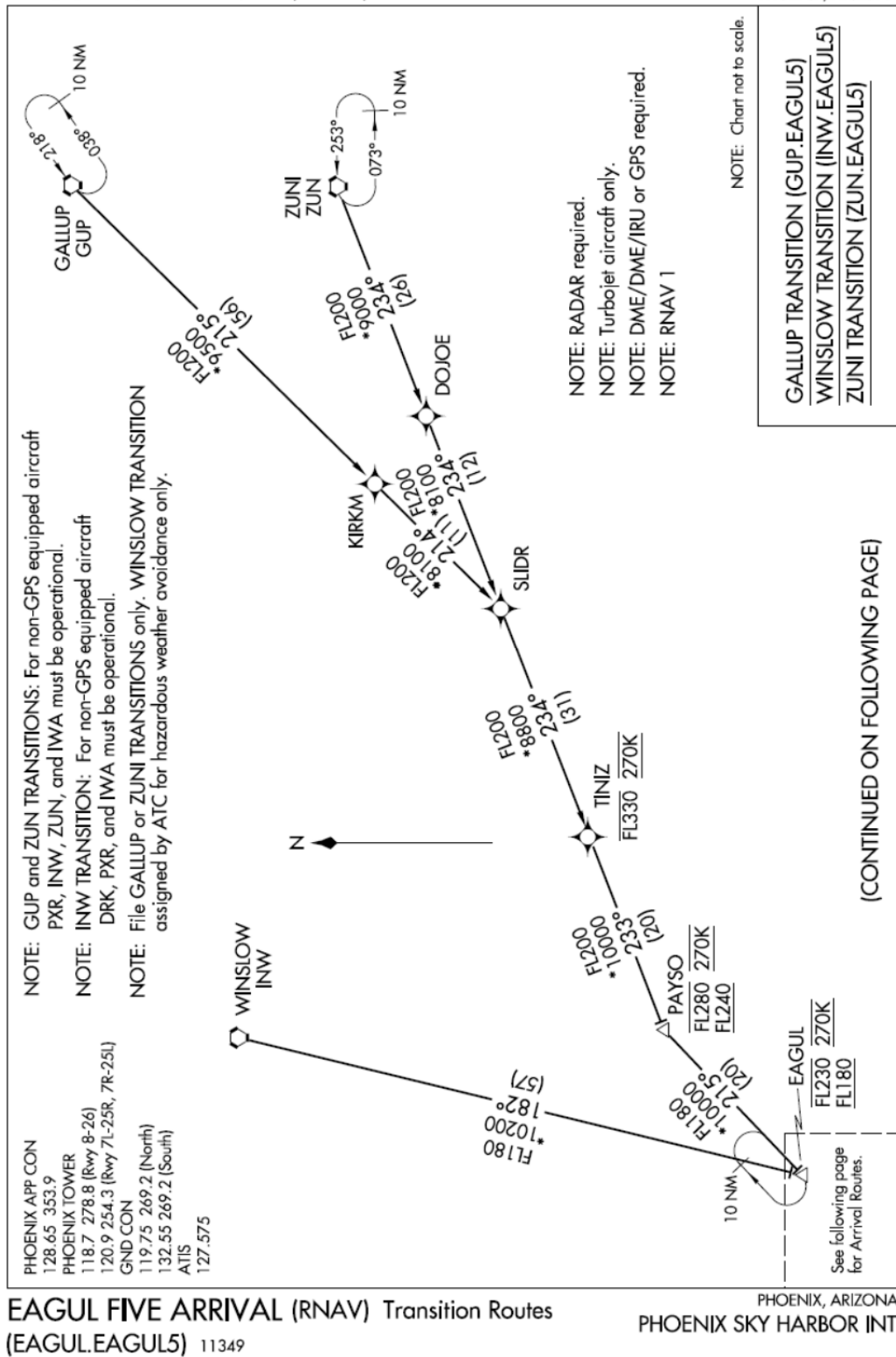
PHOENIX SKY HARBOR INTL
PHOENIX, ARIZONA

Figure 18. Arrival does connect to the Approach.

PHOENIX, ARIZONA



75

PHOENIX, ARIZONA

AL-322 (FAA)

12124

LOC/DME I-CWJ
111.75
 Chan 54 (Y)

APP CRS
258°

Rwy Idg **11489**
 TDZE **1135**
 Apt Elev **1135**

ILS or LOC RWY 26
 PHOENIX SKY HARBOR INTL (PHX)

Simultaneous approach authorized with
 Rwy 25L/R. DME required.

MISSED APPROACH: Climb to 2500, then climbing right turn to 5000 via
 heading 030° and PXR R-336 to AVENT/PXR 15.9 DME and hold.

| | | | | |
|------------------------|--|---|---|--------------------------------|
| ATIS 127.575 | PHOENIX APP CON 128.65 353.8 | PHOENIX TOWER 118.7 278.8 (Rwy 8-26) 120.9 254.3 (Rwy 7L-25R, 7R-25L) | GND CON 119.75 269.2 (N) 132.55 269.2 (S) | CLNC DEL 118.1 269.2 |
|------------------------|--|---|---|--------------------------------|

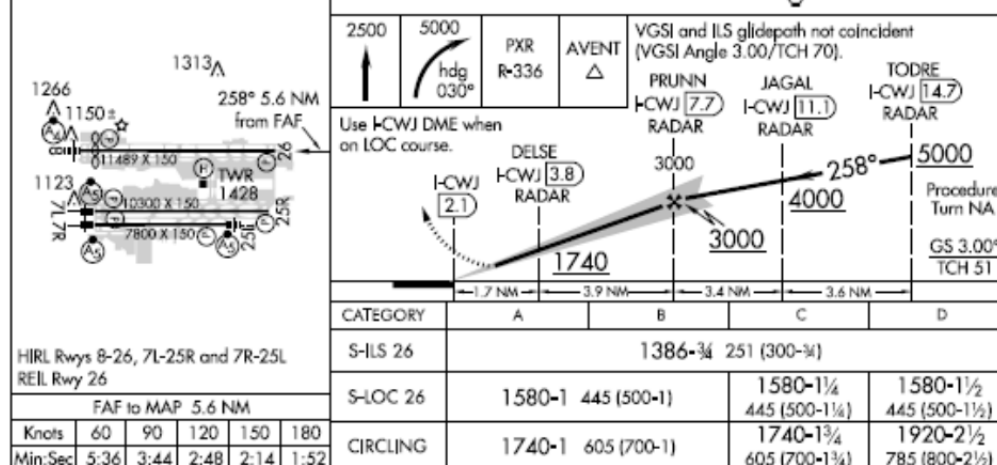
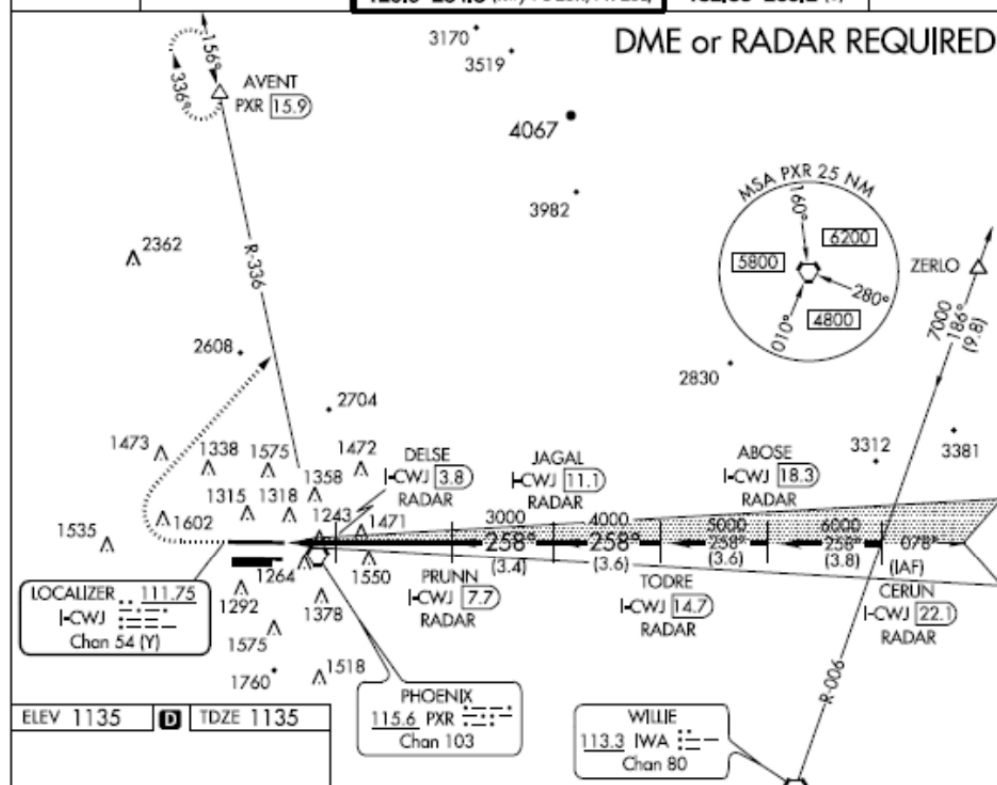


Figure 19. Approach procedure.

| REPORT DOCUMENTATION PAGE | | | | | Form Approved OMB No. 0704-0188 | |
|---|-------------|----------------------|-------------------------------|--|---|--|
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| 1. REPORT DATE (DD-MM-YYYY) | | 2. REPORT TYPE | | | 3. DATES COVERED (From - To) | |
| 01-09 - 2013 | | Technical Memorandum | | | | |
| 4. TITLE AND SUBTITLE Air Traffic Management Technology Demonstration-1 Concept of Operations (ATD-1 ConOps), Version 2.0 | | | | 5a. CONTRACT NUMBER | | |
| | | | | 5b. GRANT NUMBER | | |
| | | | | 5c. PROGRAM ELEMENT NUMBER | | |
| 6. AUTHOR(S) Baxley, Brian T.; Johnson, William C.; Swenson, Harry N.; Robinson, John E.; Prevot, Thomas; Callantine, Todd J.; Scardina, John; Greene, Michael | | | | 5d. PROJECT NUMBER | | |
| | | | | 5e. TASK NUMBER | | |
| | | | | 5f. WORK UNIT NUMBER 305295.02.31.07.01.03 | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Langley Research Center Hampton, VA 23681-2199 | | | | 8. PERFORMING ORGANIZATION REPORT NUMBER L-20241 | | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001 | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) NASA | | |
| | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) NASA/TM-2013-218040 | | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 03 Availability: NASA CASI (443) 757-5802 | | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | | |
| 14. ABSTRACT This document is an update to the operations and procedures envisioned for NASA's Air Traffic Management (ATM) Technology Demonstration #1 (ATD-1). The ATD-1 Concept of Operations (ConOps) integrates three NASA technologies to achieve high throughput, fuel-efficient arrival operations into busy terminal airspace. They are Traffic Management Advisor with Terminal Metering (TMA-TM) for precise time-based schedules to the runway and points within the terminal area, Controller-Managed Spacing (CMS) decision support tools for terminal controllers to better manage aircraft delay using speed control, and Flight deck Interval Management (FIM) avionics and flight crew procedures to conduct airborne spacing operations. The ATD-1 concept provides de-conflicted and efficient operations of multiple arrival streams of aircraft, passing through multiple merge points, from top-of-descent (TOD) to the Final Approach Fix. These arrival streams are Optimized Profile Descents (OPDs) from en route altitude to the runway, using primarily speed control to maintain separation and schedule. The ATD-1 project is currently addressing the challenges of integrating the three technologies, and their implantation into an operational environment. The ATD-1 goals include increasing the throughput of high-density airports, reducing controller workload, increasing efficiency of arrival operations and the frequency of trajectory-based operations, and promoting aircraft ADS-B equipage. | | | | | | |
| 15. SUBJECT TERMS Air Traffic Control; Controller Managed Spacing; Interval Management; Terminal Metering | | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON | |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | STI Help Desk (email: help@sti.nasa.gov) | |
| U | U | U | UU | 83 | 19b. TELEPHONE NUMBER (Include area code) (443) 757-5802 | |