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

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1.0 Introduction/Scope

This document describes the Concept of Operations (ConOps) to be researched and demonstrated in the Air Traffic Management (ATM) Technology Demonstration #1 (ATD-1). 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 Program). The goal of ATD-1 is to demonstrate the feasibility and value of the concept, and transfer the associated NASA technologies and procedures to stakeholders.

The ATD-1 ConOps integrates three (NASA) research efforts intended to achieve high throughput, fuel-efficient arrival operations throughout busy terminal airspace [ref 1]. They 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" aircraft avionics and flight crew procedures to conduct airborne spacing operations

ATD-1 aligns with the Federal Aviation Administration's (FAA) NextGen Mid-Term ConOps [ref 2], draft Time-Based Flow Management (TBFM) ConOps [ref 3], and the Interval Management – Spacing (IM-S) ConOps [ref 4]. It is also consistent with the FAA's expected National Airspace System Enterprise Architecture Operational Improvements (OI) in the 2015-2018 timeframe. 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 5], and takes advantage of Performance-Based Navigation (PBN) specifications and requirements [ref 6].

This document is consistent with FAA guidance for ConOps development, and provides concept-level requirements for supporting services, systems, technologies, tools, procedures, and airspace changes [ref 7]. Scenarios and procedures to be used during NASA's ATD-1 flight demonstration are the focus of this document. The demonstration uses TMA-TM, CMS, and FIM, is limited to arrival operations, and the expected capabilities of the ground facilities and aircraft in 2015. The end-state operational concept of these tools will likely include other flight phases (i.e., departure operations), incorporate other technologies (i.e., data comm.), and incorporate more sophisticated controller decision support tools, however procedures and technologies not expected to be fielded by 2015 are not 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 in 2003, and created the Joint Planning and Development Office (JPDO). The JPDO – composed of representatives from the Federal Aviation Administration (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,

including a description of the roles for the various operating elements within the air transportation system [ref 8]. The ATD-1 ConOps is thematically consistent with the Joint Planning and Development Office (JPDO) NextGen ConOps.

Increasing the capacity and efficiency of the NAS is a primary goal of NextGen. Achieving this goal requires that the capacity of its high-density airports and the efficiency of arrival operations be simultaneously optimized. The NextGen Operational Improvements (grouped according to Solution Set) associated with ATD-1 and the technologies that enable them are:

- Initiate Trajectory Based Operations (TBO)
  - 102137 Automation Support for Separation Management (2014-2015)
  - 104120 Point-in-Space Metering (2012-2016)
  - 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 (2010-2018)
- Increase Safety, Security, and Environmental Performance (SSE)
  - 109319 Environmentally and Energy Favorable ATM Concepts, Phase I (2011-2015)

1.2   Problem Statement

The 2011-2031 FAA Aerospace Forecast predicts commercial aviation will grow on average 3.7% throughout these twenty years – the number of revenue passenger miles doubling by 2031 [ref 9]. 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. Use of these current procedures contributes to reduced airport capacity, increased controller workload, increased arrival delay, and increased aircraft fuel burn, emissions and noise. While advanced arrival procedures exist at a limited number of sites (e.g., optimized descents), they are not well utilized due to the lack of supporting scheduling and spacing tools.

1.3   Identification

Figure 1 shows the position of the ATD-1 ConOps within the FAA Concept Levels.

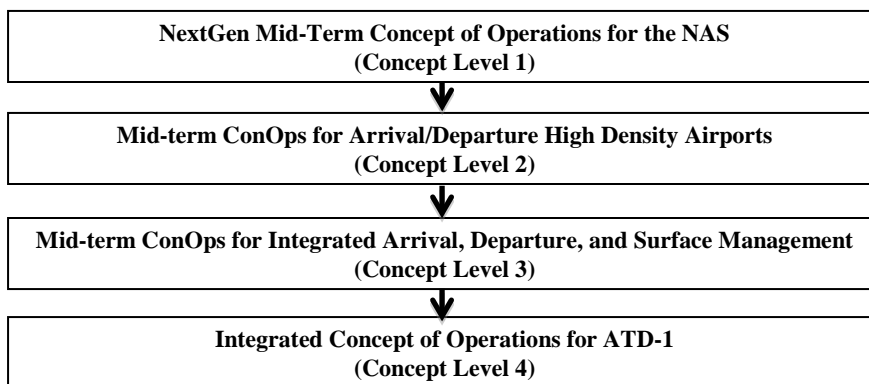| |
|---|
| **NextGen Mid-Term Concept of Operations for the NAS**
(Concept Level 1) |
| **Mid-term ConOps for Arrival/Departure High Density Airports**
(Concept Level 2) |
| **Mid-term ConOps for Integrated Arrival, Departure, and Surface Management**
(Concept Level 3) |
| **Integrated Concept of Operations for ATD-1**
(Concept Level 4) |

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 areas of capacity, flexibility, efficiency, safety, and environment [ref 2].

1.4.1 Capacity

For domestic flights in 2008, there was a total of approximately 3.2 million hours of delay from gate (departure), taxi-out, airborne, and taxi-in, according to the FAA's Aviation System Performance Metrics (ASPM) system [ref 2]. (Approximately 20% of these hours were airborne delays, however this type of delay is much more costly to airlines than ground delays [ref 10].) Airborne delay is expected to more than double in the next ten years without NextGen improvements. Capacity 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.

1.4.2 Flexibility

Today's NAS is constrained by its infrastructure, and in terms of service delivery, by the Air Navigation Service Provider (ANSP) workforce. The system offers limited flexibility to respond to changes in traffic demand, weather, Special Activity Airspace, and other events. From the perspective of the ANSP, facilities offer limited flexibility in their ATM operations. For example, challenges exist for delegating tasks to flight crews and supporting operations other than first-come/first-served schedules (e.g., best-equipped/best-served).

1.4.3 Efficiency

Trying to limit the high cost of flight operations as well as to minimize 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. Surface and flight 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, but not entered into ground or airborne automation, reduces the accuracy of conflict predictions generated by this automation, and reduces the fuel-efficiency of the aircraft's flight path. Furthermore, efficiencies gained in the en route airspace through advanced scheduling automation is often lost in terminal airspace due to that information not being available to terminal controllers.

1.4.4 Safety

As the primary mission of the FAA, safety must continue to improve in all phases of flight and 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 the runway environment, during convective weather events or periods of low visibility, and 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 predictive approach to safety improvements.

1.4.5 Environment

Environmental concerns have evolved into 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. Fortunately, emissions, noise, and fuel consumption reductions are natural outcomes of the ATD-1 initiatives to improve delay and efficiency.

1.5 Concept Overview

The ATD-1 ConOps combines advanced arrival scheduling, controller decision support tools, and aircraft avionics to enable efficient arrival operations in high-density terminal airspace. To achieve increased fuel efficiency during periods of high traffic demand, aircraft will use Area Navigation (RNAV) Optimized Profile Descents (OPDs) that include transitions to available runways by connecting to Standard Instrument Approach Procedures (SIAP). These procedures will allow flight crews to use their onboard FMS capabilities to fly from cruise altitude to landing, employing fuel-efficient vertical profiles, and without needing controllers to provide radar vectors to the final approach course. Figure 2 graphically presents the three technology elements integrated in the ATD-1 ConOps.
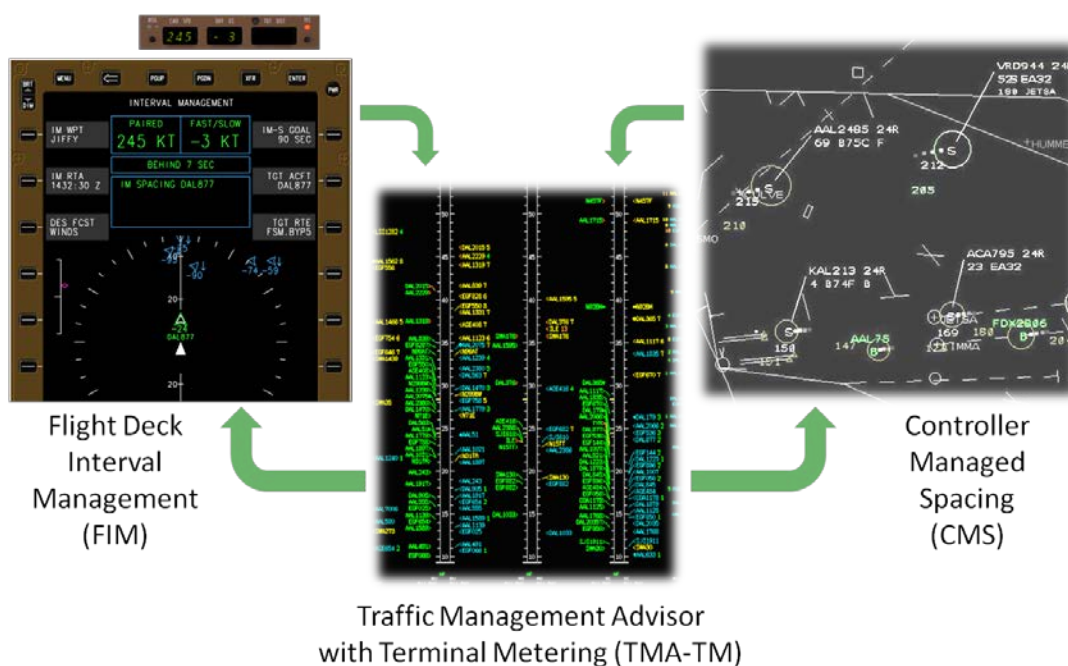

Flight Deck Interval Management (FIM)

Traffic Management Advisor with Terminal Metering (TMA-TM)

Controller Managed Spacing (CMS)

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

1.6   Integration with ANSP Ground Systems & Aircraft Systems

The ATD-1 ConOps and operations require the ATD-1 ground side technologies to be integrated with the air traffic management system (i.e., TBFM), the en route automation system (i.e., ERAM), and the terminal automation system (i.e., STARS). Furthermore, integration with the FAA's soon-to-be-fielded Ground-based Interval Management – Spacing (GIM-S) software is also required.

On the aircraft side, the FIM technology required for aircraft systems may be either "forward-fit" in advanced aircraft (in particular, fully integrated with the Flight Management System), or installed via "retro-fit" for aircraft currently in operational use (such as an Electronic Flight Bag and ADS-B Guidance Display). 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 ATD-1 proposes to change.

2.1   Description of Users in Current Operation

An aircraft landing at a high-density airport generally executes a series of step-down descents starting at its cruise altitude 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 from the Air Route Traffic Control Center (ARTCC) to the Terminal Radar Approach Control (TRACON). The aircraft will continue to fly the STAR; however, since most STARs do not connect to the runway, the aircraft is eventually given radar vectors to the final approach course from TRACON controllers.

During periods of light to moderate traffic, aircraft may be allowed to conduct a fuel-efficient profile descent from cruise to the runway called an Optimized Profile Descent (OPD). Typically, these operations are only feasible during periods of very light traffic (for example, late at night) due to the variability and unpredictability of the trajectories of those aircraft on OPDs compared to current day operations. This variability and unpredictability makes it very difficult for the ANSP to maintain aircraft separation (particularly at merge points), and therefore OPDs are difficult to maintain at high throughput.

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, as well as 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 TRACON will receive arrival demand that matches its prescribed arrival capacity. TMCs also maintain the airport configuration and decide when, due to changing conditions, the frozen TMA schedule should be recalculated. This is known as "rippling the list."

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 steams prior to the TRACON boundary, and insure 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. Path adjustments are the most commonly applied method, followed by early descents and speed adjustments. Controllers also have the option of altering the sequence of arriving aircraft (swapping) when 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. TRACON controllers assign a number of heading, speed, and altitude changes to establish the aircraft onto the final approach course of the aircraft's 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, and select the landing runway.

2.1.4 Flight Crews

Flight crews rely on ATC to maintain separation from other aircraft in their vicinity. Once the aircraft begins the arrival phase of the flight, crews adhere to ATC instructions such as altitude changes, radar vectors, and speed adjustments to achieve the appropriate sequence and required spacing interval. The flight crew is able to plan and execute a vertical profile (altitude and speed) along a lateral path that is optimized for its specific airframe using its Flight Management System (FMS). The FMS has data on the detailed performance specifications of the aircraft, including desired performance requirements, engine model, fuel onboard, and cargo weight, and it uses this data and other state information (present location, altitude, forecast winds, etc.) to optimize the vertical profile. The FMS will constrain the vertical profile to meet the speed and altitude constraints of the aircraft's assigned arrival procedure. Since the vertical profile is based on airframe-specific data and the aircraft's current energy state, 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 FMS 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 held at an intermediate altitude or vectored off the expected lateral path), the vertical profile is not automatically recalculated. During periods of high traffic demand, nearly all OPDs are interrupted to maintain separation between aircraft.

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 capacity demand during the arrival process. The identification of congested periods is often accomplished using the ad hoc experience of traffic management coordinators or the automation provided by the Traffic Management Advisor (TMA). Whether it is the ad hoc experience or the TMA automation, decisions are made to apply delay such that the arrival 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. Upon observation that controllers need to continually extend the final approach segment to maintain aircraft separation minima (frequently referred to as "tromboning"), the TRACON TMC may issue a miles-in-trail (MIT) restriction to the ARTCC to moderate the controller workload and traffic flow. The MIT 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 side 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 times-of-arrival (STAs). Though the TMA predicts congestion at the runway and moderates the flow at the meter fixes at 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 compensate for this limitation, 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, the aircraft are descended early and vectored off their routes in the ARTCC. Within the TRACON, the aircraft are also delayed by vectoring and speed reductions to maintain the required separations for the flow of arrival aircraft.

2.2.2 FAA automation to be fielded for ATD-1

Ground Based Interval Management – Spacing (GIM-S) is part of the FAA's work to enable Extended Metering. GIM-S adds additional meter points upstream from the arrival airport, and speed advisors to these points should mitigate or eliminate the dependency on miles-in-trail

constraints. GIM-S is also intended to reduce controller intervention during an aircraft's OPD, thereby also reducing controller workload in busy arrival sectors. An aircraft's STA for the arrival runway at the demonstration site 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 non-FIM operation aircraft in their sector. These speed advisories serve to condition the arrival flow at the destination airport. GIM-S speed advisories will be given by ARTCC controllers to only non-FIM operation aircraft. Notional depictions of the GIM-S tool and aircraft data tag are shown below (Figure 3).

Figure 3. Notional GIM-S displays and aircraft data tag

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 surrounding traffic, but it does not provide enough information to allow relative maneuvering except during emergency situations. The flight crew may also develop a mental model of the approximate location and intent of the other aircraft, but again, there is insufficient detail to allow relative maneuvering. This lack of knowledge of surrounding traffic makes the aircraft a passive participant in arrival management and dependent on controllers for merging and spacing with other aircraft from takeoff to landing.

3.0 Justification and Description of Changes

The ATD-1 ConOps addresses essential elements of NextGen by integrating several important flight deck and ground-based technologies to achieve trajectory-based operations into a high-density airport during peak traffic periods. ATD-1 implementation will:

- Maximize the capacity of high-density airports, especially during peak traffic periods, by implementing:
    - Comprehensive, more accurate scheduling of arriving aircraft to runway threshold.
    - Flight deck and ground-based interval management systems to improve the controller's and flight crew's ability to adhere to the precise schedule and desired in-trail spacing.
- Reduce controller workload:
    - Aircraft conducting FIM operations aircraft should require fewer vectors or speed adjustments during arrival to maintain spacing and schedule.
    - Aircraft not conducting FIM operations should also require fewer vectors or speed changes. The controller should have to issue primarily speed adjustments to the pilot as determined by the GIM-S or CMS automation.
- Increase the efficiency of arrival operations into high-density airports by permitting RNAV OPDs during peak traffic periods:
    - Reduce fuel burn
    - Reduce arrival delays
- Support RNAV OPDs for aircraft with and without FIM avionics to reduce environmental impacts at high-density airports:
    - Reduce emissions through increased use of OPD arrivals
- Increase the frequency of trajectory-based operations (PBN procedures, such as RNAV OPDs) from before top-of-descent to runway, which results in:
    - Increased reliability of the schedule
    - Reduction in fuel consumption and noise emissions by aircraft
    - Reduction in amount of airspace dedicated for PBN arrivals increases the amount of airspace available for other procedures, such as arrivals to secondary airports
- Promote accelerated ADS-B equipage, particularly ADS-B In, and enable other advanced capabilities
    - Use of FIM equipment and procedures, which rely on ADS-B In, should exhibit increased precision of aircraft spacing and reduce controller and flight crew workload during demonstration

4.0 ATD-1 Concept of Operations

4.1 Introduction

The operational goal of the ATD-1 ConOps is to enable aircraft, using their onboard FMS capabilities, to fly Optimized Profile Descents (OPDs) from cruise to the runway threshold 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 controller decision support tools to provide terminal controllers with speeds for aircraft to fly to meet times at a particular meter points, and onboard software providing flight crews with speeds for the aircraft to fly to achieve a particular spacing behind 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 (to maintain airport capacity).

The concept provides de-conflicted and efficient operations of multiple arrival streams of aircraft, passing through multiple merge points, from top-of-descent to touchdown. The ATD-1 ConOps combines PBN arrival procedures with advanced arrival scheduling through TMA with Terminal Metering (TMA-TM), Controller Managed Spacing (CMS), and Flight-deck Interval Management (FIM) capabilities in the terminal environment of a high-density airport. Aircraft use PBN procedures, such as RNAV OPDs. These RNAV OPDs provide a lateral path from the en route jet route structure to the runway threshold (including transitions that connect the Standard Terminal Arrival Routes to the Standard Instrument Approach Procedures), and specify vertical constraints, if required, and a speed for every segment of the arrival procedure. This allows flight crews to use their onboard FMS capabilities to fly from en route cruise altitude to landing at the destination airport while receiving fewer controller-issued radar vectors, speed adjustments, and level flight segments.

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 four important NextGen capabilities:

- 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 the fleet mix contains both older, less-equipped aircraft and more advanced equipage aircraft.
- 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.
- Performance-Based Navigation – Consideration of aircraft Flight-deck Interval Management capabilities will allow a "best-equipped, best-served" priority to be given to early adopters of advanced avionics.

4.2   Assumptions and Requirements

Detailed assumptions are in Appendix D. Highlights include:
- The FAA implements changes to ERAM to support FIM initiation and monitoring, display of TMA runway assignment, and use of GIM-S speed advisories by ARTCC controllers.
- NASA develops and the FAA implements TMA-TM at the ATD-1 demonstration site to support integrated scheduling/spacing within the TRACON (i.e., terminal metering).
- NASA develops and the FAA implements CMS automation and displays within STARS at the ATD-1 demonstration site (primarily for aircraft not equipped for FIM operations, but also for aircraft conducting FIM operations if required).
- The schedule information, in a format that supports current day or ATD-1 procedures, will be available to ARTCC and TRACON controllers.
- 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", Electronic Flight Bag, and FIM avionics).
- The FAA develops and implements PBN procedures from the enroute environment to the runway at the ATD-1 demonstration site (e.g., an RNAV STAR connected to a SIAP).
- Controller-to-pilot communications will be by voice during the 2015 demonstration.

Detailed requirements are in Appendix D. Highlights include:
- ANSP retains responsibility for meeting the arrival schedule and maintaining separation between aircraft.
- Flight crews retain responsibility for operating the aircraft in accordance with procedures and instructions (ATC instructions, FIM software speed guidance, etc.).
- The Scheduled Time of Arrival (STA) does not normally change once established when the aircraft crosses the "Freeze Horizon". The Traffic Manager will retain authority to change the STA (reschedule) based on current criteria, and controllers may swap the sequence of aircraft after the "Freeze Horizon".
- The Center controller will be able to issue a FIM clearance to any suitably equipped aircraft in their sector. The Target aircraft must be assigned to the same runway as the FIM aircraft. However, the Target aircraft is not required to be in that controller's sector, is not required to be on the same RNAV STAR as the FIM aircraft, and is not required to be within ADS-B range of the FIM aircraft.

4.3   Operational Environment

The operational environment for the ATD-1 ConOps is the latter part of NextGen Mid-Term. The ConOps optimizes 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 (AXIM) 5.0, and International Civil Aviation Organization (ICAO) data standards. Key related programs include En Route Automation Modernization (ERAM), Time-Based Flow Management (TBFM), Automated Radar Terminal System (ARTS), Standard Terminal Automation Replacement System (STARS), and developments in PBN such

as RNAV STARs. The ATD-1 ConOps is also relying on the FAA SBS Office requirements for GIM-S software 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 in line with the projected availability time frame.

The primary capabilities required to implement the ATD-1 ConOps are:
- An advanced version of TMA incorporating Terminal Metering (TMA-TM) [ref 11-14]
- Controller Managed Spacing (CMS) decision support software and displays [ref 15-16]
- Flight-deck Interval Management (FIM) spacing software and displays [ref 17-20]

The ATD-1 ConOps users and their relationship to each other is shown below in Figure 4.
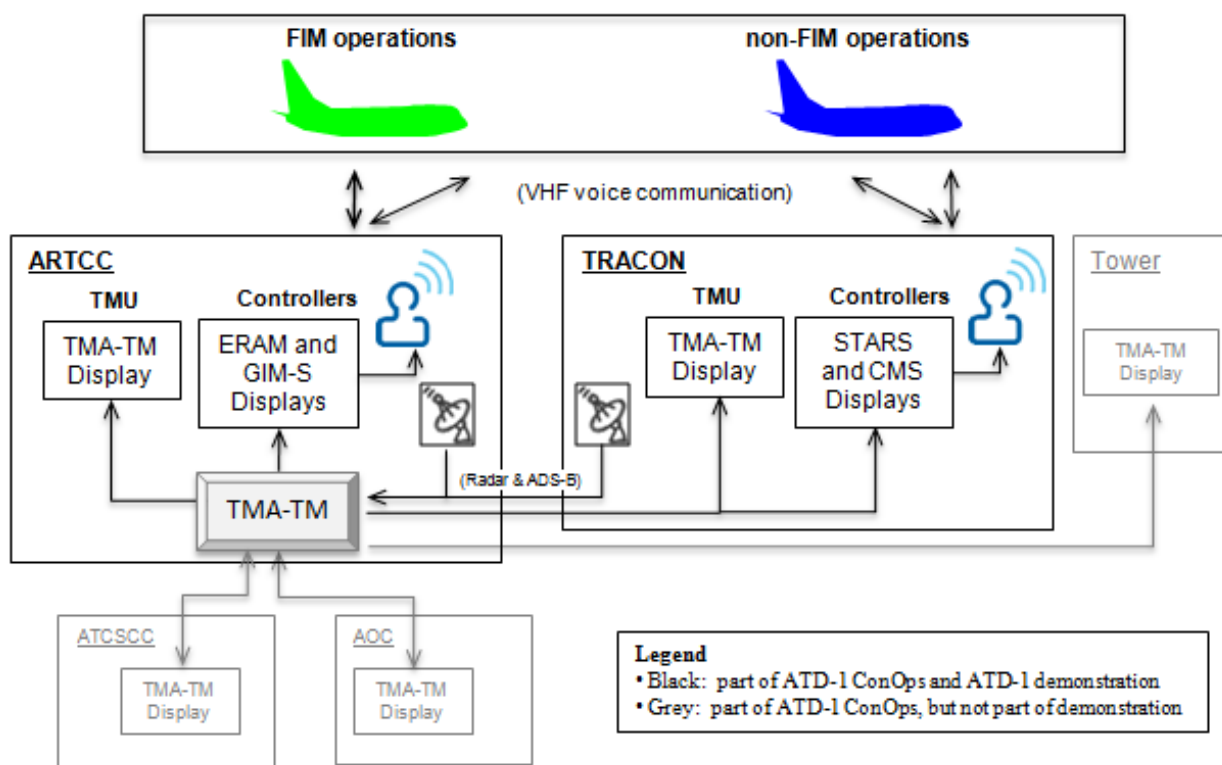
Figure 4. Block Diagram of Users in ATD-1 ConOps

4.4 Operations by ATD-1 Technology

4.4.1 TMA with Terminal Metering (TMA-TM)

The TMA-TM scheduling tool is used to optimize the flow of aircraft into capacity-constrained areas and calculates Estimated Time of Arrival (ETA) and corresponding Scheduled Time of Arrival (STA) at various meter and merge points along the aircraft flight path to an airport. TMA-TM also provides the STA and delay times to the respective En Route controllers to maintain the optimum flow rates to runways from the ARTCC to the TRACON. When

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flights approach a congested airport, TMA-TM is used to determine how the multiple streams of incoming flights can be sequenced and scheduled to fully utilize the runway(s) and other airport resources avoiding unnecessary delay while meeting all operational constraints. TMA-TM extends the capabilities of TMA to handle multiple merges of aircraft streams en route to the runway threshold.

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

While TMA and other decision support tools provided ancillary environmental benefits, their primary objective was to reduce delay and increase throughput. Recent NASA research has focused on developing procedures for the specific purpose of reducing fuel burn, emissions and noise impact. Another enhancement to TMA and controller advisory tools is support for OPDs. TMA-TM system is a trajectory-based strategic and tactical planning and 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 (EDA) Advisor technologies. NASA simulations have shown that TMA-TM is beneficial in the development of a fully integrated trajectory-based automation that enables both greater airport throughput and fuel-efficient operations from cruise to touchdown for NextGen.

4.4.2 Controller-Managed Spacing (CMS)

The CMS tools assist TRACON controllers in achieving their goal of maximizing throughput on capacity-constrained runways. They ensure that the TRACON controllers have knowledge of, and follow, the same arrival schedule that ARTCC 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 TRACON controllers to reduce the use of tactical vectoring, thereby enabling aircraft to maintain fuel-efficient PBN arrival procedure from cruise to touchdown [ref 15-16].

Figure 5 illustrates three sets of controller decision support tools to be used during ATD-1:
- Early/Late Indicators (left box)
  - Early/late indicators in an aircraft's Full Data Block (FDB) enable controllers to quickly assess the schedule-conformance information for that aircraft. The CMS early/late indicator serves the same purpose as the delay countdown timer (DCT) presently available to ARTCC controllers.
- Slot marker circles (middle box)
  - Slot marker circles translate the temporal schedule information into a spatial target on the controller's planview display. The slot marker circles indicate where an aircraft

should be at a given time if it were to fly the RNAV OPD, meeting all published speed and altitude restrictions, and arrive on schedule.

- Speed advisories (right box)
  - Speed advisories shown as airspeeds and fix names in the aircraft's FDB help controllers formulate speed clearances. Flying the advised speed until rejoining the arrival procedure's nominal speed profile at the named fix is predicted to place the aircraft back on schedule by the fix. Speed advisories can be configured to replace the early/late indicator in an aircraft's FDB.
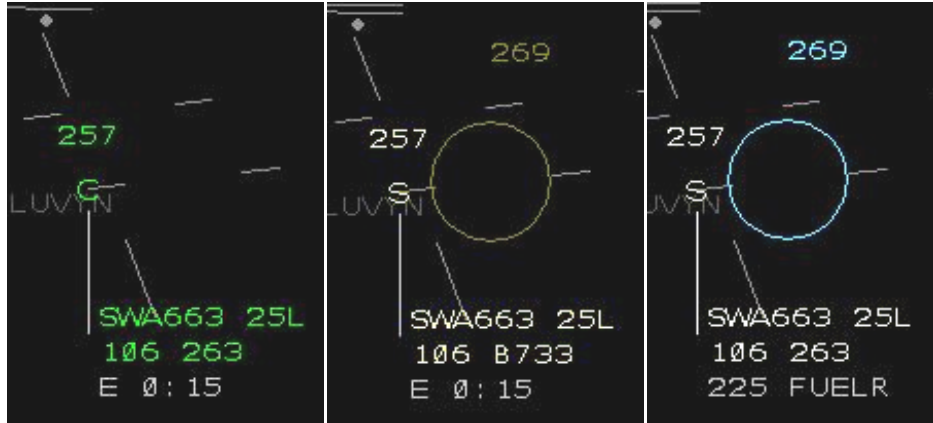

Figure 5. CMS display options.

4.4.3   Flight Deck Interval Management (FIM)

FIM enables the flight crew to actively assist both en route and terminal controllers in maximizing throughput on capacity-constrained runways. It enables the controller to issue a single strategic clearance to flight crews of spacing-capable aircraft to achieve an Assigned Spacing Goal (ASG) behind a Target (lead) aircraft at an Achieve-By Point (the Final Approach Fix (FAF) in ATD-1). The flight crew then manages their speed along their lateral and vertical path to achieve precise inter-arrival spacing by the achieve-by point. The FIM speed commanded by the FIM equipment is limited to within 10% of the speed published for that segment of the arrival procedure, and must be less than 250 knots when below 10,000 feet.

The spacing operation is initiated near top-of-descent when the flight crew receives an FIM clearance from the controller to begin spacing (see Appendix B). The controller is expected to issue the FIM clearance shortly after the TMA freeze horizon and prior to Top of Descent (TOD). The FIM clearance must include the Target aircraft identifier and the ASG; other elements may be included in the clearance if available to the controller and necessary to achieve the desired spacing goal. In cases where the Target aircraft is not yet within ADS-B range, a STA at the achieve-by point is included as part of the FIM clearance from ATC. The STA allows the aircraft to begin absorbing any necessary delay prior to being within ADS-B range. In addition, the airborne spacing tool must be aware of the Target aircraft's arrival procedure if that aircraft is not on the same route as the FIM aircraft. The Target aircraft may be on the same or

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different arrival procedure as the FIM aircraft (and therefore cross the TRACON boundary at a different meter fix).

During the ATD-1 demonstration, flight crews are expected to update the terminal area forecast winds onboard their aircraft. Controllers will issue the FIM clearance using voice communication. After the flight crew enters the FIM clearance information, the spacing tool goes into an armed mode and starts calculating the speed required to achieve the ASG. When the Target aircraft is not within ADS-B range, the spacing tool provides speeds to meet the STA at the achieve-by point until it can start actively spacing relative to the target aircraft. Aircraft are expected to transition to relative spacing well before reaching the achieve-by point. Flight crews are also expected to receive speed guidance from their FIM equipment, not their FMS, to ensure a smooth transition when relative spacing begins. Once the flight crew determines the FIM speed is feasible, they notify ATC they are commencing Interval Spacing operations and fly the aircraft at that speed. Once an FIM operation has begun, the flight crew operates the aircraft in accordance with normal procedures, with the exception that the FIM speed supersedes the RNAV STAR speed. If the flight crew is no longer able to follow the speed command or experiences a system error, they contact the controller to terminate spacing operations and revert to traditional control mechanisms. At any time, the controller can intervene with additional speed or vector clearances.

Conformance to the schedule (aircraft ETA versus the TMA-TM STA at the meter points) is expected to be within 2 minutes in ARTCC airspace, and within 1 minute in TRACON airspace. If FIM operations occur when deviation from the schedule is significantly greater than this, the STA times calculated by TMA-TM to create delay may be somewhat different than the FIM speed calculated by the airborne spacing software. Should this occur, controllers always have sole responsibility for aircraft separation (flight crew have responsibility for spacing, that is, to fly the FIM speed), and may "suspend" the FIM operation and issue a speed instruction or vector. The FIM operation must be "terminated" whenever the arrival sequence of the Target or FIM aircraft is changed, or the route or assigned runway of the Target or FIM aircraft is changed.

Cockpit displays for the flight crew to conduct FIM operations will be based on the airline and avionic partners participating in the ATD-1 demonstration. Options include displaying the FIM speed on an ADS-B Guidance Display (AGD) and Electronic Flight Bag (EFB) (expected for "retro-fit" installations), or displaying the FIM speed on the Primary Flight Display (PFD) (expected for "forward-fit" installations). Figure 6 and Figure 7 show an example of an AGD and EFB during FIM operations.

Figure 6. ADS-B Guidance Display (AGD) with FIM speed

Figure 7. Electronic Flight Bag (EFB) with FIM clearance and traffic

4.5 Benefits to be Realized

4.5.1 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 provide increased flexibility for the airspace user to select fuel-efficient descent profiles. 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 procedures 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 merge 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. These benefits can be realized at any airport during any traffic density, however, the greatest benefits are provided for complex arrivals during peak traffic periods.

An overview of the intended benefits of ATD-1 operations include:
- Consistent schedule-driven trajectory-based operations throughout entire arrival phase
  - Enables more frequent assignment of advanced arrival procedures
    - OPDs enable more fuel-efficient vertical profiles
    - PBN procedures reduce track miles
  - Enables delay to be absorbed more efficiently

- Speed control only results in less level distance flown in terminal area
- Better flow conditioning means aircraft maintain clean configuration longer
  - Allows flight crew to participate directly in the arrival process
    - Arrival plan (expected runway assignment) can be communicated earlier
      - Improve situational awareness for controller and flight crew
      - Typically lower workload for controller and flight crew in en route environment
    - Use of FIM capability by users means benefits are realized in the terminal area from their current and future avionics investments
  - Improved arrival time accuracy and in-trail spacing precision
    - Allows advanced arrival procedures to be maintained more often
      - Mitigates typical reduction in fuel-efficiency as traffic demand increases
    - Reduces excess spacing buffers needed to account for uncertainty
      - Fewer tactical interventions should decrease workload for controllers and crews
      - Increase effective airport capacity (same delay) or decease delay (same traffic)

4.5.2 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 allow 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. As a result, aircraft can absorb delay more efficiently. Operationally, this means shorter and fewer fuel-inefficient level segments at lower altitudes, and fuel consumption is reduced.

Use of CMS tools increases the arrival time accuracy as compared to today's manual operations. Increased arrival time accuracy reduces the spacing buffers and reduces the frequency of controller intervention to maintain separation. Smaller spacing buffers also increase the achievable runway throughput at high-density airports. As a result, the amount of delay that needs to be absorbed during periods of arrival congestion decreases, and fuel consumption is reduced.

Use of advanced arrival procedures minimizes the need for radar vectoring of each and every flight by controllers. Instead, flight crews are able to use their onboard Flight Management System (FMS) capabilities to efficiently navigate from cruise to landing. Radar vectoring is used less frequently and only when speed control is insufficient to maintain aircraft separation.

4.5.3 Benefits to NAS User

Use of FIM reduces the required spacing buffers further than CMS, because the inter-arrival spacing accuracy is naturally higher than the arrival time accuracy. In-trail aircraft will have some trajectory prediction errors that are correlated, and FIM allows these errors to be eliminated from the spacing buffer. Continued conformance to the arrival schedule in terminal airspace, the same schedule as in the ARTCC, through use of ATD-1 technologies and procedures, should reduce the frequency of aircraft being re-sequenced or rescheduled. If schedule deviation exceeds 2 minutes in the ARTCC or 1 minute in the TRAON, ATD-1 operations may have to be terminated during the demonstration.

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 allow the flight crews to take a more active role in arrival spacing than is currently possible under current procedures and technology.

The synergy of precision scheduling (TMA-TM) and tools to achieve that schedule (CMS and FIM) can not only be used to increase capacity by reducing delay, but is also intended to create the delay with the least cost. The ATD-1 procedures allow for much of the delay to be incurred at altitude or by small deviations from the aircraft's optimum descent speed, as opposed to achieving all the required delay within TRACON airspace. (For example, typical commercial turbo-fan engines burn 15% - 20% less fuel (pounds/hour) at holding airspeed when at en route altitudes compared to 1500 feet Mean Sea Level.)

4.5.4   Benefits to Airport

The ATD-1 ConOps and procedures should produce longer periods of sustained high-throughput at the airport runways, or could 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, reduces noise and greenhouse gas emissions from aircraft, which in turn should reduce the number of noise complaints received by the airport. Furthermore, the precision of these PBN procedures results in less airspace required during ATD-1 operations, in turn making more airspace available for other procedures (departures, arrivals to other airports, etc.).

5.0 Operational Scenarios

The procedures for a "Nominal" (expected or typical) ATD-1 scenario are described in section 5.1, followed by events that may occur during a scenario in section 5.2. During AGD-1 operations, it is expected upstream flow conditioning will allow speed control alone to be sufficient to achieve the arrival schedule.

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 B. This phraseology aligns with the international standard for Interval Management procedures [ref 20], the proposed FIM Data Link messages [ref 21], and recent amendments to the FAA's Air Traffic Control document [ref 23 and 24] to the maximum extent possible, with modifications made to accommodate the assumption of a voice-only environment.

Examples of the PBN arrival procedures expected by ATD-1 are shown in Appendix E.

5.1   ATD-1 Nominal Scenario

An overview of the ATD-1 Nominal scenario is shown in Figure 8, and controller-pilot operational procedures in Figure 9. Figure 10 through Figure 14 present details of a nominal ATD-1 scenario by phase of the operation, with each phase of flight linked back to the procedures shown in the operational procedures flowchart.

Prior to reaching the schedule freeze horizon (the goal is for the freeze horizon to occur prior to the aircraft's TOD), the TMA-TM scheduling software continuously calculates the ETA for the aircraft to all eligible runways. The trajectories associated with these ETAs incorporate the aircraft's route-of-flight, its intended speed profile, and the forecasted winds. When the aircraft crosses the freeze horizon, the TMA-TM tool assigns the most suitable runway, and determines an STA to the assigned runway that adjusts the aircraft's trajectory to ensure no time conflicts exist with the preceding aircraft at the various meter points. These meter points include the runway threshold, final approach fix, terminal meter points, meter fix, and other en route meter points. The arrival delay at each meter point is presented to associated ARTCC and TRACON controllers (display of the information is contingent on the FAA's plan to implement updated software). The ARTCC controllers will use their current displays and GIM-S software to achieve the time calculated at enroute meter points by TMA-TM. TRACON controllers will receive schedule information (time, sequence, etc), graphical information (spacing circles), as well as new information (CMS advisories) on their STARS display to correct the remaining time error.

En route controllers will use GIM-S speed advisories when speed control is sufficient to absorb the remaining meter fix or en route meter point delays. TRACON controllers will use CMS advisories when speed control is sufficient to absorb the remaining runway or terminal meter point delays. When speed control alone is not sufficient, the GIM-S and CMS speed advisories will not be displayed. 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. When the delay is predicted to exceed the capability of speed-only

operations, the en route controller will use path stretching like today to bleed off enough delay to be ready to use speed-only. At that point, the controller will begin a descend-via operation and for properly equipped flights, issue a FIM clearance. When the delay doesn't get absorbed as expected, the controller will interrupt descend-via and FIM operations to revert to ordinary vectoring. If the situation permits, the TRACON controller can use CMS once inside the terminal if the aircraft is able to resume its PBN procedure and speed control is sufficient.

FIM clearances will be initiated as soon as possible after schedule freeze. FIM clearances issued by ARTCC controllers can use Target aircraft on the same arrival as the FIM aircraft, or may be on a different arrival and crossing a different meter point to enter the TRAON. (The mechanism to provide the information necessary for ARTCC controllers to issue FIM clearances to appropriately equipped aircraft remains to be defined.) FIM clearances may be amended by ATC issuing a change to the ASG, however controllers will "suspend" or "terminate" FIM operations if the need exists to vector either the FIM aircraft or Target aircraft, or issue a speed assignment to the FIM aircraft. Changes to the arrival sequence, route of flight, or assigned runway require the FIM operation be "terminated".
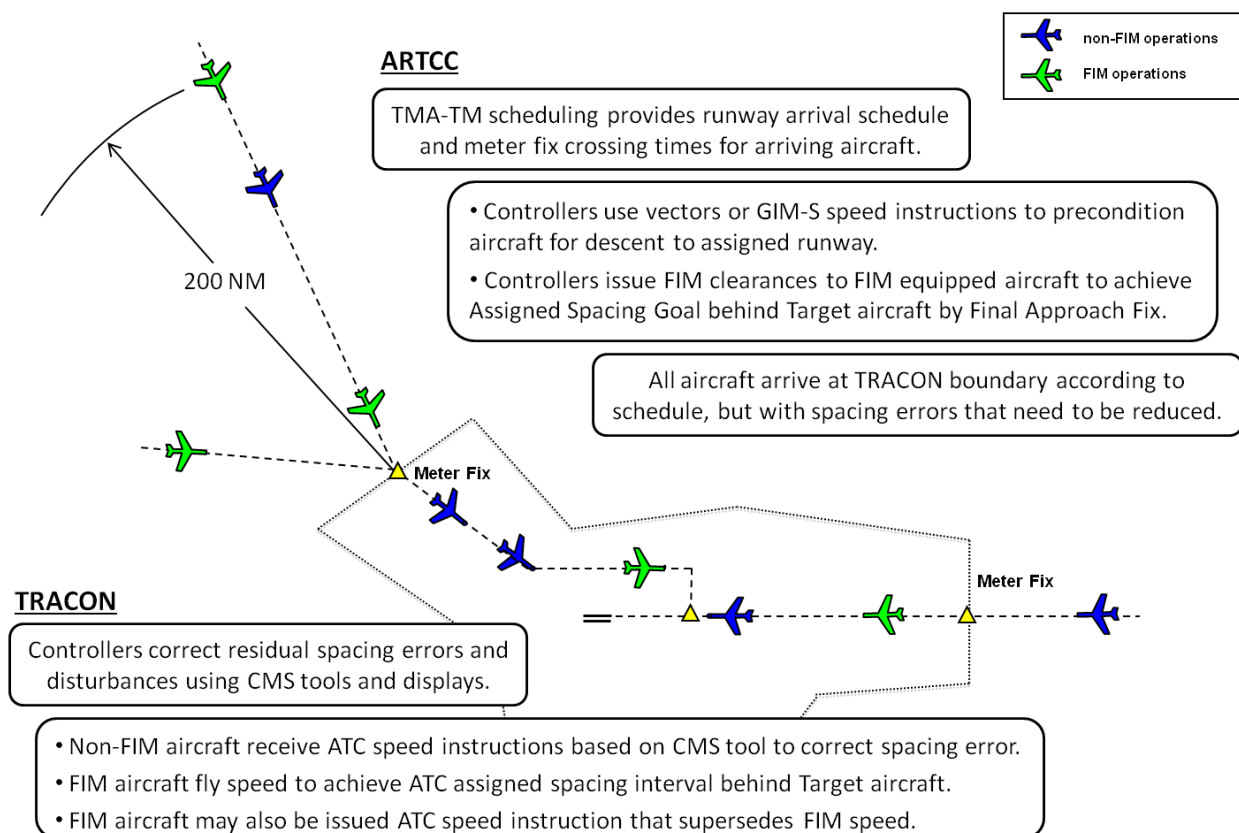

Figure 8. ATD-1 Nominal Operational Scenario

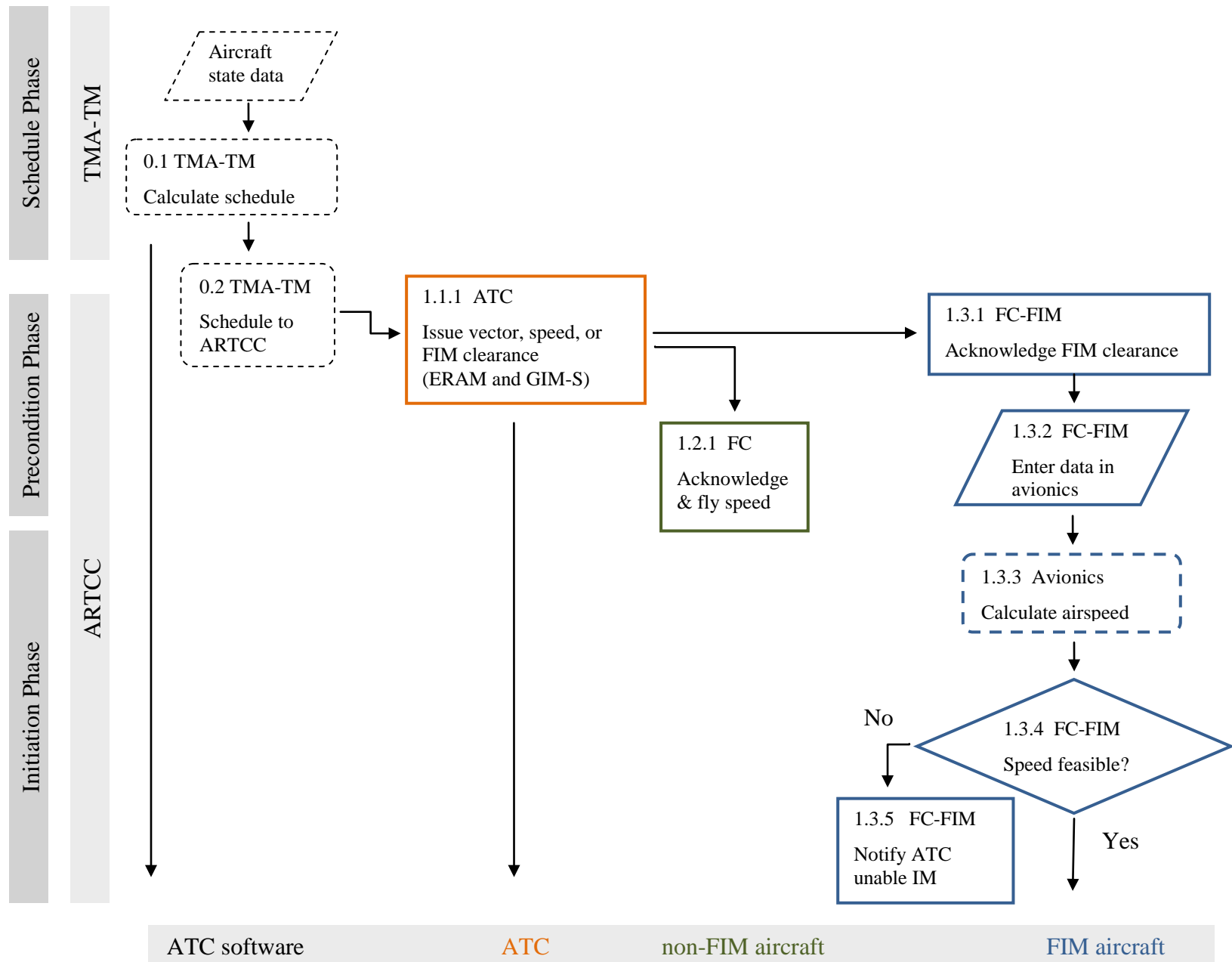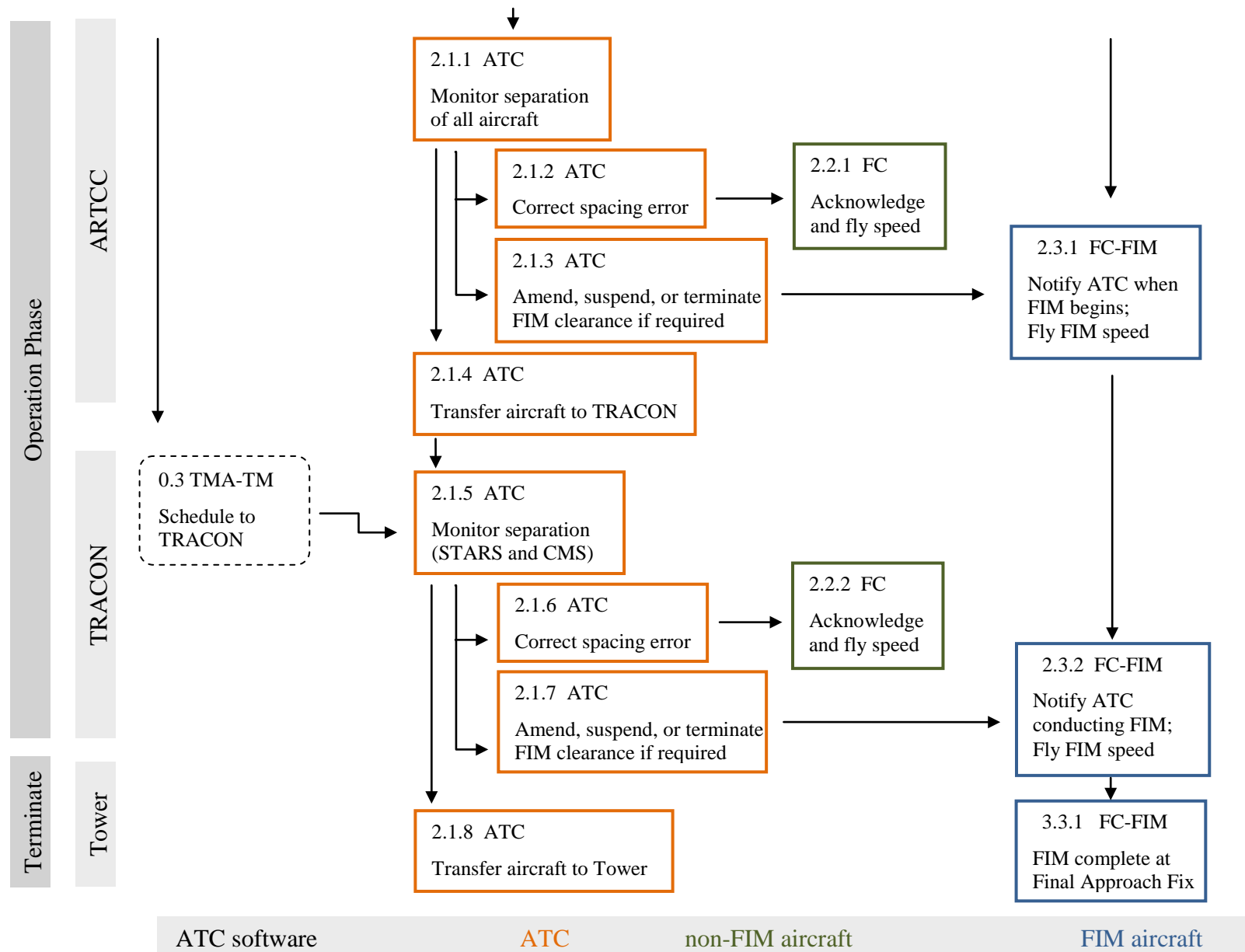**Figure 9. Operational Procedure Flowchart**

Figure 9. Operational Procedure Flowchart (continued)

ATD-1 Scenario: Schedule Phase

ARTCC

TMA-TM scheduling provides runway schedule and meter fix crossing times for arriving aircraft. Schedule is fixed after aircraft crosses the "Freeze Horizon".

• All aircraft have route from current position to assigned runway determined by scheduling software, and ETA to runway is calculated.
• A conflict-free schedule for all aircraft arriving to that runway is calculated for the runway, final approach fix, and meter fixes.
• The runway ETA becomes the STA when the aircraft crosses the "freeze horizon". The schedule is fixed unless manually changed.

200 NM

Meter Fix
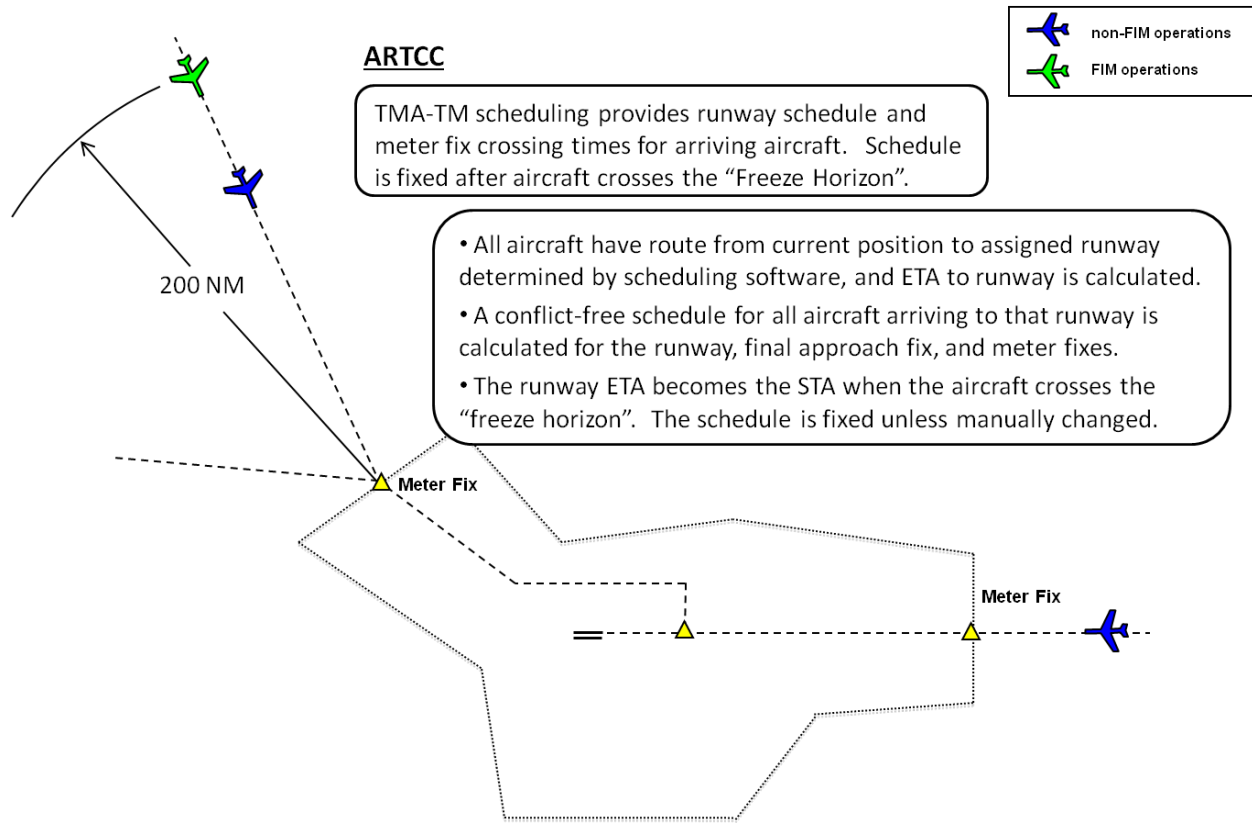
Meter Fix

non-FIM operations
FIM operations

Figure 10. ATD-1 Scenario: Schedule Phase

Figure 10 above shows the subset of aircraft and activities that occur during the "Schedule" phase of ATD-1 operations. The numbers in the left column of the table below correspond to the operational procedures shown in Figure 9.

0.1   The TMA-TM software calculates a schedule, including the delay to be absorbed at ARTCC and TRACON meter points, and the FIM clearance for appropriately equipped aircraft. The TMA-TM ETA for each aircraft is used to update delay advisories, GIM-S speed advisories, and CMS advisories.

0.2   Arrival metering information, expected runway assignment, and FIM clearance is sent to ARTCC controllers.

0.3   Arrival metering information is sent to TRACON controllers.
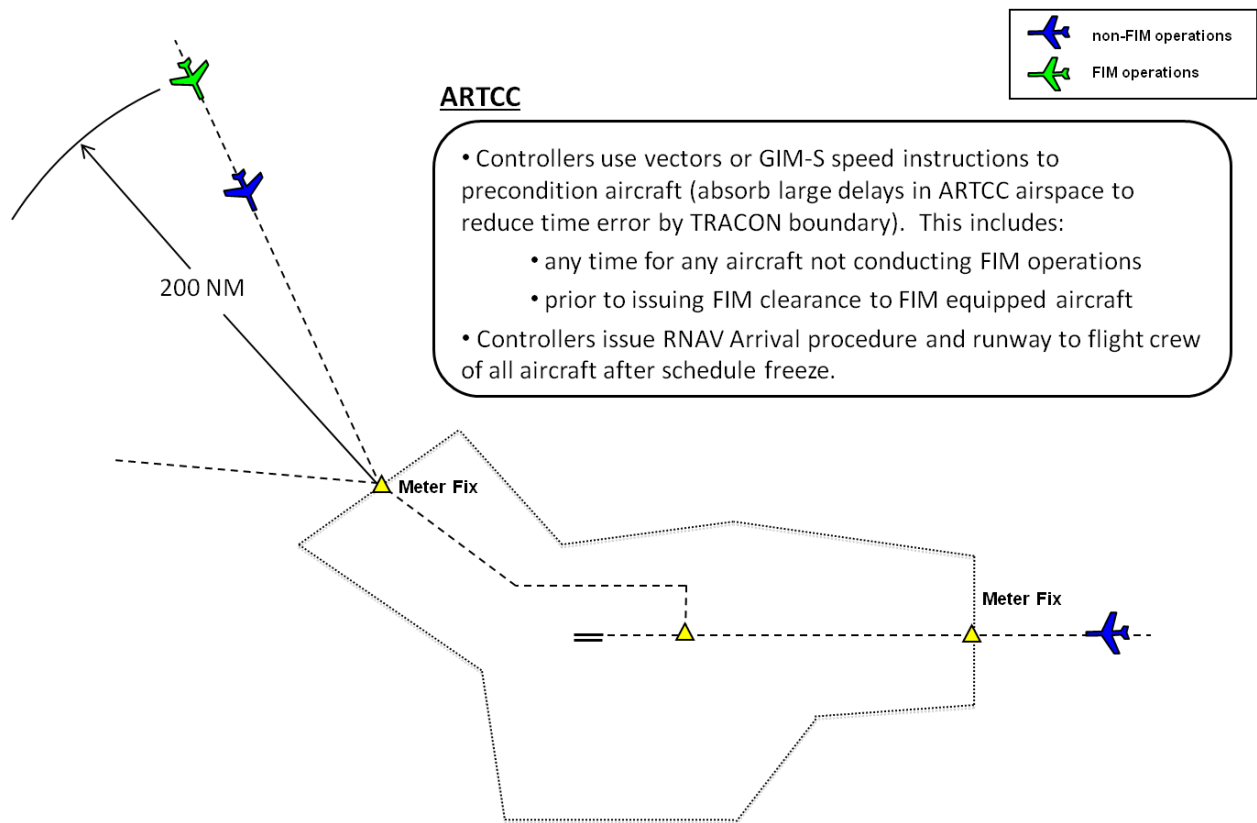
ATD-1 Scenario: Precondition Phase

Figure 11. ATD-1 Scenario: Precondition Phase

Figure 11 shows the subset of aircraft and activities that occur during the "Precondition" phase of ATD-1 operations.

1.1.1   ARTCC controller issue expected arrival route and runway assignment and speed commands to crew of all aircraft.
1.1.1   ARTCC controller issue vectors or speed instructions (if required) to achieve desired time delay (TMA-TM schedule to interface with GIM-S, which provides display) to any aircraft not conducting FIM operations.
1.1.1   Controllers clear aircraft for PBN arrival using "Descend Via" or instruction as appropriate.
1.2.1   Flight crews respond to ATC instructions.
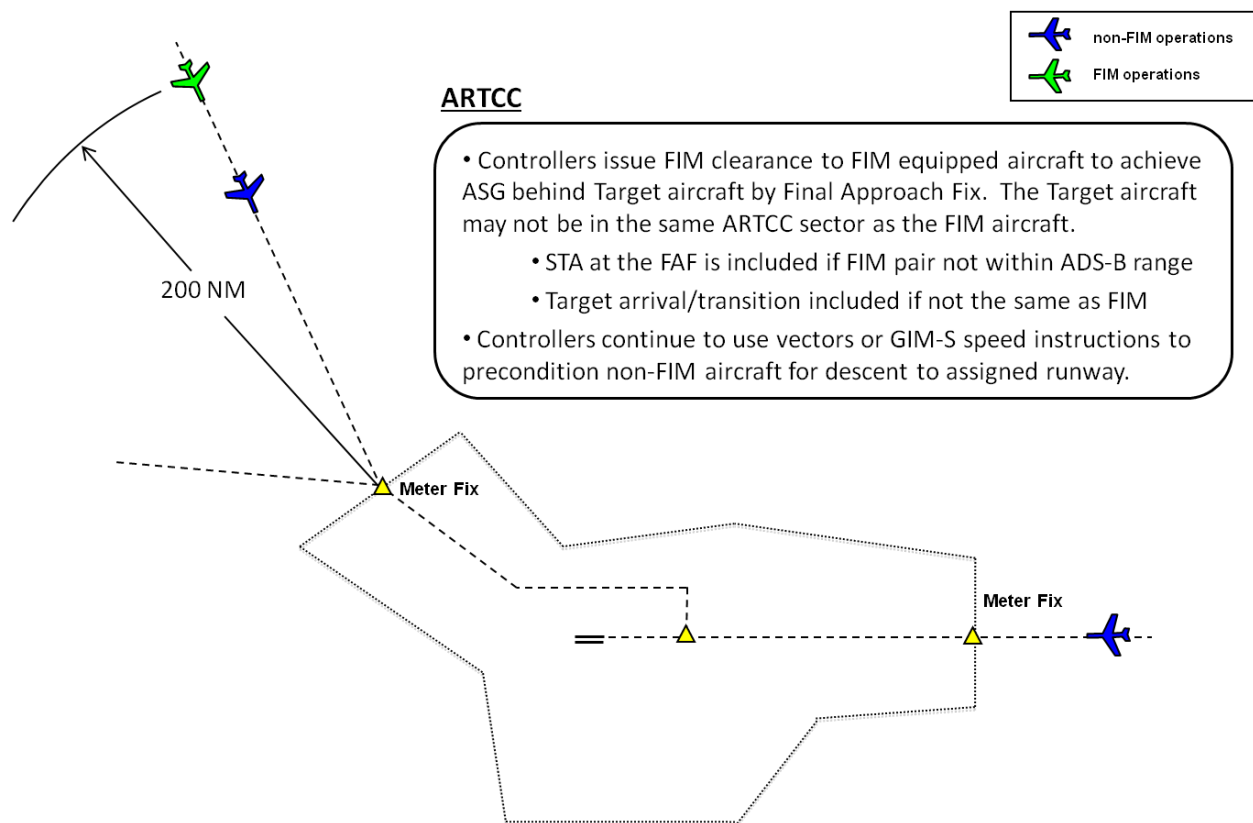
ATD-1 Scenario: Initiation Phase

Figure 12. ATD-1 Scenario: Initiation Phase

Figure 12 shows the subset of aircraft and activities that occur during the "Initiation" phase of ATD-1 operations.

1.1.1   ARTCC controller issues a FIM clearance to flight crew of FIM-equipped aircraft. This consists of the ATC assigned Target aircraft and Assigned Spacing Goal as a minimum, and may also include the STA to the FAF, and/or the Target aircraft route. (How information is to be displayed is currently under development by the FAA and NASA.)

1.3.1   FIM flight crew acknowledges the clearance from controller.

1.3.2   FIM flight crew enters the FIM clearance data into the aircraft avionics spacing software, verifies that the data is correct, and then activates the spacing software.

1.3.3   The FIM aircraft software calculates the Mach number or airspeed needed to achieve the Assigned Spacing Goal behind the Target aircraft by Final Approach Fix.

1.3.4   The FIM flight crew determines if the speed is operationally feasible.

1.3.5   If the initial FIM speed is not operationally feasible, the FIM flight crew will notify ATC that they are unable to conduct the FIM operation. ATC may elect to issue that crew a new FIM clearance, or a vector or speed instruction (see "Precondition Phase").

2.3.1   If the FIM speed is feasible, the flight crew notifies ATC with commencing FIM operations.
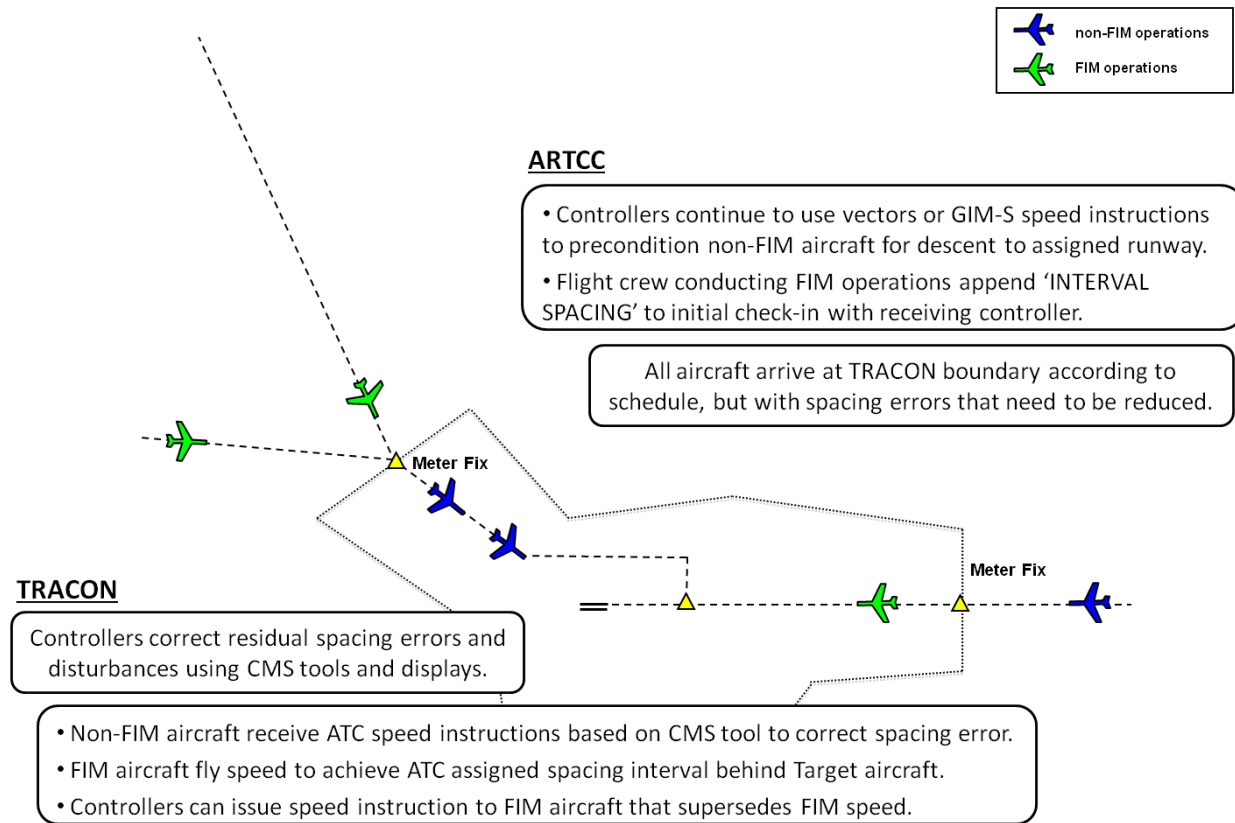
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ATD-1 Scenario: Operation Phase

Figure 13. ATD-1 Scenario: Operation Phase

Figure 13 shows the subset of aircraft and activities that occur during the "Operation" phase of ATD-1 operations.

2.1.1   ARTCC controllers maintain safe separation responsibility for all aircraft within their sector.
2.1.2   ARTCC controllers use GIM-S information to assign speeds to aircraft not conducting FIM operations (non-FIM equipped, or FIM equipped aircraft prior to issuing FIM clearance).
2.1.3   Controllers will suspend or terminate FIM operations if the need exists to vector either the FIM aircraft or Target aircraft, or issue a speed assignment to the FIM aircraft.
2.1.3   Controllers may amend or terminate a FIM clearance as operationally required. ("Amend" used to change the ASG, "terminate" if the sequence is changed, runway changed, etc.)
2.1.5   TRACON controllers maintain safe separation responsibility for all aircraft within their sector.
2.3.1   Flight crews that have accepted a FIM clearance will fly the FIM calculated speed during the arrival and approach.
2.3.2   Flight crews conducting FIM operations will append that information to the initial check-in with each subsequent (receiving) controller. (FIM operation information may not be available on TRACON controller displays by the demonstration timeframe.)
2.1.6   TRACON controllers use CMS information to assign speeds to crews of non-FIM equipped aircraft. The CMS speeds may also be used for FIM aircraft if necessary.
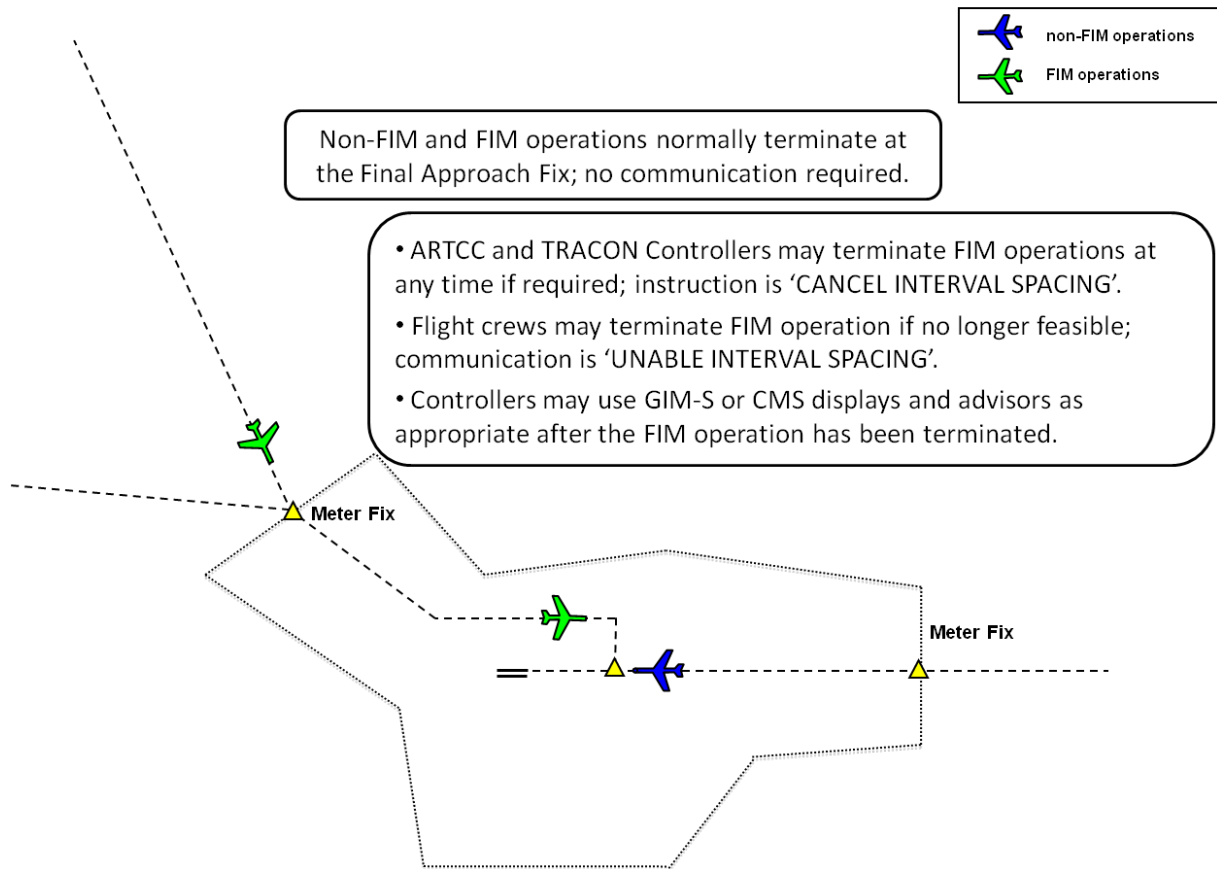
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ATD-1 Scenario: Termination Phase

Figure 14. ATD-1 Scenario: Termination Phase

Figure 14 shows the subset of aircraft and activities that occur during the "Termination" phase of ATD-1 operations. If the FIM operation terminates as intended at the Final Approach Fix, there is no controller – flight crew communication required.

2.1.3   ARTCC controllers may terminate FIM operations at any time. GIM-S may be used to provide
2.1.7   speed advisories for those aircraft.
          TRACON controllers may terminate FIM operations at any time. CMS tools may be used to
              provide speed advisories for those aircraft.
2.3.1   Flight crew may terminate FIM operation if required; must notify ATC.
3.3.1   If FIM operations terminate at the Final Approach Fix, no communication for that is required.

5.2   Events during ATD-1 Operations

This section addresses events that may occur during the demonstration that are unique to ATD-1 operations. Some of the events require a TMA-TM reschedule, and some require "suspend" or "terminate" of FIM operations. Events common to both current and ATD-1 operations (for example, a flight crew request for different route or altitude, aircraft missed approach, etc.) are not discussed.

5.2.1   ATC "amends" a FIM clearance

A controller may amend the FIM clearance by changing the Assigned Spacing Goal (ASG) (to allow space for departing aircraft, etc.). Changes to the FIM clearance STA, Target aircraft, Target aircraft route, and FIM aircraft route require ATC to "terminate" the FIM clearance, then issue a new one (if desired). Amending a FIM clearance requires less workload for the flight crew, and provides the FIM speed more quickly.

5.2.1   ATC "suspends/resumes" a FIM clearance

The ATD-1 ConOps allows for controllers to issue vectors or speed instructions to any aircraft. If that aircraft is conducting a FIM operation, ATC "suspends" (FIM operation expected to resume at a later time) or "terminates" (FIM operation not expected to resume at a later time) the FIM operation prior to issuing the vector or speed instruction. "Suspending" a FIM clearance is expected to be particularly useful when the aircraft is below 10,000 feet and the flight crew's need to interact with avionics should be restricted. (The "suspend/resume" procedure allows the crew to remove/return FIM information from cockpit displays with a single button push, while retaining the information from the FIM clearance in the spacing software.)

5.2.3   ATC "terminates" a FIM clearance

A range of operational needs may require ATC to "terminate" a FIM operation, to include a change to the route or runway of either the Target or FIM aircraft or a schedule re-sequence (creates a new Target aircraft) to give a few examples.   In these cases, controllers will terminate the FIM clearance, and have the option to issue a new FIM clearance if desired.

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 vision of ATD-1 is changes to either the Target or FIM aircraft's route would result in an automatic update to the FIM clearance for the controller to issue. This capability will not exist by the ATD-1 demonstration timeframe, therefore monitoring by the supervisor and test personnel will be required to prevent this from occurring.

5.2.4   Flight crew "terminates" a FIM clearance

Flight crew conducting FIM operations may need to "terminate" FIM operations for a range 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, the ADS-B data from the Target is not received, or failure of the FIM spacing tool. The flight crew will state 'UNABLE INTERVAL SPACING', and if possible, include the reason for termination. Controllers may use the provided GIM-S or CMS tools to complete the arrival operation.

6.0 Summary of Impacts

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

Table 1. 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.
ARTCC Air Traffic Controller	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, FIM clearances, and the expected runway assignments using TMA-TM information.
TRACON Air Traffic Controller	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. For aircraft not conducting FIM operations, this includes using CMS automation to improve the delivery accuracy to the runway.
Flight crew	Comply with all established procedures and controller instructions.	Comply with all established procedures, controller instructions, and speed adjustments provided by the FIM automation.

7.0 References

The References section credits both published and unpublished works that are used throughout the document to either support or refute statements or offer alternatives. Unpublished references are limited to those that are complete, but in the peer review process prior to publication, and annotated as such. The references section includes higher level and adjacent concepts on which this document depends.

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Appendices

Appendix A: Acronyms and Definitions

This Appendix contains acronyms and definitions that are used repeatedly and central to the ATD-1 ConOps. Well known acronyms (FAA, NASA, etc.) or used only once as a reference (AICM, AXIM, etc.) are not included.

Table 2. Acronyms and Definitions

Acronym	Term	Definition
4DT	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. NOTE: some waypoints may have time, altitude, and/or speed constraints. These restrictions can be equality or inequality constraints.
--	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).
ASG	Assigned Spacing Goal	The inter-arrival time in seconds between the Target and the FIM Aircraft assigned by the controller as part of the FIM clearance.
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.
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, speed control, and CNS technologies.
CDA	Continuous Descent Arrival (also known as Continuous Descent Approach)	A flight procedure where the vertical profile of an arrival procedure (STAR is an example) has been optimized so that it can be flown as a continuous descent with the aircraft's engines near idle from a high altitude until touch down on the runway. Typically there are no vertical constraints along a CDA. [Note: ATD-1 uses OPDs in lieu of CDAs.]
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.

Acronym	Term	Definition
ConOps	Concept of Operations	Document describing a proposed operation that utilizes new technologies or procedures.
ETA	Estimated Time-of-Arrival	The current estimate of the aircraft's time-of-arrival at a point along its flight path based on forecast winds, aircraft performance and defined arrival procedures, but not adjusted to compensate for traffic separation or metering delays. The ETA is re-calculated whenever an event occurs, such as route-of-flight change, etc.
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. Exclusively the airborne component of entire FIM system.
--	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 transmit and receive equipment, and equipped for FIM operations.
--	FIM clearanance	The FIM clearance during ATD-1 operations must contain the Target aircraft's identification (callsign) and the Assigned Spacing Goal (ASG). The STA to the Achieve By Point (the Final Approach Fix for ATD-1) may be included if the Target and FIM aircraft are not within ADS-B reception range. The Target's route of flight is issued if it is not on the same arrival procedure as the FIM aircraft. The remaining data fields identified in Reference 20 are not included (accomodation for use of voice communication).
--	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 (Final Approach Fix).
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 for that aircraft to that waypoint is no longer updated; it is frozen.
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. 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).
IM	Interval Management	Systems to achieve and maintain spacing between aircraft. Includes flight deck (FIM) and ground-based (GIM) elements.

Acronym	Term	Definition
MF	Meter Fix	A specific type of Meter Point; usually the transition fix between the ARTCC and TRACON. Also called the Arrival Flow Management Point (AFMP) by GIM-S.
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.
MP	Meter Point	Occur in en route airspace, and sometimes called En Route Flow Management Points (ERFMP). 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.
OPD	Optimized Profile Descent	Similar to CDAs, OPDs are designed to reduce fuel consumption, emissions, and noise during descent by allowing aircraft to fly an optimized descent during arrival with engines near idle from en route altitude to the runway threshold (however, it may not include the instrument approach portion). OPD procedures specify the lateral path, vertical boundaries, and a speed for every segment of the procedure. The vertical boundaries of the OPD are established to accommodate a wide range of descent profiles. Speeds are defined to capitalize on the use of speed control by controllers and flight crews to achieve spacing and maintain separation.
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 6]
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.)
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 (final approach fix).
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.). During FIM operations, controllers issue the STA to the crew, if desired, and the FIM equipment calculates the speed required to meet the STA at the Final Approach Fix until within ADS-B range of the Target aircraft (the speed is then calculated to achieve the ASG).
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.

Acronym	Term	Definition
--	Target Aircraft	The aircraft lead 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.
TCP	Trajectory Change Point	A full 4-D trajectory is defined by a series of trajectory change points (TCPs). Every point along the path 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 en route to the runway. 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.

Appendix B: Phraseology

Phraseology currently used by controllers and pilots (sector frequency check-in, initiation of descent, change of route or speed, 'Descend Via' clearances, ATIS, altimeter, etc.) remains unchanged in the ATD-1 ConOps to the maximum extent possible. Examples include: "220 knots" may be spoken as "TWO TWO ZERO KNOTS" or as "TWO TWENTY KNOTS", and flight crews may use their callsign at the beginning or end of the read-back transmissions. The current requirement for flight crews to accept an instruction with the term "WILCO" is followed in Appendix B, although it is known that frequently the clearance read-back by the flight crew is used for that purpose (especially during periods of high-volume voice communication). Furthermore, no new phraseology has been identified yet for the use of CMS tools.

The proposed phraseology in Appendix B that is unique to ATD-1 operations is derived from the FAA IM Working Group [ref 20-21], and incorporates recent changes to controller-pilot phraseology [ref 22-24]. The FIM clearance will be given by the ARTCC controller, and any controller may amend, suspend, or terminate the FIM clearance. (The end-state solution expects TRACON controllers to also be able to issue the FIM clearance; however, this capability is not expected to be fielded by the time of the ATD-1 demonstration.)

The phraseology in this paper and Appendix B is written to allow controllers to issue the FIM clearance information separately and after the clearances for the arrival and approach procedures have been given. (NOTE: the onboard spacing algorithm requires the entire continuous aircraft trajectory from current position to the Achieve-By Point (the Final Approach Fix in ATD-1 operations) to calculate the speed needed to achieve the Assigned Spacing Goal behind the Target aircraft by that point). The ATD-1 phraseology in Appendix B is further simplified from the phraseology defined in references 20 - 24 by making the Assigned Spacing Goal (ASG) always a "precise" value expressed in seconds, and the 'Terminate Point' and 'Achieve-By Point' are always the Final Approach Fix.

The elements of a FIM clearance are listed below, with the two required elements in bold:
- Scheduled Time of Arrival (STA) [optional; HHMM:SS time at Achieve-By Point]
- Achieve-By Point [issued if STA is included in the FIM clearance; always the FAF]
- **Assigned Spacing Goal** [required; in seconds, to occur by the Achieve-By Point]
- **Target (lead) aircraft identification** [required; callsign of Target aircraft]
- Target aircraft route [optional; not required if Target and FIM aircraft on same lateral and vertical path, that is, the same STAR and SIAP]

The phraseology is based on the following guidance:
- "FOR INTERVAL SPACING" is used at the beginning of a FIM clearance to alert the flight crew that FIM procedures and equipment are to be used (not the FMS)
- "CROSS (final approach fix)" is used to define the Achieve By Point if a STA is given
- "WHEN ABLE, SPACE" is used to convey the transition from the STA to the relative spacing portion of the FIM clearance
- "TARGET" may be used in lieu of "(Target-Callsign)" when a FIM clearance is amended

Several options exist when referencing the Target aircraft callsign: the phonetic alphabet (ALPHA, BRAVO, etc), the spoken callsign, or the callsign letters (A, B, etc). The intent is to differentiate between the aircraft ATC is addressing versus the Target aircraft ATC is referring to in a FIM clearance, and to ensure quick and accurate communication of aircraft callsigns that are spoken differently than the data tag used on controller and flight crew displays. Currently the phonetic alphabet is used today for similar voice transmissions, however an alternative has been suggested to reduce the time required to issue FIM instructions. For example, 'Republic Airlines' uses the callsign BRICKYARD and RPA as its ICAO data tag.

- Primary option (used in current phraseology):
    o (AMERICAN five two one), FOR INTERVAL SPACING, AT (JIFFY) SPACE (eight-five) SECONDS BEHIND (ROMEO PAPA ALPHA one five).
- Alternative option (if commonly known callsign, however may be mistaken by flight crew of Target aircraft as voice communication directed to them):
    o (AMERICAN five two one), FOR INTERVAL SPACING, AT (JIFFY) SPACE (eight-five) SECONDS BEHIND (BRICKYARD one five).
- Alternative option (reduced transmission time, however may be less clear):
    o (AMERICAN five two one), FOR INTERVAL SPACING, AT (JIFFY) SPACE (eight-five) SECONDS BEHIND (R P A one five).

Phraseology in Appendix B that is related to ATC issuing speed commands conforms to recent FAA policy letters [ref 23 and 24]. In particular, the ATC speed instructions include:

- MAINTAIN (speed)
    o Flight crew to fly speed assigned by ATC
- RESUME NORMAL SPEED
    o ATC speed assignment no longer applies, and no published restrictions apply
- RESUME PUBLISHED SPEED
    o ATC speed assignment no longer applies, but published restrictions apply
- DELETE SPEED RESTRICTIONS
    o published speed restrictions on charted procedure are no longer required

In ascending order, the flight crew will fly the following speed (for both FIM and non-FIM operations):

- optimum aircraft or company speed
    o defined by flight crew preference or airline operating procedures
- published speed for that segment
    o takes precedence over optimum speed once a clearance is issued
    o every segment of arrival and approach will have a prescribed speed
- FIM speed
    o takes precedence over published speed if conducting FIM operation
    o flight crew responds to FIM speed as they would ATC speed assignment
- ATC speed
    o takes precedence over published speed (for non-FIM operations)
    o takes precedence over FIM speed (for FIM operations; in conjunction, ATC will 'suspend' or 'terminate' FIM operation)

B.1   ATC issues and Flight Crew acknowledges a FIM clearance

The FIM clearance only impacts the speed an aircraft maintains while flying the previously assigned arrival and approach. The flight crew must enter the Target and FIM route into the aircraft spacing software for it to calculate the airspeed needed to achieve the ASG by the Achieve-By Point. Routes used by the TMA-TM software for schedule calculation should be identical to routes used by the aircraft spacing software to calculate FIM speeds.

The displays enhancements needed by ARTCC controllers to obtain the information needed to issue a FIM clearance are currently under development by NASA and the FAA in preparation for the demonstration.

B.1.1   Preparatory

A preparatory voice transmission should be made by ATC prior to issuing a FIM clearance (similar to the current procedure used by ATC to issue an aircraft route change to flight crew).

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

Crew: (Callsign) IS READY TO COPY.

B.1.2   Complete FIM clearance

ATC: (Callsign), FOR INTERVAL SPACING, CROSS (final approach fix name) AT (hour-hour minute-minute plus second-second). WHEN ABLE, SPACE (second-second) SECONDS BEHIND (Target-Callsign) ON (Target arrival and transition, waypoints connecting arrival to approach (if required), approach or runway).

Crew: (Callsign), FOR INTERVAL SPACING, CROSS (final approach fix name) AT (hour-hour minute-minute plus second-second). WHEN ABLE, SPACE (second-second) SECONDS BEHIND (Target-Callsign) ON (Target arrival and transition, waypoints, approach). WILCO.

B.1.3   FIM clearance without STA (variation)

The STA (FAF name and time) may be omitted if the Target and FIM aircraft are within ADS-B reception range when the FIM clearance is given by ATC.

ATC: (Callsign), FOR INTERVAL SPACING, SPACE (second-second) SECONDS BEHIND (Target-Callsign) ON (Target transition/arrival).

Crew: FOR INTERVAL SPACING, SPACE (second-second) SECONDS BEHIND (Target-Callsign) ON (Target transition/arrival), (Callsign), WILCO.

B.1.4   FIM clearance without STA or Target route (variation)

The Target aircraft's route may be omitted from the clearance when the Target and FIM aircraft are on the same route.

ATC: (Callsign), FOR INTERVAL SPACING, SPACE (second-second) SECONDS BEHIND (Target-Callsign).

Crew: FOR INTERVAL SPACING, SPACE (second-second) SECONDS BEHIND (Target-Callsign), (Callsign).

B.1.5   Route clearance combined with FIM clearance (variation)

At the controller's discretion, the route for a FIM aircraft and the FIM clearance may be combined as one voice transmission. 'Descend Via' is used as an example of the different route clearance options, and is not a requirement for ATD-1 operations. The example in this sub-section also assumes ATC has previously issued the FIM flight crew their expected route to the assigned runway, and the Target aircraft is on the same route as the FIM aircraft. (See section B.9 for phraseology to issue the initial route clearance.)

ATC: (Callsign), DESCEND VIA THE (name of arrival). FOR INTERVAL SPACING, SPACE (second-second) SECONDS BEHIND (Target-Callsign).

Crew: DESCEND VIA THE (name of arrival). FOR INTERVAL SPACING, SPACE (second-second) SECONDS BEHIND (Target-Callsign), (Callsign).

B.2   ATC issues an expected clearance

ATC will convey route and FIM clearance (if appropriate) information to the flight crew, preferably during low controller and pilot workload conditions. Normally this information is issued as a clearance; however there are occasions ATC may desire to issue them as expected clearances. The flight crew is not required to enter the expected clearance information into the aircraft avionics, but may do so to reduce workload later when the actual clearance is received.

B.2.1   Expected runway (or approach)

The destination airfield is frequently included by flight crew during initial check-in with Approach Control, but normally not included on subsequent transmissions. For brevity, the destination airfield is not included in this section.

ATC: (Callsign), EXPECT RUNWAY (number).

Crew: (Callsign), EXPECT RUNWAY (number).

B.2.2   Expected PBN arrival and runway (or approach)

The ATD-1 ConOps requires that flight crew expected to conduct FIM operations understand their aircraft trajectory, from their current location to the runway threshold. The phraseology in this section connects the arrival procedure to approach procedure, and includes waypoints required to make that connection.

ATC: (Callsign), AFTER (arrival name), EXPECT (waypoint), (waypoint), ILS (number).

Crew: AFTER (arrival name), EXPECT (waypoint), (waypoint), ILS (number), (Callsign).

B.2.3 Expected FIM clearance

An expected FIM clearance may not include all data elements of a complete FIM clearance. An expected FIM clearance may be issued when ATC intends to vector either soon-to-be Target or FIM aircraft to meet a time delay, yet still take advantage of a lower workload period to issue the clearance.

ATC: (Callsign), EXPECT INTERVAL SPACING TO (final approach fix name) BEHIND (Target-Callsign).

Crew: EXPECT INTERVAL SPACING TO (final approach fix name) BEHIND (Target-Callsign), (Callsign).

B.3 ATC amends and Flight Crew acknowledges a FIM clearance

The ASG may be modified by ATC as new information becomes available or operational goals change. This may be caused by ATC requiring additional time between landing aircraft to accommodate a departing aircraft. This triggers a TMA-TM "re-schedule" but not a change to the arrival sequence. (The TMA-TM "re-schedule will also cause a change to the CMS speed shown to TRACON controllers.) The benefit of amending a FIM clearance versus canceling and issuing a new FIM clearance, is the level of workload and head-down time incurred by the crew.

If the Target aircraft, Target route, or FIM aircraft route changes, the current FIM clearance must be terminated (see B.7) and a new FIM clearance issued if desired.

ATC: (Callsign), AMEND INTERVAL SPACING CLEARANCE. SPACE (second-second) SECONDS BEHIND TARGET.

Crew: AMEND INTERVAL SPACING CLEARANCE. SPACE (second-second) SECONDS BEHIND TARGET, (Callsign), WILCO.

B.4 Flight Crew notifies ATC that the FIM operation has begun

The flight crew will notify ATC when the FIM spacing has begun, specifically, when the spacing software has valid Target ADS-B data and calculates a feasible speed to meet the ASG at the FAF. Speeds calculated by the onboard spacing software to meet a STA (occurs if the aircraft are not within ADS-B range of each other) do not satisfy the criteria for this paragraph. Data from research experiments indicates it takes approximately 45 to 60 seconds after ATC issues a FIM clearance for the crew to enter the data and the software calculate the FIM speed.

Crew: (Callsign) INTERVAL SPACING BEHIND (Target-Callsign).

ATC: (Callsign), ROGER.

B.5 Flight Crew notifies ATC that a FIM operation is being or will be conducted

Flight crew will notify all subsequent (receiving) controllers during initial check-in that they are or will be (as appropriate) conducting a FIM operation.

B.5.1 FIM operation is being conducted (speed based on valid Target data)

Crew: (Callsign) PASSING (one-two thousand), INTERVAL SPACING.

ATC: (Callsign), ROGER.

B.5.2 FIM operation will be conducted (speed based on achieving STA, or no FIM speed at all)

This situation is not expected to typically occur, that is, a controller issues a FIM clearance and then hands-off the flight crew to the next controller prior to the FIM speed (to achieve the ASG behind the Target aircraft) being displayed to the flight crew. If a FIM speed based on Target aircraft data is still not displayed by the time the flight crew checks in with the receiving controller, the phrased CLEARANCE is used to indicate the FIM operation has not started.

Crew: (Callsign) PASSING (one-two thousand), WITH INTERVAL SPACING CLEARANCE.

ATC: (Callsign), ROGER.

B.6 Suspending and Resuming FIM operations

The FIM operation will 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. This enables ATC to issue a speed or heading change to the FIM (or Target) aircraft, minimize the workload to the flight crew, and retain the capability to continue FIM operations at a later time.

B.6.1 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.

B.6.2 ATC resumes the FIM operation

ATC: (Callsign), RESUME INTERVAL SPACING.

Crew: RESUME INTERVAL SPACING, (Callsign).

B.7 Terminating a FIM clearance prior to the Achieve By Point

The FIM operation is designed for the flight crew to correct spacing errors until the Achieve By Point (the FAF), at which point the crew uses normal speeds and spacing corrections are no longer made. If the FIM operation terminates at the FAF, no specific phraseology is required.

When the FIM operation is terminated prior to the FAF, the person making that decision should attempt to communicate it to the other party. Examples include ATC cancelling the FIM operation due to other operational considerations (arrival sequence change, change of route or runway, etc), the flight crew unable to continue spacing (FIM speed too fast or too slow, Target surveillance data lost, etc), or the flight crew unable to commence FIM operations (Target surveillance data never received).

To align with phraseology proposed by several FAA Interval Management working groups, when "terminating" FIM operations, ATC will state "CANCEL INTERVAL SPACING", while flight crew will state "UNABLE INTERVAL SPACING".

B.7.1   ATC initiated termination of FIM operation

Several options exist. An example of when the published arrival speeds are to be flown is:

ATC: (Callsign), CANCEL INTERVAL SPACING, RESUME PUBLISHED SPEED.

Crew: (Callsign), CANCEL INTERVAL SPACING, RESUMING PUBLISHED SPEED.

Another example of when an ATC specified speed is to be flown is:

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

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

B.7.2   Flight crew determines calculated FIM speed is not feasible (too fast or too slow)

Crew: (Callsign) UNABLE INTERVAL SPACING DUE TO (speed).

ATC: (Callsign), ROGER. CANCEL INTERVAL SPACING, CONTINUE ON THE (name of arrival), RESUME (published speed).

Crew: CANCEL INTERVAL SPACING, CONTINUE ON THE (name of arrival), RESUME (published speed), (Callsign)

B.7.3   Target aircraft surveillance data (ADS-B signal) lost

This sub-paragraph applies when valid Target ADS-B data had been received and feasible FIM speeds calculated, then surveillance data is lost and a FIM speed no longer available.

Crew: (Callsign) UNABLE INTERVAL SPACING DUE TO (lost Target).

ATC: (Callsign), ROGER. CANCEL INTERVAL SPACING, CONTINUE ON THE (name of arrival), MAINTAIN (speed) KNOTS.

Crew: (Callsign), CANCEL INTERVAL SPACING, CONTINUE ON THE (name of arrival), MAINTAIN (speed) KNOTS.

B.7.4   Target aircraft surveillance data (ADS-B signal) not received

This sub-paragraph applies when the FIM aircraft has not received Target ADS-B data prior to approximately 20 nautical miles from the Achieve-By Point, and a valid FIM speed to achieve the Assigned Spacing Goal was never presented to the flight crew.

Crew: (Approach), (Callsign) UNABLE INTERVAL SPACING DUE TO (no Target data).

ATC: (Callsign), CANCEL INTERVAL SPACING, CONTINUE ON THE (name of arrival), RESUME (normal speed).

Crew: CANCEL INTERVAL SPACING, CONTINUE ON THE (name of arrival), RESUME (normal speed), (Callsign).

B.8   ATC requests FIM operation report

ATC may request the flight crew to state their FIM clearance. This is most likely to occur in TRACON airspace where TRACON controllers do not have FIM information displayed.

ATC: (Callsign), REPORT INTERVAL SPACING CLEARANCE.

Crew: (Callsign) IS INTERVAL SPACING (second-second) SECONDS BEHIND (Target-Callsign) ON (Target transition/arrival).

B.9   Route and runway assignment

During the ATD-1 demonstration, ARTCC controllers will provide the route of flight and expected assigned runway to the flight crews of all aircraft (non-FIM and FIM operations). No new ATD-1 unique phraseology has been identified for this purpose, and this section is intended to present examples of controller-pilot communication using currently defined phraseology. (Refer to Appendix E to see the RNAV arrival and an instrument approach used as an example for the phraseology in this section.)

Guidance derived from existing FAA documents [ref 22, 23, and 24] includes:
- arrival and approach procedures do not connect
  - the arrival chart will state 'EXPECT RADAR VECTORS'
  - ATC will specify waypoints that connect the procedures so the flight crews can enter a complete route into their avionics
- arrival and approach procedures do connect
  - the name of the arrival and approach procedure will be sufficient
- arrival procedure does not contain altitude or speed restrictions
  - ATC must include that with the route clearance, if required
- arrival procedure specifies altitude and speed restrictions
  - RNAV arrivals typically have altitude and speed restrictions, non-RNAV typically do not have restrictions

- o ATC may use a 'DESCEND VIA' clearance (no altitude given in the clearance); flight crew must adhere to all published altitude and speed constraints, and descend to the altitude of the last waypoint on the arrival procedure
- arrival procedure specifies altitude and / or speed restriction ATC wants to change
  - o ATC may use a 'DESCEND VIA' clearance, however must state 'EXCEPT AFTER (waypoint), MAINTAIN (revised altitude)
- ATC advise flight crew of expected type approach or runway [ref 22, para 4.7.10]

B.9.1   RNAV arrival has speed/altitude restrictions; arrival and approach do not connect

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

Crew: (Callsign), READY TO COPY.

ATC: (Callsign), DESCEND VIA THE (MAIER THREE ARRIVAL, BOULDER CITY TRANSTION), EXCEPT AFTER (KUCOO) EXPECT (BLINE), (CERUN), ILS (TWO SIX).

Crew: DESCEND VIA THE (MAIER THREE ARRIVAL, BOULDER CITY TRANSTION), EXCEPT AFTER (KUCOO) EXPECT (BLINE), (CERUN), ILS (TWO SIX), (Callsign).

B.9.2   RNAV arrival has speed/altitude restrictions; the arrival and approach connect

Note: for this example, assume a new arrival named MAIER TEN has been approved, and this procedure terminates at 5000 feet at ABOSE (a waypoint on the ILS 26).

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

Crew: (Callsign), READY TO COPY.

ATC: (Callsign), DESCEND VIA THE (MAIER TEN ARRIVAL, BOULDER CITY TRANSITION), EXPECT ILS (TWO SIX).

Crew: DESCEND VIA THE (MAIER TEN ARRIVAL, BOULDER CITY TRANSITION), EXPECT ILS (TWO SIX), (Callsign).

B.9.3   Arrival does not have restrictions; the arrival and approach do not connect

ATC: (Callsign), CLEARED THE (SUNSS SEVEN ARRIVAL, SAN SIMON TRANSITION). AFTER (SUNSS), EXPECT (CERUN), RUNWAY (TWO SIX). DESCEND AND MAINTAIN (ONE ONE THOUSAND) BY (SUNSS).

Crew: CLEARED THE (SUNSS SEVEN ARRIVAL, SAN SIMON TRANSITION). AFTER (SUNSS), EXPECT (CERUN), RUNWAY (TWO SIX). DESCEND AND MAINTAIN (ONE ONE THOUSAND) BY (SUNSS), (Callsign).

B.9.4 Arrival clearance with ATC speed instruction

Controllers may issue speed instructions (based on GIM-S, CMS, or personal experience), and this speed supersedes any published speed or FIM speed.

ATC: (Callsign), DESCEND VIA THE (MAIER THREE ARRIVAL, BOULDER CITY TRANSITION), EXCEPT MAINTAIN (TWO SEVEN ZERO) KNOTS UNTIL (DRAKE). EXPECT RUNWAY (TWO SIX).

Crew: DESCEND VIA THE (MAIER THREE ARRIVAL, BOULDER CITY TRANSITION), EXCEPT AFTER (JUSTIN) MAINTAIN (TWO SEVEN ZERO) KNOTS UNTIL (DRAKE). EXPECT RUNWAY (TWO SIX), (Callsign).

Appendix C: Scheduling and FIM Algorithms

This Appendix is to define how the algorithms used by the ground scheduling tool and airborne spacing tool produce values expected by the other component of the ATD-1 ConOps.

C.1   Ground-based Scheduling Algorithm
- The TMA-TM scheduling algorithm will use the published PBN arrival procedure to calculate the STA to the runway threshold for each aircraft.
- The STA times will be adjusted to create conflict-free times at the runway threshold and all meter points.
- The adjusted STA time at the runway threshold will be used to calculate times at all meter points based on the speeds defined in the published OPD. The required delay is allocated to each segment to achieve the total delay necessary.
- If the meter point times for a particular aircraft must be adjusted to ensure a conflict-free trajectory, that is, the aircraft must fly a speed different than published to achieve consecutive meter point times, then CMS procedures should be used for that aircraft.

C.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 intended to be used by 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, a schedule is maintained to keep 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.

C.3   Flight-deck Interval Management Algorithm

The ASTAR algorithm [ref 25-26] is described in this document, and should be very similar to the FIM software tool provided by the ATD-1 avionics partner for the demonstration. The following are design goals of the airborne spacing algorithm assuming that the FIM clearance given to the flight crew is feasible:

- The speed control law is designed to reduce the inter-arrival spacing error gradually, but not uniformly, as the operation progresses.
  - o The error may increase if the forecasted winds are incorrect
  - o More of the error is corrected within the TRACON to avoid over-controlling far from the airport.
- 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 (for example, to ensure safe separation from other traffic), the speeds flown by aircraft conducting FIM may not align with controller CMS displays for that aircraft.
- FIM aircraft are expected to arrive at the Achieve-by Point within 5 seconds of the ASG (assumes that the flight crew monitors and commands the FIM speed).
- If safe separation exists behind the Target aircraft at initiation of FIM operation, safe separation will be maintained from the beginning to the end of the FIM operation.
- Speed changes for FIM operation in addition to those published will be minimized.
- FIM speed increases will not be commanded after the aircraft has slowed below 210 KIAS.
- 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 10% greater than or 10% less than the published speed restriction for any segment of the published route.

Appendix D: Operational Assumptions and Requirements

D.1   Schedule Phase

- The ground scheduler will use the most detailed aircraft data available. The necessary data include: callsign, state information (latitude, longitude, course, ground speed, altitude, and vertical speed, etc.), intent information (route of flight, runway assignment, etc.), and aircraft specific data (aircraft type, navigation equipment identifier, etc.).
- The arrival and approach procedures used by the ground schedule and airborne spacing software will support PBN from the current aircraft position to the assigned runway.
- The arrival and approach procedures will define a speed for each segment of the PBN procedure (both RNAV STAR and SIAP), and when required, altitude constraints at some waypoints between the current aircraft position to the assigned runway. Examples include: CROSS AT (altitude), CROSS AT OR ABOVE (altitude) , NO SLOWER THAN (speed), etc.
- Where PBN procedures are not published all the way to the runway, the TMA-TM, CMS and GIM-S functions will use adapted standard operating procedures which describe the operation from cruise to touchdown.
- 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 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 ground scheduler will calculate a feasible arrival schedule using the aircraft's ETA and its speed control range, and from that derive FIM clearances for the controller to issue to FIM-equipped aircraft.
- The TMA-TM arrival schedule will be available to ARTCC controllers via the FAA's GIM-S displays. The types of information presented to the ARTCC controller will include metering information (callsign, time to the appropriate meter point), and FIM clearance information (STA to final approach fix, Target callsign, and ASG).
- The arrival schedule will be available to TRACON controllers. The types of information presented to the TRACON controller include sequencing information (i.e., callsign, delay time to the appropriate meter point), but not FIM clearance information.
- 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.

D.2   Precondition Phase

- ARTCC controllers will use vectors and speed instructions to reduce the aircraft's time error relative to the TMA-TM schedule (coordinated through ERAM and GIM-S).
- If the TMA-TM generated schedule includes significant delay time at meter fixes, prior to issuing a FIM clearance, ATC may need to issue vectors or speed commands to aircraft that will be conducting FIM operations until that aircraft is at the desired position.

D.3   Initiation Phase

- The controller will retain positive control over all aircraft in the sector, and retains responsibility for separation of all aircraft.
- Safe separation of aircraft must exist for ATC to issue a FIM clearance.
- The ARTCC controller will have the necessary information and displays to issue speed commands (using GIM-S displays) and FIM clearances.
- The TRACON controller will have the necessary information and displays to issue speed commands (using CMS displays).
- ATC must "suspend" or "terminate" a FIM operation if either the Target or FIM aircraft is vectored, or given a speed instruction.
- ATC must "terminate" a FIM operation if either the Target or FIM aircraft is given a change to its route or assigned runway.
- ATC must "terminate" a FIM operation if the Target aircraft is changed (the arrival sequence has changed).
- Flight crew conducting FIM operations are responsible for achieving the assigned spacing goal (accomplished by flying the FIM speed).
- The Target aircraft and FIM aircraft may be on the same or different PBN 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.
- FIM clearances will be issued via voice from ATC to the flight crew.
- The FIM clearance will be issued as soon as is feasible after the schedule is frozen, and it is desired to be issued prior to the aircraft's TOD.
- 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.
- The flight crew will acknowledge the FIM clearance or amendment as expeditiously as possible, as other cockpit tasks allow.

D.4   Operation Phase

- CMS tools and FIM operations can be used simultaneously.
- CMS tools are designed to be used in any traffic density and weather condition.

- FIM operations are designed to be used in any traffic density and weather condition.
- ATC speed instructions take precedence over published speeds and the FIM speed. ATC will 'suspend' or 'terminate' FIM operations prior to issuing speed commands.
- 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, as other cockpit tasks allow.
- 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).
- Controllers will attempt to avoid vectoring aircraft unless safety concerns or other operational considerations require they do. Vectoring aircraft invalidates the FIM spacing software calculations, and reduces the accuracy of the CMS displays.

D.5   Termination Phase
- After the Final Approach Fix, the FIM software provides no speed commands to correct spacing errors, and the flight crew have no FIM related tasks or displays.
- If ATC suspends or terminates a FIM operation, that flight crew will press a button that removes all FIM information from cockpit displays.
- The flight crew will notify ATC if they terminate the FIM operation prior to the Final Approach Fix (examples: loss of Target ADS-B data, not receiving Target ADS-B data by 20 miles from the FAF, etc.).

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

Shown is an example of a RNAV arrival and an instrument approach that are not connected (therefore 'EXPECT RADAR VECTORS' is on the arrival chart). Speeds are defined for each segment of the arrival but not for the approach in these examples, however will be defined for the ATD-1 demonstration. These examples are used for phraseology in section B.9.
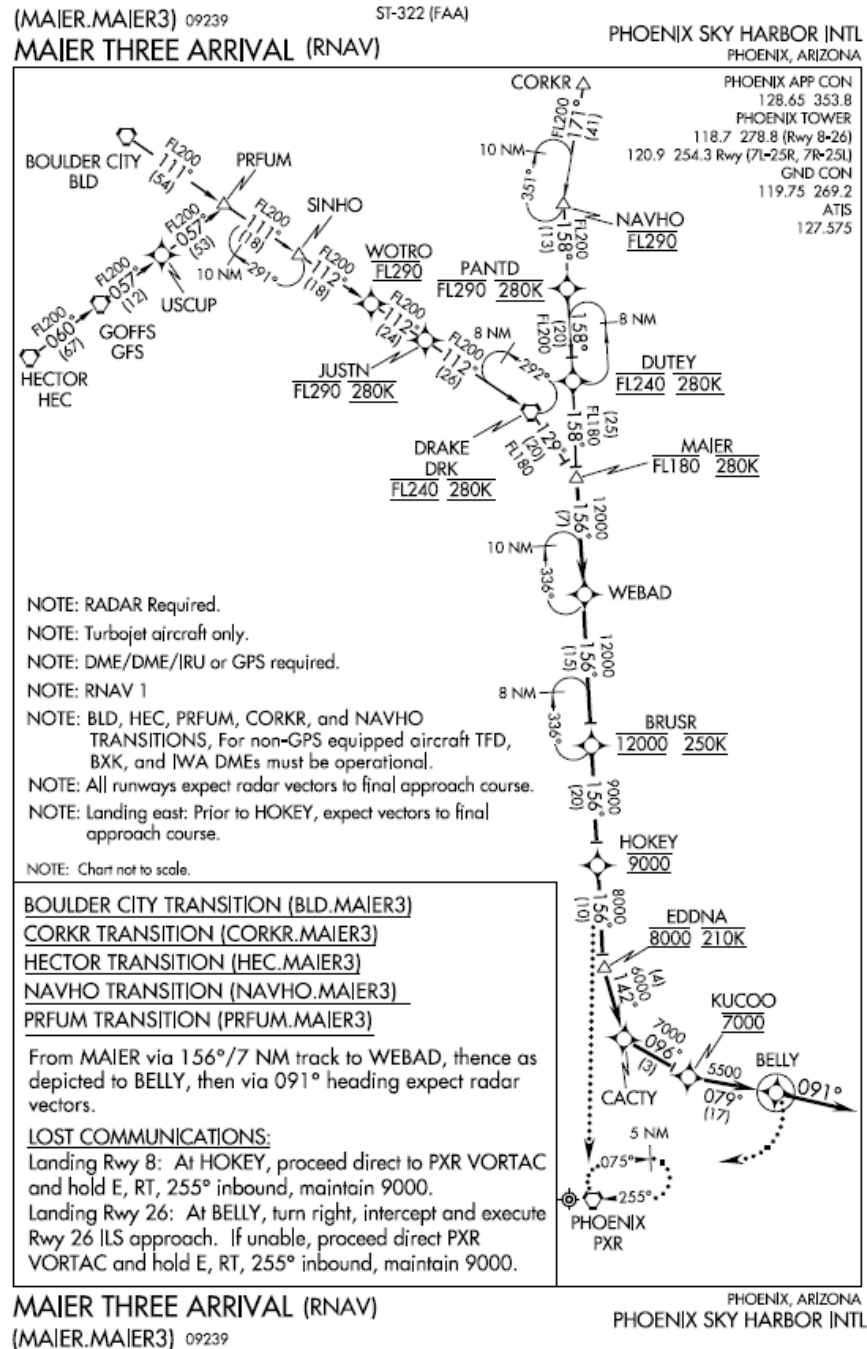
Figure 15. Sample RNAV Arrival with restrictions

Figure 16. Sample Arrival without restrictions

Figure 17. Sample Approach Procedure

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14. ABSTRACT

The operational goal of the ATD-1 ConOps is to enable aircraft, using their onboard FMS capabilities, to fly Optimized Profile Descents (OPDs) from cruise to the runway threshold at a high-density airport, at a high throughput rate, using primarily speed control to maintain in-trail separation and the arrival schedule. The three technologies in the ATD-1 ConOps achieve this by calculating a precise arrival schedule, using controller decision support tools to provide terminal controllers with speeds for aircraft to fly to meet times at a particular meter points, and onboard software providing flight crews with speeds for the aircraft to fly to achieve a particular spacing behind preceding aircraft.

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