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Air Traffic Management Technology Demonstration-1 Concept of Operations (ATD-1 ConOps), Version 3.0

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Abbreviations

| | |
|----------|---|
| ABP | Achieve-By Point |
| ADS-B | Automatic Dependent Surveillance – Broadcast |
| AFCS | Advanced Concepts Flight Simulator |
| AFMP | Arrival Flow Management Point |
| AGD | ADS-B Guidance Display |
| AICM | Aeronautical Information Conceptual Model |
| AIXM | Aeronautical Information Exchange Model |
| ANSP | Air Navigation Service Provider |
| AOC | Airline Operations Center |
| AOL | Aircraft Operations Laboratory |
| AOSP | Airspace Operations and Safety Program |
| ARC | Ames Research Center |
| ARTCC | Air Route Traffic Control Center |
| ASG | Assigned Spacing Goal |
| ASPM | Aviation System Performance Metrics |
| ASTAR | Airborne Spacing for Terminal Arrival Routes |
| ASTOR | Aircraft Simulation for Traffic Operations Research |
| ATAP | Automated Terminal Proximity Alert |
| ATC | Air Traffic Control |
| ATCA | Air Traffic Control Association |
| ATD-1 | Air Traffic Management Technology Demonstration #1 |
| ATOL | Air Traffic Operations Lab |
| CDTI | Cockpit Display of Traffic Information |
| CGD | Configurable Graphics Display |
| CMS | Controller-Managed Spacing |
| ConOps | Concept of Operations |
| CSP | Constraint Satisfaction Points |
| CVSRF | Crew-Vehicle Systems Research Facility |
| DataComm | Data Communications |
| DCT | Delay Countdown Timer |
| DSR | Display System Replacement |
| DTS | Development and Test Simulator |
| EDA | Efficient Descent Advisor |
| EFB | Electronic Flight Bag |
| ERAM | En Route Automation Modernization |
| ERFMP | En Route Flow Management Point |
| ETA | Estimated Time-of-Arrival |
| FAA | Federal Aviation Administration |
| FAF | Final Approach Fix |
| FAS | Final Approach Speed |
| FDB | Full Data Block |
| FIM | Flight Deck Interval Management |
| FIXM | Flight Information Exchange Model |
| FMS | Flight Management System |
| FOV | Field of View |

| | |
|---------|--|
| GIM-S | Ground-based Interval Management – Spacing |
| IADS | Integrated Arrival, Departure, and Surface |
| ICAO | International Civil Aviation Organization |
| ID | Identification code |
| IFD | Integration Flight Deck |
| IM | Interval Management |
| IM-S | Interval Management - Spacing |
| IMAC | Interval Management Alternative Clearances (IMAC) Experiment |
| JPDO | Joint Planning and Development Office |
| LaRC | Langley Research Center |
| MACS | Multi-Aircraft Control System |
| MF | Meter Fix |
| MIT | Miles-In-Trail |
| MP | Meter Point |
| MPT | Metering Point Time |
| MSI | Measured Spacing Interval |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| NextGen | Next Generation Air Transportation System |
| NGIP | NextGen Mid-Term Implementation Plan |
| OI | Operational Improvement |
| OPD | Optimized Profile Descent |
| PBN | Performance-Based Navigation |
| PTP | Planned Termination Point |
| REACT | Wake Turbulence Re-Categorization |
| RNAV | Area Navigation |
| RNP | Required Navigation Performance |
| SAIE | System Analysis, Integration, and Evaluation |
| SBS | Surveillance Broadcast Services |
| STA | Scheduled Time-of-Arrival |
| STAR | Standard Terminal Arrival Route |
| STARS | Standard Terminal Area Replacement System |
| TAMR | Terminal Automation Modernization and Replacement |
| TAPSS | Terminal Area Precision Scheduling & Spacing |
| TBFM | Time-Based Flow Management |
| TBO | Trajectory Based Operations |
| TCAS | Traffic Alert and Collision Avoidance System |
| TCP | Trajectory Change Point |
| TFM | Traffic Flow Management |
| TMA | Traffic Management Advisor |
| TMA-TM | Traffic Management Advisor with Terminal Metering |
| TMC | Traffic Management Coordinators |
| TMI | Traffic Management Initiatives |
| TMU | Traffic Management Unit |
| TOD | Top-Of-Descent |
| TRACON | Terminal Radar Approach Control Facility |
| TSAS | Terminal Sequencing And Spacing |
| TSS | Terminal Sequencing and Spacing |
| WXXM | Weather Information Exchange Model |

1.0 Introduction

This document describes the goals, benefits, technologies, and procedures of the Concept of Operations (ConOps) for the Air Traffic Management (ATM) Technology Demonstration #1 (ATD-1), and provides an update to the previous versions of the document [ref 1 and ref 2].

1.1 Overview

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

The NASA technologies integrated into the ATD-1 ConOps are:

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

Results from the research into these technologies will be transferred to the operational systems employed by the FAA and industry partners. These technologies and their transfer are currently in the FAA roadmap and decision making documents for operational deployment.

The ATD-1 ConOps is an integrated system that could be deployed in the 2020-2025 timeframe, and is an initial implementation of TBO in the terminal domain. The ConOps aligns with the Federal Aviation Administration's (FAA) Next Generation Air Transportation System (NextGen) Mid-Term ConOps [ref 3], the Terminal Sequencing and Spacing (TSAS) Concept of Operations [ref 4], the Time-Based Flow Management (TBFM) ConOps [ref 5], and is consistent with the FAA's expected National Airspace System Enterprise Architecture Operational Improvements (OI) in the 2015-2018 timeframe. In its NextGen Mid-Term Implementation Plan (NGIP) [ref 6], the FAA has accepted the Air Traffic Control Association (ATCA) NextGen Mid-term Task Force's Tier 1 recommendations, which included specific guidance that the FAA and the aviation industry should agree on the set of capabilities that warrant equipage incentives. The FAA has stated that it will establish priorities for incentivizing operator equipage for Performance-Based Navigation (PBN), ADS-B and Data Communications (DataComm).

The ATD-1 ConOps also closely aligns with the FAA Surveillance Broadcast Services (SBS) Program's Interval Management – Spacing (IM-S) ConOps [ref 7 and ref 8]. In addition to these ConOps, the ATD-1 ConOps also supports NASA's Integrated Arrival, Departure, and Surface

(IADS) concept for the Mid-Term [ref 9], and takes advantage of PBN specifications and requirements [ref 10]. The FIM operations described in this ConOps are limited to ATC-assigned procedures to flight crews of properly equipped aircraft to help manage the flow of traffic during high density arrival operations. Related ATM research and concepts are described in Appendix D.

This document follows the FAA template for ConOps development [ref 11], and provides concept-level requirements for supporting services, systems, technologies, tools, procedures, and airspace changes. This document focuses on the arrival scenarios and procedures to be used during the ATD-1 operational evaluation of TMA-TM and CMS (at the FAA's William J. Hughes Technical Center in 2014-2015), and flight test of FIM avionics (at Grant County International Airport in Moses Lake, Washington, in 2017). The end-state operational concept of these capabilities include other flight phases (e.g., departure operations), incorporation of other technologies (e.g., DataComm.), and incorporation of more sophisticated controller decision support tools; however only the ATD-1 operations and procedures that are enabled by the ATD-1 technologies (TMA-TM, CMS and FIM) are discussed in this document.

Over the course of the ATD-1 Project, the naming convention for some technologies and procedures has evolved, particularly when transferred to the FAA. The bulleted items below describe the terms used to describe the NASA technology, and the corresponding FAA terms.

- NASA's TMA-TM technology is a key component of the FAA's Time Based Flow Management (TBFM) system.
- NASA's TMA-TM and CMS technologies is the FAA's Terminal Sequencing And Spacing (TSAS) capability, which also incorporates enhancements to TBFM and interface support for Standard Terminal Automation Replacement System (STARS) equipment, planned for 2019. It was initially abbreviated TSS by the FAA, then changed to TSAS.
- Flight deck Interval Management (FIM) has occasionally been used interchangeably with Flight Deck-Based Interval Management (FIM) and Interval Management (IM).

1.2 Background

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

Increasing the safety, capacity and efficiency of the NAS are primary goals of the JPDO NextGen ConOps and ATD-1 ConOps. Achieving these goals require that the throughput to the high-density airports and the efficiency of arrival operations be simultaneously optimized. The

FAA's NextGen OIs (grouped by Solution Set) associated with ATD-1 and the capabilities that enable them are:

- Initiate Trajectory Based Operations (TBO)
 - 102137 Automation Support for Separation Management (2014-2018)
 - 104120 Point-in-Space Metering (2014-2018)
 - 108209 Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigation Performance (RNP) (2010-2014)
- Increase Arrival/Departure at High Density Airports
 - 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
 - 104124 Use of Optimized Profile Descents (OPD) (2010-2017)
- Increase Safety, Security, and Environmental Performance
 - 109319 Environmentally and Energy Favorable ATM Concepts, Phase I (2011-2015)

1.3 Problem Statement

The 2016-2036 FAA Aerospace Forecast predicts U.S. commercial aviation revenue passenger miles will grow on average 2.1% annually throughout these twenty years. By 2036, U.S. commercial air carriers are projected to fly 1.81 trillion available seat-miles – approximately 169% of the available seat-miles flown in 2016 [ref 13]. Arrivals into high-density airports, especially during peak traffic periods and inclement weather, experience significant inefficiencies due to the use of miles-in-trail procedures and step-down descents. These procedures contribute to not achieving the airport's maximum capacity, increase controller workload, increase arrival delay, and increase aircraft fuel burn, emissions and noise. While advanced PBN procedures (e.g., RNAV arrivals and OPDs) that take advantage of an aircraft's navigation capability exist at a limited number of airports, they are not well utilized due to the lack of supporting scheduling and spacing tools and the lack of ATC awareness of aircraft capability (flight crew training and aircraft equipage) early in the arrival sequencing process.

1.4 Identification

Figure 1 shows the position of the ATD-1 ConOps within the FAA’s structure of Concept Levels (1-Enterprise, 2-Service, 3-Sub-service, and 4-Solution). The ATD-1 ConOps was developed to directly support the Level 1 NextGen Mid-Term Concept of Operations for the NAS [ref 3].

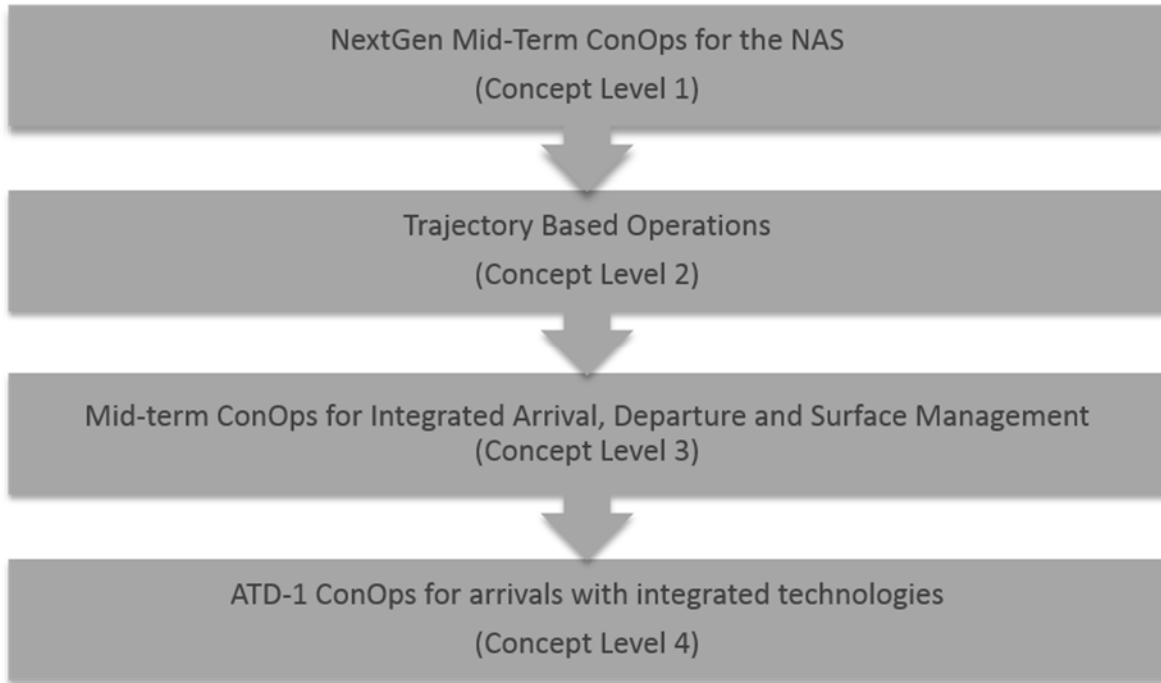


Figure 1. Position of ATD-1 within FAA operational concept hierarchy.

1.5 Operational Need

The operational need for the capabilities represented in the ATD-1 ConOps is driven by present day shortfalls in the air traffic management areas of capacity, flexibility, efficiency, safety, and the environment [ref 3].

1.5.1 Capacity

For domestic flights in 2008, there was a total of approximately 3.2 million hours of delay according to the FAA’s Aviation System Performance Metrics (ASPM) system [ref 14]. Approximately 20% of these hours were airborne delays (much more costly to airlines than ground delays), and these delays are expected to more than double in the next ten years without NextGen improvements [ref 15]. Throughput in high-density airspace, particularly around major metropolitan airports, is reaching its limit using current technology and procedures, in part due to ground automation lacking the means to identify areas of unused capacity in busy overhead and arrival/departure streams. Current automation lacks the means to not only identify areas of unused capacity, but to also forecast these areas.

1.5.2 Flexibility

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

1.5.3 Efficiency

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

1.5.4 Safety

The primary goal of the National Aviation Safety Strategic Plan and part of the JPDO NextGen ConOps [ref 13] improved safety in all phases of flight, and secondarily to accommodate increased traffic growth and new types of aircraft in the years to come. The need to improve safety is particularly important for those areas in which accidents and incidents have historically been more likely to occur, such as taxi operations, during convective weather events or periods of low visibility, and in operations in areas without surveillance services. The approach to aviation safety must evolve into one in which safety information and lessons learned are shared more freely, and a cultural transformation from a reactive to a proactive approach to safety improvements.

1.5.5 Environment

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

1.6 ATD-1 ConOps Overview

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

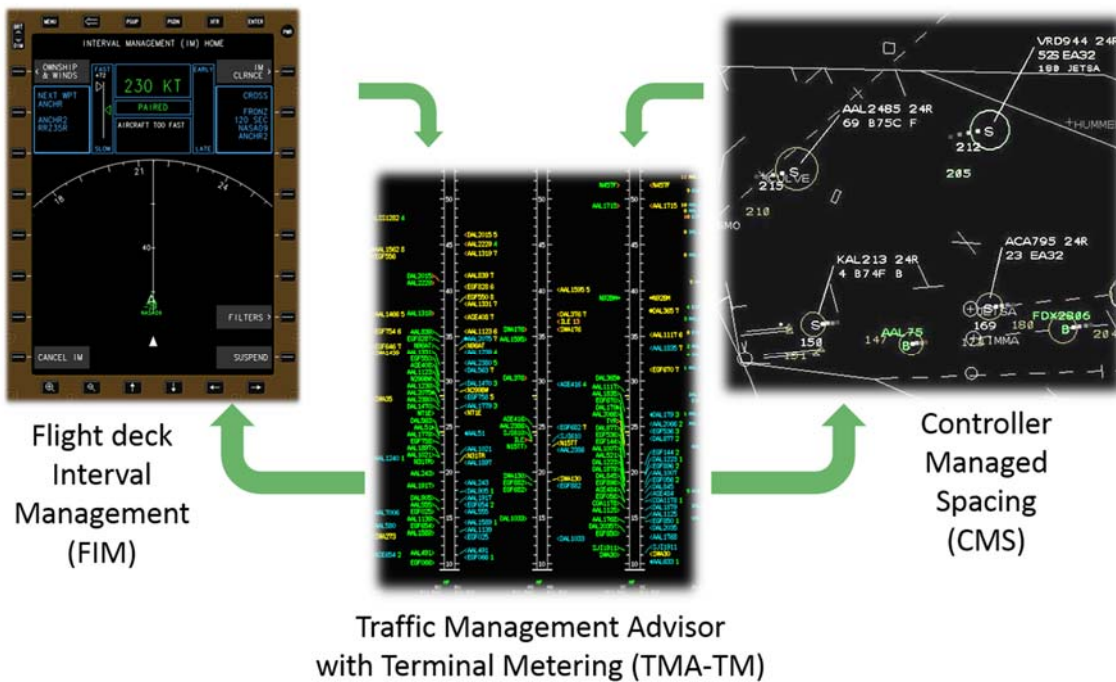


Figure 2. Integrated NASA technologies in the ATD-1 ConOps.

When an aircraft crosses the Freeze Horizon, the TMA-TM tool assigns to that aircraft the most suitable runway and freezes the time-deconflicted Scheduled Time of Arrival (STA) for the Meter Fix, terminal Meter Points, and runway threshold (detailed description in section 4.5.1). The portion of the arrival schedule relevant to a particular en route or terminal controller is shown on meter lists displayed on their scope. The CMS and FIM information displayed on their scope is also generated using the TMA-TM schedule information.

En route controllers issue the arrival procedure and expected runway to all aircraft, and use their current displays as well as speed advisories generated by the Ground-based Interval Management – Spacing (GIM-S) software to achieve the time calculated at the Meter Fix (MF) by TMA-TM. When the required delay is predicted to exceed the capability of speed-only operations, the en route controller will use path stretching (vectors) or step down the aircraft to lower altitudes to absorb the delay, and then revert to speed-only control when feasible.

En route controller then issue a clearance to descend via the arrival procedure to all flight crew, and for those aircraft suitably equipped, they subsequently issue that flight crew a FIM clearance. Depending on the operational goal of the controller and the relative geometry of the two aircraft to each other, the en route controller issued one of three FIM clearance types (see section 4.5.3).

If changes to the operational goal occur, the required delay is not being created in a timely manner, or the continued separation between aircraft is in question, the controller interrupts the descend-via arrival procedure (and suspends the FIM operation if one has been issued) and reverts to traditional control strategies such as speed instructions, vectoring, and altitude assignments (step-downs) until the delay and separation are appropriate.

Terminal controllers receive aircraft data and STA information, graphical information (spacing circles), as well as CMS advisories on their controller display to correct the remaining spacing error. When speed control is sufficient to absorb the remaining delay, terminal controllers use this information and the CMS speeds as advisories intended to assist in the decision making process.

En route and terminal controllers “suspend” the FIM operation if the temporary need exists to vector either the FIM aircraft or Target (traffic to follow) aircraft, or “terminate” the FIM operation if it no longer supports the operational goal of the controller. Any controller instruction (change in speed, heading, or altitude, etc.) takes precedence over the FIM operation.

Note: The GIM-S and CMS speeds displayed to controllers are advisory, whereas the FIM speed displayed to the flight crew is mandatory. If the crew cannot or does not intend to fly the FIM speed, they are required to terminate the FIM operation and notify the controller.

1.7 Integration with ANSP Ground Systems and Aircraft Systems

The ATD-1 ConOps and procedures require the ATD-1 ground side technologies to be integrated with the TBFM system, the En Route Automation Modernization system (ERAM), the Standard Terminal Automation Replacement System (STARS), and with the GIM-S capabilities.

On the flight deck, the FIM technology required for aircraft systems may be installed either as part of a “forward-fit” design in advanced aircraft where it can be fully integrated with the autoflight system and display FIM information in the primary field of view, or as part of a “retro-fit” for aircraft currently in operational use (as one or more auxiliary displays, to include one in the primary field of view). The “retro-fit” option will be the airborne integration option used during the ATD-1 flight demonstration in 2017.

2.0 Operations and Capabilities

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

2.1 Description of Users in Current Operation

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

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

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

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

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

2.1.2 En Route (ARTCC) Sector Controllers

En route controllers monitor flight progress and maintain separation in en route airspace, issue descent clearances, merge arrival streams prior to the TRACON boundary, and ensure that Traffic Management Initiatives (TMIs), including specifications for sequencing and spacing, are maintained. When an aircraft has been assigned an MPT by TMA, the en route controller manages the aircraft, as necessary, to ensure that the aircraft meets its assigned MPT and maintains

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

2.1.3 Terminal (TRACON) Controllers

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

2.1.4 Flight Crews

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

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

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

2.1.5 Airline Operations Center (AOC)

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

2.2 Supporting Capabilities

2.2.1 Current FAA Automation

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

Proactive use of the TMA automation identifies periods of traffic congestion, and distributes delay between the ARTCC and TRACON using meter fix crossing times, known as STAs. Though the TMA predicts congestion at the runway and moderates the flow at the meter fixes of the ARTCC/TRACON boundary, the TRACON does not have the ability to follow the TMA runway schedules due to a lack of controller interfaces and limited TMA modeling of merging procedures within the TRACON. To maintain the integrity of the schedule, TMA currently adds a buffer to the required separation to allow the TRACON to safely moderate the congestion. This means the maximum runway capacity (based on the minimum separation requirements) is not realized. Even with this limitation, the TMA’s proactive congestion identification and the arrival metering at the meter fixes has been shown to efficiently distribute arrival delay and controller workload between

the ARTCC and TRACON while maintaining the runway throughput at the desired airport arrival rate. During periods of congestion, en route controllers manage aircraft to the TMA generated meter times by issuing speed instructions, and if additional delay is required, they may descend the aircraft early or vector it off its route. Within the TRACON, terminal controllers manage the separation of aircraft by speed instructions and vectoring, as well as tromboning the turn to final.

2.2.2 FAA Automation to be Fielded for ATD-1

GIM-S is part of the FAA’s work to support Extended Metering. GIM-S adds additional meter points, called constraint satisfaction points (CSP), upstream from the arrival airport, and speed advisories to these points should mitigate or eliminate the dependency on MIT constraints. By conditioning the arrival flow, GIM-S is intended to reduce the number of interventions required by the controller, thereby reducing controller workload in busy arrival sectors. An aircraft’s arrival time at the runway will be calculated by TMA-TM (see section 4.1.1), then coordinated with the FAA’s GIM-S software to provide ARTCC controllers speed advisories for aircraft not conducting FIM operations.

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

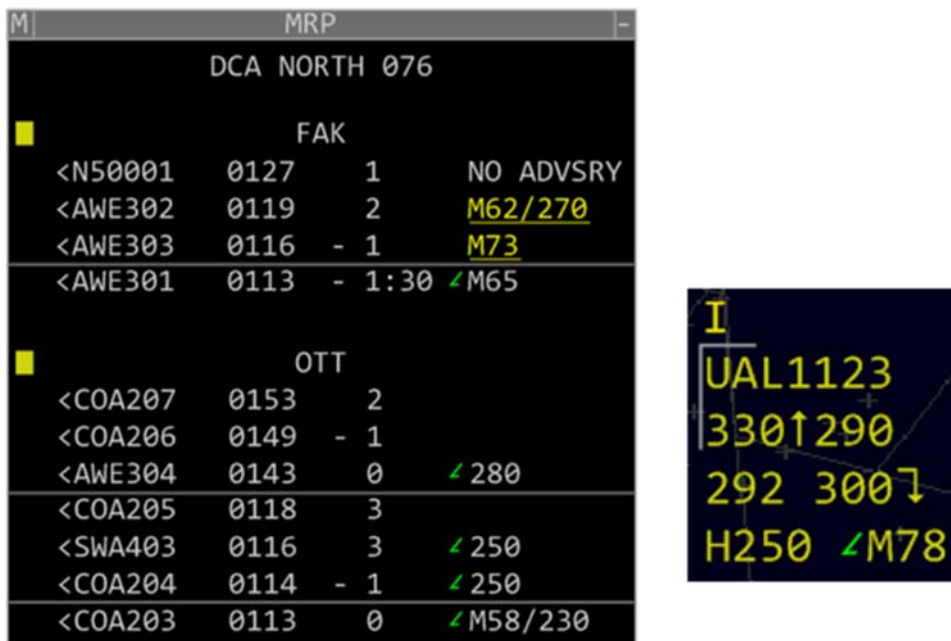


Figure 3. Notional GIM-S displays and aircraft full data block.

2.2.3 Aircraft Avionics

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

This limitation applies to the typical current minimum equipage for air transport aircraft. Certain aircraft are also equipped with Cockpit Display of Traffic Information (CDTI) devices, for example, aircraft flying oceanic routes and participating in the In-Trail Procedures evaluation. These aircraft have an onboard Air Traffic Computer that supplements the reception of TCAS with an "ADS-B In" capability. This additional equipage allows crews to locate other aircraft beyond 150 nautical miles and to conduct certain procedures, or make more informed requests, which enables more efficient operation of the aircraft.

3.0 Description and Justification of Changes

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

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

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

4.0 ATD-1 Concept of Operations

4.1 Concept Goal

The operational goal of the ATD-1 ConOps is to enable aircraft, using their onboard auto-flight systems, to plan for and fly PBN procedures to the maximum extent possible, from cruise to the runway at a high-density airport, during peak traffic demand, using primarily speed control to achieve and maintain in-trail spacing to meet the arrival schedule.

The three ATD-1 technologies achieve this by calculating a precise, time-deconflicted arrival schedule for all aircraft, sharing the common schedule with en route and terminal controllers, providing decision support tools and displays to achieve the schedule (GIM-S for en route controllers, and CMS for terminal controllers), FIM clearance information (for en route controllers only), and FIM avionics and airspeeds for flight crew. The CMS and FIM software calculates small increases or decreases in the speed flown by the aircraft during the arrival procedure to maximize aircraft fuel efficiency while still achieving the optimized TMA-TM arrival schedule and thus the desired throughput.

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

- Mixed Equipage Operations – A combination of ground-based and FIM tools can help achieve sustained fuel-efficient operations during periods of high throughput while an aircraft fleet mix containing both less capable avionics and more advanced avionics.
- Terminal Metering – Advanced arrival scheduling enables flow conditioning throughout the entire arrival phase of flight to ensure efficiency gains achieved by advanced automation in en route airspace are not lost in terminal airspace.
- PBN 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.
- FIM operations – During a FIM operation, the management of the spacing interval between aircraft is accomplished by the flight crew, thereby producing a small reduction in the controller’s workload (however the controller retains separation responsibility).

4.2 Concept Description

The ATD-1 ConOps provides time de-conflicted and efficient operations of multiple arrival streams of aircraft, passing through multiple merge points, from top-of-descent to touchdown (see Figure 4 and Figure 5). PBN arrival procedures, such as RNAV OPDs, provide a lateral and vertical path from the en route structure to the runway threshold, to include transitions that connect the STAR to the instrument approach procedure. This enables the TMA-TM software to create a more accurate schedule, and allows flight crews to use their onboard auto-flight systems to fly from en route cruise altitude to landing while requiring fewer controller interventions and fewer level flight segments [ref 16 - 18]. RNAV OPDs are developed by the FAA and are independent of the ATD-1 project; however, the ATD-1 ConOps is designed to enable aircraft to remain on PBN procedures more often, thus improving aircraft efficiency and airspace throughput.

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

During the Schedule Phase of ATD-1 operations (detailed description in section 5.1.1), it is expected that upstream flow conditioning will, in most cases, allow speed control alone to be sufficient to achieve the arrival schedule. The TMA-TM software continuously calculates Estimated Times-of-Arrival (ETAs) and STAs for aircraft to all eligible active runways. The trajectories associated with these ETAs incorporate the aircraft's route-of-flight, TOD, its intended speed profile, and forecast winds. When the aircraft crosses the Freeze Horizon (intended to occur prior to the aircraft's TOD), the TMA-TM tool assigns the most suitable runway and freezes the STAs for the runway threshold, Final Approach Fix, terminal meter points, and meter fix. The schedule information at each meter point is presented to the appropriate en route and terminal controllers. (The En Route Flow Meter Point (ERFMP) shown in Figure 4 illustrates the potential interaction between ATD-1 and other concepts in the future. In the ATD-1 ConOps, the en route controller does not have a STA for the ERFMP.)

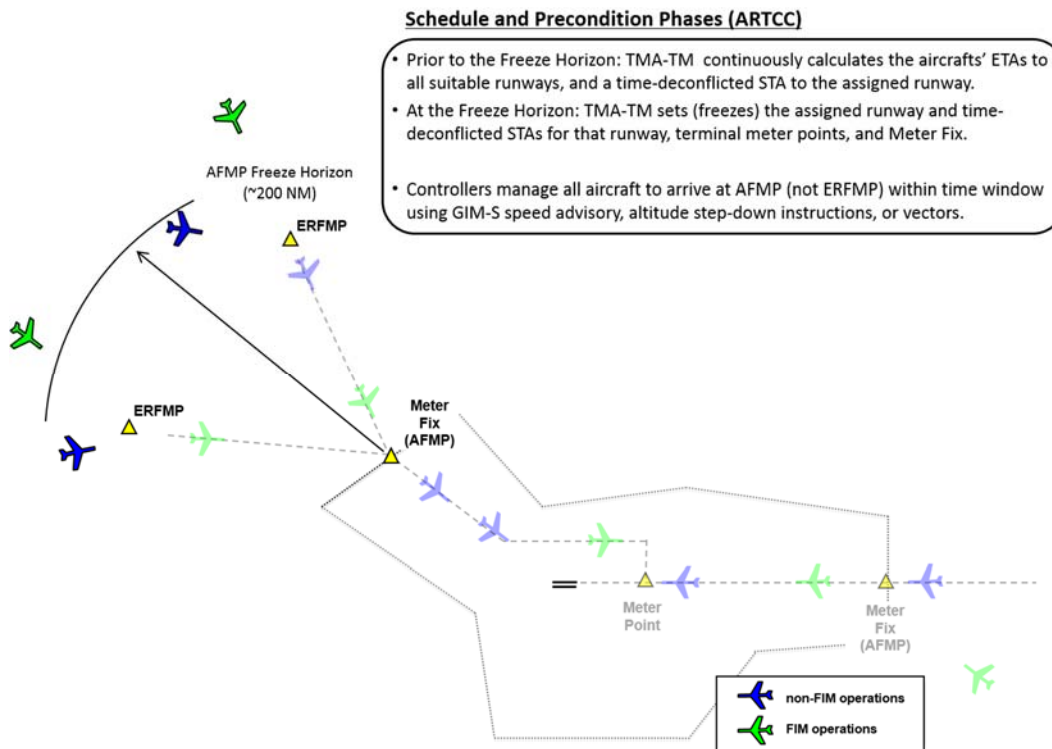


Figure 4. ATD-1 operations during en route phase.

The Precondition Phase (section 5.1.2) applies only to aircraft entering the ARTCC sector that require path stretching or a slower ground speed to achieve their Meter Fix STA. The en route controller issues vectors or altitude step-down instructions to the flight crew of those aircraft until speed only control methods can be used.

The Initiation Phase (section 5.1.3) applies only to FIM equipped aircraft. Once the FIM-equipped aircraft are established on their route and can achieve the Meter Fix STA with speed control alone, the en route controller issues the FIM clearance.

The Operation Phase (section 5.1.4) begins for non-FIM aircraft once they are established on their route and can meet their respective Meter Fix STA with speed control alone. For FIM-equipped aircraft, the Operation Phase begins immediately after the FIM clearance has been issued.

In this phase, en route controllers issue the arrival procedure and expected runway to all aircraft. They also use their ERAM tools, to include GIM-S software, to achieve the time calculated at en route meter points by TMA-TM to resolve the remaining meter fix or en route meter point delays. When the delay is predicted to exceed the capability of speed-only operations, the en route controller will use path stretching (vectors) or lower altitudes to incur the required delay, and then revert to speed-only control when feasible.

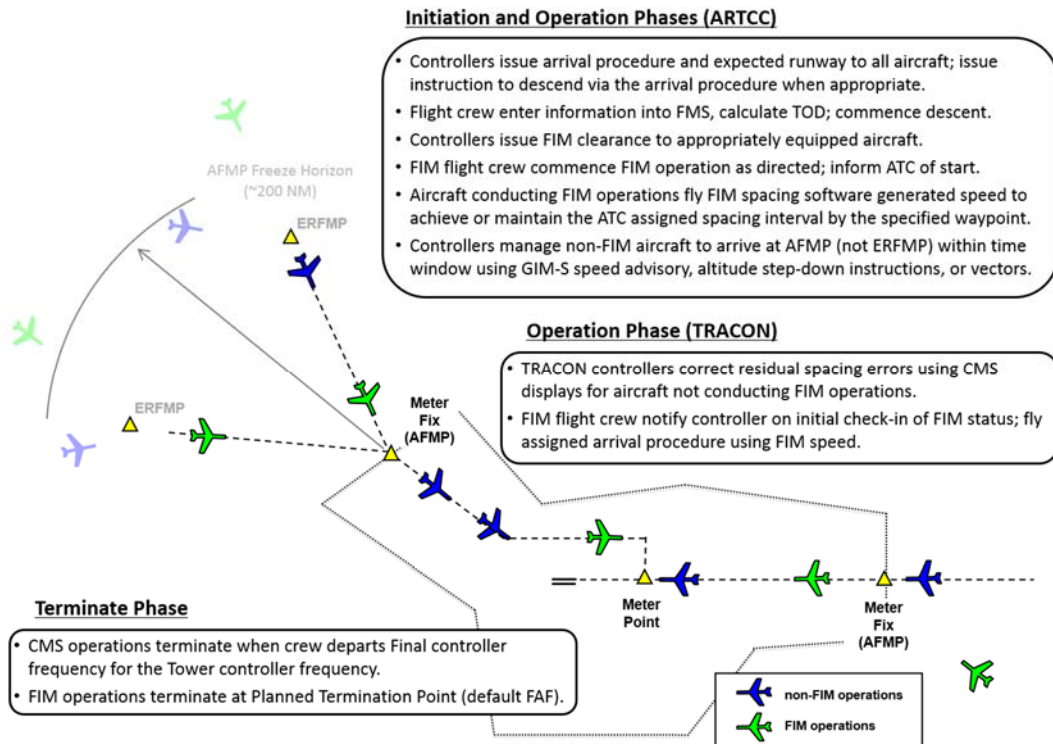


Figure 5. ATD-1 operations during descent and in terminal airspace.

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

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

FIM clearances will be issued as soon as possible after the schedule freeze but after speed-only control is expected to be sufficient for the FIM equipped aircraft to achieve its STA at the Meter Fix. The controller-pilot phraseology used during ATD-1 also required that the FIM clearance be issued after the controller had issued the "descend via" instruction. FIM clearances may use Target aircraft on the same arrival as the FIM aircraft, or on a different arrival and crossing a different meter point to enter the TRACON. Controllers will "suspend" FIM operations if the need exists to momentarily vector either the FIM aircraft or Target aircraft.

The Termination Phase (section 5.1.5) for CMS operations occurs when the flight crew switch from the Final controller to the Tower controller frequency. FIM operations terminate at the Planned Termination Point (PTP), which is typically the FIM aircraft's Final Approach Fix (FAF) (can be modified to be any waypoint common to the routes of the Target and FIM aircraft).

4.3 Assumptions and Requirements

Programmatic requirements to achieve the full benefit of the ATD-1 technologies include:

- NASA develops and the FAA implements TMA-TM to support integrated scheduling and spacing within the TRACON (i.e., terminal metering).
- FAA implements ERAM changes to support display of the TMA-TM runway assignment for every aircraft, and to support use of GIM-S speed advisories by en route controllers.
- NASA develops and the FAA implements CMS automation and displays within STARS at the ATD-1 demonstration site.
- The FAA develops and implements PBN procedures that are continuous from the en route environment to the runway.
- Most aircraft scheduled to land at the high-density airport during peak traffic periods are equipped for RNAV operations.
- Some aircraft scheduled to land at the high-density airport during peak traffic periods are equipped for FIM operations (ADS-B In plus FIM displays and software).
- Controller-pilot communications will be by voice.

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

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

4.4 Operational Environment

The operational environment targeted for the ATD-1 ConOps is the latter part of NextGen Mid-Term (2015-2020). The ConOps will optimize the efficiency of arrival operations into high-density airports as well as the throughput of the airport. This ConOps will work with current and future ATC programs, and will subscribe to FAA, Aeronautical Information Conceptual Model (AICM), Aeronautical Information Exchange Model (AIXM) 5.0, the Flight Information Exchange Model (FIXM), the Weather Information Exchange Model (WXXM), and International Civil Aviation Organization (ICAO) data standards. Key related programs include TBFM, Terminal Automation Modernization and Replacement (TAMR) and its STARS equipment, and developments in PBN such as RNAV STARs and RNP approach procedures.

Within this operational environment, the three NASA technologies required to implement the ATD-1 ConOps are (see Appendix H for a high-level description of the algorithms):

- An advanced version of TMA incorporating Terminal Metering (TMA-TM) [ref 19 - 22]
- Controller Managed Spacing (CMS) decision support software and displays, indications, warnings, training, and procedures [ref 23 - 24]
- Flight-deck Interval Management (FIM) spacing software and displays, indications, warnings, training, and procedures [ref 25 - 29]

The ATD-1 ConOps users and their notional relationship to each other during the mid-term are shown below in Figure 6. The final location of the NASA technologies will be determined by the FAA, and may vary based on the specific site. Not shown are other expected users and their interactions in the long-term version of ATD-1 operations, such as the AOC and Tower.

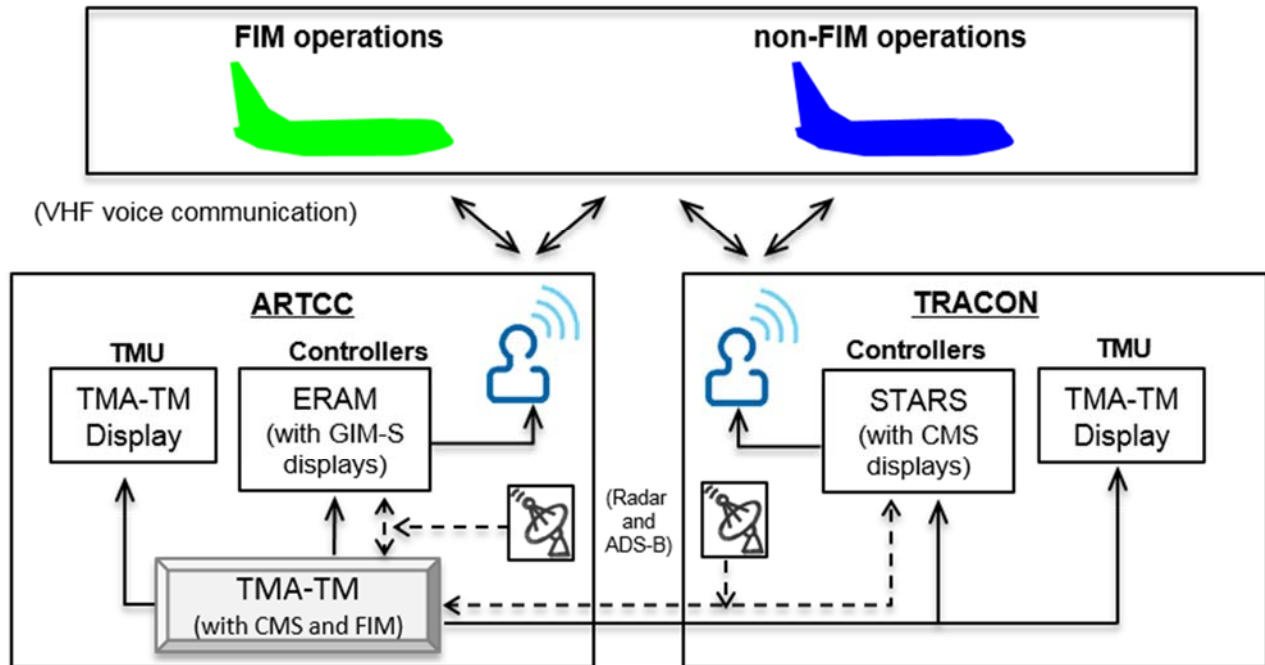


Figure 6. Block diagram of ATD-1 ConOps users.

4.5 Operations by ATD-1 Technology

4.5.1 TMA-TM

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

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

more efficient utilization of the airport's capacity, and more fuel and emission-efficient operations from cruise to touchdown for NextGen.

TMA-TM extends the basic TBFM scheduling capability by including merge fixes inside TRACON airspace, and optimizes the flow of multiple arrival stream merges into an airport. The terminal delay model is enhanced to be more compatible with PBN procedures, and to enforce separation constraints at merges within the terminal area. The TMA-TM constraint scheduling, runway balancing logic, and algorithms necessary for the diverse operational requirements of ATC are beyond the scope of this paper [see ref 22 for more detail], however the basic functional logic is a first-come-first-served algorithm that is then modified for separation requirements (radar and wake vortex). This logic is also coupled with a runway balancing algorithm that uses available runway capacity and a delay distribution in the terminal and en route airspace to create the aircraft specific STA. This creates conflict-free schedules simultaneously at the Center meter-fixes, terminal meter points, and the runway threshold. Additional details include:

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

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

The TMA-TM schedule and meter list has also been expanded to support en route controllers issuing GIM-S speed advisories and FIM clearances. Figure 7 displays the aircraft identification for NASA1 and NASA2, two aircraft proceeding to the waypoint SQUEZ. From left to right, the asterisk indicates the aircraft's runway and STA is frozen, followed by the STA at SQUEZ and the amount of delay required to achieve it. Directly below the "T" is the GIM-S speed advisory (in Mach and Airspeed) calculated to achieve the STA at SQUEZ. SCADE is the Achieve By Point for the FIM aircraft, 124 the Assigned Spacing Goal in seconds, and the data on the right is the Target aircraft identification and the Target aircraft's route. (Note: to mitigate the expected lack of datalink communications in the ATD-1 Demo timeframe, the Achieve By Point has been removed from the FIM clearance to reduce controller and flight crew workload and voice transmissions, and will be removed from the meter list shown below.)

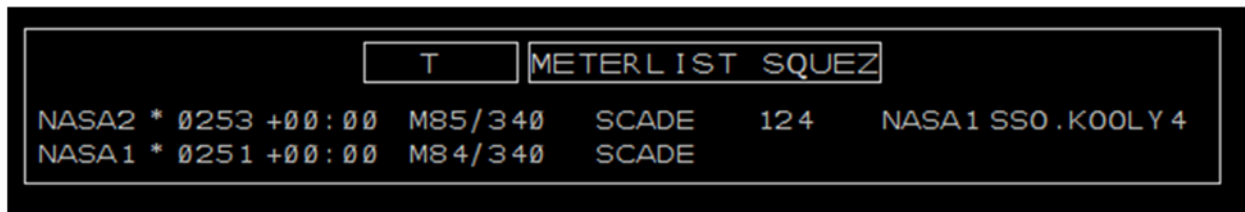


Figure 7. TMA-TM meter list.

The TMA-TM schedule will identify which aircraft are FIM capable and generate the FIM clearance. This function will also update the FIM status indicator when events occur that change the FIM clearance. (Not updating or terminating a FIM clearance when these events occur could result in the FIM aircraft attempting to achieve the assigned spacing interval behind an aircraft no longer its lead.) TBFM is expected to calculate the GIM-S speeds, and ERAM will manage the display and advisory information.

4.5.2 CMS

CMS tools assist terminal controllers in achieving their goal of maximizing throughput on capacity-constrained runways. They ensure that the terminal controllers have knowledge of, and follow, the same arrival schedule that en route controllers use to manage the flows of traffic into the terminal airspace. The CMS tools provide the information necessary to more accurately achieve arrival schedule conformance using speed commands. This information is expected to allow terminal controllers to reduce the use of tactical vectoring, thereby minimizing interruptions to fuel-efficient PBN arrival procedures [ref 23-24].

The CMS tools consist of schedule timelines, slot markers (or 'slot marker circles'), early/late indicators, and speed advisories shown in Figure 8. These tools function as follows:

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

the upstream controller initiates hand-off, and the same white as the ETA when the receiving controller accepts the hand-off.

- Slot markers (top right and bottom right panels)

Slot markers translate the temporal schedule information into a spatial target on a controller's display. The slot marker circles indicate where an aircraft should be at a given time if it were to fly the arrival and approach procedures, meeting all published speed and altitude restrictions, and arrive on schedule. The instantaneous indicated airspeed of the slot marker is also displayed adjacent to the slot marker circle. In the figure, the aircraft shown are travelling left to right. In the top right panel, an aircraft that is close to on-time appears inside the circle, while in the bottom right panel an aircraft that is slightly early appears ahead of the circle. Note that the slot markers are always positioned along the RNAV OPD used to schedule the aircraft, even if the associated aircraft has been temporarily vectored off the procedure.
- Early/Late Indicators (top right panel)

Early/late indicators in an aircraft's Full Data Block (FDB) enable controllers to quickly assess the schedule conformance of that aircraft, in a manner similar to the delay countdown timer (DCT) presently available to ARTCC controllers. An early/late indicator is displayed using three characters in the third line of the FDB. Early/late indicators display the required delay with one-second precision when the absolute delay is less than 100 seconds (e.g., -15 indicates an aircraft is fifteen seconds late); larger delay values are shown with one-minute precision (e.g., +2M indicates an aircraft is approximately two minutes early). Thus, SWA353 is currently estimated to be three seconds early.
- Speed advisories (bottom right panel)

Speed advisories display airspeeds computed to put the aircraft back on schedule. The advised airspeed is computed using information about the nominal speed profile along the assigned RNAV OPD, and are displayed in ten-knot increments. If an aircraft is late, a speed increase may be advised. The speed advisories appear in the same three-character field on the third line of the FDB that is used to display the early/late indicator. Thus, the speed advisory for SWA1184 is 190 knots, which is slower than the nominal speed of 210 knots for that segment, causing the aircraft to move towards the slot marker. If TMA-TM cannot compute a speed advisory different than the nominal speed, or the required speed is outside the available speed control margin, the early/late indicator is displayed instead. The CMS speed advisories are completely independent of the GIM-S speed advisories.

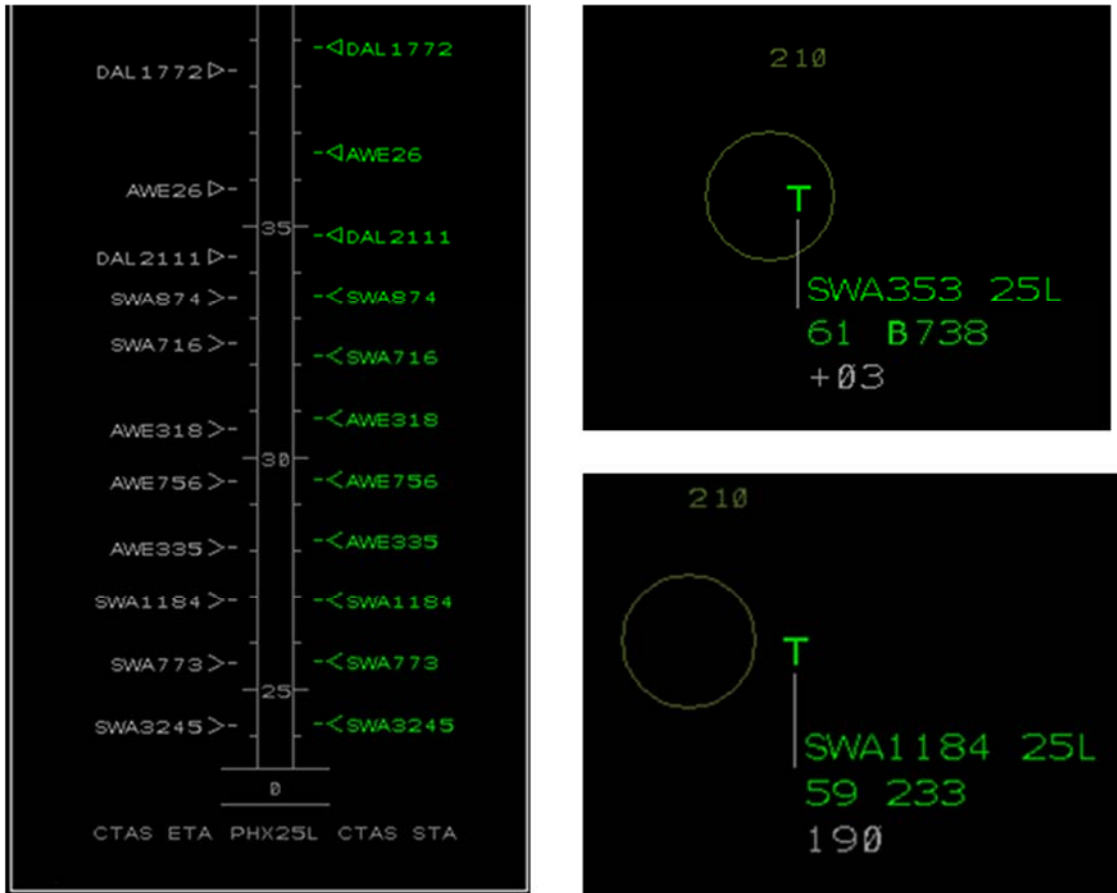


Figure 8. CMS tools and displays.

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

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

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

Additional display functionality beyond the basic CMS tools has also been developed to help controllers monitor the status of FIM operations, using either DSR in ARTCCs (top row of Figure 9), or STARS in the TRACON (bottom row of Figure 9).

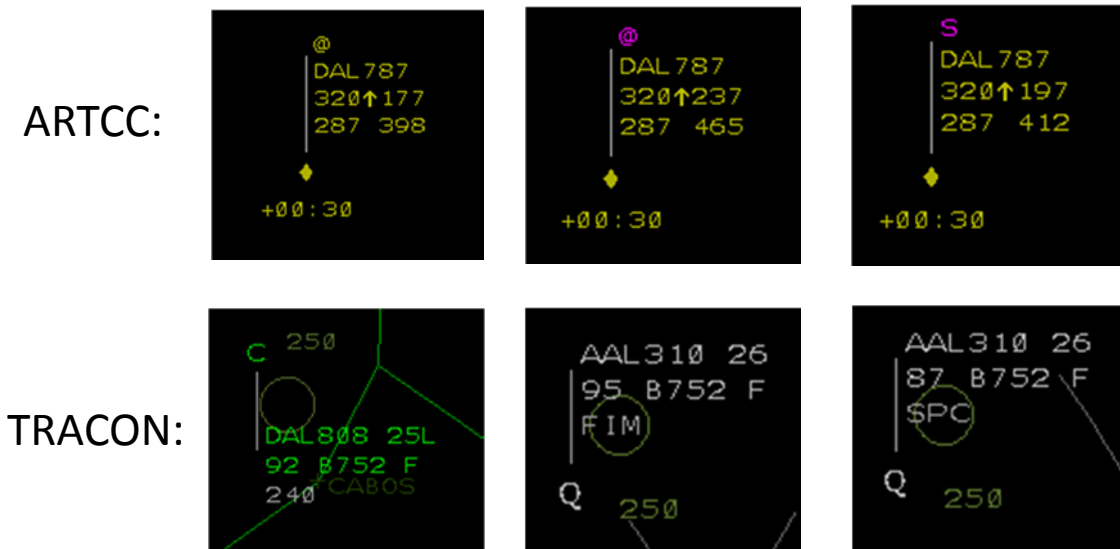


Figure 9. FIM status indications.

The top-left panel in Figure 9 illustrates how a FIM-equipped aircraft’s FDB appears to a Center controller before the FIM clearance is issued. The DSR FDB includes a yellow “@” symbol that indicates the aircraft is FIM-equipped and can therefore accept a FIM clearance (no comparable equipage symbol is provided for TRACON controllers since they do not have FIM clearance information available). (Note: recent development work indicates it may be desirable to have the “@” symbol indicate FIM-available; that is, FIM-equipped and a FIM clearance is available.) The top-middle panel in Figure 9 shows a magenta “@” symbol, which occurs when the ARTCC controller issues a FIM clearance. The top-right panel in Figure 9 shows the FDB has been updated to reflect that the flight crew reported commencing the FIM operation, and the controller updated the symbol to a magenta “S”.

FIM status information entered in the ARTCC is transferred to the TRACON, and the bottom row of Figure 9 corresponds to the same sequence of FIM status as the top row. TRACON controllers also make entries to change the FIM status indications to match aircraft reports. Suspending a FIM operation requires the controller to return the indicator to the ‘FIM issued’ status (bottom-middle of Figure 9), and terminating a FIM operation requires updating the FDB to a FIM equipped status (bottom-right of Figure 9).

4.5.3 FIM

The FIM operation enables the flight crew to actively assist both en route and terminal controllers in maximizing throughput while operating the aircraft in a fuel-efficient profile. The en route controller issues a single strategic clearance to the flight crew to achieve a specific interval behind the Target aircraft (called the assigned spacing goal, or ASG, which is expressed in either time or distance). Depending on the FIM clearance type, the controller’s voice instruction may also include the waypoint at which that spacing interval is to be achieved (called the Achieve By Point, or ABP). The waypoint at which the FIM operation terminated (called the Planned Termination Point, or PTP) in ATD-1 was always assumed to be the FAF of the FIM aircraft. Once the crew enters the required information into the spacing software (FIM aircraft routing, FIM clearance, and forecast descent wind), it calculates and then visually presents to the crew the airspeed which will enable the aircraft to precisely achieve the assigned spacing by the ABP.

The three FIM operations in the ATD-1 ConOps are:

1. **CROSS** (Achieve and then Maintain)
 - Target and FIM aircraft may be on the same or different routes (therefore the FIM clearance must include the Target route of flight)
 - The ASG is assigned by the controller based on the interval shown in the schedule
 - The ABP to meet the ASG can be as early as the merge (first waypoint common to both the Target and FIM route) or as late as the FIM aircraft’s FAF
 - Only issued by the en route controller
2. **CAPTURE** (Capture and then Maintain)
 - Target and FIM aircraft must be on the same route (therefore the FIM clearance does not need to include the Target route of flight)
 - The ASG is assigned by the controller based on the interval shown in the schedule
 - There is no ABP; a minimum rate of closure is used to achieve the ASG
 - Only issued by the en route controller
3. **MAINTAIN** (Maintain)
 - Target and FIM aircraft must be on the same route
 - The ASG is calculated by the FIM avionics (therefore is not given by the controller); this value is the Measured Spacing Interval (MSI)
 - There is no ABP; the current spacing interval is maintained
 - Issued by the en route or a terminal controller

Table 1 defines the data required for each FIM clearance type, with the cells shaded light grey indicating they are not part of the controller’s voice instruction to the flight crew.

Table 1. Data elements by FIM operation type.

| FIM Type | Traffic ID | ASG | ABP | PTP | Traffic Route | Forecast Wind |
|----------|------------|------------------|-----|------------------|---------------|------------------|
| CROSS | Y | Y | Y | N ⁽²⁾ | Y | Y |
| CAPTURE | Y | Y | N | N ⁽²⁾ | N | N ⁽³⁾ |
| MAINTAIN | Y | N ⁽¹⁾ | N | N ⁽²⁾ | N | N ⁽³⁾ |

Note 1: the unit (“time” or “distance”) is still contained in the FIM clearance instruction

Note 2: FAF is assumed by the software; may be modified by crew if so directed by controller

Note 3: forecast wind not required, but may improve operational performance if entered

During the ATD-1 Project, all FIM information was displayed on the en route controller's scope as soon as the FIM-equipped aircraft crossed the Freeze Horizon (as depicted in Figure 7). More advanced versions of this ConOps would only present the one most appropriate FIM clearance type to the controller on their display, and only after that particular operation is feasible (aircraft within ADS-B range, route geometry, etc.).

Prior to issuing the FIM clearance, the en route controller issues the arrival procedure and expected runway to the flight crew. In addition to entering the arrival procedure, approach procedure, and the forecast descent wind into the aircraft's FMS, the flight crew also enters that same information into the FIM equipment. Once the remaining required delay can be absorbed by speed-only control techniques, the controller issues the "descend via" clearance to have the crew commence the arrival procedure, followed shortly thereafter by the FIM clearance. If the aircraft's required delay to be absorbed in ARTCC airspace (the difference between the ETA and STA at the Meter Fix) is too great for speed-only control, controllers must first pre-condition the aircraft (vectors to path stretch or altitude step-down instructions to reduce ground speed) until speed-only control can be used, and then issue the FIM clearance. Examples of the phraseology used to issue the FIM clearance are in Appendix G.

The FIM airspeed calculated by the onboard spacing tool is the airspeed required to achieve the ASG by the Achieve-By Point (CROSS), to achieve the ASG at a set rate of closure (CAPTURE), or to maintain the interval (MAINTAIN). This speed is limited to 15% faster or slower than the published speed for that segment of the arrival or approach procedure; however, the FIM speed will always comply with any speed restrictions (250 KIAS or less when at or below 10,000 feet Mean Sea Level, etc.). Once the flight crew determines the initial FIM speed is feasible, they notify ATC that the FIM operation is commencing and what the FIM speed is, then set the FIM speed in the Mode Control Panel speed window. During the initial check-in with each subsequent controller, the flight crew include the FIM status (PAIRED, ARMED, etc.).

After commencing the FIM operation, the flight crew operates the aircraft in accordance with normal flight deck procedures, with the exception that the FIM speed supersedes any published speed constraint (similar to a controller issued speed instruction). If the flight crew is not able to follow the FIM speed command or experiences a system error, they notify the controller they are unable to continue the FIM operation, and the arrival operation reverts to traditional air traffic control methods. The FIM operation is complete when the FIM aircraft crosses the Planned Termination Point (PTP), at which point all FIM displays are automatically cleared.

Controllers retain responsibility for aircraft separation, and flight crews have responsibility for spacing; that is, to fly the FIM speed. The controller can intervene at any time with a speed instruction or vector, which takes precedence over a FIM generated speed and suspends the FIM operation (flight crews comply with altitude step-down instructions, but it does not suspend the FIM operation). If the controller anticipates the speed instruction or vector will resolve the issue and the aircraft will return to the arrival procedure in a timely manner, the controller will suspend the FIM operation as part of the speed instruction or vector, and may resume the FIM operation after returning the aircraft to the arrival procedure. If the controller does not anticipate a timely return to the arrival procedure, or if the assigned runway for either the Target or FIM aircraft has changed, the controller will terminate the FIM operation. If desired, a new FIM clearance can be

issued with the updated information (new Target aircraft, change to the Target route, or change to the assigned runway).

Figure 10 is an example of a cockpit display used by the flight crew to enter the information needed to conduct FIM operations. More information about the display and the flight crew data entry procedure is available in reference 28.



Figure 10. Auxiliary display with FIM clearance and traffic.

Since the size of an auxiliary display in a retro-fit avionics implementation is too large to be placed in the pilot's forward field-of-view, a subset of just the critical FIM information needed to conduct the operation is repeated on a much smaller device called a configurable graphics display. Figure 11 is an example of this display, and is located in the flight crews' forward field of view to minimize crew workload and improve the saliency of the display.

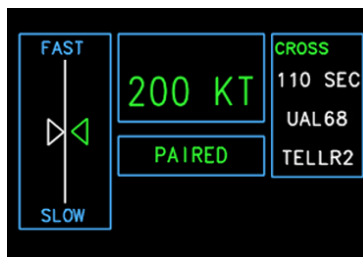


Figure 11. Configurable Graphics Display with FIM speed.

4.6 Benefits to be Realized

4.6.1 Overall Benefits

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

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

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

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

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

4.6.2 Benefits to ANSP

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

4.6.3 Benefits to Flight Crew

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

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

4.6.4 Benefits to Airline

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

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

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

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

4.6.5 Benefits to Airport

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

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

5.0 Operational Scenarios

The procedures for a “nominal” (expected or typical) ATD-1 operation are described in section 5.1 by phase of operation. Section 5.2 describes events that may occur during an ATD-1 operation, while section 5.3 describes contingency events during ATD-1 operations.

Most of the controller-pilot phraseology needed to conduct the ATD-1 operations, including FIM, remains unchanged from what is used today (sector frequency check-in, initiation of descent, clearance for an approach, etc.), and is documented in Appendix G. This phraseology also aligns to the maximum extent possible with the international standard for FIM [ref 30], the proposed FIM Data Link messages [ref 31], and the FAA’s Air Traffic Control documentation [ref 32]. Modifications to these references have been made based on feedback from ATD-1 research experiments conducted at NASA Ames and Langley Research Centers.

5.1 ATD-1 Scenario by Phase

This section breaks down the ATD-1 ConOps as initially described in Section 4.2 into an arrival operation with five phases. The phases are:

- 1) Schedule
- 2) Precondition
- 3) Initiation
- 4) Operation
- 5) Termination

A flowchart of controller-pilot procedures to be used during ATD-1 operations is shown in Figure 12. A numbering system is provided in the upper left of each box to assist in grouping and establishing relationships between various events. The schema is the first digit indicates the phase of the operation (1-Schedule; 2-Precondition; 3-Initiation; 4-Operation; 5-Termination), the second digit indicates the user (0-schedule, 1-controller, 2-flight crew not equipped with FIM, 3-flight crew equipped with FIM), and the third digit is a sequential index for that user during that phase.

Figure 13 through Figure 18 present the ATD-1 ConOps by phase, with each phase linked to the respective procedure shown in the procedure flowchart (Figure 12).

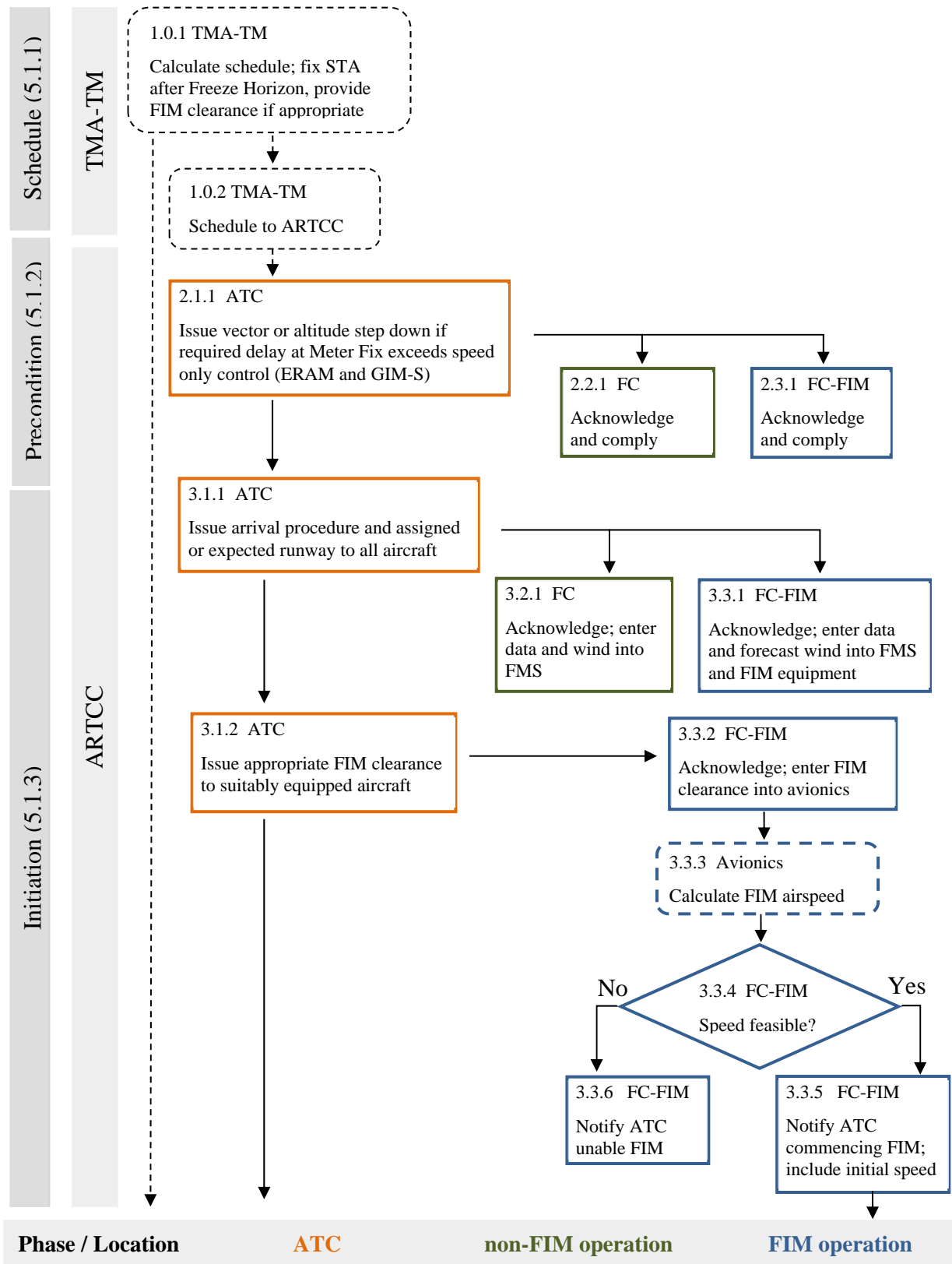


Figure 12. Flowchart of controller-pilot actions during ATD-1 operation.

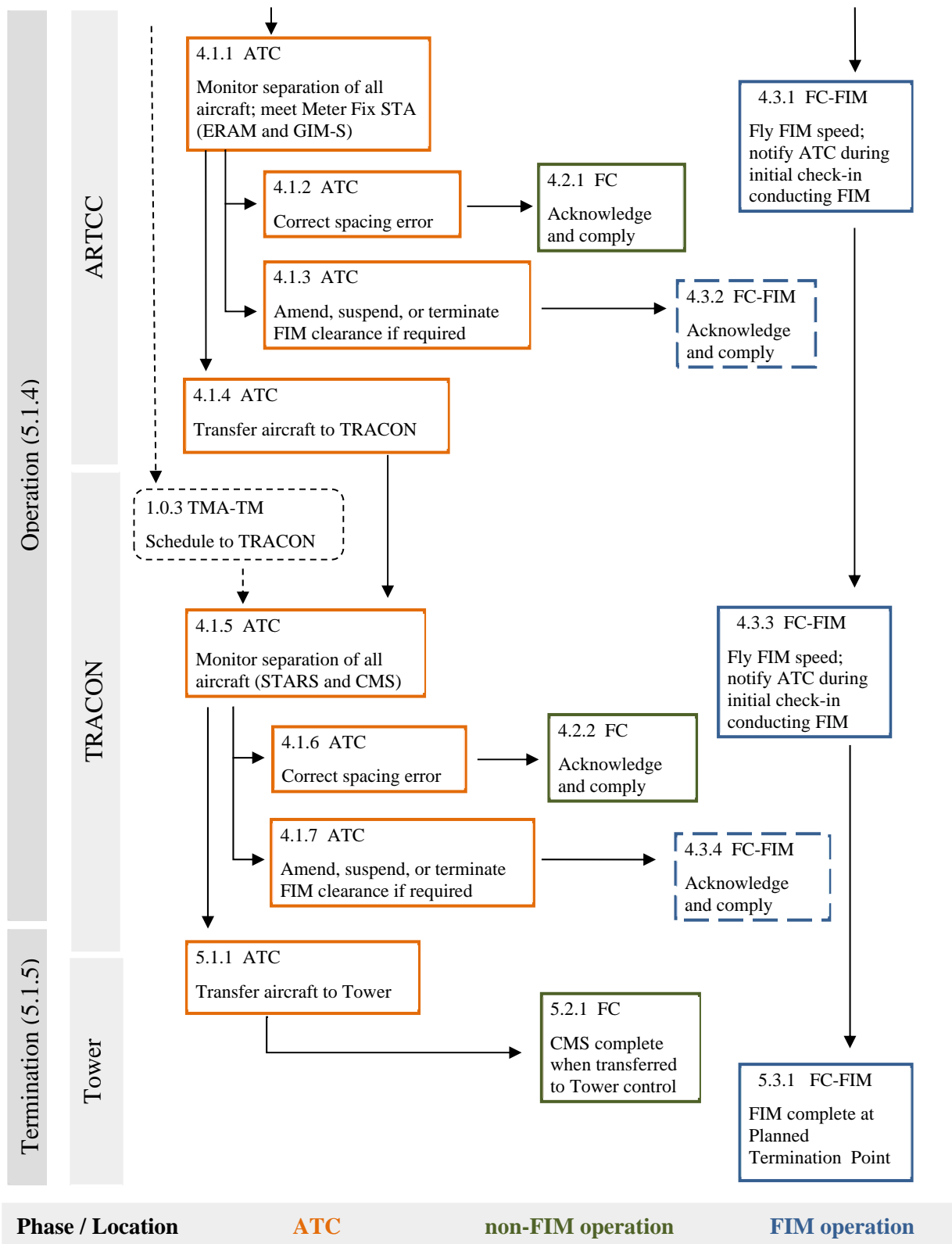


Figure 12. Flowchart of controller-pilot actions during ATD-1 operation.

5.1.1 Schedule Phase

The blue area shown in Figure 13 highlights the airspace and subset of aircraft in the schedule phase of ATD-1 operations (that is, prior to the Freeze Horizon), and an overview of activities that occur during this phase are listed on the right. The numbers in the left column of the list below correspond to the operational procedures in Figure 12.

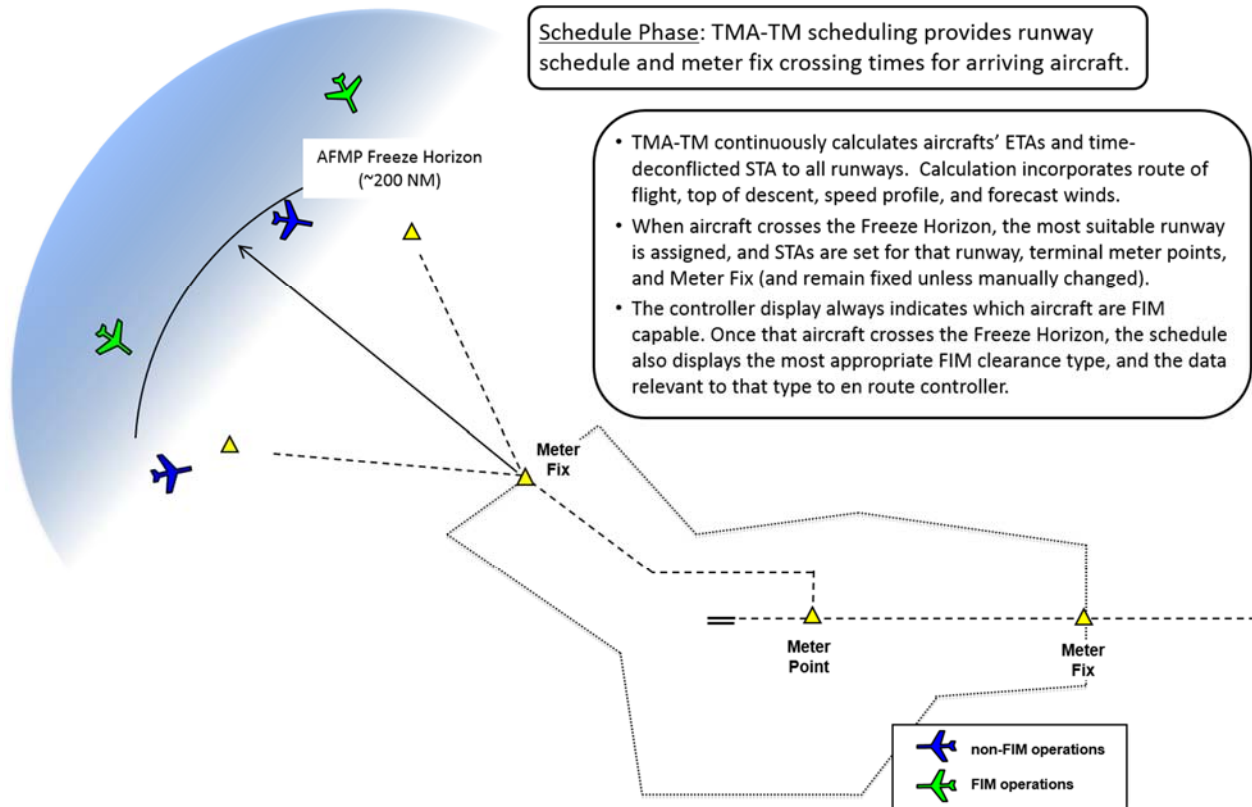


Figure 13. ATD-1 Schedule Phase.

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

5.1.2 Precondition Phase

Figure 14 illustrates the aircraft and activities that occur during the precondition phase of ATD-1 operations, that is, what occurs when speed control alone is not sufficient to absorb the required delay assigned by TMA-TM. Based on demand and the effectiveness of up-stream flow control, aircraft may or may not require this phase. When aircraft cross the Freeze Horizon and do not require vectors or step-down in altitude to meet the Meter Fix or “Arrival Flow Management Point” (AFMP) time assigned by TMA-TM, the initiation phase commences immediately after the schedule phase.

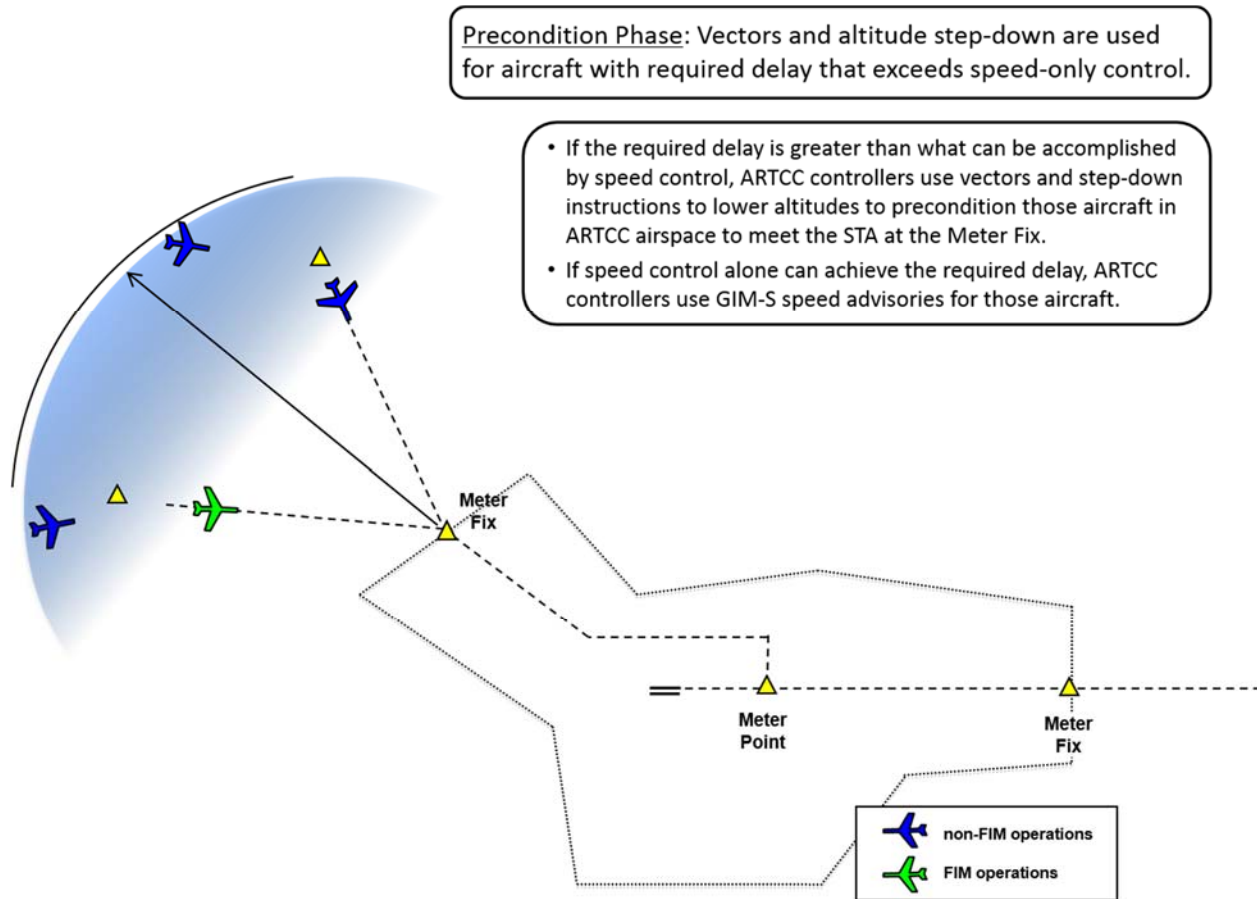


Figure 14. ATD-1 Precondition Phase.

- 2.1.1 If required, en route controller issues vectors, altitude step-downs, or speed instructions to achieve desired time delay (to any aircraft not conducting FIM operations).
- 2.2.1 The non-FIM flight crew acknowledge and comply with ATC instructions.
- 2.3.1 The FIM flight crew acknowledge and comply to ATC instructions

5.1.3 Initiation Phase

Figure 15 illustrates the activities that occur during the initiation phase of ATD-1 operations, that is, when controllers issue the arrival procedure and the FIM clearance (to equipped aircraft).

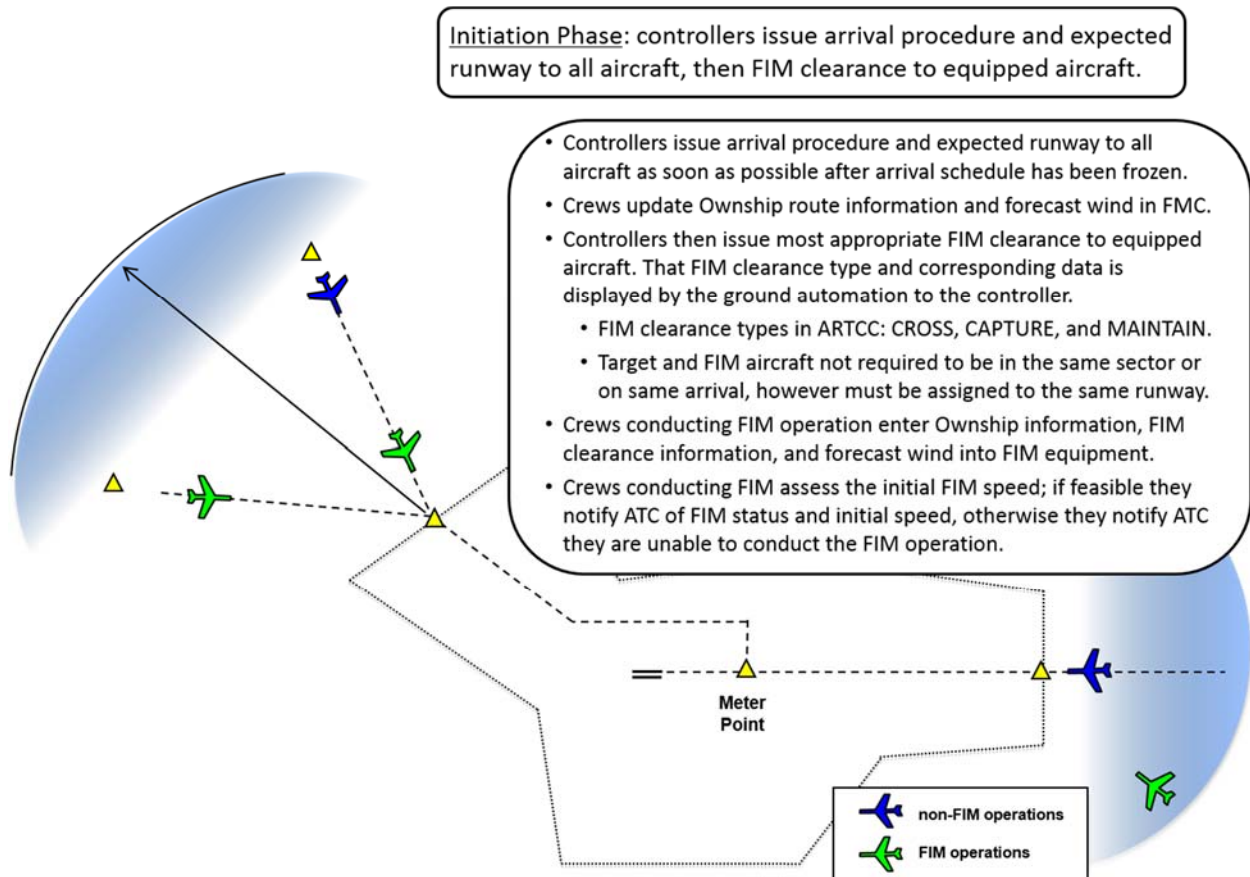


Figure 15. ATD-1 Initiation Phase.

| | |
|-------|---|
| 3.1.1 | The en route controller issues the arrival route and expected runway to all aircraft, the FIM clearance to those aircraft so equipped, and clears all aircraft for the arrival procedure. |
| 3.2.1 | The non-FIM crew enters the arrival procedure, expected runway, and forecast winds into the aircraft's FMS. |
| 3.3.1 | The FIM crew enters the arrival procedure, expected runway, and forecast winds into the aircraft's FMS and FIM equipment. |
| 3.1.2 | The en route controller issues a FIM clearance to the flight crew of FIM-equipped aircraft. |
| 3.3.2 | The FIM crew acknowledges ATC, and enters the FIM clearance into the aircraft avionics. |
| 3.3.3 | The FIM aircraft software calculates the airspeed to achieve or maintain the ASG. |
| 3.3.4 | The FIM flight crew determines if the speed is operationally feasible. |
| 3.3.5 | If the FIM speed is feasible, the flight crew notifies ATC they are commencing FIM operation, and include the FIM speed. |
| 3.3.6 | If the FIM speed is not feasible, the FIM flight crew notifies ATC that they are unable to conduct the FIM operation. |

5.1.4 Operation Phase

Figure 16 illustrates the aircraft and activities that occur during the operation phase of ATD-1 operations while in ARTCC airspace.

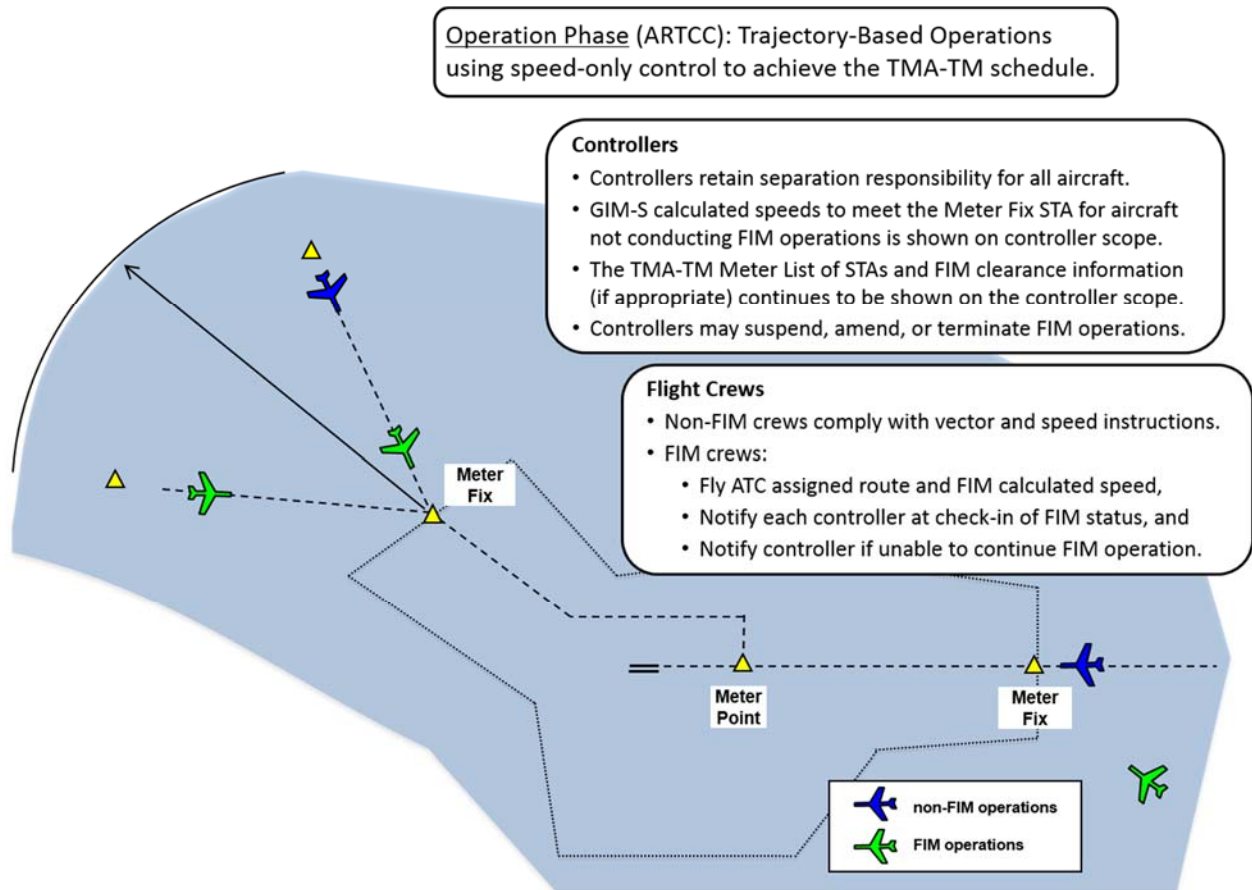


Figure 16. ATD-1 Operation Phase in ARTCC.

- 4.1.1 En route controllers retain safe separation responsibility for all aircraft within their sector.
- 4.1.2 En route controllers use GIM-S information to assign speeds to all aircraft not conducting FIM operations (non-FIM equipped, or FIM equipped aircraft prior to issuing FIM clearance).
- 4.2.1 Flight crews not conducting FIM acknowledge and comply with ATC instructions.
- 4.3.1 Flight crews conducting FIM will notify ATC when commencing the operation, and fly the FIM calculated speed during the arrival and approach.
- 4.1.3 If needed, en route controllers may amend, suspend, or terminate FIM operations. Controller instructions always take precedence over the FIM speed calculated onboard the aircraft.
- 4.3.2 Flight crews will acknowledge ATC when the FIM clearance has been amended, suspended, or terminated.
- 4.1.4 En route controller hands off the aircraft to the TRACON Feeder controller.

Figure 17 illustrates the aircraft and activities that occur during the operation phase of ATD-1 operations while in TRACON airspace.

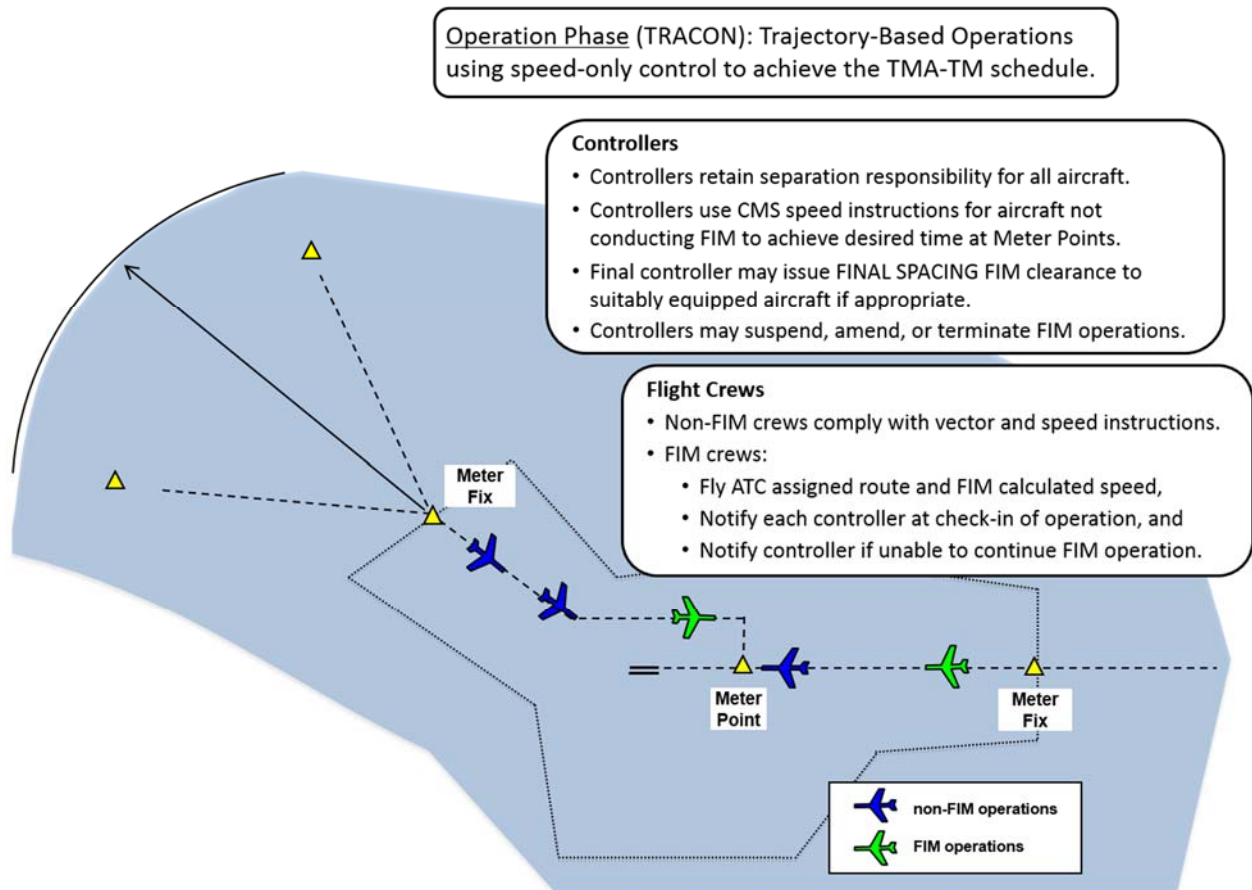


Figure 17. ATD-1 Operation Phase in TRACON.

- 4.1.5 Terminal controllers retain safe separation responsibility for all aircraft within their sector.
- 4.1.6 Terminal controllers use CMS information to assign speeds to crews of non-FIM aircraft. CMS speeds may also be used for FIM aircraft if necessary.
- 4.2.2 Flight crews not conducting FIM acknowledge and comply with ATC instructions.
- 4.3.3 Crews conducting FIM operations will state so during initial check-in with each controller.
- 4.1.7 If needed, terminal controllers may amend, suspend, or terminate FIM operations. Controller instructions always take precedence over the FIM speed calculated onboard the aircraft.
- 4.3.4 Flight crews conducting FIM operation acknowledge and comply with ATC instructions.

5.1.5 Termination Phase

Figure 18 shows the aircraft and activities that occur during the termination phase of ATD-1 operations. CMS operations cease when the flight crew changes to the Tower frequency, and FIM operations terminate at the Achieve-By Point or when the controller issues a vector to intercept the final approach. Operations may also be suspended or terminated if vectors or altitude step-downs are needed to absorb the required time delay. Crews may terminate FIM operations (no Target data, FIM equipment failure, etc.) by notifying the controller, who then issues a new FIM clearance or reverts to normal control procedures.

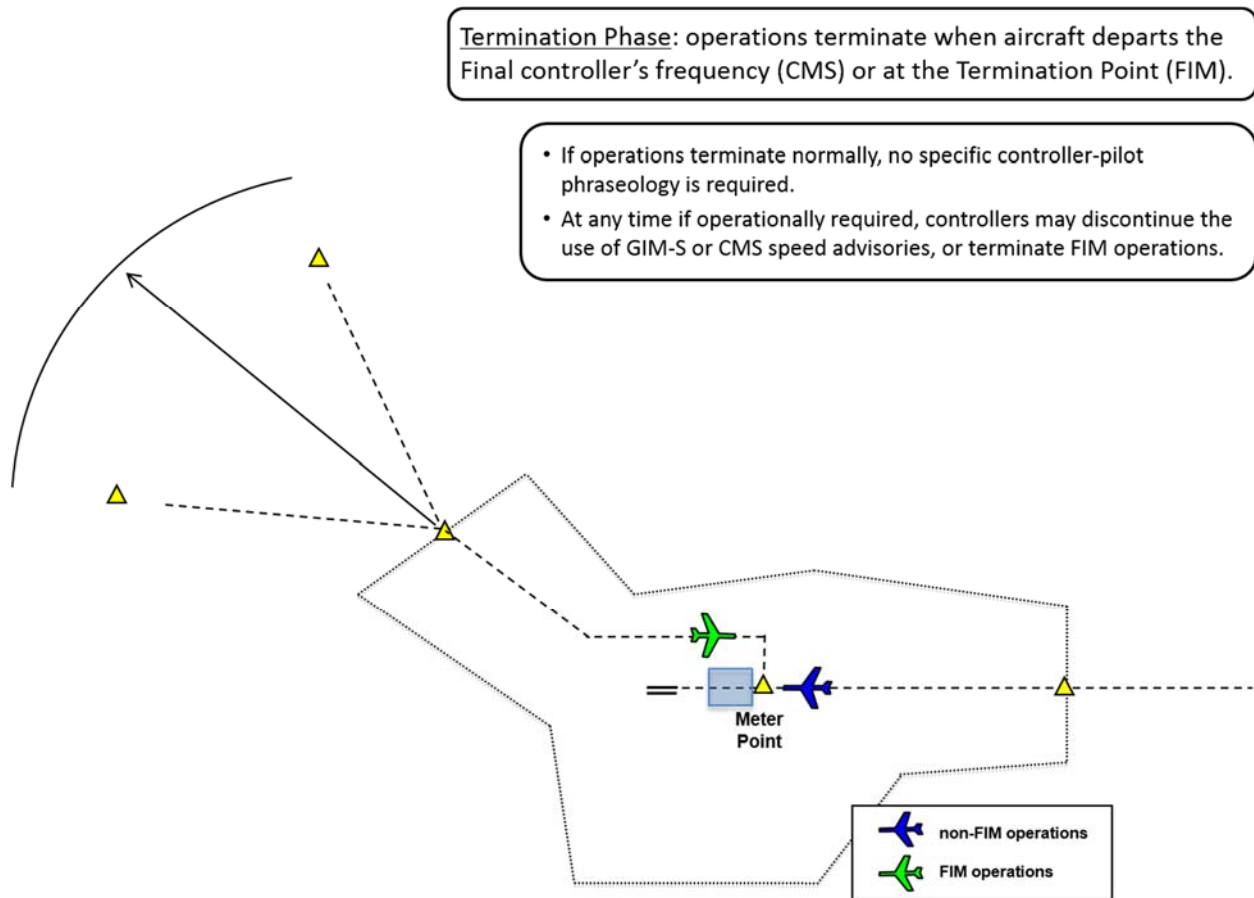


Figure 18. ATD-1 Termination Phase.

- 5.1.1 Final controller hands off the aircraft to the Tower controller.
- 5.2.1 CMS operations are complete when the flight crew switches from the Final controller to Tower frequency.
- 5.3.1 FIM operations are complete when the aircraft crosses the Achieve-By Point.

5.2 Events Expected During ATD-1 Operations

This section addresses procedures to be used in response to uncommon but expected events while conducting ATD-1 operations. These events may require a TMA-TM sequence swap, a TMA-TM reschedule, discontinue use of GIM-S or CMS speed advisories, or modifying the FIM clearance or operation.

5.2.1 Arrival Sequence Change by ATC

The en route controller may need to change arrival sequence. When the schedule is updated, the CMS and FIM displays are automatically updated to reflect the new TMA-TM schedule. If the sequence swap affects either the Target or FIM aircraft of a FIM operation, the existing FIM clearance must be terminated by the controller, and a new one issued if desired. (The long-term vision for the ATD-1 ConOps has the ground automation providing the controller a message that the FIM clearance must be cancelled, and offer a new clearance.

5.2.2 CMS or FIM Information Displayed is Outdated

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

5.2.3 FIM Clearance Amended by ATC

A controller may amend the FIM clearance by changing the ASG, update the Target’s route, or update the FIM aircraft route. Compared to terminating the current FIM clearance and entering a new one, amending a FIM clearance requires less workload for the flight crew.

5.2.4 FIM Operation Suspended or Resumed by ATC

A controller may suspend a FIM operation for a variety of operational reasons (absorb additional delay, unexpected crossing traffic, etc.) that are temporary in nature. When ATC suspends (and therefore expects to resume at a later time) a FIM operation, the flight crew uses a single button push on the auxiliary display to remove the FIM speed from cockpit displays, but retain the FIM clearance information in the application. FIM operations are also suspended when a controller issues a vector or speed instruction to the FIM aircraft, even if not explicitly stated so by the controller. Altitude change instructions to the FIM aircraft do not suspend FIM operations.

Vectors or speed instructions to the Target aircraft also cause the FIM operation to be suspended, however the controller for the FIM aircraft may not be aware of those instructions to the Target aircraft. Therefore the logic in the FIM software will cause the FIM application to automatically switch to a suspend mode whenever it determines the Target aircraft is greater than 2.5 nmi off the arrival or approach procedure. Altitude changes by the Target aircraft do not cause the FIM software to switch to a suspend mode.

The resume procedure allows the crew to return the FIM speed for the previously issued FIM clearance to the cockpit displays with a single button push.

5.2.5 FIM Operation Terminated by ATC

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

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

5.2.6 FIM Operation Terminated by Flight Crew

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

5.2.7 FIM clearance Issued by ATC is Infeasible

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

5.3 Contingency Events During ATD-1 Operations

This section addresses procedures to be used in response to uncommon, contingency events that exceed the design assumptions of using speed- only control techniques to achieve a feasible schedule. When these contingencies occur during ATD-1 operations, controllers and flight crews will revert to current day procedures. Examples of events that trigger these procedures include incorrect or undesirable controller displays, incorrect or infeasible displays for flight crew, failure of hardware or software, or changes to the goal of the air traffic plan.

5.3.1 User terminates use of ATD-1 technology

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

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

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

5.3.2 Significant weather

Weather events will have a range of impacts on ATD-1 operations based on the type and location of the event. Generally, conditions such as fog, rain, low ceiling or visibility, and convective weather that prevent aircraft from flying through it, will reduce the airport's arrival throughput. However, low ceiling or low visibility weather typically causes a stable condition that can be managed with TMA-TM over long periods of time. Convective weather on the other hand, is more dynamic and makes strategic tools like TMA-TM more difficult to manage especially in cases where the growth, decay, and movement of weather is not easy to predict. The location of

the weather is another major factor in determining the magnitude of the impact to ATD-1 operations. Weather requiring a re-routing of traffic in the en route environment may have little impact on ATD-1 operations or airport throughput, while weather overhead the airport may require suspending all arrival and departure operations. This will require a varied response that allows some aircraft to deviate and rejoin their routes, possibly changing the arrival sequence or rippling the list, and some areas will be impacted to such a degree that ATD-1 operations and tools would not be usable.

5.3.3 Airport configuration change or runway closure

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

5.3.4 Aircraft emergency or priority handling

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

6.0 Summary of Impacts

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

Table 2. Summary of Impacts

| User | Current Operational Use | Enhanced Use with ATD-1 ConOps |
|--|--|---|
| Traffic Management Coordinators (TMC) | Use the TFM automation and TMA to establish the sequence and schedule for aircraft arriving at the high-density airport. TFM command and control is allocated to the ARTCC TMC feeding the TRACON. | Use the TFM automation and TMA-TM to establish a higher fidelity sequence and more precise schedule for aircraft arriving at the high-density airport. TFM command and control responsibilities are allocated between the ARTCC and TRACON TMCs. |
| En route Controller (ARTCC) | Comply with facility procedures for delivering aircraft to meet the TMA schedule (DCT expressed in minutes). This includes issuing route clearances and “Descend Via” instructions using standard operating procedures. | Comply with facility procedures for delivering aircraft to meet the TMA-TM schedule (DCT expressed in 10 second interval). This includes issuing route clearances and the expected runway assignments using TMA-TM information. Issue FIM clearances to those aircraft suitably equipped, issue speed instructions (based on GIM-S) to aircraft not conducting FIM operations. Monitor safe separation of all aircraft. |
| Terminal Controller (TRACON) | Comply with facility procedures for delivering aircraft to meet the posted airport acceptance rate. Maintain aircraft separation and deliver them to the runway. There is no access to the TMA runway assignments or schedule. | Comply with facility procedures for delivering aircraft to meet TMA-TM scheduled metering plans to the assigned runway. Use CMS automation to improve the delivery accuracy to the runway of aircraft not conducting FIM. Update or terminate FIM operations if required. Monitor safe separation of all aircraft. |
| Flight crew of non-FIM equipped aircraft | Comply with all established procedures and controller instructions. | Comply with all established procedures and controller instructions. Expect greater use of PBN procedures, and great use of speed control instead of vectors. |
| Flight crew of FIM equipped aircraft | Comply with all established procedures and controller instructions. | Comply with all established procedures and controller instructions. Crews conducting FIM operations will also enter FIM clearance and forecast winds into the spacing avionics, monitor the FIM status, notify ATC when that status changes, and fly the speed calculated by the FIM software. |

7.0 References

The References section credits published and unpublished works used throughout the document, and includes higher level and adjacent concepts on which this document depends.

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Appendices

Appendix A: Terms and Definitions

Table 3. Terms and Definitions

| Acronym | Term | Definition |
|---------|--|---|
| -- | Four-dimensional trajectory | The centerline of a path formed by segments that link consecutive trajectory change points; each point defined by a longitude, latitude, altitude, however not every point will have a time. NOTE: some waypoints may have time, altitude, and/or speed constraints, and can be equality or inequality constraints. |
| -- | Closed trajectory | The ANSP automation, the controller, and the aircraft automation have the same view of what the aircraft is doing. There is agreement between automation on the ground and in the air, and actions are synchronized. (FAA APNT) |
| -- | Open trajectory | The aircraft is no longer flying to an agreement with the automation. The aircraft and the ground are not in synchrony and the aircraft is flying off the agreed-upon trajectory for operational reasons like weather avoidance, a vector for sequencing or spacing, and/or a speed adjustment that will impact timing. (FAA APNT) |
| ABP | 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). |
| ANSP | Air Navigation Service Provider | Government or private organizations that manage flight traffic on behalf of a company, region, or country. |
| AOC | Airline Operations Center | Responsible for decision-making and operational control of an airline's daily schedules and facilitating disruption recovery. |
| ARTCC | Air Route Traffic Control Center | A facility providing air traffic control service to aircraft operating on IFR flight plans within controlled airspace, principally during the en route phase of flight. |
| ASG | Assigned Spacing Goal | The interval (given in time or distance) that the controller has instructed the FIM aircraft to achieve or maintain relative to the Target aircraft. |

| Acronym | Term | Definition |
|----------------|--|---|
| ASTAR | Airborne Spacing for Terminal Arrival Routes | Advanced flight deck-based automation that constantly calculates the airspeed required to position an aircraft at the Achieve By Point at the Assigned Spacing Goal behind the Target aircraft. |
| ATD-1 | Air Traffic Management Technology Demonstration #1 | The first of a planned series of NASA NextGen Airspace Systems Program technology demonstrations; integrates three research efforts to achieve high throughput fuel-efficient arrival operations using precision time-based schedules, aircraft speed control, and controller display technologies. |
| CGD | Configurable Graphics Display | Cockpit display device used to show FIM information in the pilot's forward field of view |
| CMS | Controller-Managed Spacing | Terminal 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. |
| DSR | Display System Replacement | Displays and equipment used by en route controllers. Flat screen displays replaced older equipment suite in 2000. |
| EDA | Efficient Descent Advisor | Decision-support tool for air-traffic controllers managing arrival airspace in en route facilities. |
| ERAM | En Route Automation Modernization | FAA program that provides platform for NextGen improvements, including System Wide Information Management, Data Comm, and Automatic Dependent Surveillance-Broadcast. |
| ERFMP | En Route Flow Management Point | Flow management point prior to Top-Of-Descent. Time assigned by TBFM. |
| ETA | Estimated Time-of-Arrival | The current estimate of the aircraft's time-of-arrival at a point along its flight path based on forecasted winds, aircraft performance and defined arrival procedures, but not adjusted to compensate for traffic separation or metering delays. The ETA is re-calculated on events and radar updates. |
| FAF | Final Approach Fix | The fix from which the final approach to an airport is executed and which identifies the beginning of the final approach segment. |
| FAS | Final Approach Speed | The speed flown by the aircraft from the Final Approach Fix to touchdown on the runway. There are flight crew and airline variances for when this speed is achieved. |
| FDB | Full Data Block | Lines of information next to aircraft icon containing pertinent data for the air traffic controller. |
| FIM | Flight Deck Interval Management | Flight crew makes use of specialized avionics that provides speed commands for interval management. |
| -- | FIM 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. |

| Acronym | Term | Definition |
|----------------|--|---|
| -- | Freeze Horizon | After an aircraft crosses the Freeze Horizon for an Arrival Flow Management Point (AFMP), the Scheduled Time-of-Arrival for that aircraft to that waypoint is “frozen” (no longer updated). |
| GIM-S | Ground-based Interval Management - Spacing | Ground-based functions intended to support aircraft crossing the TRACON boundary along the route of flight at specific metered times or STAs, as well as stand-alone CSPs. Part of ERAM v4.1. Providing effective sequencing & scheduling services for advanced equipage operations such as FIM-S. |
| -- | 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). |
| ID | Identification code | The alphanumeric code used to identify an aircraft. The aircraft ID is shown on controller and cockpit displays, and used to define the Target aircraft within a FIM clearance when using voice communication. The aircraft code is not always the same as the aircraft call sign. |
| MF | Meter Fix | A Constraint Satisfaction Point (CSP) used for managing arriving aircraft; one of several points referred to as Arrival Flow Meter Points (AFMP). This ATD-1 document uses Meter Fix as the transition from en route to terminal airspace. |
| MP | Meter Point | A Constraint Satisfaction Point (CSP) used for managing en route aircraft; one of several points referred to as En Route Flow Management Points (ERFMP). Examples include Airspace Meter Point (AMP), Extended Metering Point (XMP), and Coupled Metering Point (CMP). Meter Points in Terminal airspace (Terminal Meter Points) are a new functionality for ATD-1. |
| 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. |
| MSI | Measured Spacing Interval | The time difference between when the Target and FIM aircraft at the same waypoint. Used in the MAINTAIN phase of FIM. |
| -- | 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 | OPDs are designed to reduce fuel consumption, emissions, and noise during descent by allowing aircraft to fly an optimized descent with engines near idle. OPD procedures specify a lateral path and vertical boundaries, and some segments include a speed. Vertical boundaries are established to accommodate a wide range of descent profiles, and speeds are defined to enable the use of speed control only by controllers and flight crews. |
| PBN | Performance-Based Navigation | Area navigation based on performance requirements for aircraft on a route, approach procedure, or designated airspace. Navigation performance requirements are expressed in terms of accuracy, integrity, continuity, availability, and functionality needed for the proposed operation. |

| Acronym | Term | Definition |
|----------------|---|---|
| PTP | Planned Termination Point | The limit of the FIM clearance. FIM operations are terminated at this point without explicit communication from controller to crew. |
| 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 an ATD-1 requirement.) |
| -- | Separation | The spacing of aircraft to achieve their safe and orderly movement in flight and while landing and taking off (FAA Pilot/Controller Glossary). For the ATD-1 ConOps: 1) Separation minima unchanged by any ATD-1 operation. 2) Controller remains responsible for providing separation. 3) FIM flight crew responsible for achieving assigned spacing. |
| STA | Scheduled Time-of-Arrival | Calculated by the ground scheduling software to meet all of the scheduling and sequence constraints; set at 'Freeze Horizon'. Changing a frozen STA is a 'reschedule', and is triggered manually by the TMC in response to a significant event. |
| 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. |
| STARS | Standard Terminal Area Replacement System | Displays and equipment used by controllers in terminal radar approach control facilities and towers. |
| -- | Target Aircraft | The lead aircraft specified by ATC for the FIM aircraft. Must be equipped with ADS-B Out (transmit), but is not required to be ADS-B In (receive) equipped or capable of FIM operations. |
| TBFM | Time-Based Flow Management | An operational concept using time to efficiently utilize available airport capacity without decreasing safety or increasing workload. |
| TBO | Trajectory Based Operations | The use of four-dimensional aircraft trajectories to manage the safety and capacity of flight operations. |
| TCP | Trajectory Change Point | A full 4-D trajectory is defined by a series of trajectory change points (TCPs). Every point along the track where an altitude, heading, or speed transition occurs. |
| TMA | Traffic Management Advisor | A traffic flow management tool that calculates Estimated Times-of-Arrival (ETA) and corresponding Scheduled Times-of-Arrival (STA) at various points along the aircraft flight path to an airport to optimize the flow of aircraft into capacity-constrained areas. TMA also provides the STA and delay times to the respective En Route controller to maintain the optimum flow rates to runways from the ARTCC to the TRACON. |
| TMA-TM | Traffic Management Advisor with Terminal Metering | An enhancement to TMA that calculates precise time-based, conflict-free schedules to the runway and all meter points. This information is available to TRACON controllers. |

| Acronym | Term | Definition |
|----------------|--|--|
| TMC | Traffic Management Coordinators | Creates the plan to deliver aircraft to the runway at a rate that will meet the capacity of the airport, based on runway configuration, wind, and aircraft type. |
| 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. |
| TOD | Top-Of-Descent | The computed transition from the cruise phase of flight to the descent phase, the point at which the descent to final approach altitude is initiated. |
| TRACON | Terminal Radar Approach Control Facility | Radar control facility associated with an airport. |
| TSAS | Terminal Sequencing and Spacing | The FAA name for the NASA TMA-TM and CMS technology. Originally called TSS, but then changed due to conflict. |
| TSS | Terminal Sequencing and Spacing | The FAA original name for NASA's TMA-TM and CMS technology. Changed to TSAS due to conflict. |

Appendix B: Changes to ATD-1 ConOps

The initial ATD-1 ConOps document [ref 1] benefited greatly from an in-depth review by the FAA and industry partners that generated over 350 individual comments and numerous pages of feedback. Version 2 of the ATD-1 ConOps [ref 2] incorporated early ATD-1 experiments conducted at NASA Ames and Langley Research Centers.

Version 3 of the ATD-1 ConOps (this document) has been updated to reflect the lessons learned of all the ATD-1 experiments conducted at NASA Ames, NASA Langley Research Centers, and the FAA Technical Center. A summary of that research is described in Appendix C, with highlights of the changes to the ConOps listed below:

- Added Abbreviations section
- Chapter 1: Introduction
 - Added section title 1.1 (Overview) for consistency; other sections renumbered
 - Updated information about ground and flight test of ATD-1 technologies
 - Updated FAA aerospace forecast
 - Added description of technology name change from NASA to FAA
 - Expanded ConOps Overview section
- Chapter 2: Operations and Capabilities
 - Updated current capabilities in the NAS
- Chapter 3: Description and Justification of Changes
 - No updates
- Chapter 4: ATD-1 Concept of Operations
 - Concept description updated, figure expanded and realigned with operation phases described in Chapter 5
 - Corrected direction of traffic description in CMS slot marker section
 - Expanded FIM section to include three clearance types
 - Updated figure of pilot's forward field-of-view device with Configurable Graphics Display (CGD)
- Chapter 5: Operational Scenarios
 - Modified vertical columns on left side of flow chart (Figure 12) to reflect respective section number for that phase of the operation
 - Updated the numbering within the flow chart so that the first digit within each shape matches the last number of the respective section
 - Corrected flow chart termination phase figures
 - Changed ConOps to reflect the controller issues the "descend via" instruction prior to issuing the FIM clearance
 - Expanded the Operation Phase sub-section; now by ARTCC and TRACON
 - Moved paragraph in section 5.2 pertaining to contingency operations to 5.3
 - Added respective sub-section numbers to table in contingency operations
- Chapter 6: Summary of Impacts
 - Clarified actions by non-FIM and FIM flight crew
- References and Appendix C
 - Added documents and lessons learned of all ATD-1 experiments and work
- Previous Appendix C – F become D – F and H (G remains Phraseology)
- Previous Appendix H removed

Appendix C: ATD-1 Research and Results

This part of the Appendix describes the principal experiments conducted by NASA and the FAA to validate and refine the ATD-1 ConOps (Version 2) as well as the systems that are used to implement it. Specifically, experiments were designed to evaluate:

- The functional requirements of new automation capability
- Interface requirements between new automation capabilities and existing systems
- Controller procedures and the resulting controller workload
- Pilot procedures and the resulting pilot workload
- Performance gains to be expected from implementing some or all elements of the ATD-1 ConOps (capacity, flexibility & efficiency)

The list of ATD-1 research and results is:

- C.1 IM for Near-term Operations Validation of Acceptability (IM-NOVA)
- C.2 Fully Integrated ATD-1 Test #3 (FIAT-3)
- C.3 Terminal Sequencing and Spacing (TSAS) #1
- C.4 Interface Study for Interval Management (ISIM)
- C.5 Terminal Sequencing and Spacing (TSAS) #2
- C.6 Controller Managed Spacing for ATD-1 #5 (CA-5.1 & CA-5.2)
- C.7 CMS-ATD1 Flight Deck Study II: CA-4 Operations in PHX Airspace
- C.8 Research and Procedural Testing of Routes (RAPTOR)
- C.9 Fully Integrated ATD-1 Test #4 (FIAT-4)
- C.10 Controller Managed Spacing for ATD-1 #5 (CA-5.3)
- C.11 Fully Integrated ATD-1 Test #5 (FIAT-5)
- C.12 GIM-S Performance Evaluation
- C.13 OIA Risk Mitigation (ORM)
- C.14 Operational Integration Assessment (OIA)
- C.15 Terminal Sequencing and Spacing Computer-Human Interface (TSS-CHI)
- C.16 Interval Management Alternative Clearances (IMAC)

C.1 Interval Management for Near-term Operations Validation of Acceptability (IM-NOVA)

Experiment:

- Human-in-the-loop simulation in the Air Traffic Operations Lab (ATOL) at NASA Langley Research Center (LaRC)

Time Frame:

- August/September 2012

Objective:

- To assess if the ATD-1 Concept of Operations and procedures, when used with a minimum set of FIM equipment and a prototype crew interface, were acceptable to and feasible for use by flight crews in a voice communications environment.
- Verify integration of Ames GIM tools into the Langley ATOL

Tools/Functionality Integrated:

- Airborne Spacing for Terminal Arrival Routes (ASTAR) algorithm integrated in the Electronic Flight Bag (EFB) with the ADS-B Guidance Display (AGD) positioned in the forward field of view of the pilot
- FIM Clearance issued verbally and manually entered into the FIM system via EFB
- Ground-based air traffic control tools consisting of the TMA-TM and CMS tools developed at the NASA Ames Research Center (ARC) were integrated with ATOL.

Types of Participants:

- 10, two-person, same airline, active 757/767 crews in the Integration Flight Deck (IFD)
- Pseudo-pilots flying the Aircraft Simulation for Traffic Operations Research (ASTOR)
- Confederate controllers using Multi-Aircraft Control System (MACS) stations

Simulation Configuration:

- DFW airspace in the South Flow configuration with forecast winds
- Five scenarios allowing examination of flight crew procedures for ATC issuing, amending, terminating, suspending/resuming FIM clearances, and flight crew terminating FIM clearances

Data Collection:

- Data were collected from 10 crews of current, qualified 757/767 pilots asked to fly a high-fidelity, fixed based simulator during scenarios conducted within an airspace environment modeled on the DFW TRACON area.

Findings:

- Qualitative data obtained from pilot participants indicate that for all scenarios completed during the experiment:
 - The crew procedures used to receive and execute FIM clearances in a voice communications environment were found to be acceptable
 - The proposed procedures were found to be logical, easy to follow, and did not contain any missing or extraneous steps.
 - For all experiment scenarios, the pilot participants rated the required workload level as being acceptable.

- More detailed findings include:
 - FIM speed commands occurred at a rate of less than one per minute, and pilots found the frequency of the speed commands to be acceptable at all times throughout the experiment scenarios.
 - Pilots also reported that the FIM commanded speeds were operationally acceptable and appropriate during all scenarios.
 - The delivery accuracy at both the FAF and the runway threshold was within ± 5 sec and the delivery precision was less than 5 sec.
 - The results of this experiment demonstrate the effectiveness of the airborne spacing algorithm and the air/ground procedures investigated.
 - The empirical data and pilot feedback also suggest ways in which the algorithm and procedures may be improved.

Publications

- Wilson, et al., *Evaluation of Flight Deck-Based Interval Management Crew Procedure Feasibility*, GNC2013
- Murdoch, et al., *Acceptability of Flight Deck-Based Interval Management Crew Procedures*, GNC2013
- Kibler, et al., *ATD-1 Interval Management for Near-Term Operations Validation of Acceptability Experiment*, NASA Tech Pub 2015
- Wilson, et al., *Model Specification and Confidence Intervals for Voice Communication*, Quality Engineering Journal, Vol 27, Jul 2015

C.2 Fully Integrated ATD-1 Test #3 (FIAT-3)

Experiment:

- Human-in-the-loop simulation in the ATC Lab at NASA ARC

Time Frame:

- August/September 2012

Objectives:

- Ensure ATD-1 tools ported into STARS system without any loss of functionality.
- Simulated realistic PHX traffic with realistic winds

Tools/Functionality Integrated:

- Integration of Research TMA-TM with CMS, MACS/ADRS, ASTOR, and STARS ELITE
- Implemented supporting functionality including 2-way HDIF (provides center metering) and MACS/ADRS handoffs, others

Types of Participants:

- 4 Center (ZLA & ZAB) and 4 TRACON (SCT & P50) controllers
- 3 ASTOR pilots and 12 MACS pseudo-pilots

Simulation Configuration:

- PHX airspace in the East Flow configuration with RNAV, non-RNAV, and crossover routes
- Traffic scenarios consisting of arrivals with wind errors, realistic aircraft mix (jets and turboprops)
- ASTORs operated as non-FIM aircraft

Data Collection:

- The FIAT 3 simulation took place over five days, 26-31 August 2012.
- Data was collected over 16 data collection runs and three additional experimental runs. Each data run lasted approximately 45 minutes.

Findings

- Controllers did not report loss of functionality with ATD-1 Tools ported to STARS
- Controllers appeared to like using the ATD-1 tools on STARS
- TMA appeared to increase throughput for both staggered and non-staggered approaches
- In staggered approaches, the communication between the two final positions appeared to reduce with the use of the ATD-1 tools.

Publications

- Witzberger, et al., *NextGen Technologies on the FAA's Standard Terminal Automation Replacement System*, DASC2014

C.3 Terminal Sequencing and Spacing (TSAS) #1

Experiment:

- Human-in-the-loop simulation in the ATC Lab at NASA ARC

Time Frame:

- September 2012

Objective:

- Joint simulation with FAA TSAS Project to assess the feasibility and evaluate performance of ATD-1 controller technologies, including RNP-AR terminal arrival procedures and constant RF Legs for airport operations with mixed-equipage

Tools/Functionality Integrated:

- TMA-TM enhanced with advanced PBN procedures (RNP-AR with RF Legs in the terminal area) in a mixed equipage environment, non-uniform mismatched winds, Terminal Proximity Alert, Predicted Track Lines

Types of Participants:

- Both en route and terminal controllers
- MACS pseudo-pilots

Simulation Configuration:

- Traffic scenarios consisted of East, West and South arrivals to LAX Runways 24R and 25L using routes proposed by OAPM Design Team
- Weather scenario consisted of actual RUC wind forecasts combined with later RUC wind forecasts to match RMS wind error

Data Collection:

- September 2012

Findings:

- TSAS greatly assists in the ability to perform multiple RNP arrival procedures simultaneously with current procedures during heavily congested periods
- Controller preference and RNP compliance conformance highest with full ATD-1 controller advisories (Slot Markers, Timelines and Speed Advisories/E-L)
- Merging arrival routing procedures a significant factor in an efficient operations
- Simulation results are anecdotal and only provide insight for future work
- Lessons Learned:
 - rTMA-TM, CMS(MACS) and MACS can be quickly adapted to a complex “notional” advance airspace (RNAV and RNP for LAX)
 - NATCA controller team indicated that these automation technologies had a great potential to aid them in conducting mixed RNAV and RNP procedures
 - Requirement to understand the airspace design implications on the automation adaptation; i.e., a bad airspace topology will led to capacity reductions

Publications:

- TSAS-1 ATD-1 Brief-out 2/22/13

C.4 Interface Study for Interval Management (ISIM)

Experiment:

- Human-in-the-loop simulation in the ATOL at NASA LaRC

Time Frame:

- April 2013

Objective:

- Evaluate whether two Electronic Flight Bag (EFB) interfaces for entering FIM clearance data and two primary Field-of-View (FOV) displays (numerical & graphical) for monitoring the FIM operation are minimally acceptable
- Determine the difference in usability and acceptability between the two primary FOV displays

Tools/Functionality Integrated:

- 2 EFB interfaces: (1) Multiple data entered on a single page & (2) Separate pages for each piece of entered data
- 2 FOV displays: (1) Auxiliary Guidance Display (AGD) with numerical information and 2 LED indicator & (2) Configurable Glass Display (CGD) with both numerical and graphical information

Types of Participants:

- Active airline pilots running two-crew ASTOR stations
- Retired controllers running ATC stations
- Remote ASTOR Pseudo-Pilot station operators

Simulation Configuration:

- PHX airspace in the West Flow configuration in ATOL Lab

Data Collection:

- April 2013

Findings:

- The graphical AGD was found to be more acceptable and intuitive than the numerical AGD (the difference in acceptability was the saliency of alerting of new FIM speeds).
- Pilots found the additional text information shown on the graphical AGD helpful.
- Future auxiliary FIM displays should have the capability of displaying text information such as the target aircraft's ID and the operational state of the FIM equipment in the forward field-of-view.

Publications:

- Swieringa, et al., *An Evaluation of Retrofit Flight Deck Displays for Interval Management*, ATIO2014

C.5 Terminal Sequencing and Spacing (TSAS) #2

Experiment:

- Human-in-the-loop simulation in the ATC Lab at NASA ARC

Time Frame:

- April 2013

Objective:

- Joint NASA/FAA high-fidelity HITL simulation using MACS to demonstrate that the TSS tools better enabled PBN arrival procedures and advanced concepts under robust wind conditions and sustained, heavy traffic scenarios

Tools/Functionality Integrated:

- Controller Managed Spacing (CMS) slot marker and speed advisory algorithms integrated into the RTMA baseline
- ATC lab integration with PHX airspace

Types of Participants:

- Active TRACON controllers from New York, Boston and Phoenix, Center controllers
- ASTOR pilots and MACS pseudo-pilots

Simulation Configuration:

- PHX airspace in the West Flow configuration
- Two ATD-1 Scenarios: 01/04/2011 8:30a and 09/03/11 3:30p PHX arrival rushes
- RUC winds and forecast winds 12/2/2011 14Z and 16Z winds

Data Collection:

- 12 experiment runs
- On the average, 60 aircraft landed in a run

Findings:

- Terminal Area Precision Scheduling And Spacing (TAPSS) System has a potential to enable efficient Performance-Based Navigation
- TAPSS system has a potential to reduce controllers' communication task load.
- Participants found the TAPSS system and its advisories useful
- An increase in schedule nonconformance can adversely affect performance of schedule-based terminal area arrival operations, in terms of time efficiency, lateral route efficiency, and controller workload.
- Notable relations were found between the introduced schedule nonconformance metric and the time efficiency, lateral route efficiency, and controller workload.

Publications:

- Thippavong, et al., *Evaluation of the Terminal Sequencing and Spacing System for Performance-Based Navigation Arrivals*, DASC2013
- Jung, et al., *Assessing Relation between Performance of Schedule-Based Arrival Operation and Schedule Nonconformance*, Aviation2014

C.6 Controller Managed Spacing for ATD-1 #5 (CA-5.1 & CA-5.2)

Experiment:

- Human-in-the-loop simulation in the Aircraft Operations Lab (AOL) at NASA ARC

Timeframe:

- July- September 2013

Objectives:

- Compare baseline and ATD-1 performance measures for realistic PHX traffic and winds
- Calibrate expectations for introduction ATD-1 technologies.

Tools/Functionality Integrated:

- PHX East- and west-flow operations (scenario and winds)
- ERAM functionality & display options in en-route controller workstations
- Latest ATD-1 simulation capabilities

Types of Participants:

- 11 retired ZAB & P50 controllers, 2 ZAB & P50 TMCs, 5 confederate controllers
- 8 experienced ASTOR pilots, 18 MACS pseudo-pilots

Simulation Configuration:

- East- and west-flow PHX operations; High- and low-altitude en-route sectors; Arrivals, departures, and crossing traffic
- Two ATD-1 Scenarios: East-flow 12/28/2011 @ 08:45 and West-flow 11/14/2011 @ 18:00 PHX arrival rushes
- Winds: East-flow P1, P2, P3, P4 and West-flow P1, P2, P7, P3
- ASTORs as RNAV-equipped arrivals

Data Collection:

- CA-5.1: 15-18 July 2013
- CA-5.2: 16-19 September 2013

Findings:

- ATD-1 operations during CA-5.2 exhibited efficiency gains over the CA-5.1 current day operations.
- During CA-5.2 en route controllers were able to learn to meter aircraft to the TMA-TM schedule times and provide well-conditioned arrival flows to the TRACON.
- TRACON controllers then used the Controller Managed Spacing (CMS) tools to effectively merge and space arrivals using primarily speed clearances with minimal vectoring of aircraft off RNAV arrival routes.
- Comments by controller participants during CA-5.2 centered on excessive clearance / read-back phraseology, ambiguities surrounding en route speed instructions and descend-via clearances, and aircraft speed-compliance during initial descent.

Publications:

- Callantine, et al., *System-Level Performance Evaluation of ATD-1 Ground-Based Technologies*, ATIO2014

C.7 CMS-ATD1 Flight Deck Study II: CA-4 Operations in PHX Airspace

Experiment:

- Human-in-the-loop simulation in the CVSRF at NASA ARC

Time Frame:

- November/ December 2013

Objective:

- Evaluate how crews respond to “nominal” CMS speed clearances
- Analyze performance with window altitude constraints
- Compare results with variations in clearance phraseology
- Explore potentially problematic scenarios (identified in CA-4)

Tools/Functionality Integrated:

- Advanced Concept Flight Simulator (ACFS)
- Glass cockpit simulator with black box FMS and flight dynamics of a B737-800 aircraft.

Types of Participants:

- 12 commercial flight crews
- 1 Confederate controller

Simulation Configuration:

- PHX airspace in the West Flow configuration, CA-4 operations
- ATD-1 wind patterns

Data Collection:

- November and December 2013

Findings:

- Two forms of phraseology were used in the simulation: “until....at” and “cross at”.
- Data suggests that clearances using “cross....at” may be more problematic for pilots and required more workload.
- The participants generally did not think that training was required to fly OPDs.
- Crews’ approaches to flying the descents were impacted by the speed of the clearances but also by the phraseology that was used to deliver them. The results suggest that these clearances can be used operationally, but some refinement of clearance phraseology and a general awareness of the goals of the controller tools would be beneficial

Publications:

- Martin, et al., *Flight Deck Crew Experiences Flying Profile Descents During Metering Operations*, AHFE2014

C.8 Research and Procedural Testing of Routes (RAPTOR)

Experiment:

- Human-in-the-loop simulation in the ATOL at NASA LaRC

Time Frame:

- January & February 2014

Objectives:

- Demonstrate the successful use of ADS-B In airborne spacing applications.
- Assess if ASTAR12 meets requirements for percentage of controller and pilot-interrupted FIM operations, pilot acceptability of FIM, and pilot workload during FIM operations.

Tools/Functionality Integrated:

- ASTAR-12 version 12.02.34, ATOS version ATOS_14_1_C_2014JAN21R
 - Change ASTAR allowable speed deviation from 10% to 15% based on results from FIAT-2
- RTMA version 12.11.13 (ATD1_2013_12_11), ADRS/MACS version 1.14.14 AdrsMacsWin_14_1_2014JAN14R

Types of Participants:

- 4 two-person crews of current, qualified 757/767, 777, and 787 pilots
 - 1 two-person crew in the Integration Flight Deck (IFD)
 - 1 two-person crew in the Development and Test Simulator (DTS)
 - 2 two-person crews on dual-crew ASTORs
- 5 recently retired air traffic controllers, all trained in ARC simulations
- 5 MACS pseudo-pilots, 4 single-crew ASTOR pseudo-pilots

Simulation Configuration:

- PHX airspace in West Flow configuration; EAGUL5 and MAIER5 routes, CA-5.1 traffic
- Winds: 01/10/2011 and 06/12/2011 truth winds and corresponding forecast winds

Data Collection:

- February 5 & 6, 2014

Findings:

- Pilots reported the FIM concept, procedures, operations, and interfaces to be acceptable.
- Researchers believe that the data indicate there were issues with:
 - The frequency of speed changes and speed reversals due to the high degree of coupling between the FIM aircraft and the Target aircraft.
 - The controller issuing the Target a slower than published speed prior to the FAF.
- The ASTAR-12 algorithm performed as designed but some of the assumptions made about the compatibility between the FIM and ground tool performance need to be revisited.
- The inaccurate temperature modeling affected the spacing on final (separation issues).
- Some confusion with phraseology resulted in some recommended changes.

Publications:

- Wilson, et al., *ATD-1 Research and Procedural Testing of Routes*, NASA Tech Memorandum 2015

C.9 Fully Integrated ATD-1 Test #4 (FIAT-4)

Experiment:

- Human-in-the-loop simulation in the ATC Lab at NASA ARC

Time Frame:

- February 2014

Objectives:

- Validate the performance of ASTAR12 across a range of realistic, high-density arrival operations into PHX

Tools/Functionality Integrated:

- RTMA-TM with CMS tools, MACS/ADRS, ASTOR with ASTAR 12, STARS ELITE TCWs

Types of Participants:

- 4 Center (ZLA & ZAB) and 4 TRACON (SCT) controllers
- 6 single-crew ASTOR pilots and 10 MACS pseudo-pilots

Simulation Configuration:

- PHX airspace in the East Flow configuration with RNAV arrivals only
- Traffic scenarios consisting of all RNAV-equipped jets, high density traffic but not representative of PHX traffic mix
- ASTORs operated as FIM aircraft; FIM pairs only on North side (MAIER, EAGUL) or South side (GEELA, KOOLY)

Data Collection:

- February 5-14, 2014
- 6 ASTOR aircraft
- 54 aircraft in each simulation run
- Total of 31 simulation runs with 54 aircraft in each simulation run
 - 24 simulation with FIM aircraft; 7 simulation without FIM aircraft

Findings:

- The mean aircraft delivery accuracy to the Final Approach Fix when using ASTAR12 to conduct FIM is within or close to the desired value.
- The number of speed changes commanded by ASTAR12 is higher than anticipated, particularly when the Target aircraft's speed was dissimilar to the published procedure.
- Controller and pilot acceptability increased over the duration of the experiment; however, the workload required to enable (controller) and conduct (pilot) the FIM operation compared to current day operations was higher in some scenarios.

Publications:

- None (results corrupted by simulators using different temperatures)

C.10 Controller Managed Spacing for ATD-1 #5 (CA-5.3)

Experiment:

- Human-in-the-loop simulation in the AOL at NASA ARC

Timeframe:

- April 2014

Objectives:

- Test updated ATD-1 operations with FIM for realistic traffic in P50 and ZAB/ZLA airspace
- Examination of all aspects of ATD-1 operations in a realistically complex traffic environment. The TMA-TM used runway allocation and an adaptation updated to include all aircraft types typically led to several aircraft scheduled on crossover routes. Tests were run with & without FIM aircraft.

Tools/Functionality Integrated:

- PHX East- and west-flow operations (scenario and winds)
- ERAM functionality & display options in en-route controller workstations

Types of Participants:

- 12 retired ZAB & P50 controllers, 2 ZAB & P50 TMCs, 5 confederate controllers
- 8 experienced ASTOR pilots, 18 MACS pseudo-pilots

Simulation Configuration:

- East- and west-flow PHX operations with runway balancing; Turbojet, turboprop, and piston arrivals to PHX
- High- and low-altitude en-route sectors; Arrivals, departures, and crossing traffic
- Two east- and west-flow traffic scenarios derived from recorded ZAB and P50 traffic including peak-period arrivals into PHX
- Three different sets of historical ZAB truth and forecast winds
- ASTORs as RNAV-equipped arrivals

Data Collection:

- 13-17 April 2014

Findings:

- A system-level simulation of ATD-1 integrated air-ground operations using the ATD-1 prototype technologies demonstrated consistent PBN-procedure conformance and FIM benefits under conditions when FIM aircraft flew connected routes to their assigned landing runways.
- The simulation also identified aspects of FIM operations that need improvement before FIM can reliably provide benefits in conjunction with TSS operations in a near-term environment.
- An ATD-1 study is planned to investigate alternative FIM clearance types [13] such as speed-matching capabilities that may allow for better FIM-TSS integration. Due to the apparent advantages of utilizing connected routes for FIM operations, the study plans to examine arrival operations at Denver International Airport (DEN), where newly published RNP approach procedures provide the required connectivity. The study will also afford a first look at RNP operations within an integrated TSS-FIM system. Results from this and

future studies will inform government and industry stakeholders across the United States, Europe and Japan. Following this year's simulation efforts, validation flight tests are planned for 2016-2017.

- Results indicate that, at a system-level, the ATD-1 ground-based technologies support increased PBN operations for high-density traffic.
- Positive effects of the tools most evident in the west-flow scenarios, when the arrival traffic was least homogenous; the schedule provided a workable plan that controllers would otherwise have to formulate on the fly.
- Improvements to the TMA-TM to provide accurate airspeed predictions for the 5.3 simulation resulted in improved schedule-achievability along with increased DCT and speed-advisory usage.

Publications:

- Callantine, et al., *System-Level Performance Evaluation of ATD-1 Ground-Based Technologies*, ATIO2014
- Callantine, et al., *Flight-Deck Interval Management in Near-Term Arrival Operations*, 11th USA/Europe Air Traffic Management Research and Development Seminar (ATM2015)

C.11 Fully Integrated ATD-1 Test #5 (FIAT-5)

Experiment:

- Human-in-the-loop simulation in the ATC Lab at NASA ARC

Time Frame:

- July to December 2014.

Objectives:

- To reduce the risk of the ground automation technology demonstration called the Operational Integration Assessment (OIA).
- Not an experiment per se; primarily a verification and validation simulation for STARS and RTMA up-leveled to v4.2 with Terminal Sequencing & Spacing (TSAS) technologies.

Tools/Functionality Integrated:

- RTMA v4.2 with TMA-TM and CMS, also with TBFM flexible scheduling and GIM-S
- STARS SCOUT Release 1 and Release 2, with FIM messaging
- MACS with ERAM emulation, 4 STARS TCWs

Types of Participants

- 4 Center, 4 TRACON controllers, 1-2 controllers-in-charge (Traffic Managers)
- 10 MACS pseudo-pilots

Simulation Configuration

- West-flow PHX operations, RNP routes, Adaptation with coupled meter points & extended meter points
- Multiple off-nominal events (missed approach/go-around, unscheduled & scheduled internal departures, runway assignment change, priority aircraft, Center & TRACON swaps, independent to staggered runway configuration change, future spacing matrix change)

Data Collection:

- October 13-17, 2014: data collection simulation with 16 runs (6 nominal, 10 off-nominal)
- December 2-9, 2014: data collection simulation with 22 runs (7 nominal, 15 off-nominal)

Findings:

- In general, FIAT-5 results are same or better than FIAT-3
- Lessons learned:
 - Learning curve for incorporating GIM-S into FIAT-5 steeper than expected
 - Off-nominal events identified more software/adaptation defects than expected & exposed MACS/ADRS limitations
 - Voice-communication limitations in ATC lab can become a simulation constraint

Publications:

- None

C.12 GIM-S Performance Evaluation

Experiment:

- Human-in-the-loop simulation in the AOL at NASA ARC

Time Frame:

- April 2015

Objective:

- Validate meter fix delivery accuracy for Terminal Sequencing and Spacing (TSS) with and without Ground-based Interval Management Speed Advisories (GIM-S).
- Determine impact of delay display (10s of seconds vs. minute rounded) and GIM-S speed advisories on delivery accuracy, flight efficiency, controller workload and acceptability.

Tools/Functionality Integrated:

- TBFM 4.2.3 with TSS using November 13, 2014 CCU (adaptation)
- MACS/ERAM Displays

Types of Participants:

- ARTCC-only: 6-8 controllers, 2 ‘worlds’ depending on how sectors are split up
- 8-10 pilots

Simulation Configuration:

- ZAB/P50 airspace
- EAGUL6 arrivals, overflight traffic
- Variables:
 - DCT Resolution (i.e., tenths of minute or rounded minute)
 - Display of cruise/descent speed advisory (i.e., on/off)

Data Collection:

- April 20-24, 2015

Findings:

- General:
 - Controllers were able to deliver aircraft to the TRACON accurately in all conditions; however, GIM-S was more accurate than baseline.
 - The tens-of-seconds delay countdown timer (‘10-sec DCT’) was more accurate than the one-minute-rounded delay indication (‘1-min DCT’).
 - GIM-S advisories used frequently in extended metering sectors, but not in merge and descent sectors.
- Subjective:
 - Participants accepted the GIM-S advisory about 65% of the time.
 - About 33% of aircraft did not receive advisories in the 10sec DCT condition; while only 24% did not receive advisories in the 1 minute DCT condition.
 - Most controllers were aiming to absorb all the delay; however, 12% tried to put their aircraft early and another 25% tried to keep their aircraft a little late.
 - 76% of the participants preferred the 10 seconds rounded DCT over the 1 minute rounded DCT
 - In the GIM-S 10- sec condition, 75% of the time controllers reported that 90 – 100% of their clearances were speed alone, while this was only true 58% of the

time in the No GIMS 10 sec condition, and only 50% of the time in both of the 1 min conditions.

- Participants rated two of the tools (DCT, meter list) as useful in all conditions, and rated the speed advisories as slightly better than moderately useful.
- Workload ratings on the TLX sub scale were all moderately low on in all conditions, except for Controller Performance which was moderately high.

Publications:

- None

C.13 Operational Integration Assessment Risk Mitigation (ORM)

Experiment:

- Human-in-the-loop simulations in the ATC Lab at NASA ARC and FAA Technical Center

Time Frame:

- ORM-1: Jan 20-23, 2015 (ATC Lab)
- ORM-2: Jan 27-29, 2015 (ATC Lab)
- ORM-3: Feb 24-26, 2015 (FAA Technical Center)
- ORM-4: Mar 10-13, 2015 (ATC Lab)

Objective:

- ORM-1: validate CCU 1412
- ORM-2: train the FAA Traffic Managers
- ORM-3: simulation with NASA-supplied controllers (integration checkout)
- ORM-4: validate NASA's TSS-enhanced TBFM 4.2.3 and CCU 1412

Tools/Functionality Integrated:

- TMA-TM and CMS tools

Types of Participants:

- ORM-1: 4 retired ARTCC controllers, 4 retired TRACON controllers, 10 pseudo-pilots
- ORM-2: 5 retired ARTCC controllers, 4 retired TRACON controllers, 11 pseudo-pilots, 2 current Traffic Managers
- ORM-3: 4 retired ARTCC controllers, 4 retired TRACON controllers, 10 pseudo-pilots from FAA Technical Center
- ORM-4: 5 retired ARTCC controllers, 4 retired TRACON controllers, 11 pseudo-pilots

Simulation Configuration:

- Phoenix (PHX, west-flow); Phoenix TRACON (P50); Albuquerque ARTCC (ZAB)

Data Collection:

- None

Findings:

- ORM-1: validation confirmed
- ORM-2: lessons learned for how controllers use TBFM operationally
- ORM-3: list of issues for the FAA Technical Center to analyze and correct
- ORM-4: confirmed the TSS prototype is ready for the OIA

Publications:

- None

C.14 Operational Integration Assessment (OIA)

Experiment:

- Human-in-the-loop simulation at the FAA William J. Hughes Technical Center

Time Frame:

- August 2014 – May 2015

Objective:

Identify risks that need to be addressed prior to transitioning TSS from the laboratory to the National Airspace System (NAS). These risks are broad and include, but are not limited to, such risks as technical, policy, procedures, training, TSS computer human interface (CHI), and TSS interoperability with extended metering and GIM-S.

Tools/Functionality Integrated:

- NASA's TSS-enhanced TBFM (version 4.2.3) in a single machine (TBFM IAB)
- STARS ELITE String 5
- ERAM Test Bed 4
- Target Generation Facility (TGF)

Types of Participants:

- 4 TMCs (NATCA)
- 8 center controllers (NATCA)
- 4 terminal controllers (NATCA)

Simulation Configuration:

- Extended metering with GIM-S to precondition the aircraft flying through Denver (ZDV) and Albuquerque (ZAB) airspace.
- Aircraft enter Phoenix (P50) airspace to land at Phoenix Sky Harbor Airport (PHX).
- GIM-S cruise advisories available for aircraft entering P50 on the northeast arrival gate.
- GIM-S cruise and cruise/descent advisories available for the southeast arrivals.
- Controller participants used traditional metering to precondition the arrivals from the northwest and southwest that were flights originating in Los Angeles (ZLA) airspace.

Data Collection:

- The Run for the Record used two traffic scenarios comparable to the PHX AAR when conducting staggered Instrument Landing System and visual approaches, respectively:
 - A lower Arrival Rate (AAR) of 50-60 aircraft per hour with peaks and valleys
 - A higher AAR of 65-75 aircraft per hour with peaks and valleys
- Off-nominal events were also included:
 - "Global" off-nominal events (such as a transition from independent to dependent staggered operations) and "Local" off-nominal events (such as go-arounds, priority aircraft, and pop-up aircraft).
- The 19 data collection runs, using the two traffic scenarios in conjunction with off-nominal event, were conducted May 12-21.
- 60-75 minutes per scenario, corresponding to 40-55 minutes of continuous landings.

Findings:

- Results from the simulation provided insight into TSAS tools and procedures for both system and human performance metrics.
- Overall, the percentage of aircraft that were delivered between ± 30 seconds at the four meter fixes varied from 77% to 86% depending on the arrival procedure, and 91% of all flights were delivered between ± 60 seconds.
- One objective of TSAS is to enable more frequent use of PBN procedures during all levels of traffic demand. The PBN Success Rate (PSR) (the percentage of RNAV- and Required Navigation Performance (RNP) equipped aircraft that remained on their PBN arrival procedures, after crossing the meter fix and before reaching the end of the published lateral path) was 84% across the scenarios.
- Off-nominal events did affect the PSR, dropping the percentage to below 70% in some runs, particularly when there was both a high arrival rate and at least one off-nominal event.
- The self-reported workload measures of the en route and terminal controller participants revealed some differences between the higher and lower airport arrival rate, and the type of off-nominal events. Workload ratings averaged out to a low rating for all participants in the OIA.
- The data suggest that Global off-nominal events resulted in more self-reported workload than the Local events and the runs without off-nominal events.
- When examining the use of the metering tools, en route participants reported their metering tools were “moderately useful” for working off-nominal problems.
- Terminal participants rated their TSAS tools as only “slightly useful” during off-nominal events, with the exception of the slot marker which they rated as “moderately useful”.
- The OIA simulation revealed no major risks for the planned operational fielding of the TSAS tools.

Publications:

- Witzberger, et al, *Air Traffic Management Technology Demonstration (ATD-1) Operational Integration Assessment (OIA) Final Report*
- Sharma, S., Wynnyk, M., *Assessment of Delivery Accuracy in an Operational-Like Environment*, AIAA Aviation 2016

C.15 Terminal Sequencing and Spacing Computer-Human Interface (TSS-CHI)

Experiment:

- Human-in-the-loop simulation in the AOL at NASA ARC

Time Frame:

- September 2015

Objectives:

- Identify potential issues and generate recommendations for integrating TSS with
 - Automated Terminal Proximity Alert (ATPA), a conflict alert that uses cones to alert controllers to potential separation violations
 - Wake Re-categorization (RECAT), a new wake separation matrix based on weight and wing span of leading and trailing aircraft
- Evaluate interoperability
- Test different CHI concepts

Tools/Functionality Integrated:

- Terminal controller use-interfaces for ATD-1 operations
 - CMS: slot markers, speed advisories, early/late indications, runway, and sequence
 - Automated Terminal Proximity Alert: monitors, alerts, and warnings
 - Wake-separation re-categorization: new wake separation standards

Types of Participants:

- Both en route and terminal controllers
- MACS pseudo-pilots

Simulation Configuration:

- Traffic scenarios consisted of East, West and South arrivals into Phoenix TRACON (P50), using routes proposed by OAPM Design Team
- Landed runways 24R and 25L
- Weather scenario consisted of actual RUC wind forecasts combined with later RUC wind forecasts to match RMS wind error

Data collection:

- June 2015

Findings:

- All conditions were workable and acceptable
- With Center feed based on TSS schedule there were only few RNP cancellations
 - ATPA only condition was least preferred
 - RECAT not much of an issue
 - Strong controller preference for having CMS tools available on feeder and both CMS and ATPA available on feeder and final
 - Controller liked having several configuration options
 - Clutter can easily be reduced through small redesign
 - Controllers overall very positive about integrated systems

Recommendations:

- Use TSS scheduling for Center metering and TSS runway and sequence number in the TRACON to organize complex TRACON traffic flows (e.g. RNP arrivals)
- Make CMS slot markers available on feeders and finals. Speed advisories and early late should be optional for finals
- Reduce clutter by making certain information available upon dwell only (e.g. slot marker for arrivals to other runway, speed advisories...)
- ATPA useful on final, switch point from CMS to ATPA should be adaptable/configurable
- Re-visit alert times for ATPA (may need more lead time)
- If controllers follow TSS schedule, consider also using TSS runway and sequence number to filter ATPA cones
- Implement RECAT in TSS If not fully implemented, make sure TSS spacing is equal or greater than RECAT spacing

Publications:

- TSS-1 CHI Outbrief 9/2/15

C.16 Interval Management Alternative Clearances (IMAC)

Experiment:

- Human-in-the-loop simulation in the ATOL at NASA LaRC

Time Frame:

- July & August 2015

Objectives:

- To investigate the expanded ATD-1 ConOps, which included the FIM clearance used in previous research and added two new FIM clearance types.
- Research questions investigated during IMAC include the efficacy and acceptability of the three different FIM operations, the impact of mixed equipage operations on the FIM operations, and identifying possible issues with implementation into real-world operations.
- Descriptions of the three FIM clearance types evaluated in IMAC were:
 - Achieve-by Then Maintain (*CROSS*): aircraft on the same or different routes, ATC assigns a spacing interval, the FIM clearance type used in previous ATD-1 research.
 - Capture then Maintain Spacing (*CAPTURE*): aircraft on the same route, ATC assigns a spacing interval, reduced phraseology required by ATC to issue.
 - Maintain Current Spacing (*MAINTAIN*): aircraft on the same route, ATC does not assign a spacing interval (avionics calculates it), reduced ATC phraseology.

Tools/Functionality Integrated:

- ASTAR-13, ATOS version ATOS_14_1_C_2014JAN21R
- EFBs and CGDs
- RTMA version 12.11.13 (ATD1_2013_12_11)
- ADRS/MACS version 1.14.14 AdrsMacsWin_14_1_2014JAN14R (from NASA ARC)

Types of Participants:

- Two groups of 4 subject controllers (8 subject controller total)
- Two groups of 6 two-crew subject commercial pilots (24 pilots total), each group:
- 2 confederate controllers and 6 confederate pilots

Simulation Configuration:

- Denver airspace in North and South Flow configurations
- Each scenario consisted of 41 aircraft arriving to KDEN from the east, another 41 aircraft arriving from the west, and approximately 20 over-flight aircraft (i.e., not landing at KDEN but transiting the airspace). The landing direction (north or south) was specified by scenario, and each aircraft landed on the runway closest to the direction from which they came. Within each scenario, only one of the arrival directions (east or west) was part of the data collection while the opposite arrival direction was completely automated.
- The scenario types were:
 - TMA-TM and CMS tools only,
 - TMA-TM, CMS and the CAPTURE clearance,
 - TMA-TM, CMS and the CROSS clearance,
 - TMA-TM, CMS and the MAINTAIN clearance, and
 - TMA-TM, CMS and any of FIM clearance type (controller's discretion).
- Winds used in the IMAC experiment were:

- Winds west of Denver very strong from the west, and vary little by altitude
- Winds east of Denver strong from the west, and vary by altitude
- Surface winds a light cross wind from the west
- Single FIM clearance format (CROSS) always shown on controller scope, not optimized clearance type as intended by ConOps (resource and time limitation).

Data Collection:

- July & August 2015

Findings:

- In general, the FIM concept and technologies demonstrated promise in IMAC, but the current instantiation of FIM in a busy, current day voice environment has too many challenges to be implemented in the real-world operations as is.
- While the FIM procedures and the spacing software achieved the primary objective of improved aircraft delivery precision compared to TSS procedures and displays, several critical deficiencies and unmet requirements must be resolved prior to the FIM concept being implemented in real-world operations. A partial list of the most pressing issues identified during IMAC include:
 - CROSS operations when the Target and FIM aircraft not in the same sector
 - MAINTAIN operations in the ARTCC that continue into the TRACON
 - frequency of FIM commanded speed changes
 - reversals (speed increase) of the FIM commanded speed
 - comprehensible FIM cockpit displays to trigger appropriate crew reaction
- Issues that were analyzed and solid conclusions can be stated include:
 - “Report paired” to be moved to ATC acknowledgement instruction
 - third-party identification should not be a significant issue in a voice environment, however most controllers and pilots preferred the Target call sign be issued phonetically in the FIM clearance to ensure clarity in identifying uncommon call signs, and better delineation from and instruction issued to the FIM aircraft
 - when appropriate for the geometry and aircraft position, the MAINTAIN clearance was preferred in the voice environment due to the reduced voice communication and because it was the most intuitive operation
- Less critical issues that require further discussion and research include:
 - similarity of ground and airborne trajectory generators
 - similar methodology to apportion delay by ground and airborne software
 - knowledge to Target aircraft predicted wind field when not on same arrival

Publications:

- Baxley, Wilson, Swieringa, Roper, *Flight Crew Responses to the Interval Management Alternative Clearances (IMAC) Experiment*, AIAA Aviation 2016
- Swieringa, Wilson, Baxley, *System Performance of an Integrated Airborne Spacing Algorithm with Ground Automation*, AIAA Aviation 2016
- Baxley, Wilson, S., Swieringa, K., Johnson, W., Roper, R., Hubbs, C., Goess, P., Shay, R., *Description and Results of the Interval Management Alternative Clearances (IMAC) Experiment*, NASA Technical Paper, 2016

Appendix D: Related ATM Concepts

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

D.1 TBFM and Terminal Sequencing and Spacing (TSAS)

Several planned TBFM enhancements have relevance to or can be supported by the long-term ATD-1 ConOps, in particular TSAS which is directly tied to NASA's TMA-TM development. The FAA TBFM and TSAS documentation is paraphrased below.

D.1.1 Time-Based Flow Management

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

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

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

D.1.2 Terminal Sequencing and Spacing

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

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

D.2 Interval Management

The NASA FIM procedures used in ATD-1 are a subset of the Arrival Interval Management – Spacing (IM-S) concept and procedures developed by the FAA [ref 7 and ref 8]. The NASA research has been closely linked with the FAA’s development, and the ATD-1 demonstration is intended to support the FAA’s decision making process regarding NextGen decisions. The FAA IM-S ConOps documentation is paraphrased below.

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

The arrival IM-S concept utilizes ADS-B. The deployment of ADS-B will support increased accuracy in trajectory prediction for the ground-based flow component, and will also be a critical enabler for the flight deck-based spacing component. FIM-S is identified as the flight deck-based spacing component for this concept. For the FIM-S descriptions in this document, the FIM-S aircraft is the “trailing” aircraft performing FIM-S operations and receiving speed guidance from onboard avionics to achieve the assigned spacing goal behind its “target” (or “leading”) aircraft, with this aircraft providing ADS-B Out surveillance information.

Some of the differences between the ATD-1 ConOps and the IM-S AA&C ConOps [ref 8] are described below in Table 4.

Table 4. Differences between ATD-1 and IM-S AA&C ConOps

| NASA ATD-1 ConOps | FAA IM-S AA&C ConOps |
|---|---|
| <p>Integration of three technologies to provide solution to one particular environment (high-density arrivals)</p> <ul style="list-style-type: none"> Does not include en route cruise operations | <p>A single technology to provide solutions in multiple environments (arrival, approach, and cruise)</p> <ul style="list-style-type: none"> Does include en route cruise operations |
| Assigned ATD-1 to Concept Level 4 | Assigned IM-S AA&C to Concept Level 3 |
| <p>Assumes there is not a FIM-aware scheduling function within TMA-TM</p> <ul style="list-style-type: none"> All FIM information presented to en route controller as soon as aircraft crosses Freeze Horizon; in format for Achieve and Maintain clearance type Sequence swap does not trigger new FIM clearance information Spacing buffer not adjusted for FIM ops | <p>Assumes there is a FIM-aware scheduler</p> <ul style="list-style-type: none"> Only most appropriate FIM clearance type is displayed; only data elements relevant to that type of FIM clearance is displayed The FIM clearance and data is presented only after the operation is feasible (within ADS-B range, route geometry, etc.) Sequence swap triggers message to cancel FIM operation and issue new clearance Spacing buffer adjusted for FIM ops |
| <p>Since the FIM clearance can be issued prior to it being feasible, the controller phraseology included the term “WHEN ABLE” to accommodate that possibility</p> | <p>The “WHEN ABLE” phraseology is not needed since the FIM clearance is issued only after the operation is feasible</p> |
| <p>Specifies the FIM clearance is given after the “descend via” the arrival instruction</p> | <p>Not clearly specified when the FIM instruction is to occur</p> |
| <p>FIM clearance information is not presented to the terminal controller, therefore a FIM clearance cannot be given in the TRACON</p> | <p>Allows for issuing a FIM clearance in the TRACON</p> |
| <p>Does not include FIM final approach spacing operations</p> | <p>Does include FIM final approach spacing operations (IM FAS)</p> |
| <p>Flight crew are required to include the FIM status in the initial check-in with each controller as a mechanism to back-up the controller’s data tag update procedure</p> | <p>Flight crew are not required to include the FIM status in the initial check-in with each controller</p> |
| <p>Assumes the only information provided to controllers to assess performance is the CMS displays, which is based on the TMA-TM schedule</p> | <p>Assumes there will be displays and information specifically designed to assess the FIM operation</p> |

D.3 RNAV and RNP

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

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

A second example of this type of work is the RNP approaches in Atlanta being developed by Delta Airlines and the FAA. “Peachy Skies” is an effort to use the “Greener Skies” capabilities in visual meteorological conditions in lieu of changes to the FAA air traffic regulation. The current spacing requirements [ref 32, Chapter 5, Section 9] create large inefficiencies in the NAS when an airport conducts simultaneous operations. This work used RNAV and RNP to provide a means to reduce these inefficiencies through path keeping capability, monitoring, and alerting.

D.4 Tailored Arrivals

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

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

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

D.5 Time-Based Procedures

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

Appendix E: Capabilities Tested During the ATD-1 Demonstrations

This Appendix contains a partial list of ATM capabilities and functions that were tested during the ATD-1 Ground Demonstration (OIA at the FAA Technical Center in 2015) and the ATD-1 Flight Demonstration (Seattle, WA area in 2017).

Ground Demonstration (OIA at FAA Technical Center, accomplished in 2015)

1. ATD-1 arrival operations to a single airport with independent runway operations using ground tools and procedures (TMA-TM and CMS).
2. An integrated, time-deconflicted schedule for all aircraft to that runway.
3. CMS displays and decision support tools for terminal controllers.
4. OIA explored additional roles for TRACON TMC.
5. Scenarios included both planned and unplanned events, such as:
 - VMC/IMC, parallel and staggered operations, metering turned off, sequence swaps, runway configuration changes, internal departures, missed approach, and priority aircraft.

Flight Demonstration (in Seattle, Washington area, to be accomplished in 2017)

6. ATD-1 arrival operations to a single airport with a single runway, using airborne tools and procedures (FIM).
 - All three FIM clearances types (CROSS, CAPTURE, and MAINTAIN).
7. Scenarios simulated various levels of aircraft delay and route geometry.

Capabilities and functions not tested during the ATD-1 Ground Demonstration and Flight Demonstration include:

1. Ground automation systems (TMA-TM, ERAM, STARS) will not yet have capability to exchange all data between each other, therefore the aircraft's trajectory from its current position to the runway will not be known by all users and the automation.
2. Data communication functionality will not be available, therefore ground and airborne equipment will not be able to exchange aircraft trajectories or FIM clearance information.
3. Complete integration of the FAA's different software systems is not complete, therefore not all controller displays will have the ability to display CMS or FIM data.
4. Coupled scheduling between ARTCCs will not be in use, therefore more aircraft may need preconditioning (vectors or altitude step-downs) prior to Initiation or Operation Phase of the ATD-1 procedure.
5. The AOC is not part of either demonstration, therefore the functionality of coordination with them to ensure the desired arrival sequence will not be tested.
6. No FIM functionality in ground automation test conducted at the FAA Technical Center.
7. No FIM functionality in ground systems during the flight test in the Washington area, therefore no FIM clearance information issued by controllers to the flight crew.

Appendix F: Assumptions and Requirements for ATD-1 Operations

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

F.1 Schedule Phase

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

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

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

F.2 Precondition Phase

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

F.3 Initiation Phase

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

- The Target aircraft and FIM aircraft may be in the same or different airspace sectors, and may be on the same or different arrival procedure (therefore cross the same or different TRACON Meter Fix).
- The Target aircraft and FIM aircraft of a FIM pair will be assigned to the same runway.
- The FIM aircraft must receive ADS-B data from the Target aircraft, but is not required to receive ADS-B data from any other aircraft.

F.4 Operation Phase

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

F.5 Termination Phase

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

Appendix G: Controller-Pilot Phraseology

Current controller-pilot phraseology (initial check-in, issuing route instructions, 'Descend Via' clearances, etc.) remains unchanged during ATD-1 operations to the maximum extent possible, and no new phraseology has been identified for CMS operations. Phraseology in this Appendix unique to FIM operations has been derived from the FAA FIM Working Group [ref 30-31] and current controller-pilot phraseology [ref 32], although several modifications were made to enable shorter transmissions for voice communication operations, and some words were changed for increased clarity (for example, "Paired" instead of "Interval Spacing" to report FIM engaged). Any FAA guidance or direction has precedence over phraseology described in this Appendix.

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

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

NOTE: Since subsequent air traffic control instructions supersede previously issued instructions, the FIM clearance must be issued after the Descend Via instruction to enable the flight crew to fly the FIM speed and not the published arrival speed.

The terminal feeder controller issues the actual runway assignment to all crews, and the Final controller normally issues the approach clearance to all crews. If the arrival and approach connect via the published procedures, controllers are not expected to issue vectors and crews may use the auto-pilot system to fly the procedures. If the arrival and approach procedures do not connect, controllers issue vectors to place the aircraft on final.

When referring to the Target aircraft, controllers and pilots use their judgment whether to use the phonetic alphabet or the call sign itself (principally driven by if the call sign is dissimilar to the data tag code or not). For completeness, this appendix shows examples in both formats.

G.1. ATC Issues Preparatory Call for FIM Clearance

Controllers give a preparatory call to the flight crew prior to issuing the FIM clearance to ensure the crew is prepared and can write down the FIM instruction. The preparatory call and the FIM clearance are issued after the “descend via” instruction.

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

Crew: (Call sign), READY TO COPY.

G.2 ATC Issues FIM Clearance Instruction

The en route controller issues the FIM clearance that meets their operational goal and that is appropriate for the geometry and spacing of the FIM and Target aircraft.

G.2.1 CROSS Clearance when the APB and PTP are both the FAF

A CROSS clearance in which the APB and PTP are both the FAF of the FIM aircraft (and therefore the controller does not need to issue them) is:

ATC: (Call sign), FOR INTERVAL SPACING, CROSS FRONZ 120 SECONDS BEHIND SWA3033 ON THE ANCHR2 ARRIVAL.

Crew: (Call sign), FOR INTERVAL SPACING, CROSS FRONZ 120 SECONDS BEHIND SWA3033 ON THE ANCHR2 ARRIVAL.

ATC: ROGER, REPORT PAIRED.

G.2.2 CROSS Clearance when the APB and PTP are both not the FAF

A CROSS clearance in which the APB and PTP are not the same and not the default of the Ownship final approach fix (and therefore the controller does need to issue them) is:

ATC: (Call sign), FOR INTERVAL SPACING, CROSS CTFSH 120 SECONDS BEHIND November Alpha Sierra Alpha Zero Niner ON THE ANCHR2 ARRIVAL, TERMIANTE AT DOGGG.

Crew: (Call sign), FOR INTERVAL SPACING, CROSS CTFSH 120 SECONDS BEHIND November Alpha Sierra Alpha Zero Niner ON THE ANCHR2 ARRIVAL, TERMIANTE AT DOGGG.

ATC: ROGER, REPORT PAIRED.

G.2.3 CAPTURE Clearance

A CAPTURE clearance (Target and FIM aircraft must be on the same route) is:

ATC: (Call sign), FOR INTERVAL SPACING, CAPTURE 120 SECONDS BEHIND United Seven Eight One.

Crew: (Call sign), FOR INTERVAL SPACING, CAPTURE 120 SECONDS BEHIND United Seven Eight One.

ATC: ROGER, REPORT PAIRED.

G.2.4 MAINTAIN Clearance

A MAINTAIN clearance (Target and FIM aircraft must be on the same route) is:

ATC: (Call sign), FOR INTERVAL SPACING, MAINTAIN CURRENT TIME BEHIND SWA3033.

Crew: (Call sign), FOR INTERVAL SPACING, MAINTAIN CURRENT TIME BEHIND SWA3033.

ATC: ROGER, REPORT PAIRED.

G.3 Flight Crew Notification that FIM Operation Commencing

The flight crew notifies the controller when commencing the FIM operation, and include the initial FIM speed.

Crew: (Call sign) IS PAIRED BEHIND U-A-L Seven Eight One. AIRSPEED IS (two-niner-zero) KNOTS.

ATC: (Call sign) ROGER.

G.4 ATC Amendment to the FIM Clearance

Any field of the FIM clearance can be modified except for the Target call sign. Shown here is a change to the ASG of 115 seconds.

ATC: (Call sign), AMENDMENT TO YOUR CLEARANCE. ADVISE WHEN READY TO COPY.

Crew: (Call sign) READY TO COPY.

ATC: (Call sign), SPACE 115 SECONDS BEHIND Sierra Whiskey Alpha Three Zero.

Crew: (Call sign), SPACE 115 SECONDS BEHIND Sierra Whiskey Alpha Three Zero.

ATC: ROGER, REPORT PAIRED.

G.5 ATC Suspending the FIM Operation

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

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

G.6 ATC Resuming the FIM Operation

ATC: (Call sign), RESUME INTERVAL SPACING BEHIND (Delta six-two-two). REPORT PAIRED.

Crew: (Call sign), RESUME INTERVAL SPACING BEHIND (Delta six-two-two). REPORT PAIRED.

G.7 ATC or Flight Crew Cancelling the FIM Operation

The FIM operation can be cancelled by controller or the flight crew.

G.7.1 ATC Cancels the FIM Operation

ATC: (Call sign), CANCEL INTERVAL SPACING, MAINTAIN CURRENT SPEED.

Crew: (Call sign), CANCEL INTERVAL SPACING, MAINTAIN CURRENT SPEED.

G.7.2 Flight Crew Cancels the FIM Operation

Crew: (Call sign), INTERVAL SPACING SUSPENDED, TARGET OFF PATH.

ATC: (Call sign), CANCEL INTERVAL SPACING, MAINTAIN (two-one-zero) KNOTS.

Crew: (Call sign), CANCEL INTERVAL SPACING, MAINTAIN (two-one-zero) KNOTS.

G.8 Flight Crew Check-in with Subsequent Controllers

Until all controllers have FIM information available on their scopes, the flight crew will append their FIM status to the initial check-in with each subsequent controller. The example includes the Target call sign, however in a busy voice environment, only the FIM status of PAIRED is required.

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

ATC: (Call sign), ROGER.

Appendix H: Description of Algorithms

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

H.1 Ground-based Scheduling Algorithm

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

H.2 Controller Managed Spacing Algorithm

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

Slot marker circles are computed via the following process:

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

Speed advisories are computed via the following process:

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

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

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

H.3 Flight-deck Interval Management Algorithm

The FIM software tool provided by the ATD-1 avionics partner for the demonstration should be similar to the ASTAR algorithm [ref 33 - 34] used by the NASA research team. Behavior and design goals of the airborne spacing algorithm include:

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

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