

NASA'S ATM TECHNOLOGY DEMONSTRATION-1: INTEGRATED CONCEPT OF ARRIVAL OPERATIONS

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Abstract

This paper describes operations and procedures envisioned for NASA's Air Traffic Management (ATM) Technology Demonstration #1 (ATD-1). The ATD-1 Concept of Operations (ConOps) demonstration will integrate three NASA technologies to achieve high throughput, fuel-efficient arrival operations into busy terminal airspace. They are Traffic Management Advisor with Terminal Metering (TMA-TM) for precise time-based schedules to the runway and points within the terminal area, Controller-Managed Spacing (CMS) decision support tools for terminal controllers to better manage aircraft delay using speed control, and Flight deck Interval Management (FIM) avionics and flight crew procedures to conduct airborne spacing operations. The ATD-1 concept provides de-conflicted and efficient operations of multiple arrival streams of aircraft, passing through multiple merge points, from top-of-descent (TOD) to touchdown. It also enables aircraft to conduct Optimized Profile Descents (OPDs) from en route altitude to the runway, using primarily speed control to maintain separation and schedule. The ATD-1 project is currently addressing the challenges of integrating the three technologies, and implantation into an operational environment. Goals of the ATD-1 demonstration include increasing the throughput of high-density airports, reducing controller workload, increasing efficiency of arrival operations and the frequency of trajectory-based operations, and promoting aircraft ADS-B equipage.

Introduction

The 2011-2031 Federal Aviation Administration (FAA) Aerospace Forecast predicts commercial aviation will grow on average 3.7% throughout the next twenty years – doubling the number of revenue

passenger miles by 2031 [1]. For domestic flights in 2008, there was a total of approximately 3.2 million hours of gate (departure), taxi-out, airborne, and taxi-in delay, according to the FAA's Aviation System Performance Metrics (ASPM) system. Arrivals into high-density airports, in particular, experience significant inefficiencies due to the use of miles-in-trail procedures and step-down descents. These air traffic control techniques contribute to reduced airport throughput, increased controller workload, increased arrival delay, and increased aircraft fuel burn, emissions and noise.

While more advanced, fuel-efficient arrival procedures, such as Optimized Profile Descents (OPDs), exist at a limited number of sites, current control techniques and arrival scheduling tools do not yet allow for their consistent use during periods of peak traffic [9] due to the lack of supporting scheduling and spacing tools. Capacity in high-density airspace, particularly around major metropolitan airports, is reaching its limit using current technology and procedures, in part due to ground automation that lacks the means to maximize the use of available capacity while enabling performance-based navigation.

Significant research has been conducted both in the United States and Europe to develop trajectory-management tools for enabling aircraft to simultaneously execute efficient descents while maintaining high throughput. Controller advisory tools have been developed that work with current arrival scheduling tools like the FAA's Traffic Management Advisor (TMA) or the European Arrival Manager (AMAN) [2]. However, generally the research systems, as well as the scheduling and control systems, have separated the en route [3] and terminal airspace [4][5] problems and studied them independently. Research and development of flight deck automation using ADS-B In technology has also

been conducted in the US and Europe [6][7]. Some of this research has included scheduling and air traffic control constraints for simple arrival flows [8], but relatively little research has examined fully integrated arrival operations with advanced scheduling systems, controller tools, and airborne spacing for complex arrival flows into congested airports.

NASA's Air Traffic Management (ATM) Technology Demonstration #1 (ATD-1) seeks to integrate and conduct a field demonstration of three NASA technologies to achieve high throughput, fuel-efficient arrival operations into busy terminal airspace: Traffic Management Advisor with Terminal Metering (TMA-TM) for precise time-based schedules to the runway and points within the terminal area; Controller-Managed Spacing (CMS) decision support tools for terminal controllers to better absorb delay using speed control along OPDs, and Flight deck Interval Management (FIM) avionics and flight crew procedures to conduct airborne spacing operations. The integrated arrival solution proposed in ATD-1 is intended to address several objectives, including increasing the throughput of high-density airports, reducing controller workload, increasing efficiency of arrivals through trajectory-based operations, and promoting performance-based navigation and ADS-B equipage.

The ATD-1 Concept of Operations (ConOps) described in this paper provides de-conflicted and efficient operations of multiple arrival streams of aircraft, passing through multiple merge points, from top-of-descent (TOD) to touchdown. It also enables aircraft to conduct OPDs from en route altitude to the runway, using primarily speed control to maintain separation and schedule. The paper begins by describing the ATD-1 technologies, in terms of their alignment with other ATM capabilities planned for the demonstration time frame, as well as their form and functions. It then describes the ConOps

developed to support the ongoing integration and refinement of the component technologies. Each phase of operations is then detailed from flight deck, ATM, and ground perspectives. Where applicable, operational considerations relevant to the planned ATD-1 field demonstration are noted. The paper concludes with a discussion of challenges related to integrating the ATD-1 technologies and implementing them field.

ATD-1 Component Technologies

Goals and Compatibility

The ATD-1 operational goal is to enable aircraft to fly OPDs published as Area Navigation (RNAV) routes from cruise to the runway threshold at a high-density airport during peak traffic demand, using primarily speed control to maintain in-trail spacing and arrival schedule conformance [10][11]. The ATD-1 ConOps has been developed such that each of the three component technologies (Figure 1) contributes specific capabilities toward achieving these objectives: TMA-TM generates a time-based schedule to the runway and meter points; CMS decision-support tools for terminal-area controllers provide better information for managing aircraft delay using speed control; and FIM avionics enable flight crews to conduct airborne spacing operations.

The ATD-1 technologies and procedures are compatible with the FAA's NextGen Mid-Term ConOps [12], Time-Based Flow Management (TBFM) ConOps [13], and the Interval Management–Spacing (IM-S) ConOps [14]. Furthermore, they extend the soon-to-be-fielded Ground-based Interval Management–Spacing (GIM-S) capabilities into terminal airspace [15]. For aircraft, the ATD-1 ConOps leverages the ADS-B capabilities that are a cornerstone of NextGen.

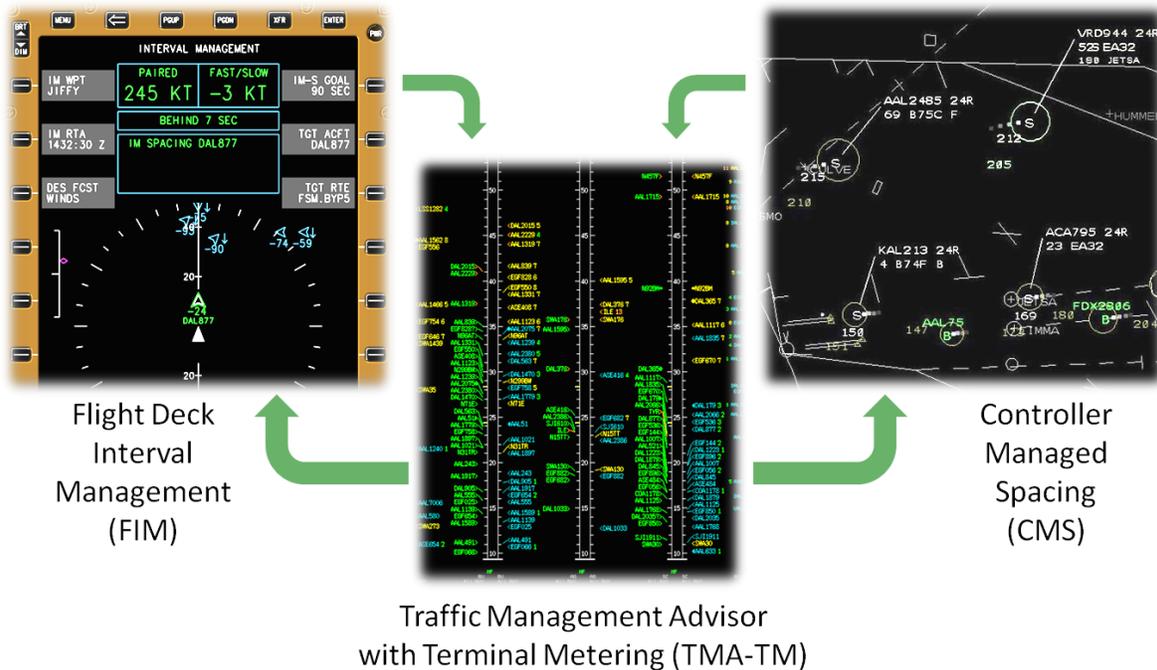


Figure 1. NASA Technologies Integrated in the ATD-1 ConOps

Technology Description

TMA with Terminal Metering (TMA-TM)

A key element of this project is an advanced ATM ground tool that determines an appropriate arrival schedule and the landing time intervals between aircraft, and provides controllers with the information necessary to issue speed clearances appropriate for spacing aircraft close to the minimum time or distance allowed for the runway conditions and meter points. The TMA, as presently deployed by the FAA, provides en route controllers and traffic managers with scheduled times-of-arrival (STAs) that correspond to the desired separations and airport arrival rate, while also meeting other constraints. The FAA is also developing systems for extended metering and coupled scheduling to precondition upstream traffic flows. TMA-TM extends the TMA concept downstream, using knowledge of published RNAV OPDs to sequence and schedule aircraft within the terminal area.

TMA-TM first performs trajectory predictions for arriving aircraft along their projected OPDs and establishes Estimated Times-of-Arrival (ETA) for each aircraft at successive metering and merge points along each aircraft’s flight path to the airport (e.g., en

route metering points, the meter fix, terminal metering points, Final Approach Fix (FAF), and runway threshold). The terminal metering points are typically arrival-procedure merge points where traffic flows converge, and are necessary to ensure that the arrival schedule maintains aircraft separation at these points between the terminal airspace boundary and runway threshold. As each aircraft reaches an airport-specific range or time, referred to as the ‘freeze horizon,’ the TMA-TM locks in a de-conflicted STA at each scheduling point [16][17]. The assigned STAs ensure no time conflicts exist with the preceding aircraft at the various scheduling points. TMA-TM then provides the STA and delay times to the respective en route controllers to maintain the desired flow rates to runways from the en route to the terminal. When flights approach a congested airport, TMA-TM is used to determine how the multiple streams of incoming flights can be sequenced and scheduled to fully utilize the available runways, minimizing delay while meeting all operational constraints.

While TMA and other decision support tools provided ancillary environmental benefits, their primary objective was to reduce delay and increase throughput. The TMA-TM system is a trajectory-

based strategic planning and tactical control tool that performs trajectory predictions, constraint scheduling and runway balancing, controller sequencing and spacing advisories, and flow visualization. The trajectory prediction, constraint scheduling, and runway balancing functions are built upon the existing TMA capabilities. The schedules and trajectory predictions are in turn leveraged to produce information required to display CMS decision support tools to controllers, following the methodologies developed in prior Controller Managed Spacing (CMS) and Efficient Descent Advisor (EDA) research.

Controller-Managed Spacing (CMS)

CMS tools assist terminal-area controllers in achieving their goal of maximizing use of OPDs during congested operations [18][19]. Using 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 accurately achieve arrival schedule conformance using speed commands. This information allows terminal controllers to reduce the use of tactical vectoring, thereby enabling aircraft to maintain fuel-efficient arrival procedures from cruise to touchdown. Among the CMS tools planned for display on the Standard Terminal Area Replacement System (STARS) workstation (Figure 2) are:

- Early/Late Indicators (left) – The information in the third line of the aircraft’s Full Data Block (FDB) enables controllers to quickly assess the schedule-conformance information for a particular aircraft. An early/late indicator serves the same purpose as the delay countdown timer (DCT) presently available to en route controllers.
- Slot markers (middle) – Slot markers (or slot-marker ‘circles’) translate the temporal schedule information into a spatial target on the controller’s planview display. They indicate where an aircraft should be at the present time if it were to fly the remainder of the RNAV OPD, meeting all published speed and altitude restrictions, and arrive on schedule.

- Speed advisories (right) – Speed advisories displayed in the aircraft’s FDB help controllers formulate speed clearances. The advisories depicted in Figure 2 are formulated such that flying the advised speed until rejoining the arrival procedure’s nominal speed profile at the named fix is predicted to place the aircraft on schedule by the fix. A speed advisory can be configured to replace an early/late indicator in a FDB, when an advisory for that aircraft is available.

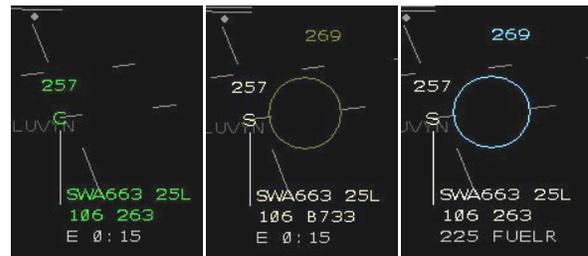


Figure 2. Potential CMS Displays

Flight Deck Interval Management (FIM)

FIM enables the flight crew to actively assist both en route and terminal controllers in maximizing throughput on capacity-constrained runways by precisely achieving the assigned spacing interval behind the preceding aircraft [6][20]. En route controllers issue the FIM clearance after an aircraft crosses the TMA-TM freeze horizon, once speed control alone is expected to be sufficient to meet the schedule. A flight crew enters the FIM clearance information into the FIM avionics, and then follows the speeds it calculates along the RNAV OPD.

A FIM clearance contains the Assigned Spacing Goal (ASG) and the Target (lead) aircraft’s callsign. Other elements may be included in the clearance if available to the controller and necessary to achieve the desired spacing goal. In cases where the Target aircraft is not yet within ADS-B range, an STA at the achieve-by point is included as part of the FIM clearance from ATC. The STA allows the aircraft to begin absorbing any necessary delay prior to being within ADS-B range. In addition, the airborne spacing tool requires information about the Target’s arrival procedure if that aircraft is not on the same

route as the FIM aircraft. The Target may be on the same or different arrival procedure as the FIM aircraft (and therefore cross the terminal boundary at a different meter fix). The following is an example of a FIM clearance, and the corresponding cockpit indications on an Electronic Flight Bag (Figure 3):

FOR INTERVAL SPACING, CROSS JIFFY AT 1432:30Z. WHEN ABLE, SPACE 90 SECONDS BEHIND DAL877 ON THE BONHAM FIVE ARRIVAL, FORT SMITH TRANSITION.



Figure 3. Electronic Flight Bag with FIM clearance and Target aircraft

The FIM avionics will continually correct towards, and finally achieve, the ASG behind the

Target by the Achieve-By Point. The Final Approach Fix is planned for use as the Achieve-By Point in the ATD-1 demonstration. The FIM technology required for aircraft systems may be either forward-fit in advanced aircraft (in particular, fully integrated with the Flight Management System), or retro-fitted in currently operational aircraft (via an Electronic Flight Bag and ADS-B Guidance Display). The retrofit option will be used during the ATD-1 demonstration.

ATD-1 Concept of Operations

Overview

ATD-1 operations begin during the en route portion of an aircraft's flight, prior to TOD, and continue until touchdown (Figure 4). For each meter point, TMA-TM calculates a schedule to meet the required aircraft separation and to condition the traffic flow with the necessary amount of delay. The resulting STAs drive the GIM-S and CMS controller displays, and enable formulation of FIM clearances by determining Targets and ASGs. Aircraft navigate along RNAV OPDs that include transitions to connect the Standard Terminal Arrival Route (STAR) to the Standard Instrument Approach Procedure (SIAP). This allows flight crews to use their onboard FMS capabilities to navigate the aircraft and to fly fuel-efficient OPDs. The ATD-1 operations and displays should allow controllers to keep aircraft on their assigned OPDs using more speed control and fewer vectors to meet the required times at the metering points, FAF, and the runway.

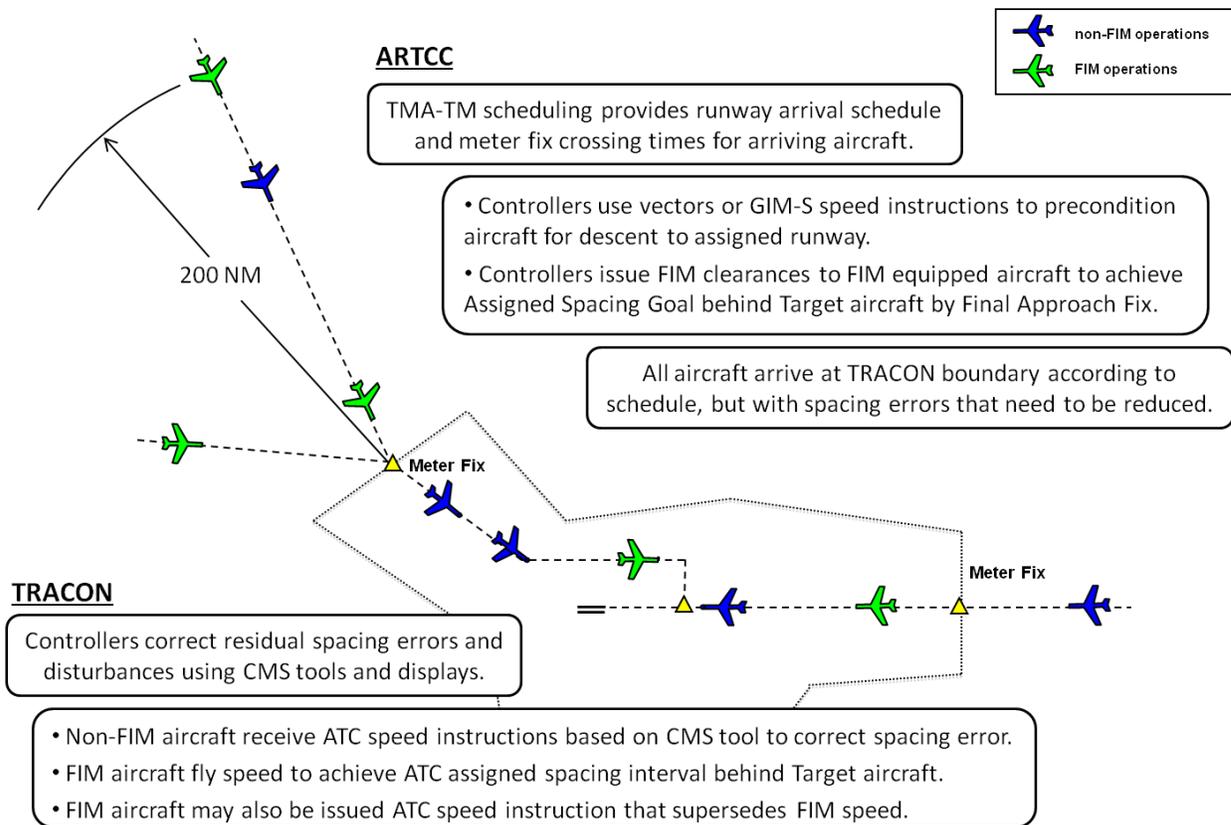


Figure 4. ATD-1 Operations

Phases of the ATD-1 ConOps

The ATD-1 ConOps consists of five chronological phases: scheduling, preconditioning, initiation, operations, and termination. The following subsections describe each phase from relevant flight-deck, controller, and ground-automation perspectives.

Scheduling Phase

The scheduling phase occurs while the aircraft is still at cruise altitude, and is nominally complete when the aircraft crosses the freeze horizon established for the destination airport. As aircraft are still well before their TODs, TMA-TM acquires them and begins updating their ETAs. The ETA computations consider the aircraft’s route-of-flight, its intended speed profile, and the forecasted winds. When the aircraft crosses the freeze horizon (specified as 200 nmi for the airport in Figure 4),

TMA-TM locks in the STA at each scheduling point (unless manually changed by air traffic control), while the ETA calculation continues to be updated by TMA-TM. The STA is then made available for computations underlying CMS tools, and if appropriate, a FIM clearance for that aircraft is also provided to the controller.

TMA-TM calculates the STA for each meter point to meet or exceed the required aircraft separation, and to distribute the amount of required delay to enable speed control alone to be sufficient. If the necessary amount of delay exceeds what can be achieved by speed control alone, that delay is successively passed back to upstream meter points. As a result, aircraft absorb more of their required delay at higher altitudes, which is generally more fuel-efficient.

The STA at each scheduling point becomes the control target for controllers. En route controllers will

use their current displays and GIM-S software to achieve the time calculated at enroute meter points by TMA-TM, and terminal controllers will receive schedule information as well as CMS advisories and spacing circles on their STARS display to correct the remaining time error. Transmission of FIM clearance information from TMA-TM to the en route controller displays will not be implemented in time for the ATD-1 demonstration; therefore, FIM clearances will be formulated and manually provided to controllers. The ATD-1 ConOps anticipates no new phraseology or coordination tasks for controllers or flight crew during the scheduling phase.

Preconditioning Phase

The preconditioning phase of the ATD-1 ConOps is designed to ensure that aircraft can be controlled using speed alone, either via FIM operations or controller management using CMS tools. Ideally, this phase would be unnecessary, with upstream flow conditioning yielding schedule errors for arriving aircraft that are already small enough to correct using speed control. However, when there is too much delay to absorb using speed, en route controllers will use speed combined with path stretching (i.e., heading vectors) to absorb enough delay to make speed-only control feasible. If required, the preconditioning phase begins after an aircraft crosses the freeze horizon and its STAs have been established.

Activities during this phase include controllers issuing vectors (path-stretching) to aircraft that are predicted to not meet the meter time STA with speed control alone. When speed control alone is not sufficient, the GIM-S (en route) and CMS (terminal) speed advisories will not be displayed. No new unique ATD-1 phraseology or coordination tasks are anticipated in this phase for controllers or flight crew.

Initiation Phase

The initiation phase of the ATD-1 ConOps marks the point when en route controllers are able to achieve the TMA-TM STA for a particular aircraft using speed control only. Events in this phase include issuing the arrival route and assigned runway to all aircraft and, for suitably equipped aircraft, the FIM clearance. En route controllers also issue speed

instructions to meet the meter point STA using information from the GIM-S display to aircraft not equipped for FIM operations.

The controller issues the FIM clearance as soon as feasible after the freeze horizon; that is, after the arrival sequence has been determined and vectors are no longer needed to achieve the required time delay. Ideally, a flight crew will receive the FIM clearance prior to TOD, and it will include the STA at the achieve-by point (the FAF during the ATD-1 demonstration), the Target aircraft's identifier and route (if the Target is on a different route), and the ASG (the time interval behind the Target at the achieve-by point). Beyond the demonstration timeframe, this information could be provided in the en route controller's meter list.

After the flight crew determines the FIM speed is feasible, they notify ATC that they are commencing Interval Spacing operations and fly the aircraft along the published arrival, following the speed commands calculated by the onboard FIM spacing software.

Examples of phraseology given by controllers to flight crew are given below.

- Route and runway assignment:

DESCEND VIA THE MAIER THREE ARRIVAL, BOULDER CITY TRANSITION, EXCEPT AFTER KUCOO EXPECT BLINE, CERUN, RUNWAY TWO-SIX.

- FIM clearance:

FOR INTERVAL SPACING, CROSS JIFFY AT 1432:30Z. WHEN ABLE, SPACE NINE-ZERO SECONDS BEHIND DELTA EIGHT-SEVEN-SEVEN ON THE BONHAM FIVE ARRIVAL, FORT SMITH TRANSITION.

Operations Phase

The operations phase occurs once speed control alone along the assigned route is sufficient to meet the STA, and after the en route controller issues the FIM clearance. If the aircraft must be vectored off the RNAV OPD to achieve other operational objectives, the ATD-1 ConOps operational phase may be considered over.

During the operations phase, en route and terminal controllers issue speed instructions to aircraft not equipped for FIM operations to absorb

delay and correct residual schedule-time errors. When speed control alone is not sufficient, the GIM-S and CMS speed advisories will not be displayed. However, as long as an aircraft has an STA and a nominal RNAV route for the aircraft is known to the TMA-TM, the CMS slot marker circles can still be displayed to facilitate the return of the aircraft to the RNAV procedure after vectoring.

Controllers monitoring aircraft conducting FIM operations may also ‘suspend’ and ‘resume’ FIM operations any time operational needs require it. This is expected to be particularly useful when the aircraft is below 10,000 feet and minimal flight crew interaction with the avionics is desired. For the crew, the ‘suspend’ action requires a single button push to remove FIM information from cockpit displays while retaining the information from the FIM clearance in the spacing software; for the ‘resume’ action, a single button push restores the FIM guidance.

A controller may also ‘amend’ the FIM clearance by changing the ASG. Any changes to the FIM clearance STA, Target, Target route, or FIM aircraft route require ATC to ‘terminate’ the FIM clearance, then issue a new one (if desired). Amending a FIM clearance requires less workload for the flight crew, and provides the FIM speed guidance more quickly.

Once a FIM operation has begun, the flight crew operates the aircraft in accordance with normal procedures, with the exception that the FIM speed supersedes the RNAV STAR speed. If a flight crew is no longer able to follow their FIM speed command or experiences a system error, they should contact air traffic control to terminate spacing operations, and the controller should use the CMS tools as appropriate to issue speeds to the aircraft. Flight crews are also required to announce to each receiving controller they are conducting FIM operations.

Examples of phraseology given by controllers to flight crew are:

- Descent with CMS speed

DESCEND VIA THE MAIER THREE ARRIVAL, BOULDER CITY TRANSITION, EXCEPT MAINTAIN TWO-SEVEN-ZERO KNOTS UNTIL DRAKE.

- Amend FIM clearance

AMEND INTERVAL SPACING CLEARANCE. SPACE ONE-THREE-FIVE SECONDS BEHIND TARGET.

- Suspend FIM operation

SUSPEND INTERVAL SPACING, SLOW TO TWO-THREE-ZERO KNOTS.

- Resume FIM operation

NASA ONE-SEVEN, RESUME INTERVAL SPACING.

- Report the FIM clearance

NASA ONE-SEVEN, REPORT INTERVAL SPACING CLEARANCE.

Examples of phraseology given by flight crew to controllers to are given below.

- Commencing FIM operation

NASA ONE-SEVEN, INTERVAL SPACING BEHIND DELTA EIGHT-SEVEN-SEVEN.

- Check-in while conducting FIM

NASA ONE-SEVEN PASSING ONE-TWO THOUSAND, INTERVAL SPACING.

Termination Phase

The nominal termination of the ATD-1 ConOps for a particular aircraft is at the FAF of the SIAP that is part of the RNAV OPD (approximately five nautical miles from the runway threshold). Controllers or flight crew may terminate use of the TMA-TM timeline, CMS tools, or FIM spacing guidance at any time if operational considerations require it.

If the operation terminates at the FAF, there are no ATD-1-specific events or required phraseology. If a controller ceases to use GIM-S or CMS tools, no ATD-1-specific phraseology or actions are required. However there is specific phraseology required if FIM operations are terminated prior to the FAF by either the controller or the flight crew.

Examples of phraseology used to terminate FIM operations prior to the FAF are:

- FIM operation terminated by ATC

(ATC): NASA ONE-SEVEN, CANCEL INTERVAL SPACING, RESUME PUBLISHED SPEED.

(Crew): CANCEL INTERVAL SPACING, RESUME PUBLISHED SPEED, NASA ONE-SEVEN.

- FIM operation terminated by flight crew

(Crew): NASA ONE-SEVEN UNABLE INTERVAL SPACING, NO TARGET AIRCRAFT DATA.

(ATC): NASA ONE-SEVEN, CANCEL INTERVAL SPACING, CONTINUE ON THE BONHAM FIVE ARRIVAL, MAINTAIN TWO-FOUR-ZERO KNOTS.

Crew: NASA ONE-SEVEN, CANCEL INTERVAL SPACING, CONTINUE ON THE BONHAM FIVE ARRIVAL, MAINTAIN TWO-FOUR-ZERO KNOTS.

Challenges

Integration of Technologies

The seamless integration of three different technologies is an important challenge for ATD-1, since each technology was originally supported by different users and each has a slightly different methodology to solve the same operational problem. A key example is ensuring that the algorithm used by TMA-TM to estimate time-deconflicted STAs at every meter point behaves similarly to the spacing algorithm onboard the FIM equipped aircraft. Aircraft conformance to STAs will need to be determined, for both aircraft responding to controller speed advisors and aircraft conducting FIM operations. Limits also need to be defined when it is not suitable for a FIM clearance to be issued (the difference between aircraft location estimated by TMA-TM and location driven by the FIM speed exceeds a defined criteria).

Controller and flight crew procedures during off-nominal events have been under common development, however, they need to be validated in operationally challenging simulations with both live subject controllers and subject pilots. Some of the events currently under study include an aircraft go-

around that needs to be reinserted into the arrival stream and reordering the arrival sequence of aircraft.

Operational Implementation

The air traffic control environment in 2015 to 2017 (the approximate ATD-1 demonstration time-frame) will not have all the functionality envisioned by the research of the three technologies. Examples include data communication, expanded ADS-B message sets, FIM information available to controllers, etc. Furthermore, the design and implementation of published trajectories (latitude, longitude, altitude, and speed) from the en route airway structure to the assigned runway will be only partially complete by this time.

Another significant challenge is not all of the ATD-1 controller displays, nor the communication link between TMA-TM and the controllers, will be available by the demonstration time-frame. Finding a feasible alternative solution that does not compromise the assessment of ATD-1 technologies will be an important challenge.

Summary

The number of aircraft operations is predicted to continue increasing for the next 20 years. NASA, in partnership with the FAA and many aviation industry stakeholders and experts, has been conducting research to achieve more efficient air traffic operations that are needed to reduce current delay and to support the projected increase in traffic. The ATD-1 concept of operations integrates three of these research efforts, TMA-TM, CMS, and FIM. Each exhibit benefits individually, however when integrated will realize significantly more benefits, especially at high-density airports during peak traffic periods.

The advanced scheduling of TMA-TM within terminal airspace allows better planning of arrival operations by considering separation at key merge points, and creates a time-deconflicted arrival sequence for each runway. The CMS tools use this schedule to provide controllers information to achieve the appropriate time at meter fixes. The TMA-TM schedule also generates the information needed by the FIM equipment, which enable flight crew procedures that produce precise spacing behind

the preceding aircraft. The ATD-1 operation is divided into five phases: schedule, precondition, initiation, operation, and termination. Controller and flight crew procedures are described for each phase of the operation, and examples of phraseology for ATD-1 specific communication are given.

Seamless integration of the three technologies is an on-going effort, ranging from algorithm performance characteristics to procedures during off-nominal events. Work is also under way to address the challenge of implementing the ATD-1 operations in a current day, real-world environment that does not yet fully support trajectory-based operations from en route airspace to the runway threshold.

The goals of the ATD-1 demonstration include retaining maximum capacity of high-density airports, reducing controller workload, increasing efficiency of arrival operations and the frequency of trajectory-based operations, and promoting aircraft ADS-B equipage.

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