NASA's ATM Technology Demonstration-1: Transitioning Fuel Efficient, High Throughput Arrival Operations from Simulation to Reality

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ABSTRACT

In this paper, we describe NASA's Air Traffic Management Demonstration-1 (ATD-1). The objective of ATD-1 is to operationally demonstrate the feasibility of fuel-efficient, high throughput arrival operations using ground-based and airborne NASA technologies for precision scheduling and spacing in conjunction with Automatic Dependent Surveillance Broadcast (ADS-B). ATD-1 integrates three research efforts that were conducted in the simulation laboratories at NASA's Ames and Langley Research Centers in parallel for many years into the Interval Management-Terminal Area Precision Scheduling System (IM-TAPSS). IM-TAPSS will be further fine-tuned, verified and validated in laboratories and transitioned to a field prototype for an operational demonstration at a major US airport targeted for 2015. This paper describes the ATD-1 concept of operations, IM-TAPSS core components, research results to date, and the ATD-1 plans and status.

Keywords

Scheduling, automation, ADS-B, interval management, controller tools, terminal area, terminal metering, technology demonstration

INTRODUCTION

The FAA forecasts commercial aviation will grow on average 3.7% over the next twenty years, with the number of revenue passenger miles to double by 2031 [1]. Arrivals into high-density airports, especially during peak periods and inclement weather, experience significant inefficiencies resulting from use of miles-in-trail procedures and step-down descents. Use of these current procedures contribute to reduced airport capacity, high controller workload and increased arrival delay, as well as increased aircraft fuel burn, emissions and noise.

Advanced avionics and ground-based decision support tools are expected to enable significant increases in the capacity and efficiency of the National Airspace System (NAS). Arrival scheduling and merging and spacing tools are integral parts of the FAA's Next Generation Air Transportation System (NextGen) [2] and Europe's Single European Sky ATM Research (SESAR) Joint Undertaking [3]. Arrival scheduling will efficiently balance the demand for congested airspace and airports, and merging and spacing tools will allow controllers and flight crews to meet those schedules more precisely. Aircraft will use ADS-B satellite-based surveillance technology to share information with air traffic controllers and nearby aircraft.

NASA has a long history of research and technology development in the areas of air traffic management (ATM), air traffic control (ATC), and flight guidance. Among them are three arrival management technologies for planning and executing efficient arrival operations in the terminal environment of a high-density airport. Indicated in Fig. 1 are the core components of the Interval Management-Terminal Area Precision Scheduling System (IM-TAPSS) [4]:

- TMA-TM: Traffic Management Advisor with Terminal Metering (TMA-TM) for generating precise time-based schedules to the runway and intermediate merge points within the terminal area [5]
- CMS: "Controller-Managed Spacing" (CMS) decision support tools for terminal area controllers to manage aircraft schedule and spacing conformance along efficient descent profiles [6]
- FIM: "Flight deck Interval Management" (FIM) aircraft avionics and flight crew procedures to conduct efficient airborne spacing operations from cruise to touchdown [7]

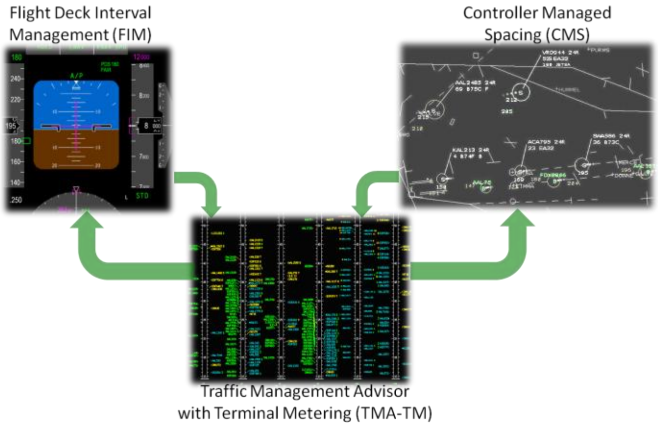


Figure 1. ATD-1/IM-TAPSS core components

NASA initiated the ATM Technology Demonstration (ATD) sub-project within the Airspace Systems Programs System Analysis Integration and Evaluation Project in 2011 to focus on operational demonstrations of innovative NASA technologies that have attained a sufficient level of maturity in the foundational stage and merit more in-depth research at the system level in relevant environments. IM-TAPSS is the first such ATD activity, referred to as ATD-1.

Within NASA, ATD-1 is a collaborative effort between the Ames and Langley Research Centers. Engagement with the stakeholder community is vital to achieving the ATD objectives regarding the benefits, costs, and operational feasibility of its concepts and technologies. The key stakeholders are the aeronautics and research and development communities, aircraft and avionics manufacturers, system integrators, aircraft owners and operators such as commercial airlines, and key government agencies such as the Joint Planning and Development Office (JPDO) and the Federal Aviation Administration (FAA).

This paper is organized as follows: In the following section, we will review the complexities associated with conducting fuel-efficient descents in busy terminal areas and briefly discuss related research. Next, we will explain the IM-TAPSS approach and concept of operations. Then, we will review the NASA technologies and research results to date that were largely gathered in Human-In-The-Loop (HITL) simulations. Lastly, we will outline how we intend to progress from the laboratory to the operational demonstration and conclude with a summary of goals and success criteria.

PROBLEM: EFFICIENT DESCENTS IN BUSY TERMINAL AIRSPACE

In today's operations, an aircraft landing at a high-density airport generally executes a series of step-down descents starting at its cruise altitude along a published airway, transitions to a Standard Terminal Arrival Route (STAR), and enters terminal airspace at a metering fix or corner-post. At this point the aircraft is handed off from en route controllers in the Air Route Traffic Control Center (ARTCC) to approach controllers in the Terminal Radar Approach Control (TRACON). The aircraft will continue to fly the STAR; however, since most STARS do not connect to the runway, approach controllers eventually issue radar vectors to the final approach course.

During periods of light to moderate traffic, aircraft may be able to conduct a fuel-efficient descent from cruise to the runway called an Optimized Profile Descent (OPD). Typically, these operations are not feasible during periods of heavy traffic due to the variability and unpredictability of the aircraft trajectories. Uncertainties in the aircrafts' descent profiles and landing times can be accommodated if there is enough extra spacing between aircraft; this is usually the case in light traffic (for example late at night). Imposing larger spacing at the runway to enable OPDs during congested periods would lead to a significant reduction in runway throughput, thus increasing delays, and reducing efficiency.

In order to maintain throughput during periods of heavy traffic, significant research has been conducted both in the United States and Europe to develop trajectory management tools enabling aircraft to simultaneously execute efficient descents while maintaining separation with other aircraft and high throughput. This research has added controller advisory tools to work in concert with current arrival scheduling tools like the FAA's Traffic Management Advisor (TMA) [8] or the European Arrival Manager (AMAN) [9]. However, these research systems are usually limited to either en-route [10] or terminal airspace [11, 12] only application.

In addition to research on controller aids, flight-deck based technologies for precise spacing are enabled through the introduction of ADS-B In and Out. Research, simulation and field trials on airborne precision spacing have been conducted in the US and Europe, [13, 14]. While some of this research has included scheduling and air traffic control aspects for simple arrival flows [14, 15], to our knowledge, little to no research has looked at fully integrated arrival operations with advanced scheduling systems, controller tools, and airborne spacing for complex arrival flows into congested airports.

Since the efficient scheduling and control of aircraft from cruise to touchdown during congested periods is a highly complex problem, current procedures and arrival scheduling tools do not yet allow use of advanced arrival procedures such as Area Navigation (RNAV) OPDs during periods of peak traffic [16]. IM-TAPSS is intended to enable fuel-efficient, high throughput arrival operations for complex arrival flows in busy terminal areas.

APPROACH: INTEGRATION OF PRECISE SCHEDULING AND SPACING CAPABILITIES

In the previous section, we touched on some of the complexities associated with current operations and arrival management technologies. The IM-TAPPS approach integrates the ground-based and airborne scheduling and spacing solutions in order to transition from today's largely ad hoc tactical terminal area operations to the NextGen vision of precise trajectory-based operations. This is expected to simultaneously increase the use of OPDs (i.e., decrease fuel burn) and reduce excess spacing (i.e., increase throughput).

Figure 2 shows a notional depiction of the progression from today's operations to full NextGen operations in terms of the IM-TAPSS scheduling and spacing capabilities [16].

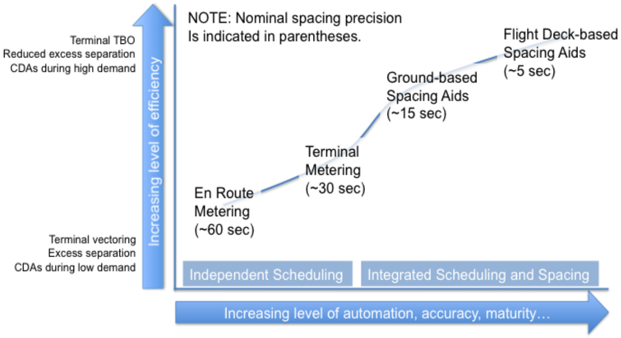


Figure 2. Notional depiction of transition from terminal vectoring to terminal trajectory-based operations [16]

Current day NAS operations provide independent scheduling and manual en route metering to terminal area boundaries with a precision (3σ) of approximately one minute. Ongoing modernization efforts will add controller tools to reduce vectoring and increase efficiency in the en route domain. [10]

IM-TAPSS is moving towards fully integrated scheduling and spacing along RNAV OPDs. It uses terminal metering to provide de-conflicted meter times at merge points. Controllers use ground-based CMS aids to manage the speed of unequipped aircraft to meet these times as precisely as necessary. Flight crews use FIM aids to further increase the inter-arrival spacing precision. In the next section, we describe the concept of operations using an operational scenario.

IM-TAPSS CONCEPT OF OPERATIONS

In order to introduce the concept of operations, we use the operational scenario depicted in Figure 3.

IM-TAPSS focuses on the arrival phase of flight, beginning just prior to the aircraft's top-of-descent. Aircraft are navigating along RNAV OPDs. The RNAV OPDs include runway transitions that connect to instrument approach procedures. These advanced arrival procedures allow flight crews to use their onboard FMS capabilities to fly from cruise to landing without controllers providing radar vectors to the final approach course.

An arrival schedule is generated that includes fix crossing times for en route meter points, as well as terminal meter points. Arriving aircraft are assigned runways and fix crossing times at approximately 100 NM from entry into terminal airspace. The terminal meter points are arrival procedure-specific merge points where traffic flows converge. These additional meter points are necessary to ensure that (1) the arrival schedule considers separation constraints at important merge points between the arrival meter fix and runway threshold, and (2) all aircraft maintain the arrival schedule from top of descent to the runway. This allows for seamless merging of aircraft spaced by controllers using CMS technologies (referred to as CMS aircraft) and aircraft spaced by flight crews using FIM technologies (referred to as FIM aircraft).

At each meter point, scheduled times-of-arrival are calculated that meet the required aircraft separation and successively condition the traffic flow with the necessary amount of delay. In order to ensure speed control alone is sufficient to maintain aircraft separation, the amount of delay absorbed between each meter point is carefully distributed. Delay that exceeds the amount afforded by speed control alone 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.

Once the initial delay is absorbed such that the arrival plan can be implemented with speed control alone CMS aircraft receive speed instructions from en route and terminal area controllers to meet the scheduled times of arrival at the associated merge fixes, and FIM aircraft receive instructions to initiate FIM operations for precise spacing behind their designated lead aircraft.

The FIM operation is initiated near top-of-descent when the flight crew receives a clearance from the controller to begin spacing. The clearance includes the target aircraft's identifier, the spacing goal (e.g., spacing interval and achieve-by point) and, in cases where the target aircraft is not yet within ADS-B range or there is no ADS-B equipped target aircraft, an RTA at the achieve-by point. In addition, the FIM application uses the arrival procedure of the target aircraft and its planned final approach speed (if the achieve-by point is the runway threshold).

With the proper setup in the en route airspace, FIM and CMS aircraft arrive at the intermediate merge points with residual spacing errors that can be corrected by small speed adjustments by the flight crews of FIM aircraft and by the controllers for CMS aircraft.

IM-TAPSS TECHNOLOGIES

IM-TAPSS utilizes and integrates NASA technologies for scheduling, controller spacing aids and FIM algorithms. The following is a description of these technologies:

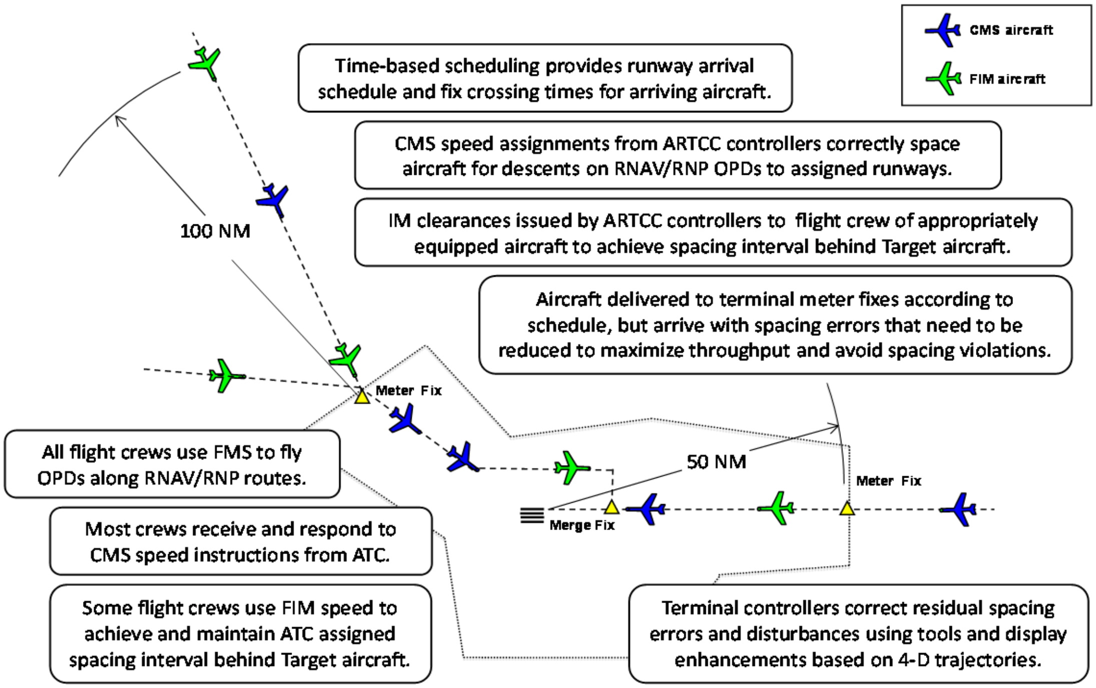


Figure 3. Operational scenario for IM-TAPSS

Traffic Management Advisor with Terminal Metering (TMA-TM)

A key element of IM-TAPSS is an advanced ground tool for ATM that determines an appropriate arrival schedule and landing time intervals between aircraft, and then computes the appropriate speed required to space aircraft close to the minimum time or distance allowed by the runway conditions. The FAA's TMA, as presently deployed, assists ARTCC controllers and traffic managers in meeting scheduled times of arrival (STA) to closely match the desired separations and Airport Arrival Rate, among other constraints. Extended metering and coupled scheduling is used to coordinate flows from multiple ARTCCs feeding an airport close to their boundaries where the basic TMA would not suffice.

While TMA and time–based metering in the en route provide ancillary environmental benefits, the primary objective of each is to reduce delay or to increase throughput. TMA-TM extends the current arrival scheduling capabilities of TMA and incorporates the terminal metering capabilities planned for and described in the FAA's Time-Based Flow Management (TBFM) and IM mid-term plans. In particular, TMA-TM creates additional meter points in terminal airspace at critical merge points along the entire route to the runway threshold.

The TMA-TM enhancements are focused on enabling use of advanced arrival procedures that reduce fuel burn, emissions and noise impact. These enhancements include modifications to the terminal delay model to accurately reflect the reduced terminal area flight times for OPDs. This enables the conduct of efficient arrivals with increased metering precision to provide the required separation at all merge points. The TMA-TM system is a trajectory-based strategic and tactical planning and control tool that consists of trajectory prediction, constraint scheduling, runway balancing, controller advisories and flow visualization. The improved terminal area trajectory prediction, constraint scheduling and runway balancing functions are built into TMA-TM in line with the existing TMA design.

Simulation and associated analyses have shown that TMA-TM is beneficial in the development of a fully integrated trajectory-based system that enables both greater airport throughput and more fuel-efficient operations from cruise to touchdown for NextGen. Figures 4 and 5 show results from HITL simulations using the TAPSS system [5], which includes the ground-based components of the IM-TAPSS system described here.

Figure 4 plots the throughput for a 10% demand increase scenario at Los Angeles International airport (LAX). Throughput is referenced to aircraft landed per hour as a running average. The green line represents aircraft throughput if they are not delayed and allowed to fly without intervention by controllers. This would cause hundreds of separation violations at the various merges and is shown only for reference purposes; it represents the unconstrained demand on the airport in this scenario. The red line was a run using the current TMA tools and exhibited the classic TMA front-loading behavior, before the throughput reaches the steady current airport acceptance rate. The blue line shows the TAPSS tools condition. The TAPSS tool had a higher average and peak throughput at times achieving 84 aircraft/hour and provided an average throughput increase of 10% under the same demand as compared to today's ATC operation using TMA.

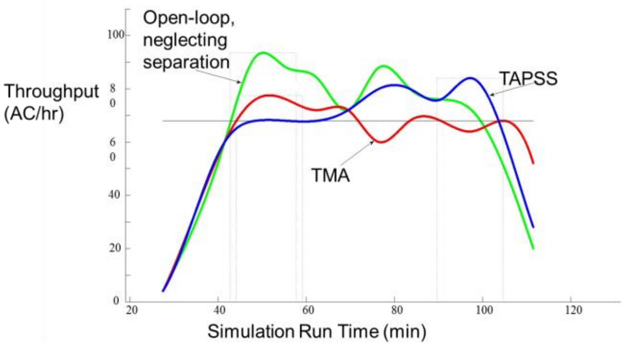
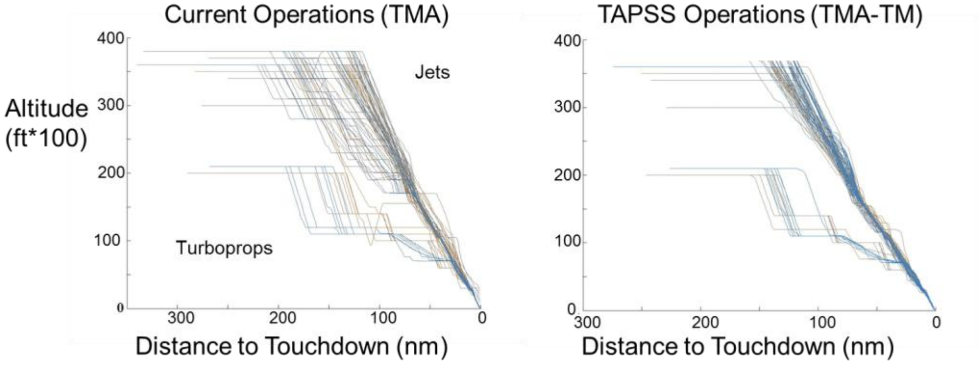


Figure 4. Airport throughput comparison [5]


Current Operations (TMA)

TAPSS Operations (TMA-TM)

Figure 5. Comparison of descent profiles between simulated current day operations using TMA and TAPSS operations using TMA-TM, EDA and CMS [5]

Figure 5 suggests that while throughput was increased, fuel efficiency was also increased. The aircraft altitude is shown as a function of range to touchdown. As can be clearly seen, the TAPSS tools (Fig. 5 right) enable many more efficient descent operations from cruise to touchdown for the jet aircraft. This is contrasted sharply with the TMA operations (Fig. 5 left) in which the Center controllers used step-down descents to meter the aircraft. Details of this simulation and these results are discussed in [5].

Controller-Managed Spacing (CMS)

The 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 schedule that en route controllers used to manage the flows of traffic into the terminal airspace. The CMS tools provide the information necessary to achieve arrival schedule conformance using speed commands. This information is intended to allow controllers to reduce the use of tactical vectoring, thereby enabling aircraft to fly the arrival procedure as efficiently as possible [6, 11].

Figure 6 illustrates the controller decision support tools used during the CMS research and development.

Timelines (left-most box) have been used by traffic management personnel operating TMA for over a decade. With the increased precision of TMA-TM, timelines become increasingly useful on the controllers' scopes as well. Timelines allow controllers to visually assess the overall merging and spacing situation at meter fixes, intermediate merge points and the runway including each aircraft's schedule conformance by comparing its estimated time-of-arrival (ETA) with its STA. The difference between the aircraft's ETA and STA is also shown as an *early/late indicator* in the aircrafts Full Data Block (FDB) (left box in top row). This enables controllers to monitor schedule-conformance for each aircraft without taking their eyes from the primary traffic display.

Slot marker circles (middle box in top row) translate the temporal schedule to a spatial target on the controller's display. The slot marker circles indicate where an aircraft would be now if it were to fly the RNAV OPD, meeting all published speed and altitude restrictions, and arrive on schedule at the next merge point or an intermediate waypoint. Slot markers provide a powerful graphical reference to monitor the aircrafts' progress towards absorbing delay or catching up. Keeping aircraft close to or within their slot marker enables seamless merging operations and helps ensure controllability by downstream controllers.

Speed advisories (right box in top row) show an airspeed and fix name in the aircraft's FDB to help controllers formulate trajectory-based speed clearances. Flying the advised speed until rejoining the nominal OPD speed profile at the named fix is predicted to place the aircraft back on schedule by that fix. Speed advisories replace the early/late indicator in an aircraft's FDB when spacing errors exceed a prescribed minimum threshold and an appropriate advisory can be computed.

CMS research has been conducted in a series of HITL studies and included analyzing the effectiveness of these tools, the associated controller workload, and the tool usage and acceptability. One of these simulations investigated how well controllers could control aircraft to land them as close to their STA as possible using speed control alone. Controllers were assigned one of three levels of tools: (1) *Timeline:* timelines and early/late indicators, (2) *Slot marker:* timelines, early/late indicators and slot markers, (3) *Advisory:* timelines, slot markers and speed advisories. Controllers also had to compensate for errors in the forecasted winds that had not been taken into account by the scheduler. Results show that speed clearances were sufficient under all conditions to maneuver aircraft closer to their STAs. From participant reports, this form of control incurred acceptable workload and two of the three levels of tools were deemed easy to use [6][11].

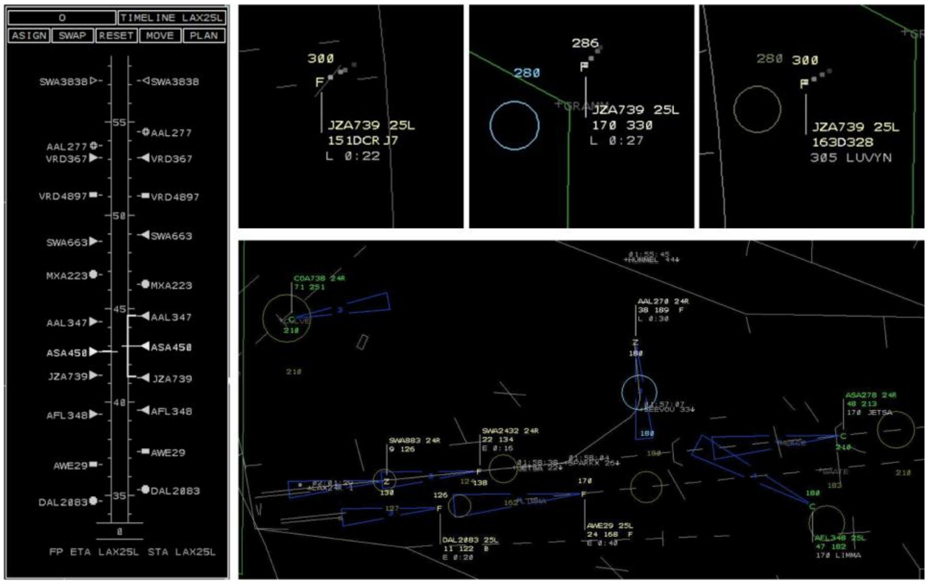


Figure 6. Clockwise from the left: (a) timeline including spacing bracket, (b) Full Data Block (FDB) with early/late indicator, (c) dwelled FDB and slot marker (d) FDB, slot marker and seed advisory (e) spacing cones and route display.

That study found that controllers reported they used the slot markers 93% of the time in the advisory condition and 90% of the time in the slot marker condition. Controllers also reported they used the speed advisories 30% of the time. Controllers' commented that they preferred the slot markers over the speed advisories and the timelines as their "tool of choice". Controllers used the early/late indicators about the same amount in the timeline and slot marker conditions but more than they reported using the speed advisories that replaced them in the advisory condition. Fig.7 illustrates these results. Details and additional findings are available in [6, 11].

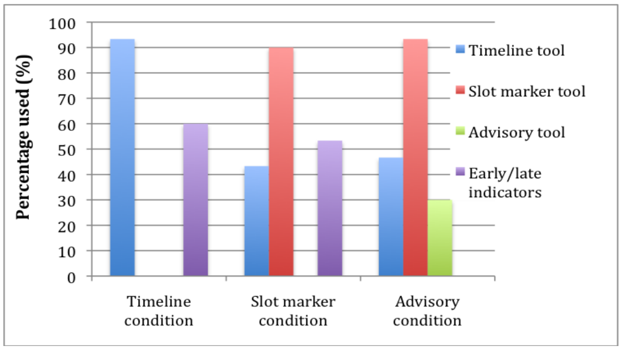


Figure 7. Amount participants "used" the tools in each toolset condition. [11]

While ATD-1 is not expected to include off-nominal situations, the design of the IM-TAPSS components goes beyond the scope of the initial operational demonstration.

TMA-TM and CMS have recently been enhanced and positively evaluated for go-around and missed approach operations. Future plans call for the system to add capabilities to incorporate off-nominal conditions such as automated go-around replanning and airport configuration changes during busy periods. Future scheduling enhancements of opportunistic time advance and time recovery are being developed. Recent simulation studies at higher levels of fidelity have shown that the system is also robust to current day operations and TRACON routings without full connectivity to the runway. These activities have accelerated the introduction of TMA-TM into the National Airspace System meeting mid-term NextGen requirements for terminal metering.

Flight Deck Interval Management (FIM)

FIM enables the controller to issue a single strategic clearance to flight crews of spacing-capable aircraft to achieve the required spacing interval behind a target (lead) aircraft at an achieve-by point. It enables the flight crew to actively assist both en route and terminal controllers in achieving their goal of maximizing throughput on capacity-constrained runways. The flight crew then manages their speed along their lateral and vertical path to achieve precise inter-arrival spacing by the achieve-by point. Speed changes are limited to ±10% of the arrival procedure's published speeds and less than 250 knots when below 10,000 feet.

The spacing operation is initiated near top-of-descent when the flight crew receives an IM clearance from the controller to begin spacing. The flight crew selects the target aircraft from a list of ADS-B targets and enters the STA, the spacing interval, the target aircraft's arrival procedure, and final approach speed (if provided). Once this information is entered, the spacing tool goes into an armed mode and starts calculating the desired speed. When the target aircraft is not within ADS-B range, the spacing tool provides speeds to meet the STA at the achieve-by point until it can start actively spacing relative to the target aircraft. When there is no valid target aircraft, the STA function can be used to meet an RTA at the achieve-by-point. Otherwise, aircraft are expected to transition to relative spacing (i.e., they will be within ADS-B range of each other) well before reaching the achieve-by point. Flight crews are expected to receive speed guidance from their FIM equipment, not their FMS, to ensure a smooth transition when relative spacing begins. Once the flight crew is comfortable with the new speed, they manually match the speed command. From this point forward, the flight continues as normal with the only alteration being that the on-board spacing tool generates the speed commands instead of the controller. If the flight crew is no longer able to follow the speed command, or experiences a system error, they contact the controller to terminate spacing operations and revert to traditional control mechanisms. At any time, the controller can intervene with additional speed or vector clearances.

The FIM Human Computer Interaction (HCI) implementation for the flight deck is expected to encompass three key interfaces consisting of 1) cockpit displays in the forward field-of-view for FIM speed advisories, FIM system status, and visual alerting 2) Interactive components for FIM data entry of system input parameters and, 3) Aural channels for alerting. Interface 1 may be achieved via several different possible displays including the ADS-B Guidance Display (AGD), similar to the UPS flight trials at their Louisville hub in 2008, or the Primary Flight Display (PFD) similar to research conducted by NASA Langley. Interface 2 may be achieved via an Electronic Flight Bag (EFB) or a Control Display Unit (CDU). Interface 3 may be achieved via standard flight deck aural channels. Aural alerting requirements are expected in order to provide scalability of the Flight deck Interval Management – Spacing (FIM-S) industry standards to support future FIM development such as Flight deck Interval Management – Defined Interval (FIM-DI). Cockpit Display of Traffic Information (CDTI) may also be required as FIM standards are developed. In this case, the CDTI requirement may be met with either an EFB, Navigation Display (ND), or other CDTI-enabled display. Figure 8 is an example of a PFD with the FIM speed calculated by the onboard spacing software shown in the upper left corner in green numbers, and shown as a green speed bug on the right side of the speed tape.

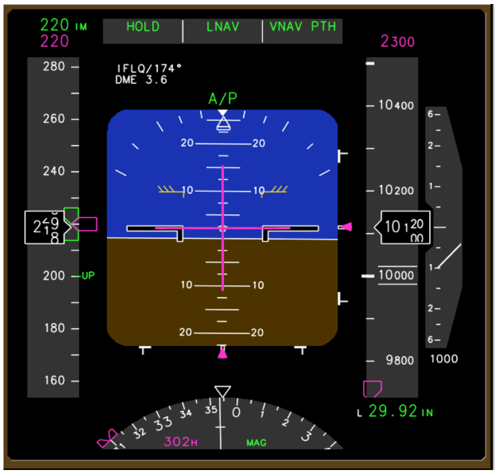


Figure 8. Primary flight display with IM speed

NASA's research and development activities for airborne spacing have included simulations and field trials and participation in various FIM working groups. In 2006, NASA participated in an FAA-led group to develop and test airborne spacing with the United Parcel Service (UPS). The goal was to combine the fuel reduction, flight time savings, and noise reduction of OPDs (then called Continuous Descent Arrivals) with airborne spacing. Between 2006 and 2008, NASA performed batch and HITL studies testing the combination of OPD with airborne spacing and found that the results were quite promising; UPS fielded a limited spacing tool to complement their use of OPDs in 2008.

In 2011, NASA conducted a HITL experiment to evaluate FIM operations to dependent parallel runways. The simulated environment was Dallas/Fort Worth International Airport under high-density conditions and all of the participating aircraft flew RNAV OPDs. The results are expected to show that FIM enables OPD arrivals to parallel dependent runways under high-density conditions with no loss of throughput and without tactical intervention by controllers. At the heart of

NASA's FIM research is the Airborne Spacing for Terminal Arrival Routes (ASTAR) algorithm and software developed at NASA Langley. ASTAR differs from similar algorithms in that it enables Trajectory Based Operations (TBO) for airborne terminal arrival operations. ASTAR has been refined over several years for research and, going forward, ASTAR is expected to play a large role in FIM standards development.

Ongoing FIM research & development focuses on integration of FIM with TMA-TM and CMS, validating the ATD-1 Concept of Operations, evaluating flight deck HCI options, and defining FIM requirements for standards development.

FROM SIMULATION TO REALITY: ATD-1

The IM-TAPSS components described in the previous section have been evaluated in separate laboratory settings at NASA's Ames and Langley Research Centers with promising results. ATD-1 integrates these research efforts to operationally demonstrate the feasibility of fuel-efficient, high throughput arrival operations by 2015.

ATD-1 was initiated in 2011. Currently, in 2012, the first phase, simulation integration, is well under way. The components are being integrated to address specific requirements for the IM-TAPSS demonstration. Five NASA facilities for air traffic control and flight deck research will be integrated and used. The core set of capabilities has already been installed in the air traffic laboratories at NASA Ames and Langley, and an initial integration simulation was conducted in January 2012 to further investigate mixed operations of CMS and FIM aircraft. The layout of this laboratory is depicted in Figure 8. The initial simulation included the timeline display of the TMA-TM system in each control room, four en route controllers metering to the terminal area boundaries, four terminal controllers conducting CMS operations, one tower controller, nine multi-aircraft pilots for non-FIM operations, and eight single-aircraft pilots conducting FIM operations.

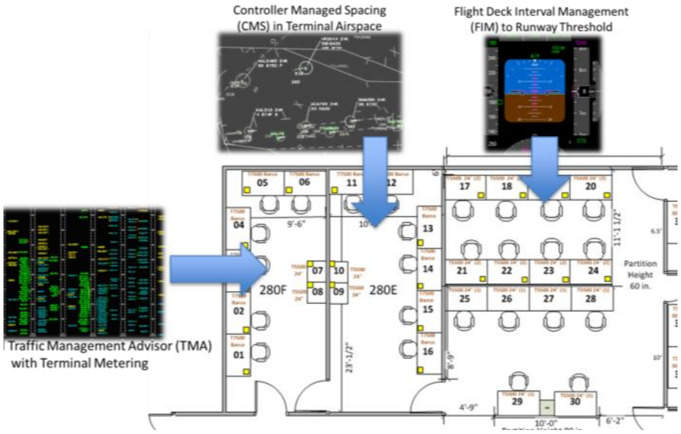


Figure 4. Layout of one laboratory for initial IM-TAPSS simulation

At the same time, significant effort is being conducted to establish partnerships with FAA, Industry, and user community stakeholders. Direct participation in both the development and execution of the demonstration is critical for the success of IM-TAPSS. In this effort, NASA is working directly with stakeholders to advance the development of the concepts, technologies, and capabilities by integrating key portfolios, identifying technology insertion points, defining requirements for the key capabilities, and conducting technology transfer discussions. The maturation of the NASA research products will culminate with the complete integration of all of the elements in a series of high-fidelity HITL simulations in 2013. During this phase, the simulations will incorporate increasingly higher fidelity models of the operational components. The simulations will also transition from predominantly focusing on individual components to focusing on a fully integrated set of capabilities. Some of this integration has already been completed. For example, the Terminal Area Precision Scheduling and Spacing (TAPSS)[5] simulation integrated the TMA and CMS capabilities. The experimental questions addressed during this stage will be key outstanding issues of the IM-TAPSS demonstration. Complementary analyses and simulations will also address broader research questions related to the deployment of integrated scheduling and merging and spacing capabilities throughout the NAS.

The second phase, development of operational hardware, software, and procedures, will start by building prototype subsystems and procedures that demonstrate the necessary operational capabilities, and it will culminate with demonstration-ready operational systems and procedures. This stage will require the most resources and leveraging of partnerships with FAA and Industry stakeholders. It is critical for technology transfer that the development be performed using the partners' operational platforms. For example, the terminal metering capabilities are being integrated into NASA's Research TMA (ReTMA), a recent version of the FAA's operational TMA. Similarly, the CMS tools are being integrated into a prototype version of the FAA's operational controller workstations. Initial contracted efforts for feasibility and trade-studies have been initiated. Contracted efforts will also start to develop both ground and airborne software in target FAA and avionics systems. During 2013, operational prototypes and procedures will be developed. In the latter half of 2013 and throughout 2014, the operational prototypes and procedures will have to be approved for use during the demonstration.

The final phase, execution of the demonstration, will start with a series of dry-run exercises and shadow operations in the latter half of 2014, proceed with check out exercises during periods of low traffic demand, and culminate with demonstrations during periods of routine traffic demand in 2015. The traffic scenarios for the final demonstrations will be chosen in coordination with FAA and Industry partners in order to satisfy their objectives for the demonstration.

SUMMARY OF GOALS AND SUCCESS CRITERIA

The primary goal of IM-TAPSS is to demonstrate sustained use of fuel-efficient procedures during periods of high runway throughput at a high-density airport using an integrated set of NASA arrival scheduling and merging and spacing technologies. Sustained use of fuel-efficient procedures throughout the entire arrival phase of flight reduces overall fuel burn, greenhouse gas emissions, and noise. Demonstrable fuel savings at a high-density airport during a broad range of traffic conditions will hasten the return-on-investment by early adopters of advanced avionics, such as ADS-B In and Out, and is expected to motivate faster equipage rates by other operators.

ATD-1 will be fully successful if three outcomes can be accomplished: First, arrival operations during the demonstration are considered acceptable by controller and flight crew participants, and aircraft achieve higher use of efficient arrival procedures that were not possible without the integrated capabilities.

Second, FAA and Industry stakeholders are able to use the data collected during the demonstration, as well as during the associated HITL simulations and attendant analyses, to make investment decisions regarding deployment of integrated scheduling and merging and spacing capabilities.

Third, the technologies are developed to Technology Readiness Level (TRL) 6. NASA will not independently maintain an operational capability in the field after the demonstration but it must advance the capabilities to a level that can be used by the FAA and aviation industry for additional operational testing and evaluation if warranted.

We believe that the goals of ATD-1 are achievable with NASA's continued determination and strong partnerships. When successful, we expect IM-TAPSS to make a significant contribution towards the realization of NextGen.

ACKNOWLEDGMENTS

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