Concept of Operations for Interval Management Arrivals and Approach

Daniel S. Hicok[1]
Regulus Group, LLC, Washington, DC, 20024

Dr. Bryan E. Barmore[2]
National Aeronautics and Space Administration, Langley Reseaerch Center, Hampton, Virginia, 23681

This paper presents the concept of operations for interval management operations to be deployed in the US National Airspace System (NAS) by the Federal Aviation Administration (FAA) after 2020. The use of interval management operations is described that begin in en route airspace and continue to a termination point inside the arrival terminal area, in a terminal environment that includes other arrival management tools such as arrival metering, Ground-based Interval Management – Spacing (GIM-S), and Terminal Sequencing and Spacing (TSAS). The roles of Air Traffic Controllers and Flight Crews and the ground automation tools that are used by Air Traffic Controllers to enable the primary operation and variations are described.

I. Introduction

Improvements in communication, navigation, and surveillance systems in the National Airspace System (NAS) have led to the development of multiple concepts to improve efficiency and enhance safety. For example, the deployment of Automatic Dependent Surveillance-Broadcast (ADS–B) will provide controllers access to more accurate aircraft state information and more frequent update rates than currently available via radar systems. Aircraft equipped with ADS–B transmitters (ADS–B Out) transmit highly accurate Global Navigation Satellite System-based position and velocity information. Aircraft that are additionally equipped with ADS–B receivers (ADS–B In) are able to receive surveillance information about other aircraft in the surrounding airspace.

Given that equipage is a critical factor to realizing the full benefits of NextGen, FAA is taking a holistic look at how to most effectively move forward with all equipage requirements in an integrated fashion. In June 2012, in response to a prior industry recommendation, the FAA chartered an ADSB-In Aviation Rulemaking Committee (ARC). The ADS-B-In ARC provided a forum for the U.S. aviation community to define a strategy for incorporating ADS-B In technologies into the National Airspace System, while ensuring compatibility with the ADS-B Out avionics standards defined in Title 14 of the Code of Federal Regulations §93.225 and 93.227.

The ADS-B In ARC undertook an extensive review of the ADS–B In applications listed in the FAA's Application Integrated Work Plan [1] and ranked the applications by order of maturity, operational impact, and level of interest from operators [2]. Interval Management – Spacing for Arrivals, Approach & Cruise (IM-S AA&C), called Flight Deck-based Interval Management – Spacing in the report, was second out of ten on their priority list with a targeted development date of 2015.

Interval Management (IM) is an ADS–B-enabled suite of applications that use ground and flight deck capabilities as well as procedures designed to support the flight crew-managed relative spacing of aircraft. The controller is able to instruct the flight crew of an IM Aircraft, equipped with ADS-B In and FIM avionics, to achieve and/or maintain a spacing, in time or distance, relative to a controller-specified Target Aircraft. Relative spacing refers to managing the position of one aircraft (in time or distance) relative to another aircraft, as opposed to a static reference such as a point on the ground or clock time. Studies have shown that the airborne management of relative spacing results in improved inter-aircraft spacing precision and will allow aircraft to be consistently spaced closer to the necessary spacing than current operations, resulting in reduced delays in capacity-constrained operations [3].

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[1] FAA Interval Management Systems Engineering Lead, Regulus Group, LLC, 600 Maryland Ave SW, Suite 820E, Washinton, DC, AIAA Member.

[2] Aerospace Engineer, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA 23681, member.

The necessary spacing may either be driven by the applicable separation standards or by metering constraints at points other than the runway. IM relies on speed control to achieve precise spacing and does not use off-path maneuvering.

The Air Traffic Controller is provided with automation support and procedures to identify pairs of aircraft which are eligible for the IM Operation and necessary information to issue an IM Clearance. This information includes the type of IM Operation to perform; the aircraft to space relative to, called the Target Aircraft, and any associated routing information, called the Intended Flight Path Information; the desired spacing, called the Assigned Spacing Goal; the point where the Assigned Spacing Goal needs to be achieved, called the Achieve-by Point; and the clearance termination, called the Planned Termination Point. Ref [4] provides a detailed description of all possible IM Clearance elements. Upon receiving the IM Clearance, the flight crew enters the information into their avionics, called the FIM avionics. The FIM avionics then calculates and presents the IM Speed, which, if followed, will achieve the Assigned Spacing Goal at the Achieve-by Point and maintain that spacing until the Planned Termination Point. Both the flight crew and the controller are provided with situation awareness information to monitor the progress of the IM Operation.

For arrival operations with metering in use, IM is a tool in the controller's toolbox to assist in delivering a smooth flow of traffic from prior to top-of-descent to the runway. Starting as early as several hundred miles from the destination airport, the initial arrival plan starts forming. The Time Based Flow Management (TBFM) automation system builds the overall plan for arrivals including runway assignments and a schedule to the runway and associated metering points. The controllers then manage the tactical traffic situation to that schedule using tools such as Ground-based Interval Management – Spacing (GIM-S) and Terminal Sequencing and Spacing (TSAS). For aircraft equipped with the FIM avionics, the controller can instruct the aircraft to achieve and maintain a relative spacing to another aircraft. This is the IM Operation.

The TBFM automation system assesses each pair of aircraft to determine if an IM Clearance is feasible. When a feasible IM Operation is found, the schedule is set to take advantage of the high precision delivery that IM provides by assigning a slightly smaller spacing for that pair in the schedule. The IM Aircraft is able to deliver with higher precision allowing for the controller to manage the aircraft to the smaller spacing interval.

Since most of the IM functionality is on the aircraft, it is available for use in other environments and for other operations. This paper focuses on the use of IM for arrivals and approach in a post-2020 en route and terminal environment.

II. Near Term Arrival Operations Prior to Interval Management

The description of near term operations (2019) in a metering environment is organized following a flight passing over Kansas to arrive at Phoenix Sky Harbor International Airport (KPHX). A schematic diagram of the airspace and aircraft routing is shown in Fig. 1.

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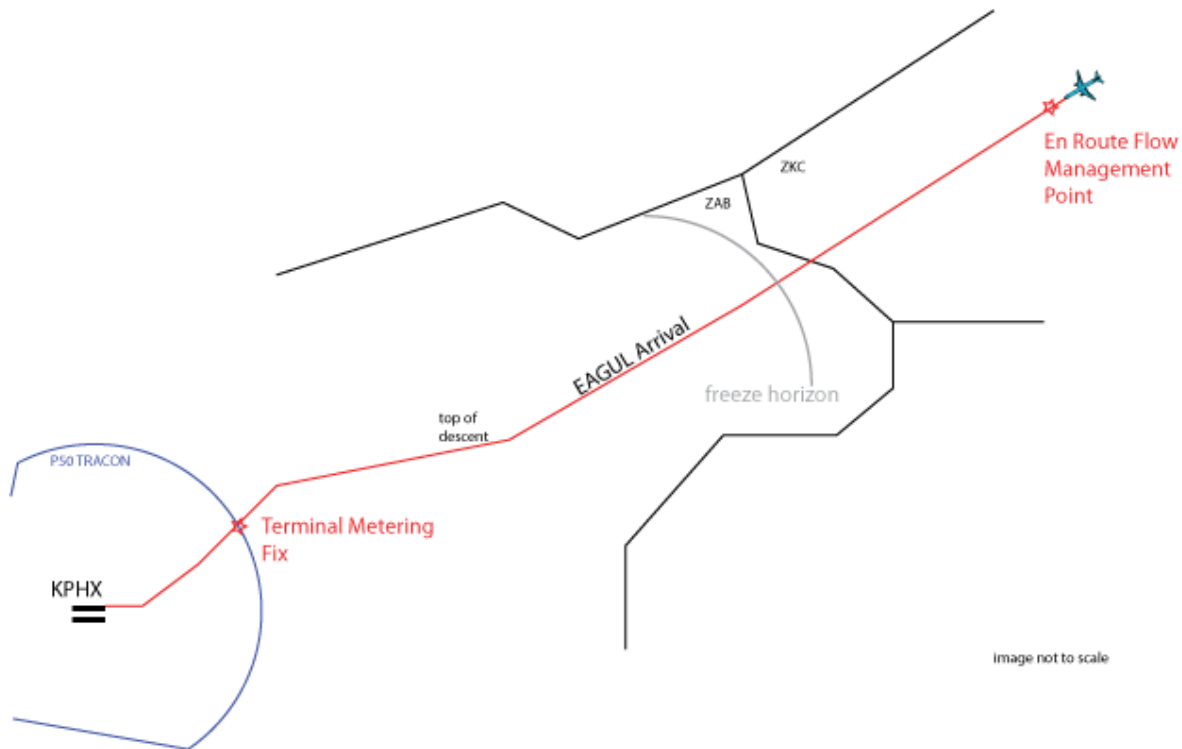
Figure 1. Schematic Diagram of the Airspace Describing Near Term Arrival Operations.

The command center has been coordinating flow management initiatives and the use of metering for aircraft arriving to KPHX. The Traffic Managegment Coordinators (TMCs) have set up TBFM to meter flows leading to the EAGUL arrival. The flight crew has received their updated forecast winds from their Airline Operation Center (AOC) and entered the wind data into their Flight Management System (FMS). This includes winds at cruise altitude along their expected route plus 3-5 altitudes for descent. The winds provided may be hours old depending on the airline's forecast update cycle and the duration of the flight. The coarseness of the forecast wind data, at only 4-6 altitudes, possibly at a single geographic point, adds error between the wind data used by the aircraft's FMS and the winds that will actually be experienced during the descent. TBFM has different wind forecast information. TBFM uses the aircraft's filed flight plan with entered amendments, the filed cruise speed, the wind forecast data, and an aircraft performance model to calculate the aircraft's expected trajectory and Estimated Times of Arrival (ETAs) at metering points. The TBFM aircraft performance data are less precise than that in the aircraft's FMS. The lack of aircraft-specific data, including current weight and use of deicing equipment, and flight crew-selected descent speeds, along with different wind forecast information, introduces differences between the TBFM-calculated trajectory, the FMS-calculated trajectory and the trajectory that the aircraft will actually fly.

The flight crew already has the en route transition and arrival (EAGUL) entered into the FMS which is providing flight guidance to conform to the current navigation clearance. While TBFM has started to include this aircraft in arrival scheduling, it has not yet reached the En Route Flow Management Point (ERFMP) freeze horizon so does not have a frozen Scheduled Time of Arrival (STA) nor does any schedule information appear on the controller's display. Traffic in the controller's sector, as well as weather data, appears on the controller's displays via En Route Automation Monderization (ERAM). The controller will give speed and heading instructions to the flight crew as necessary to maintain separation and an orderly flow of traffic. When TBFM generates a trajectory for the aircraft the modeled aircraft performance is unable to account for the actual weight and configuration of the aircraft. The aircraft's current airspeed is derived from the groundspeed and then converted to an indicated airspeed using the forecasted, not true, winds. All of this adds inaccuracy to the TBFM trajectory calculation.

Once the aircraft has crossed the freeze horizon for the ERFMP, TBFM freezes the STA for that aircraft. The aircraft needs to absorb delay prior to the ERFMP, so the Ground Interval Management – Spacing (GIM-S) automation provides a Speed Advisory to the controller on their ERAM display. The trajectories uncertainties described above mean that the Speed Advisory may not be the optimal value to absorb the delay. When the Speed Advisory is presented, the controller may be focused on other aircraft or in the middle of a radio communication and may not notice the new Speed Advisory until the next time they scan the ERAM Meter Reference Point (MRP) list

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or the aircraft's flight data block. The controller would then need to decide if they wish to issue the Speed Advisory and then communicate the speed instruction to the flight crew. During this time, the controller may be interrupted by a radio call from another aircraft or other events going on in their sector. Once the controller issues the speed instruction to the flight crew, it will take time for the flight crew to respond and implement the new speed. The delay between when the Speed Advisory was calculated and when the aircraft actually reaches the desired speed makes the Speed Advisory less likely to exactly resolve the delay than if the Speed Advisory was implemented immediately after it was calculated.

If a speed instruction is necessary, the controller must issue it in round ten-knot values. Since it is unlikely that the ideal speed is a round ten-knot value, the execution of the solution will not be as precise as desired. The flight crew will enter the speed into their autoflight system (e.g., mode control panel). The aircraft may depart from the planned vertical profile to achieve the speed. In some cases the speed cannot be maintained without the flight crew adjusting drag or thrust. This leads to small variations around the instructed speed. The execution of the solution will not be as precise as desired.

The GIM-S system includes an airframe-specific model of acceptable speeds to meet the STA. If a Speed Advisory cannot be calculated due to a speed solution not being sufficient to absorb the necessary delay, GIM-S notifies the controller that no speed-based solution is available and the controller will need to use other methods to meet the required delay per the Delay Countdown Timer (DCT) or timeline. The DCT presented to the controller is rounded or truncated to provide a stable value. However, the truncation or rounding methods used ultimately reduces the precision with which the controller can deliver the aircraft to the STA.

During this time, the flight crew will listen to Automatic Terminal Information Service (ATIS) to learn the active runways and surface winds and then brief the arrival and approach procedures and prepare for initial descent. The controller may also provide the flight crew with an expected runway at this time. If the controller issues them a speed instruction, they will dial it in to the autoflight system and the autoflight system will maintain that speed to within a few knots (or 0.01 Mach, depending on the system and operating conditions). As the aircraft progresses along its path, it passes from sector to sector. Throughout this time, TBFM is updating the aircraft's ETA to the Terminal Metering Fix using the latest surveillance information. The TBFM ETA has many sources of uncertainty. As set by local adaptation, new Speed Advisories are calculated and presented as needed. A Speed Advisory is also presented for the recommended descent speed prior to the aircraft reaching their expected Top of Descent (TOD)[3]. Since this Speed Advisory is based on an inexact ETA, the Speed Advisory will not exactly match the speed that would be necessary to completely resolve the STA error at the Terminal Metering Fix.

The center controller does not know where the aircraft plans to start its descent. So well prior to the expected TOD, if traffic allows, the controller will clear the aircraft to descend via the EAGUL arrival. The aircraft's FMS has calculated a TOD point that will efficiently allow the aircraft to meet the altitude and speed constraints present on the EAGUL arrival. This calculation uses the aircraft's performance data as well as the crew-entered wind forecast data. It will be different from the TBFM-calculated TOD. This uncertainty in the location of the TOD point is a source of error in the ETA and hence any Speed Advisories presented and the DCT.

If given a descent speed instruction by the controller, the flight crew will enter that into their FMS. Otherwise, they will use the FMS-calculated, or procedure-based, descent speed(s). The FMS-calculated speeds are generally not known by TBFM and are an additional source of uncertainty in the TBFM-calculated ETA. Prior to the TOD point, the FMS will calculate a descent profile, altitude and airspeed that will meet all of the published constraints based on the available wind information. Many FMSs will not update this profile. The flight crew will use the FMS to manage the lateral and vertical path of the aircraft during the descent.

As long as traffic allows, the controller will leave the aircraft alone. If the delay is not reducing quickly enough or too quickly, the controller may decide to issue a new speed instruction. Speed and heading instructions can also be used to ensure that separation at merges meets standards. Any speed or heading instruction will force the flight crew to partially or fully disengage the FMS. As the aircraft departs from the planned trajectory, it will be more difficult for the avionics systems to manage the descent and airspeed of the aircraft simultaneously. The aircraft's autoflight system will allow for some deviation away from the selected speed before trying to correct the error. This will partially use the 10 knot buffer afforded to flight crews to conform to a speed instruction. Similarly, changing winds may make the aircraft's indicated airspeed depart from the selected airspeed. Most flight crews will allow the speed to deviate by several knots before making corrections to reduce their workload and engine wear and increase

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[3] The presentation of a Speed Advisory for descent is dependent upon the individual facility and is influenced by the route structure and procedures. For initial GIM-S operations, ZAB is using a route with existing high-altitude speed constraints so no descent Speed Advisory is being presented. This has the consequence of reducing the amount of delay that can be absorbed during descent.

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passenger comfort. The varying speeds will change the ETA at the next metering point and make any speed instructions issued by the controller less precise in meeting the STA.

The aircraft is in the last en route sector and approaching the Terminal Metering Fix and entry into the terminal airspace. The last en route controller may make a speed adjustment in order to meet the STA at the Terminal Metering Fix to within ±60 sec. However, doing so may disrupt the aircraft's ability to fly the Optimized Profile Descent (OPD) so it is only used sparingly. Also, the controller must deliver the aircraft at 240 knots Indicated Air Speed at the Terminal Metering Fix.

As the aircraft approaches the terminal area boundary, a ZAB controller initiates a hand-off to a TRACON controller. The altitude and speed ranges for the aircraft at the hand-off are set by an Letter of Agreement (LOA) between facilities.

Terminal controllers are provided with the aircraft's STA at the next meter point or the runway as well as TSAS slot markers to help them meet the STA without the need for vectoring. These TSAS slot markers are a visual indication on the controller's scope of where the aircraft should be to meet the schedule. As necessary, controllers will issue speed instructions to the aircraft to meet the STA. The trajectory uncertainties, such as wind forecast data, aircraft performance, and actual groundspeed, remain making the slot marker and controller's speed instructions not as precise as desired to deliver the aircraft on time. As an example, assume that the winds used by TBFM for the remainder of the flight underestimate the aircraft's current velocity by 3 knots. Given that assumption, over the course of the remaining flight this would cause a 10-second shift in the ETA away from the "perfect" value. Such a deviation would cause the controller to issue a speed instruction that is appropriate for the situation presented to them, but will not deliver the aircraft at the STA. Therefore, the controller is unable to execute the solution as precisely as desired. Since the controller is responsible for other aircraft in their airspace and is in frequent radio contact with different aircraft, it may be some time before the controller notices that a correction is needed and can contact the flight crew to implement a new speed instruction. These additional speed instructions will increase the controller's and flight crew's workload due to the attention and radio communications needed.

For any given speed instruction, the flight crew will implement it as before. Also during this time, the flight crew will start extending flaps to provide adequate lift for the slower speeds and configure for landing. This will change the aircraft's performance in ways that are not fully accounted for in the TBFM trajectory calculation, adding additional uncertainty to the ETA calculation and TSAS information displayed to the controllers.

As the aircraft approaches the final approach course, the final controller will switch from trying to meet the STA to spacing the aircraft relative to the traffic preceding and following it in order to achieve a balance between throughput and safety. The controller will use tools such as Automated Terminal Proximity Alerts (ATPA) to help determine how well the aircraft are spaced and if new speed instructions are needed. If needed, the controller will issue a speed instruction to the flight crew who will enter it into their autoflight system. The flight crew will adjust throttle and flap settings appropriately and the aircraft will start to decelerate. Depending on the atmospheric conditions and the autoflight system, the aircraft may overshoot the commanded speed and need to recover. The whole process from when the aircraft first needs to adjust speed to when it actually achieves that speed can take tens of seconds, adding uncertainty to the final spacing.

If the winds are gusty, or particularly slow or fast speeds have been commanded, the flight crew may make use of a 10 knots conformance window they have on speeds to delay changing the configuration of the aircraft. This adds additional uncertainty to the aircraft's spacing.

If visibility is poor, the controller cannot use visual approaches to allow the flight crew to separate themselves from the preceding aircraft. As the aircraft approaches the final approach fix, the final controller hands them off to the tower controller and the aircraft is cleared to land. At this point the flight crew will begin slowing to their final approach speed.

The aircraft's final approach speed is dependent upon it's model, weight, landing configuration and wind conditions. TBFM does not know most of this information and uses an aircraft category-based average approach speed. The difference between the actual approach speed and what TBFM uses adds further uncertainty to the final spacing between the aircraft and runway throughput.
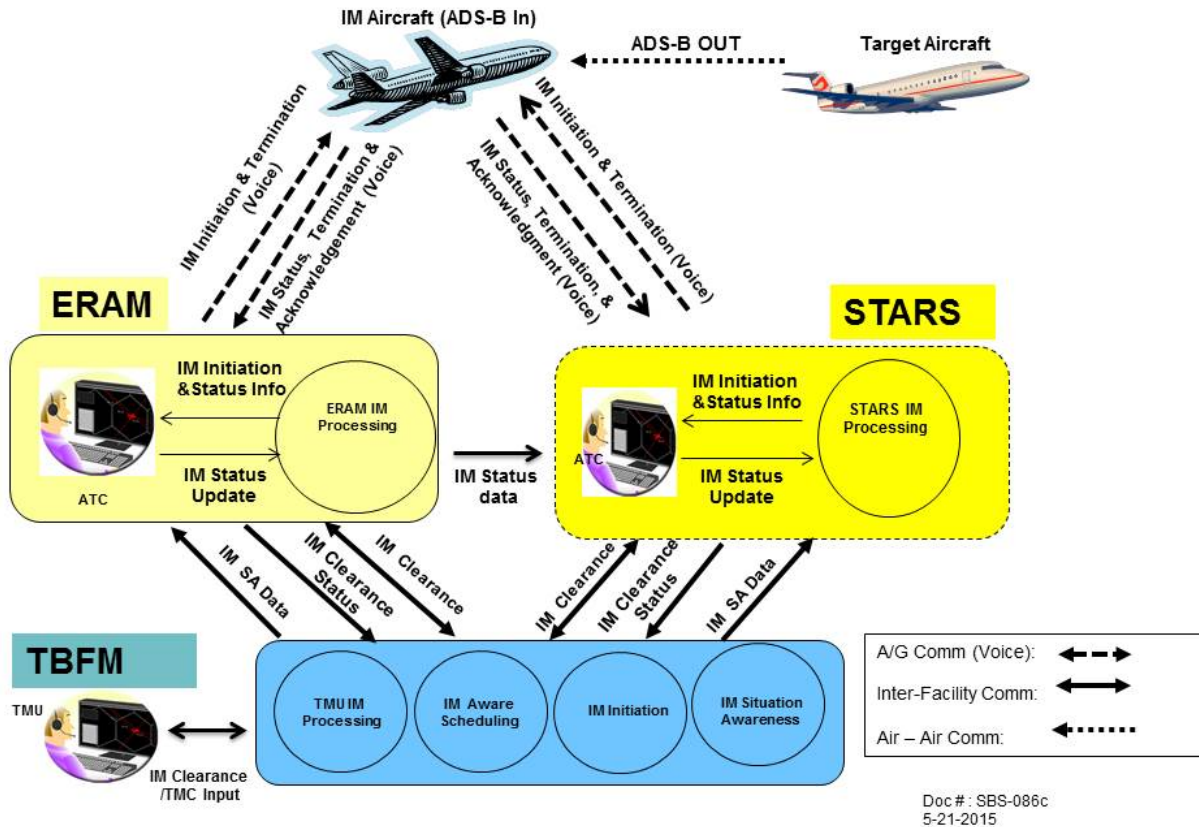
III.   Interval Management Operations

The use of airborne surveillance technology and allocation of the spacing task to provide a tighter control loop allows flight crews flying one aircraft to achieve more delivery precision than a controller managing many aircraft at once.

Delivery precision is defined as the standard deviation of the difference (error) between the desired and actual inter-arrival times (IAT) as these aircraft cross a fixed point. To avoid separation violations, controllers must

account for operational delivery precision, which leads to the addition of a spacing margin (buffer) above the separation standard. With improved delivery precision, the spacing margin can be reduced which effectively leads to a decrease in the mean operational IAT for the same separation standard. The overall decrease in the mean IAT at the runway threshold translates to reduced delay during capacity-constrained operations.

The IM application as described can be used during cruise and arrival and approach operations. This section describes the core IM Operation in detail. Figure 2 shows a system-level diagram of the envisioned IM-S AA&C system where metering operations are in use.

Figure 2. Diagram of Interval Management Operations Supporting Systems [5].

The TBFM scheduler will have a new function, called IM Aware Scheduling, which looks for aircraft that are capable of performing the IM Operation and determines whether a viable Target Aircraft exists (Target Aircraft is ADS-B Out, will merge onto the same route as the IM Aircraft at or prior to the Achieve-by Point and is on a published navigation route). If a viable pair of aircraft exists, then the scheduler assigns an IM specific spacing value to the pair. For example, if two aircraft would normally be scheduled 100 seconds apart, they might be scheduled 90 seconds apart if the trailing aircraft is expected to conduct an IM Operation. The exact reduction in the IM spacing value is a settable parameter and may vary between facilities.

Once an aircraft crosses the freeze horizon for the Terminal Metering Fix, its STA is frozen. Its position in the arrival sequence was frozen previously. At this time, and once the IM and Target Aircraft are within the expected air-to-air ADS-B range, the IM Clearance information is presented to the controller. The IM Clearance information includes the proposed IM pair (IM and Target Aircraft) and provides other information needed to provide the IM Clearance including the Target Aircraft's Intended Flight Path Information. The controller may then issue the IM Clearance. Once the flight crew accepts the IM Clearance, the controller will indicate to ATC automation that the IM Operation has begun. ATC automation changes the IM Aircraft's status and the Target Aircraft's status to "active", which notifies the controller with responsibility for the Target Aircraft that it is now involved in an IM operation. If the controller decides not to issue the IM Clearance, the controller sets the status as Rejected.

When they receive the IM Clearance, the flight crew will accept the clearance and enter the IM Clearance information into their FIM avionics. The FIM avionics will start producing IM Speed guidance for the flight crew. The calculation of the initial IM Speed may take several seconds as the equipment may need to do significant calculations. The flight crew of the IM Aircraft then manages aircraft speed per guidance from the FIM avionics to achieve the relative spacing behind the Target Aircraft; the controller no longer actively controls the aircraft to its STA. When the IM status is set to active, Speed Advisories are not displayed to the controller for the IM Aircraft. The controller is provided with IM Situation Awareness Information to assist them in assessing whether the IM Aircraft is meeting its Assigned Spacing Goal.

As either the Target or IM Aircraft transfers from one sector to another or one facility to another, the IM Clearance information and IM Status are passed along by the automation so that the responsible controller for that sector has access to that information. The controllers are also provided with IM Situation Awareness information to assist them in monitoring the IM Operation and determining whether the operation should be suspended or terminated. The monitoring will take place at two stages depending on the phase of the IM Operation. The first stage is from the time that the clearance has been issued until the IM Aircraft reaches the Achieve-by Point (the "achieve stage"). The second stage is from the time the IM Aircraft reaches the Achieve-by Point until the Planned Termination Point (the "maintain stage").

The controller manages non-IM Aircraft to meet their STAs at the Terminal Metering Fix and appropriate locations within the terminal airspace. The controller will use existing automation tools along with IM Situation Awareness Information to monitor the interaction between IM and non-IM Aircraft to ensure that the non-IM Aircraft can successfully merge behind an IM Aircraft and that the controller is able to successfully space the non-IM Aircraft behind the IM Aircraft once the two aircraft are in-trail. The IM Operations continue into terminal airspace and terminate at the Planned Termination Point which can be as close to the runway as the Final Approach Fix. For this operation, both the Target and IM Aircraft must be landing on the same runway.

If there is a re-sequencing event, ground automation will re-evaluate the feasibility of each IM pair, and update the IM information presented to the controller, which may result in the need to amend one or more IM Clearances.

IV. Example Scenario

In Fig. 3, seven aircraft are shown. In real operations there would be additional aircraft preceding number 1 and following number 7 but they are removed from the diagram for clarity. Table 1 shows the equipment levels and starting positions for this scenario.

The airspace (Fig. 3) is modeled after a busy terminal environment with multiple arrival routes that have been extended into terminal airspace to intercept published Instrument Approach Procedures. Metering is applied per runway so only the arrivals to one runway are shown and discussed. Metering is in use with PLOVR, ILAND, HAGRD and ANDRE being the defined meter points for the en route airspace. Terminal Metering Fixes for the terminal airspace are at CRDNL, STRMM and GIANT. There are two terminal merge points: STONE and FIELD. The Achieve-by and Planned Termination Points are co-located[4] at the Final Approach Fix, YOKKO.

Table 1. Equipage Levels and Starting Locations For Aircraft Shown in Fig. 3.

Aircraft number	ADS–B Out	FIM	Scheduled spacing	Starting location
1	X			near CRDNL
2	X	X	85 sec	25 nmi prior to STRMM
3			90 sec	middle of descent to CRDNL
4	X	X	90 sec	freeze horizon for STRMM and started initial descent
5	X	X	85 sec	approaching ILAND
6	X	X	85 sec	approaching HAGRD
7	X	X	85 sec	30 nmi prior PLOVR

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[4] While setting the Achieve-by Point at the various merge points is also permissible, this scenario uses the Final Approach Fix as the Achieve-by Point for all IM Operations.
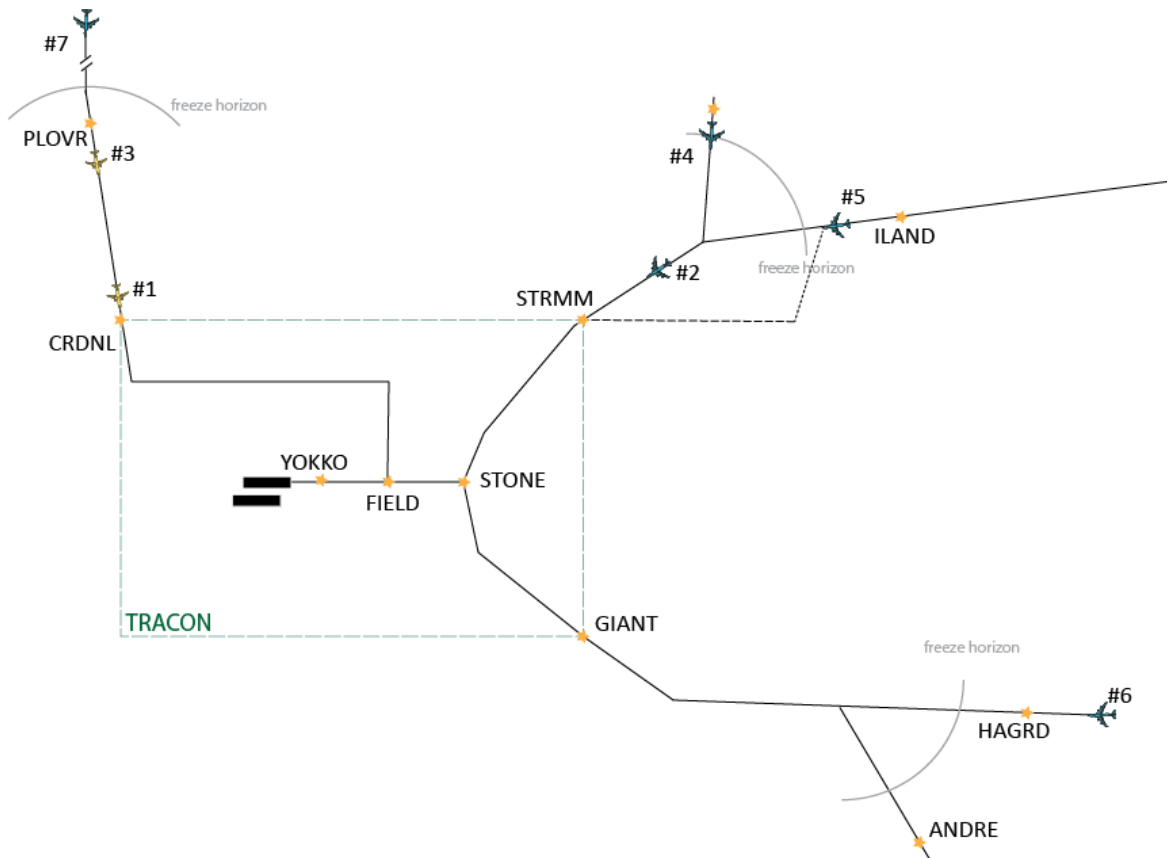
Figure 3. IM Initiated En Route on Multi-Stream Arrivals.

When aircraft #1 crossed the freeze horizon for CRDNL, the STAs at CRDNL and subsequent meter points were frozen. The en route controller was provided with a DCT for aircraft #1 showing how much delay was needed to meet the STA at CRDNL along with a recommended Speed Advisory. The controller was able to adjust the descent speed for aircraft #1 to deliver it to CRDNL close to the STA. The terminal controller who will be managing aircraft #1 now receives the hand-off from the en route controller. The terminal controller has access to the target status information and the applicable IM Clearance information. The terminal controller is provided with additional information such as TSAS slot markers to help the controller manage the speed of aircraft #1 along the published RNAV arrival procedure and meet subsequent STAs at STONE and FIELD. The operation for this aircraft is the same as described in Section II.

When aircraft #2 crossed the freeze horizon for STRMM, TBFM identified Aircraft #2 as IM capable and that aircraft #1 would be a valid Target Aircraft. Since an IM Clearance is expected, the scheduler scheduled aircraft #2 85 seconds behind aircraft #1 (predicted to be about 4.0 nmi at the Final Approach Fix) instead of the normal 90 seconds (4.25 nmi). At the freeze horizon the distance between aircraft #1 and #2 was greater than the expected ADS-B air-to-air range, so the IM Clearance information for aircraft #2 was not presented to the controller. The en route controller received a GIM-S speed advisory for aircraft #2 and slowed it down from 310 knots to 270 knots. When aircraft #2 is within ADS-B range of aircraft #1 the en route controller receives notification that an IM Operation is possible for aircraft #2. The controller views the IM Clearance information that includes the proposed Target Aircraft, recommended Assigned Spacing Goal and the Target Aircraft's Intended Flight Path Information. The standard Planned Termination Point and Final Approach Fix, YOKKO, is published as part of the arrival procedure and set appropriately in the ATM automation. The en route controller issues the IM Clearance to the flight crew of aircraft #2[5].

ATC: AIRCRAFT 2, FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND AIRCRAFT 1 ON THE CRDNL3 ARRIVAL.

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[5] The clearance phraseology presented in this paper is proposed and could be altered before operations commence.

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*AIRCRAFT 2: WILCO. FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND
AIRCRAFT 1 ON THE CRDNL3 ARRIVAL, AIRCRAFT 2.*

The flight crew of aircraft #2 enters the IM Clearance information into their FIM avionics. After five seconds of calculating, the FIM avionics presents an IM Speed of 280 knots to the flight crew. The IM Speed provided is acceptable to the crew, so they implement the IM Speed. In response to aircraft #1 being slowed down as it approaches CRDNL, the FIM avionics commands a similar slow down for aircraft #2. Aircraft #2's flight crew implements the new IM Speed.

When the flight crew has accepted the IM Clearance, the controller changes the IM status to active. Changing the status also changes the target status of aircraft #1. That information is available to the controller managing aircraft #1, who now knows that vectoring aircraft #1 will result in adverse effects for aircraft #2. Any changes to the routing of aircraft #1 will be communicated to the controller of aircraft #2. The DCT, speed advisories and other information used by controllers to meet an aircraft's STA are now replaced by the IM Situation Awareness information.

When aircraft #2 approaches STRMM, the en route controller transfers responsibility to the terminal controller. The terminal controller receives the IM Clearance information and status as well as sees spacing information for aircraft conducting IM. The flight crew of aircraft #2 continues to receive and implement IM Speeds. Aircraft #2 is close to the Assigned Spacing Goal when reaching FIELD, where aircraft #2 merges behind aircraft #1 (see Fig. 4). At the appropriate point, Aircraft #2 is transferred to the final controller. As aircraft #2 reaches YOKKO, the final controller transfers Aircraft #2 to the tower controller in time for Aircraft #2 to receive its landing clearance. If the IM Operation has not been terminated by this time, the tower controller is notified of the IM Operation. The IM Operation is automatically terminated at YOKKO and the flight crew slows to their final approach speed. This is the expected nominal behavior for an IM Operation. Subsequent aircraft in this scenario will show variations on this behavior.
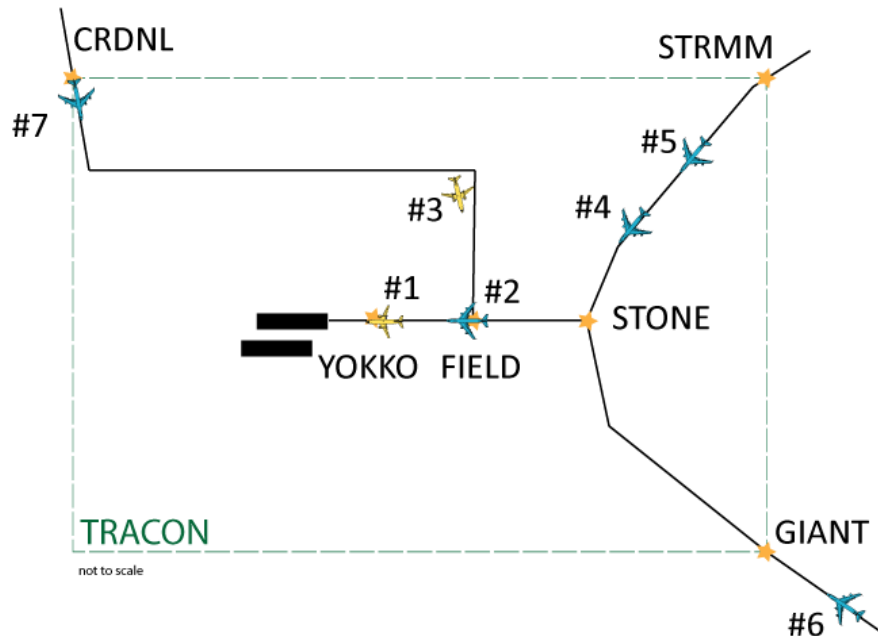
Figure 4. The Airspace with All Six Aircraft in the Terminal Area.

Aircraft #3 has malfunctioning ADS-B out equipment and is managed by the controllers to meet its STAs at CRDNL, FIELD and YOKKO similar to how aircraft #1 was handled. As aircraft #3 cannot participate in an IM Operation, no IM or target status information is shared between controllers. The controller's automation will provide speed advisories and a slot marker to the controller to assist in meeting the STAs. Since aircraft #3 will not be performing an IM Operation, it is scheduled to arrive at YOKKO 90 seconds after aircraft #2. Aircraft #4 will be conducting IM Operations relative to aircraft #2. The approach and final controllers will need to adjust aircraft #3's position relative to its slot marker so that aircraft #3 is delivered within the gap between aircraft #2 and #4. The approach controller can see the slot markers for and the relative position of aircraft #2 and #4 and can make adjustments as necessary to enable the final controller to merge aircraft #3 into position. Once aircraft #3 is on final

behind aircraft #2, the controller will need to ensure a timely response to speed changes by aircraft #2. The controller can use IM Situation Awareness information to assist in managing the mixed IM and non-IM traffic.

When aircraft #4 crosses the freeze horizon for STRMM, the scheduler identifies Aircraft #4 as IM capable. In the planned sequence, Aircraft #4 will land following aircraft #3. But since aircraft #3 is ineligible to be a Target Aircraft due to lack of ADS–B Out, the ground automation suggests that aircraft #4 can conduct IM Operations with aircraft #2 as a Target Aircraft. Aircraft #2 is crossing the same Terminal Metering Fix, STRMM, and Aircraft #2 is already within ADS–B range. Therefore, the IM Clearance information is presented to the controller immediately. Since aircraft #4 will not be spacing relative to the immediately preceding aircraft, aircraft #3, the scheduler uses the standard, non-IM spacing between aircraft #3 and #4. This ensures an adequate gap between aircraft #2 and #4 for the controller to insert aircraft #3. This results in an Assigned Spacing Goal behind aircraft #2 of 180 seconds.

> *ATC: AIRCRAFT 4, FOR INTERVAL SPACING CROSS YOKKO 180 SECONDS BEHIND AIRCRAFT 2 ON THE STRMM8 ARRIVAL.*

> *AIRCRAFT 4: WILCO. FOR INTERVAL SPACING CROSS YOKKO 180 SECONDS BEHIND AIRCRAFT 2 ON THE STRMM8 ARRIVAL, AIRCRAFT 4.*

The IM Operation proceeds as it did for aircraft #2 above. Note that there is now a string of three spacing aircraft with aircraft #2 performing IM Operations as well as being the Target Aircraft for aircraft #4. Aircraft #2 now has both an IM status and target status setting.

As aircraft #5 reaches the freeze horizon, the scheduler identifies the aircraft as IM capable and that aircraft #4 is a valid Target Aircraft. The spacing for aircraft #5 behind #4 will be 85 seconds. However, aircraft #5 arrived ahead of its scheduled time. The controller recognizes that it will be difficult for aircraft #5 to be far enough behind aircraft #4 at their merge point even if aircraft #5 will be able to achieve the 85 second spacing by YOKKO. So instead of issuing the IM Clearance, the controller turns aircraft #5 to the left to lengthen their path. After a short time, the controller clears aircraft #5 direct to STRMM. There will now be sufficient time for aircraft #5 to open up adequate spacing prior to STRMM, so the controller issues the IM Clearance.

> *ATC: AIRCRAFT 5, FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND AIRCRAFT 4 ON THE STRMM8 ARRIVAL.*

> *AIRCRAFT 5: WILCO. FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND AIRCRAFT 4 ON THE STRMM8 ARRIVAL, AIRCRAFT 5.*

The flight crew of aircraft #5 enters the IM Clearance information and begins following the IM Speeds. Aircraft #5 is approximately 6 nmi behind Aircraft #4 and going slower by the time Aircraft #5 reaches STRMM. Aircraft #5 continues to open up the spacing until their flight crew reaches the Assigned Spacing Goal of 85 seconds by YOKKO.

After aircraft #6 crosses the freeze horizon for GIANT, the automation system determines that aircraft #6 should perform an IM Operation behind aircraft #5; however, ATM automation recognizes that Aircraft #5 has been vectored off the published arrival, so is not eligible for IM operations until aircraft #5 is direct to STRMM (a fix on the published arrival). Once aircraft #5 is direct to STRMM, the en route controller managing aircraft #6 will receive notification that aircraft #6 is a candidate for an IM Operation with aircraft #5 as a Target Aircraft and an Assigned Spacing Goal of 85 seconds. The Intended Flight Path Information for aircraft #5 will be "direct STRMM then the STRMM8 arrival."

> *ATC: AIRCRAFT 6, FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND AIRCRAFT 5 DIRECT STRMM THEN THE STRMM8 ARRIVAL.*

> *AIRCRAFT 6: WILCO. FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND AIRCRAFT 5 DIRECT STRMM THEN THE STRMM8 ARRIVAL, AIRCRAFT 6.*

The flight crew of aircraft #6 accepts the IM Clearance and begins implementing the IM Speeds. The controller changes the IM Clearance status of aircraft #6 to active. While aircraft #6 is in descent, but before reaching GIANT, the tower makes a request for some additional space between a pair of aircraft in order to get a delayed departure out. The Traffic Management Coordinator determines that the best place for the additional space is between aircraft #5 and #6. This change to the arrival schedule is communicated to the controller managing aircraft #6. A small weather cell is moving across the GIANT3 arrival as well. The controller decides to resolve both issues at once and suspends the IM Operation to vector aircraft #6 around the weather.

ATC: AIRCRAFT 6, SUSPEND INTERVAL SPACING, TURN LEFT HEADING 250.

AIRCRAFT 6: WILCO, SUSPEND INTERVAL SPACING AND TURN LEFT HEADING 250, AIRCRAFT 6.

Once the aircraft is past the weather cell, the controller clears the flight crew of Aircraft #6 direct to GIANT and resumes the IM Operation with a new Assigned Spacing Goal of 145 seconds.

ATC: AIRCRAFT 6, DIRECT GIANT THEN DESCEND VIA GIANT3 ARRIVAL.

AIRCRAFT 6: WILCO, DIRECT GIANT THEN DESCEND VIA GIANT3 ARRIVAL, AIRCRAFT 6.

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ATC: AIRCRAFT 6, RESUME INTERVAL SPACING, ADJUST SPACING TO 145 SECONDS.

AIRCRAFT 6: RESUMING INTERVAL SPACING, ADJUST SPACING TO 145 SECONDS, AIRCRAFT 6.

The flight crew changes the Assigned Spacing Goal and resumes IM. They continue to follow IM Speeds as Aircraft #6 transitions into the terminal area. As aircraft #6 turns onto the final approach course, the IM Situation Awareness Information indicates to the controller that aircraft #6 is going to be too early relative to their Assigned Spacing Goal. The controller terminates the IM Operation and slows the aircraft further to gain extra spacing.

ATC: AIRCRAFT 6, TERMINATE INTERVAL SPACING, SLOW AND MAINTAIN 160 KNOTS.

AIRCRAFT 6: TERMINATING INTERVAL SPACING, MAINTAIN 160 KNOTS, AIRCRAFT 6.

Aircraft #7 originally was expected to arrive two-and-a-half minutes behind aircraft #6. But with the gap added in front of aircraft #6, the predicted spacing between aircraft #6 and #7 is small enough that the automation system identifies them as a proposed IM pair. As aircraft #7 approaches the freeze horizon for CRDNL, Aircraft #7 is still well outside the expected ADS-B air-to-air range, so the IM Clearance is not presented to the controller. The controller provides a Speed Advisory for a descent speed. When aircraft #7 is about 10 nm from the Terminal Metering Fix, CRDNL, Aircraft #6 is within ADS-B air-to-air range of Aircraft #7 and the automation system provides the IM Clearance information to the controller.

ATC: AIRCRAFT 7, FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND AIRCRAFT 6 DIRECT GIANT THEN THE GIANT3 ARRIVAL.

AIRCRAFT 7: WILCO. FOR INTERVAL SPACING CROSS YOKKO 85 SECONDS BEHIND AIRCRAFT 6 DIRECT GIANT THEN THE GIANT3 ARRIVAL, AIRCRAFT 7.

By the time the flight crew of aircraft #7 enters the IM Clearance information and the FIM avionics calculates the first IM Speed, aircraft #7 has transitioned into terminal airspace. As aircraft #7 approaches the base leg turn the controller terminated the IM Operation for aircraft #6 and slowed Aircraft #6 (as described above). The FIM avionics detects the speed change by Aircraft #6 and provides appropriate speed guidance to the flight crew of Aircraft #7. The flight crew responds, slowing Aircraft #7 to its minimum allowed speed in order to achieve the assigned 85 second spacing.

V. Summary

The use of Interval Management Operations will include changes in procedures, and potentially changes in airspace. The allocation of the responsibility for managing the relative spacing interval to the flight deck will lead to training for both controllers and flight crews. The most appropriate integration and adaptation of the IM capability for a given airspace environment will need to be determined.

The use of Interval Management equipment and procedures is expected to bring several benefits to ATM and flight operations. The size of the benefits and relative contribution of each benefit mechanism will vary based on the specific operation used and the airspace environment.

By precisely managing the inter-aircraft spacing, aircraft are expected to be spaced closer together without increasing the likelihood of violating the separation standard.

Interval Management leverages several emerging technologies to improve the delivery precision of aircraft and supports the use of OPD arrivals. The use of ADS–B surveillance data for both ground automation improvements and for flight deck applications allows for better predictions of future aircraft positions and allows for more robust planning. This paper has described the Interval Management operation and variations that will leverage the IM capabilities to assist controllers and flight crews in improving arrival operations and spacing aircraft on final approach. These operations are part of a larger plan for using Interval Management capabilities to improve the efficiency and safety of NextGen operations.

References

[1] FAA. "Application Integrated Work Plan (version 2)," Washington, DC, 2010.

[2] "Recommendations to Define a Strategy for Incorporating ADS–B In Technologies into the National Airspace System," A Report from the ADS–B In Aviation Rulemaking Committee to the Federal Aviation Administration, Sept. 30, 2011.

[3] Thipphavong, J. and Mulfinger, D., "Design Considerations for a New Terminal Area Arrival Scheduler," 10th AIAA Aviation Technology, Integration, and Operations (AITO) Conference, Fort Worth, Texas, AIAA 2010-9290, September, 2010.

[4] RTCA DO-328A, "Safety, Performance and Interoperability Requirements Document for Airborne Spacing – Flight-deck Interval Management (ASPA-FIM)", Sep 22, 2015.

[5] FAA, November 2014, High Level Operational Concept Graphic (OV-1) for Time-Based Flow Management (TBFM) Work Package 3 (WP3) To-Be – A Final Investment Decision (FID) Product, Washington, DC.

[6] "Recommendations in Response to the Federal Aviation Administration May 30, 2012, Tasking," A Report from the ADS-B In Aviation Rulemaking Committee to the Federal Aviation Administration, October 31, 2012.

[7] "Automatic Dependent Surveillance–Broadcast In Aviation Rulemaking Committee — Recommendations in Response to Federal Aviation Administration May 30, 2012, Tasking," Final Letter from the Aviation Rulemaking Committee, Nov. 21, 2012.

[8] Callantine, T.J., Lee, P.U., Mercer, J., Prevot, T., "Terminal Area Traffic Management with Airborne Spacing," 5th AIAA Aviation, Technology, Integration, and Operations (ATIO) Conference, Arlington, Virginia, AIAA 2005-7403, September 2005.

[9] Prevot, T., Callantine, T.J., Homola, J., Lee, P.U., Mercer, S, "Air/Ground Simulation of Trajectory-Oriented Operations with Limited Delegation," Seventh USA/Europe Air Traffic Management Research & Development Seminar, Barcelona, Spain, June 2007.

[10] Murdoch, J.L., Barmore, B.E., Baxley, B.T., Abbott, T.S., Capron, W.R., "Evaluation of an Airborne Spacing Concept to Support Continuous Descent Arrival Operations," Eighth USA/Europe Air Traffic Management Research & Development Seminar, Napa, California, June 2009.

[11] Wilson, S.R., Murdoch, J.L., Hubbs, C.E., Swieringa, K.A., "Evaluation of Flight Deck-Based Interval Management Crew Procedure Feasibility," Aviation 2013 Conference, Los Angeles, California, AIAA 2013-4910, August 2013.

[12] Murdoch, J.L., Wilson, S.R., Hubbs, C.E., Smail, J.W., "Acceptability of Flight Deck-Based Interval Management Crew Procedures," Aviation 2013 Conference, Los Angeles, California, AIAA 2013-5155, August 2013.

[13] Weitz, L.A., Katkin, R., Moertl, P., Penhallegon, J., Hammer, J.B., Bone, R., Peterson, T., "Consideration for Interval Management Operations in a Mixed-Equipage Environment," 12th AIAA Aviation, Technology, Integration, and Operations (ATIO) Conference, Indianapolis, Indiana, AIAA 2012-5616, September 2012.

[14] Shay, R., Swieringa, K., and Baxley, B., "Aircraft Configuration and Flight Crew Compliance Procedures while Conducting Flight-deck-based Interval Management (FIM) Operations," AIAA Aviation Technology, Integration, and Operations Conference, September 2012.