Concept of Operations for Interval Management Arrivals and Approach

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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) Interval Management Program. The arrivals and approach operations are explored in detail including the primary operation and variations. 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 the highly automated 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 and Pilots and the ground automation tools that are used by Air Traffic Controllers to enable the operations are explored.

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.

In the Federal Aviation Administration (FAA) Reauthorization Action of 2012, Section 211(b), [1] Congress directed the Administrator to initiate a rulemaking proceeding within one year after the date of enactment to issue guidelines and regulations relating to ADS-B In technology. In addition, the rulemaking must require all aircraft operating in capacity constrained airspace, at capacity constrained airports, or in any other airspace deemed appropriate by the Administrator, to be equipped with ADS–B In technology by 2020. Early in 2012, the FAA modified the existing ADS-B In Aviation Rulemaking Committee (ARC) charter to extend its duration and address this reauthorization requirement as a new tasking. The ARC's findings did not support moving forward with the mandate. 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.

The ADS-B In ARC undertook an extensive review of the ADS–B In applications listed in the FAA's Application Integrated Work Plan [2] and ranked the applications by order of maturity, operational impact, and level of interest from operators [3]. 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, one equipped with ADS-B In and Out and FIM avionics, to achieve and/or maintain a spacing, in time or distance, relative to the controller-specified Target Aircraft. Relative spacing refers to

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managing the position of one aircraft to a time or distance relative to another aircraft, as opposed to a static reference point such as a point on the ground or clock time. 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. The necessary spacing may either be driven by the applicable separation standards or by metering constraints at points other than the runway. IM increases throughput in capacity constrained airspace. IM relies on speed control to achieve precise spacing and does not use off-path maneuvering.

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 builds the overall plan for arrivals including runway assignments and a schedule to the runway and associated Meter 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 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 availability of the IM Clearance depends on several conditions which the automation checks. Once all of the initial conditions are met, the TBFM automation then presents the IM Clearance information to the controller. If the controller desires to use IM, they issue the IM Clearance to the aircraft. When the flight crew receives the IM Clearance, they enter the information into the FIM avionics, which then starts providing the flight crew with speed guidance to conform to the IM Clearance. The aircraft will adjust speed to meet the Assigned Spacing Goal at the Achieve-by Point and maintain until the IM Operation is terminated. The location of the Achieve-by and Planned Termination Points are set by local adaptation. Both the controller and the flight crew are provided IM situation awareness information. The controller uses this information to assist in integrating the IM Aircraft with surrounding traffic being managed using TSAS. The flight crew uses this information to assist them in achieving the Assigned Spacing Goal and notifying the controller if they are no longer able to perform the IM Operation. If conditions warrant, the controller can terminate IM at any time and resume conventional control. At the latest, the IM Operation terminates approximately 5 nmi prior to the landing runway so that the flight crew can perform a stabilized approach and landing.

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 highly automated en route and terminal environment.

II. Near Term Arrival Operations Prior to Interval Management

The description of the 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.

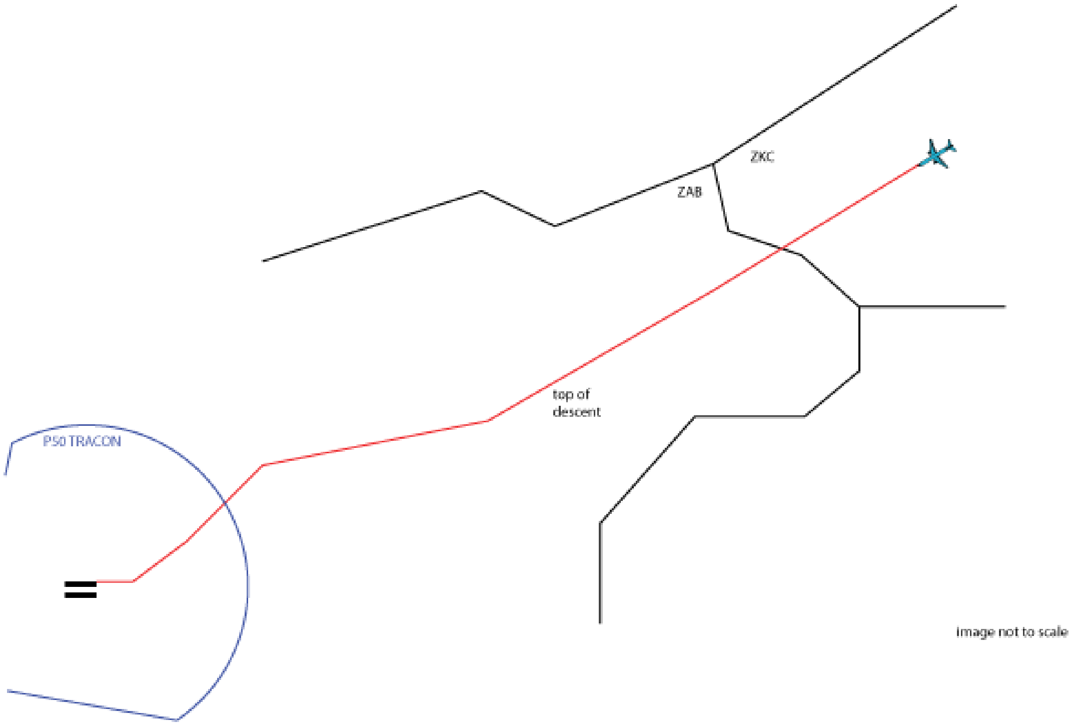

Figure 1. Schematic Diagram of the Airspace Describing Near Term Arrival Operations

The command center has been coordinating flow management initiatives and the use of metering for aircraft arriving to KPHX. The Traffic Management Coordinators (TMCs) have set up TBFM to meter flows leading to the EAGUL arrival. The pilots have 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. This is a very coarse picture of the winds for the descent and can introduce errors into the aircraft's planned trajectory. 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 additional 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 the 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). No Speed Advisories or Delay Countdown Timers (DCTs) are presented to the controller and the controller is not executing to the schedule yet. Traffic in the controller's sector, as well as weather data, appears on the controller's displays. 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 it uses a model of the aircraft's expected performance, standard values for the pilot-selected descent speed, an estimate of the aircraft's current airspeed, and forecast wind data. 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 GIM-S provides a Speed Advisory to the controller on their scope. The trajectory's 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 will not notice the new Speed Advisory until the next time they scan the Meter Reference Point (MRP) list 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 new speed 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 generated.

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 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, they will dial it in to the autoflight system and the autoflight will maintain that speed to within a few knots. As the aircraft progresses along their path, they pass from sector to sector. Throughout this time, TBFM is updating the aircraft's ETA to the Meter Fix using the latest surveillance information. The TBFM ETA has many sources of uncertainty and thus is imprecise. As the aircraft enters into a new sector, a new Speed Advisory is calculated and presented to the controller if necessary. 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 imprecise ETA, the Speed Advisory will not exactly match the speed that would be necessary to completely resolve the STA error at the Meter Fix.

The center controller does not know when the aircraft needs to start their 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 top-of-descent 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 top-of-descent. This uncertainty in the location of the top-of-descent point is a source of error in the ETA and hence any Speed Advisories presented and the DCT.

If given a descent speed, the flight crew will enter that into their FMS. Otherwise, they will use the FMS-calculated, or procedure-based, descent speed. This speed is generally not known by TBFM and is an additional source of uncertainty in the TBFM-calculated ETA. 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 again. The FMS will manage the lateral and vertical path of the aircraft as it executes 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. Speed and vectors can also be used to ensure any merges occur safely and no conflicts arise. Any speed or heading instruction will force the pilot 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 making a change. This will partially use the 10 kt buffer afforded to pilots to conform to a speed instruction. Similarly, changing winds may make the aircraft depart from the selected airspeed. Most pilots will allow the speed to deviate by several knots before making corrections to reduce their workload and engine wear and increase passenger comfort. The varying speeds will change the ETA at the next metering point and make any speeds issued by the controller less precise in meeting the STA.

The aircraft is in the final en route sector and approaching the Meter Fix and entry into the terminal airspace. The final ZAB controller may make a final speed adjustment in order to meet the STA at the Meter Fix to within ±60 sec. However, doing so will 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 kt at the Meter Fix. 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 pilot will enter the speed into their autoflight system

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[3] The presentation of a Speed Advisory for descent is dependent upon the individual facility and is influenced by the available route structure. For initial GIM-S operations, PHX 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.

(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 pilot adjusting drag or thrust. This leads to small variations around the instructed speed. Again, the execution of the solution will not be as precise as desired.

As the aircraft approaches the terminal area boundary, the ZAB controller initiates a hand-off to the P50 approach controller. The altitude and speed ranges for the aircraft at the hand-off are set by a Letter of Agreement (LOA) between facilities.

The 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, the controller will issue speed instructions to the aircraft to meet the STA. The trajectory uncertainties, such as wind forecast data, aircraft performance, and imprecise aircraft velocity, remain, making the slot marker and controllers speeds not as precise as desired to deliver the aircraft on time. For example, the winds used by TBFM for the remainder of the flight may be off by several knots and the aircraft's current velocity is underestimated by 3 kt. Over the course of the remaining flight this could cause a 10 second shift in the ETA away from the "perfect" value. This deviation would cause the controller to issue a speed that is appropriate for the situation presented to them but will not deliver the aircraft to the STA. The controller is unable to execute the solution as precisely as desired. As the aircraft proceeds along their flight, the current state of the aircraft and the desired position will not converge 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 change. These additional speed instructions will increase the controller's and flight crew's workload through attention and radio communications.

For any given speed instruction, the flight crew will implement it as before. During this time the flight crew will start extending flaps to configure for landing and provide adequate lift for the slower speeds. 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 speeds are needed. If needed, the controller will issue a speed instruction to the flight crew who will enter it into their autoflight system. The engines will adjust 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 several tens of seconds, adding uncertainty to the final spacing.

If the winds are gusty, or particularly slow or fast speeds have been commanded, the pilot may make use of a 10 kt 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 final approach speed is dependent upon the aircraft model, weight, landing configuration and wind conditions. TBFM does not know most of this information and uses a 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 flight crews provides a tighter control loop allowing individual aircraft to achieve more delivery precision than a controller managing many aircraft at once can achieve.

Delivery precision is defined as the standard deviation of the difference (error) between the desired and actual inter-aircraft times (IAT) as these aircraft cross a fixed point. To avoid separation violations, controllers must account for operational IAT variability, which leads to the addition of a spacing margin (buffer) above the separation standard. With lower variability in the IAT, 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 an increase in throughput.

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.

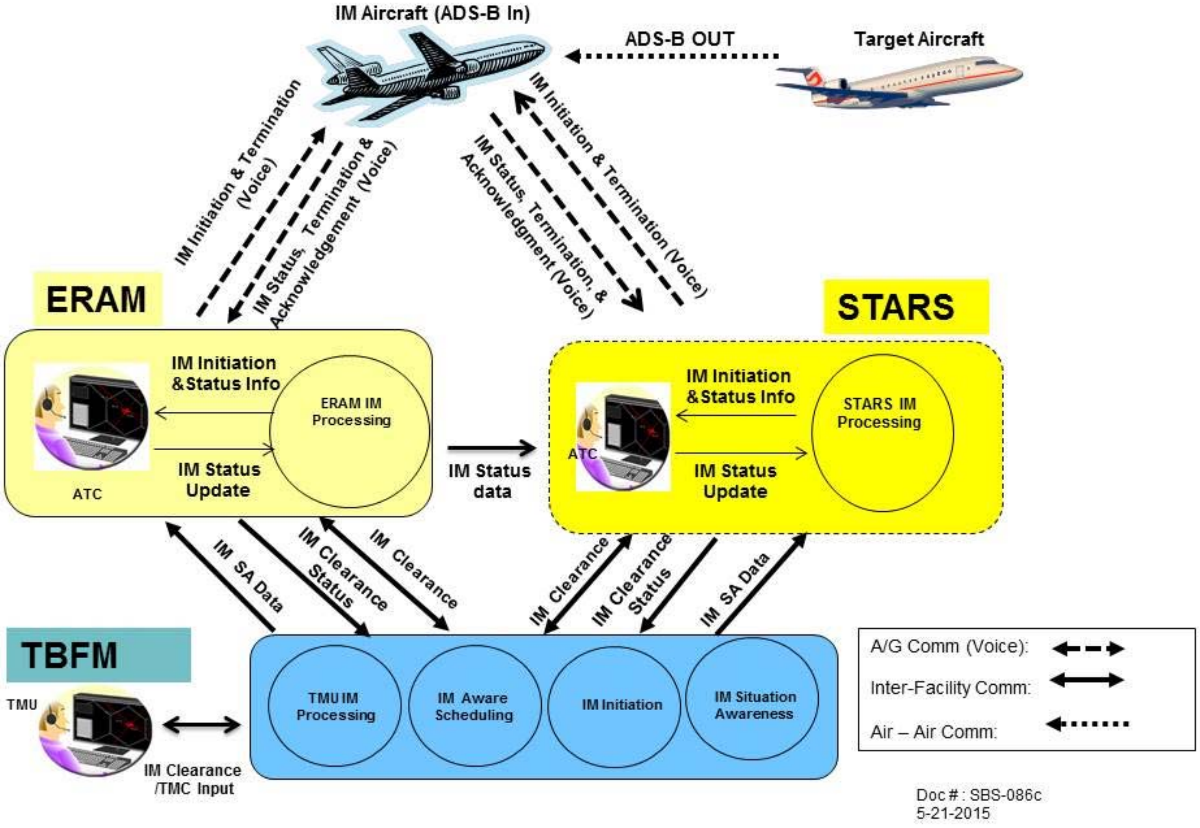

Figure 2. Diagram of Interval Management Operations Supporting Systems

This operation is designed to be used in an environment, such as the top 35 airports in the NAS, when there are multiple arrival routes entering a terminal airspace and en route and terminal metering is in effect. The operation begins with initiation in en route airspace and continues through to the final approach fix or another predetermined, adaptable point. The IM Aircraft and Target Aircraft can be on different arrival routes with the two routes merging either in en route or terminal airspace. The Achieve-by Point will be placed at a point at or after where the IM and Target Aircraft join a common route and at or prior to the Final Approach Fix. It is expected that the selection of the Achieve-by Point will be a facility decision and will differ from facility to facility.

The IM Aware scheduler 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 adjusts the spacing needed between those aircraft to the appropriate IM spacing value. 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 spacing is a settable parameter and may vary between facilities and over time.

Once an aircraft crosses the freeze horizon for their Meter Fix, their STA is frozen. Their position in the arrival sequence was frozen previously at the Coupled Metering Point. At this time, and once the remaining initiation criteria are met (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 possible IM pair (IM and Target Aircraft) and provides 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 the automation that the IM Operation has begun. The IM Aircraft's status will change to active as will the Target Aircraft's status. This notifies the controller with responsibility for the Target Aircraft. The Target Aircraft's controller will coordinate changes to the Target Aircraft's Intended Flight Path with the controller of the IM Aircraft. If the controller decides not to issue the IM Clearance, they set 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 Speeds for the flight crew to follow. 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 their speed to achieve the relative spacing behind the Target Aircraft; the controller no longer manages the aircraft to their 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 their 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 new controller has access to that information. The controllers are also provided with 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 termination point (the "maintain stage").

The controller manages non-IM Aircraft to meet their STAs at the Meter Fix and appropriate locations within the terminal airspace[4]. 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.

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. Extended metering is in use with PLOVR, ILAND, HAGRD and ANDRE being Meter Points. Meter Fixes for the terminal airspace are at CRDNL, STRMM and GIANT. There are two terminal merge points where terminal metering is used: STONE and FIELD. The Achieve-by and Planned Termination Points are co-located[5] 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] The behavior of how controllers meet STAs for non-IM Aircraft and how IM Aircraft achieve their assigned relative spacing needs to be coordinated so that their behaviors complement each other and do not cause flow disturbances.

[5] 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.

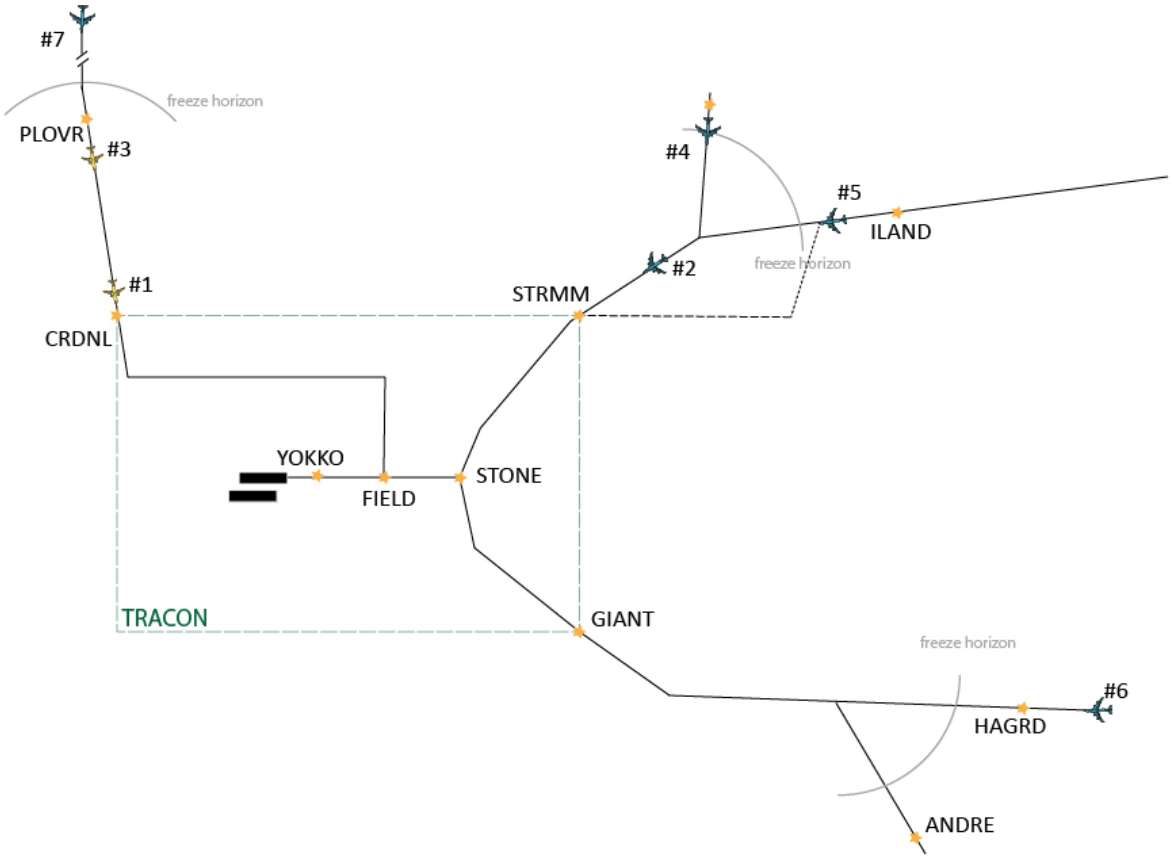

Figure 3. **IM Initiated En Route on Multi-Stream Arrivals**

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 them 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. This includes 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 them manage the speed of aircraft #1 along the published RNAV arrival procedure and meet subsequent STAs.

When aircraft #2 crossed the freeze horizon for STRMM, the scheduler identified them as IM capable and that aircraft #1 would be a valid Target Aircraft. Since an IM Clearance is expected, the scheduler schedules aircraft #2 85 seconds behind aircraft #1 (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 80 nmi ADS-B air-to-air range so the IM Clearance information for aircraft #2 was not presented. The en route controller saw a DCT for aircraft #2 and slowed them down from 310 kt to 270 kt. When aircraft #2 is within 80 nmi 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. This information is determined by TBFM. The standard Planned Termination Point, YOKKO, is published as part of the arrival procedure and set appropriately in the ground automation. The en route controller issues the IM Clearance to the flight crew of aircraft #2.

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

Once 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. When possible, 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.

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 kt 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 they approach CRDNL, the FIM avionics commands a similar slow down for aircraft #2. The flight crew implements the new IM Speed.

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 IM conducting aircraft. 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 the final approach fix, YOKKO, the final controller transfers aircraft to the air traffic control tower controller in time for the aircraft to receive 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.

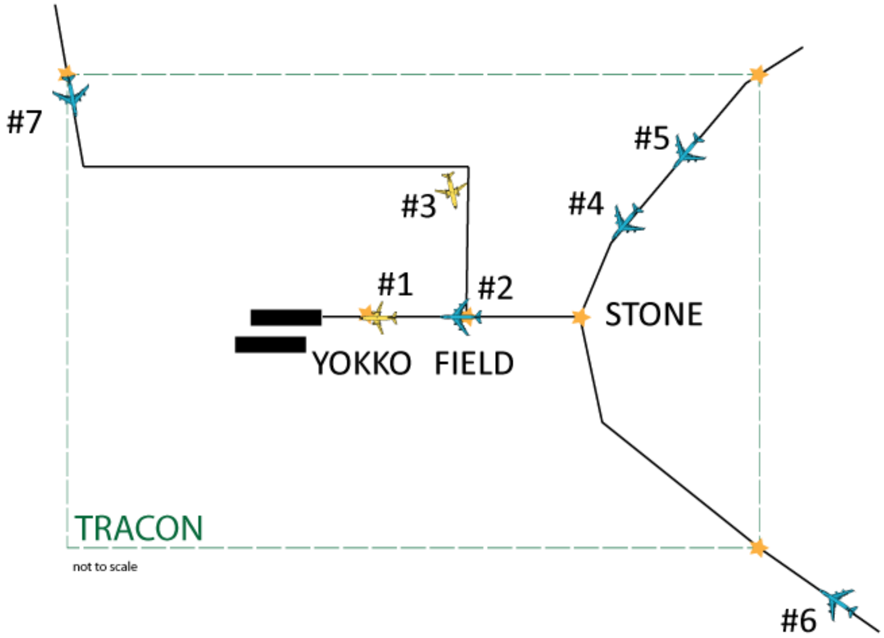

Figure 4. The Airspace with All Six Aircraft in the Terminal Area

Aircraft #3 has no ADS–B equipment and is managed by the controllers to meet their 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, they are 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 their freeze horizon, the scheduler identifies them as IM capable. In the planned sequence, they 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 Meter Fix, STRMM, and they are 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 their schedule 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 they issue 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. They are spaced at 70 seconds (approximately 6 nmi) behind aircraft #4 and going slower by the time they reach STRMM. Aircraft #5 continues to open up the spacing until they reach 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, the IM Clearance information is held in automation until aircraft #5 is direct to STRMM. 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 approximately 15 minutes in order to get a delayed departure out. The TMC determines that the best place for the additional space is between aircraft #5 and #6. This change to the scheduler 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 MANAGEMENT, TURN LEFT HEADING 250.*
>
> *AIRCRAFT6: WILCO, SUSPEND INTERVAL MANAGEMENT AND TURN LEFT HEADING 250, AIRCRAFT 6.*

Once the aircraft is past the weather cell, the controller clears them 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.

...

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 they transition into the terminal area. As aircraft #6 turns onto the final approach course, the controller's monitoring tool 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 their freeze horizon, they are still well outside the expected 80 nmi air-to-air surveillance 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 nmi from the Meter Fix, CRDNL, they are finally within air-to-air surveillance range 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 the terminal airspace. As aircraft #7 approaches the base leg turn the controller terminates the IM Operation for aircraft #6 and slows them (see description above). Aircraft #7 responds by slowing to their minimum allowed speed in order to achieve the assigned 85 second spacing.

The IM Operation will allow IM aircraft to be spaced closer to their target aircraft than a pair of non-IM Aircraft. This will reduce the total amount of delay required during high-demand arrival operations.

IV. Conclusion

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 additional 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 the NAS and its users. 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. The determination of the Assigned Spacing Goal accounts for the improved precision. With a reduced spacing variance from IM Operations, the average spacing can be moved closer to 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 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

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