Surveillance and Broadcast Services (SBS) Group

Automatic Dependent Surveillance - Broadcast (ADS-B) In Retrofit Spacing (AIRS) Initial–Interval Management (I-IM) Operational Evaluation

Year 1 Project Review Report (2022-2023)

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Initial–Interval Management (I-IM) Operational Evaluation
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Executive Summary

Global demand for air travel continues to rise with 3.8% year-over-year increases projected over the next 20 years. There is a pressing need for new capabilities and procedures to increase air traffic throughput without compromising safety. The Automatic Dependent Surveillance-Broadcast (ADS-B) In Retrofit Spacing (AIRS) Evaluation of Initial-Interval Management (I-IM) operations evaluated one such system and involved a collaboration between government and industry partners to quantify benefits resulting from relative spacing operations.

Improvements in aircraft communication, navigation, and surveillance systems in the National Airspace System (NAS) have led to the development of multiple concepts to improve efficiency, capacity, and enhance safety. These include the deployment of ADS-B and expanded use of Trajectory-Based Operations (TBO). Aircraft that are equipped with ADS-B receivers (ADS-B In) with Aircraft Surveillance Applications (ASA) Systems can receive surveillance information about other aircraft in the surrounding airspace and display this information as well as application-specific information to the pilot. ADS-B is a key component of the Next Generation Air Transportation System (NextGen). ADS-B In enabled applications such as Interval Management (IM), Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS), and Cockpit Display of Traffic Information (CDTI) Assisted Separation on Approach (CAS-A), are designed to realize TBO and NextGen objectives by improving aircraft speed management along their planned paths leading to flight efficiency and throughput benefits. These ADS-B In-enabled applications help mitigate growth in NAS-wide delays and projected airport capacity shortfalls as the number of flights continue to increase.

Interval Management (IM) is an ADS-B-enabled operation that uses a combination of ground automation, flight-deck capabilities, and procedures to support relative spacing of aircraft. Air traffic control can instruct the flight crew of an equipped IM aircraft to achieve and then maintain an assigned spacing goal relative to a specified lead aircraft. Relative spacing from the lead aircraft is managed by implementing speed guidance on the IM aircraft. The relative spacing goal may be issued as a distance or time value to support time-based metering operations. The IM speed guidance onboard the IM aircraft yields more precise inter-aircraft spacing intervals than possible when speed instructions are issued by air traffic controllers, even when using decision support systems. Prior IM performance analyses have assumed IM aircraft can achieve and maintain their assigned spacing goals within 10 seconds, 95% of the time. The spacing precision possible from IM operations can lead to smaller inter-aircraft spacing intervals, on average, which yields throughput improvements at constrained resources (e.g., arrival meter fixes for managing aircraft flows into terminal airspace and arrival runways). Additionally, precise inter-aircraft spacing is expected to result in reduced controller vectoring, allowing flights to remain on their planned routes more frequently, resulting in reduced carbon emissions.

The ADS-B In Retrofit Spacing (AIRS) project was established for the purpose of conducting a large-scale operational evaluation of ADS-B In technologies during revenue service flights. The primary goal of the AIRS evaluation is to demonstrate the operational feasibility and value of ADS-B In capabilities using a retrofit solution. A sub-set of IM operations, termed Initial-IM (I-IM), were studied as part of the AIRS Evaluation.

The first year of the AIRS I-IM operational benefits evaluation was conducted in partnership with the Albuquerque Air Route Traffic Control Center (ZAB), Federal Aviation Administration (FAA) headquarters organizations, American Airlines (AAL), and avionics manufacturer Aviation Communication & Surveillance Systems, LLC (ACSS). Other partners on the project include representatives from the National Air Traffic Controllers Association (NATCA) and the Allied Pilots Association (APA). Operations began in November 2022 and data collection for the first year was completed in November 2023.

American Airlines conducted a retrofit of their entire Airbus A321 fleet, consisting of A321ceo (current engine option) and A321neo (new engine option) aircraft, with the commercially available SafeRoute+ ADS-B In avionics suite. In total, 298 aircraft were equipped, of which 218 were A321ceos and 80 were A321neos.

Data was collected and analyzed as a part of the operational evaluation. Data sources included FAA trajectory data, Aviation System Performance Metrics (ASPM), FAA voice transcript data, and FAA Time-Based Flow Management (TBFM) data. Other data sources included SafeRoute+ traffic computer data, ZAB controller feedback forms and observations, and AAL/APA flight crew feedback and observations.

During the first year of the operational evaluation, a total of 581 IM operations were attempted, resulting in 533 completed IM operations. Of the 533 completed IM operations, 376 were categorized as successful and 157 were categorized by controllers as unsuccessful, resulting in a success rate of 71%. Operations were considered unsuccessful if the operation exhibited a concern or issue that was tracked by the project. Examples of issues and concerns included phraseology interpretation and understanding, pilot uncertainty with managing IM Speed Commands, and avionics issues, including use of the pilot interface to the Multi-purpose Control and Display Unit (MCDU). These concerns and issues were tracked and studied throughout the year. Recommendations for future changes to procedures and the SafeRoute+ system are included in this report.

Analyses compared IM spacing accuracy to the spacing accuracy of those aircraft not doing IM operations at meter points. Aircraft conducting time-based IM operations demonstrated a smaller average interarrival time and standard deviation as compared to the non-IM flights. Results were similar for distance-based IM operations and achieved a smaller average and standard deviation as compared to non-IM flights. Analyses of IM distance-based operations data indicates that at a common point (known as a Cross Point (CP)), the difference between the observed distance and the distanced-based spacing goal is an average of 0.2 nautical miles (NM), with 95% of the flights being within 1 NM of the mean. Similarly, analyses of IM time-based operations data indicates that at the CP, the difference between the observed time and the time-based spacing goal is an average of 4 seconds with 95% of the flights being within 24 seconds of the mean.

We also compared the IM spacing accuracy at the arrival meter fix on the “EAGUL” Area Navigation (RNAV) Standard Terminal Arrival (STAR) to Phoenix Sky Harbor International Airport (KPHX) to time-based metering operations. When filtering IM operations to only those where flight crews were compliant with at least 70% of the IM Speed Commands, 90% of IM operations met their spacing goal within 10 seconds. In comparison, only 23% of flights managed using time-based metering decision support tools were within 10 seconds of their scheduled times. These results show the spacing precision claimed in prior work can be achieved in a real-world environment with controllers initiating operations, pilots implementing the IM Speed Commands manually (i.e., without coupling the SafeRoute+ system to the aircraft flight guidance system), and given operational uncertainties, such as winds and unexpected speed changes from the lead aircraft. The IM spacing performance shows a significant incremental benefit beyond what can be achieved using time-based metering decision support tools and controller-issued speed instructions alone. Prior benefits studies showed that increased spacing precision at arrival meter fixes, like those operations studied as a part of the AIRS Evaluation, can lead to flight efficiency benefits as flights are able to remain on their planned procedures at higher rates.

Discussions with ZAB subject matter experts and ZAB line controllers indicated that, aside from the previously mentioned issues, IM operations worked well and controllers could see the potential benefits of IM. However, controllers indicated they would be more inclined to use IM if the information they needed to conduct the operation was displayed on their En Route Automation Modernization (ERAM) displays.

The American Airlines pilots received their IM training through bulletins, iPad-based Distance Learning modules, and basic videos. It was not possible to practice an IM operation until receiving a clearance from a controller. Given this operation was a first of its kind and several months had passed for many pilots between training and the start of the evaluations, there was a learning curve that had to be achieved with the SafeRoute+ system and IM operation. However, as flight crews became more familiar with the operation, most found IM to be straight forward and intuitive. AAL developed a Quick Reference Guide (QRG) that was reported to be effective and helpful for pilots prior to and during IM operations. Airbus pilots are accustomed to flying fully automated aircraft. Many pilots expected the IM Speed Command to be coupled with the flight automation system versus the requirement to manually select the speeds indicated. Bulletins were quickly issued to clarify the requirement for manual input.

The AIRS Evaluation demonstrated the operational feasibility and benefits of ADS-B In and IM operations, showing significant improvements in spacing precision over today’s operations, including time-based metering operations. The objective findings, along with controller and flight crew feedback, support continued development and integration of IM operations into the NAS to meet the growing demands of air traffic.

Acknowledgements

This report includes contributions from several members of the AIRS I-IM team. Contributing organizations include the following.

- Allied Pilots Association (APA)
- American Airlines (AAL)
- Aviation Communication & Surveillance Systems, LLC (ACSS)
- National Air Traffic Controllers Association (NATCA)
- Albuquerque Air Route Traffic Control Center (ZAB)
- Federal Aviation Administration (FAA) employees and their support
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    - Blue Mountain Aero, LLC
    - The MITRE Corporation
    - The Regulus Group

Contents

1 Introduction

1.1 AIRS Project Overview

Global air traffic demand continues to rise with predicted year-over-year increases of 3.8%[1]. New capabilities and procedures are needed to increase air traffic throughput without compromising safety to address this increased demand. Improvements in aircraft communication, navigation, and surveillance systems in the National Airspace System (NAS) have led to the development of multiple concepts to improve efficiency, capacity, and enhance safety. These include the deployment of Automatic Dependent Surveillance-Broadcast (ADS-B) and expanded use of Trajectory-Based Operations (TBO). Aircraft that are equipped with ADS-B receivers (ADS-B In) and Aircraft Surveillance Applications (ASA) Systems can receive surveillance information about other aircraft in the relevant surrounding airspace and display this information as well as application specific information to the pilot. ADS-B, and the operations that it enables, are key components of the Next Generation Air Transportation System (NextGen), will enhance TBO, and help mitigate the growth in NAS-wide delay and projected airport capacity shortfalls. ADS-B In enabled applications such as Interval Management (IM), Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS), and Cockpit Display of Traffic Information (CDTI) Assisted Separation on Approach (CAS-A), are designed to help improve capacity and realize TBO and NextGen objectives[2].

The ADS-B In Retrofit Spacing (AIRS) project was established for the purpose of conducting a large-scale operational evaluation of ADS-B In technologies during revenue service flights. This public-private partnership, covered under a Memorandum of Agreement (MOA), includes a collaboration between the Federal Aviation Administration (FAA), American Airlines (AAL), and avionics manufacturer Aviation Communication & Surveillance Systems, LLC (ACSS). Other partners on the project include representatives from the National Air Traffic Controllers Association (NATCA) and the Allied Pilots Association (APA).

The primary goal of the AIRS Evaluation was to demonstrate the operational feasibility and value of ADS-B In capabilities via a retrofit solution.

The evaluation enabled the FAA and the aviation industry to:

- Evaluate and confirm operational benefit assumptions
- Evaluate the use of an ADS-B Guidance Display as a retrofit solution for displaying ADS-B In guidance in the flight deck forward field of view
- Validate ADS-B In avionics performance given real-world conditions
- Gather real-world experience to validate future Air Traffic Control (ATC) automation requirements and costs
- Evaluate flight crew and controller acceptance of the operations
- Determine better guidance on phraseology and procedures for future NAS-wide implementations
- Accelerate the development and deployment of ADS-B In technology

1.2 AIRS Project Operational Evaluation Approach

The AIRS operational evaluation involves a unique approach to managing the risks associated with introducing new technologies and operations into the NAS. The operational evaluation is being conducted using certified aircraft operating in revenue service but are limited to specified airspace regions for a period of two years. The evaluation does not include significant, potentially costly, ATC automation necessary for all envisioned operations. Operational evaluations are not flight tests involving experimental aircraft, nor are they NAS-wide implementations. The operations and certified avionics are intended to be representative of potential solutions that could be deployed NAS-wide.

The operational evaluation approach allows the FAA and industry to make modifications based on data obtained during the evaluation. For example, based on feedback obtained during the trial, it was determined that modifications to the initially proposed phraseology would improve the clarity and overall flow of the operations. Similarly, it was determined that changes to the avionics display would improve flight crew understanding and conduct of the operations. The initial solutions were acceptable, but the operational evaluation approach allowed the proposed implementations to be improved prior to potential NAS-wide deployment.

To support the evaluation, AAL retrofitted their entire Airbus A321 fleet, comprising A321ceo (current engine option) and A321neo (new engine option) aircraft, with the commercially available ACSS SafeRoute+ ADS-B In avionics suite. This flight deck system and applications enable Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS), CDTI Assisted Separation on Approach (CAS-A), and Initial-Interval Management (I-IM) operations. In total, 298 aircraft were equipped, of which 218 were A321ceos and 80 were A321neos.

1.3 Document Scope

The first year of the AIRS Initial-Interval Management (I-IM) operational benefits evaluation was conducted in partnership with the Albuquerque Air Route Traffic Control Center (ZAB) beginning in November 2022 and ending in November 2023. The purpose of this report is to document the results from the AIRS (I-IM) operational benefits evaluation over this period. This document provides an overview of the evaluation, a description of the data collection process, analyses of the data obtained, a summary of the effort and key lessons learned during the operational evaluation, and recommendations for future research areas.

2 Initial-Interval Management (I-IM) Operational Benefits Evaluation

2.1 Interval Management (IM) Overview

Interval Management (IM) is an ADS-B-enabled operation that uses a combination of ground automation, flight-deck capabilities, and procedures to support relative spacing of aircraft. Air traffic control can instruct the flight crew of an equipped IM aircraft to achieve and then maintain a spacing relative to a specified lead aircraft (see Figure 1). Relative spacing is managing the position of one aircraft relative to another aircraft, as opposed to a static reference such as a point on the ground or clock time. The relative spacing may also be issued as a distance or time value to support time-based metering operations.

Figure 1 - Depiction of basic IM operation

IM operations support achieving consistent, low variance spacing between paired aircraft during the level cruise or arrival phase of the IM aircraft's flight. Enabled by ADS-B reports from the lead aircraft, the IM aircraft calculates the necessary speeds to achieve and/or maintain the spacing goal and presents those speeds to the flight crew for execution. Consistent, low variance spacing is expected to allow a reduction in inter-aircraft spacing intervals, thereby reducing the time interval between the aircraft at the arrival runway threshold, resulting in increased arrival throughput. Overall efficiency is also increased by avoiding costly, low-altitude maneuvering[2].

In an end state, air traffic controllers would be 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 (including coordination across sectors). Upon receiving the IM clearance, the flight crew enters the information into their IM avionics. The IM avionics then calculates and presents the IM Speed (also referred to as the Commanded Speed), which, if followed, will achieve the relative spacing assigned by the controller, called an Assigned Spacing Goal (ASG) at a controller specified waypoint, called the Cross Point (CP), and maintain that spacing until a controller defined waypoint, called the Planned Cancellation Point (PCP), or until the controller cancels the operation. The ASG can be a time-based goal (in seconds) or a distance-based goal (in nautical miles). Both the flight crew and the controller are provided with situational awareness information to monitor the progress of the IM operation.

The full set of IM operations is described in Radio Technical Commission for Aeronautics (RTCA) DO-328B "Safety, Performance and Interoperability Requirements Document for Airborne Spacing—Flight Deck Interval Management (ASPA-FIM)"[3]. The IM avionics requirements are specified in RTCA DO-361A, "Minimum Operational Performance Standards (MOPS) for Flight-Deck Interval Management (FIM)"[4]. The IM operations and the avionics requirements have been developed to support a 10-second spacing tolerance.[1]

[1] The spacing tolerance refers to the accuracy with which the IM Aircraft should meet the ASG. The spacing performance is defined as 10 seconds, 95%, at the CP. This means 95% of IM operations should be within 10 seconds of the ASG at the CP. Additionally, the spacing performance is specified as 10 seconds, 95%, when maintaining the ASG between the CP and PCP. This means an IM Aircraft should be within 10 seconds of the ASG for 95% of the flight time between the CP and PCP.

IM operations enable more precise inter-aircraft spacing, which allows smaller inter-aircraft spacing intervals, on average, and results in increased throughput. Several studies have quantified IM benefits given the assumed 10-second spacing tolerance. Howell et al. studied IM throughput benefits using an FAA fast-time simulation model and airport-specific arrival/departure curves adjusted to account for the reduction in mean inter-aircraft spacing enabled by IM [5] . That study assumed IM operations ending at the Final Approach Fix. Table 1 shows the maximum arrival throughput increases for different IM operations[2] (see Table II in Howell et al.). The different IM operations in Table 1 are described in more detail in the ADS-B In Strategy document developed by the Equip2020 ADS-B In Working Group [6].

Table 1. Maximum Arrival Throughput Increases by Airport and For Different IM Operations (Table II in (Howell, Dean, & Paull, 2019))

Airport	SR VMC,MMC,IMC	SR+DCCR	SR+DCCR+DSA/PA
ATL	12%, 13%, 10%		
BOS	5%, 6%, 1%	MMC 12%, IMC 10%	IMC 15%
BWI	16%, 12%, 9%		
CLE	13%, 14%, 10%		
CLT	13%, 11%, 10%		
CVG	13%, 14%, 11%		
DCA	11%, 14%, 11%	VMC 14%, MMC14%	
DEN	14%, 14%, 11%		
DFW	14%, 14%, 11%		
DTW	14%, 6%, 5%		
EWR	9%, 4%, 1%	VMC 12%	MMC 35%,IMC 36%
FLL	0%, 2%, 2%		
HNL	19%, 19%, 15%	20%, 23%, 18%	
IAD	13%, 12%, 11%		
IAH	5%, 0%, 3%		
JFK	13%, 6%, 10%		
LAS	14%, 16%, 12%	MMC 17%	
LAX	12%, 12%, 10%		
LGA	14%, 14%, 12%		
MCO	13%, 14%, 11%		
MDW	26%, 26%, 24%		
MEM	12%, 10%, 10%	VMC 12%, MMC10%	
MIA	12%, 13%, 12%	12%, 13%, 12%	
MSP	6%, 11%, 10%	VMC 6%, MMC 11%	
ORD	13%, 13%, 10%		
PDX	13%, 13%, 10%		
PHL	21%, 10%, 4%	21%, 10%, 4%	
PHX	14%,0%,0%		
PIT	28%, 29%, 24%		
SAN	13%, 11%, 9%		
SEA	10%, 8%, 7%		MMC 9%, IMC 7%
SFO	11%,0%,0%		MMC 18%, IMC 31%
SLC	18%, 18%, 15%		
STL	9%, 0%, 6%		MMC 13%, IMC 7%
TPA	29%, 17%, 15%		

[2] The IM operations shown are Same Runway (SR), Dependent Crossing and Converging Runways (DCCR), Dependent Staggered Approaches (DSA), and Paired Approach (PA).

To provide context for IM benefits, the ADS-B In Strategy document shows the portion of overall excess delays in the NAS that may be addressed by ADS-B In applications. As shown in Figure 2, 38% of excess delays in the NAS are attributed to airborne delays. Other NextGen improvements will address 29.9% of those airborne delays, and the use of flight-deck (ADS-B In) applications will address 19.7% of those airborne delays.

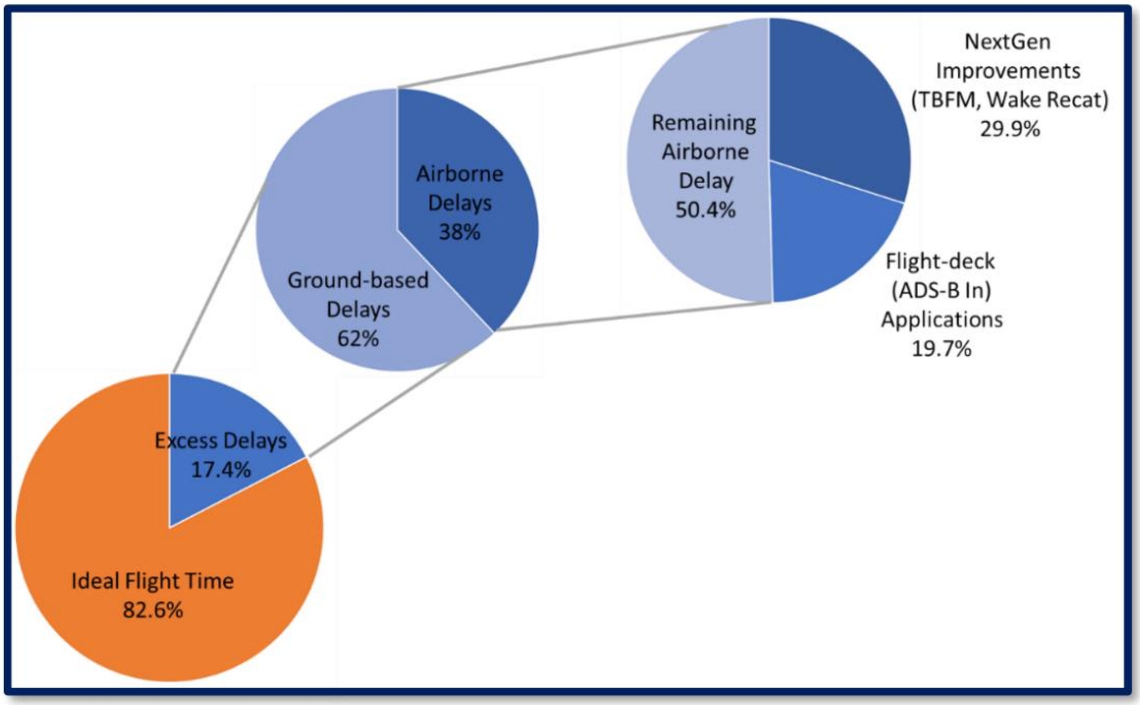


Figure 2 - Remaining shortfalls in airborne delays addressed by ADS-B In applications (see Figure 11 in (ADS-B Equip2020, Working Group 4, 2019))

2.2 Initial-Interval Management (I-IM) Overview

Initial-Interval Management (I-IM) is a subset of the capabilities described in RTCA DO-328B. This subset consists of two IM clearance types, Cross (Achieve-by then Maintain in RTCA DO-328B) and Maintain (Capture then Maintain in RTCA DO-328B), which allow a properly equipped aircraft with a properly trained flight crew, known as the IM Aircraft, to achieve and/or maintain a desired ASG behind another aircraft, known as the Lead Aircraft (also referred to as "Traffic-To-Follow" or TTF). A complete description of the AIRS I-IM concept is contained in the FAA document entitled "ADS-B In Retrofit Spacing (AIRS) Initial–Interval Management (I-IM) Operational Description"[7].

The Maintain clearance type is used when the IM Aircraft and Lead Aircraft are on a common route (see Figure 3). The SafeRoute+ equipment provides speeds (known as IM Speeds) such that when flown, the IM Aircraft will achieve the ASG as soon as possible and then maintain the ASG until the controller cancels it or the IM Aircraft reaches the PCP (if assigned).

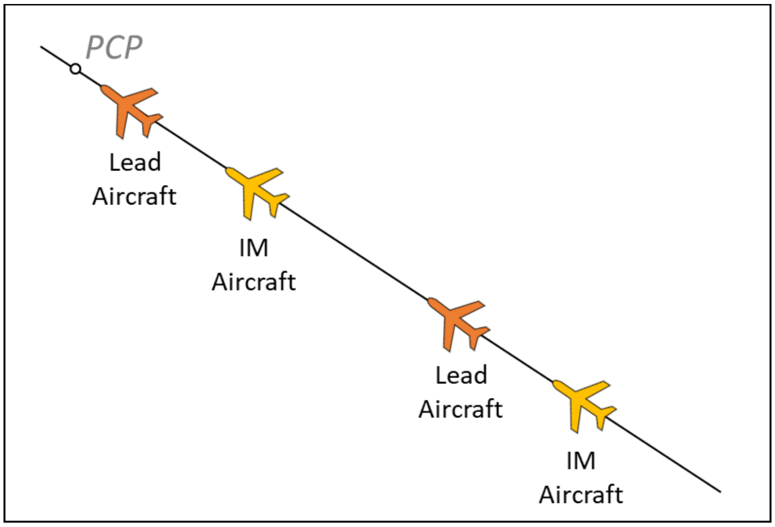


Figure 3 - IM Maintain Operation

The Cross clearance type is used when the IM aircraft and Lead aircraft need to achieve a spacing goal by the Cross Point (CP), which must be a common point on their routes. Typically, this is used when the lead aircraft and IM aircraft are initially on different routes that will merge and continue along a common route (see Figure 4). The aircraft routes must be direct to the CP with no turns. The SafeRoute+ equipment will provide speeds such that the ASG will be attained at or before the CP. Once the CP is reached, the flight crew continues to fly IM speeds until ATC cancels the operation or the IM aircraft reaches the PCP. The PCP may be co-located with the CP.

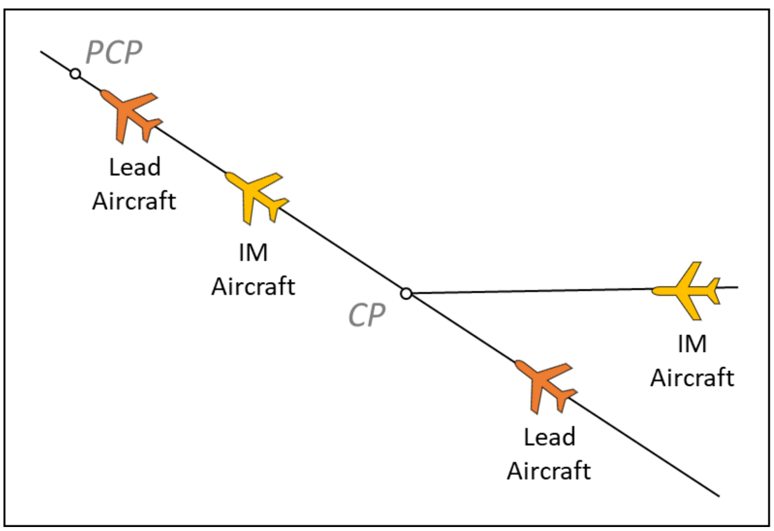


Figure 4 - IM Cross Operation

The SafeRoute+ system was developed before RTCA DO-361A was completed; therefore, it is not fully compliant with the Minimum Operational Performance Standards (MOPS). The I-IM operations used for this operational evaluation were limited based on the SafeRoute+ application capabilities. Some important limitations that directly impact the controller and flight crew application of I-IM included the following:

Path Conformance and Infeasibility Checking

- Aircraft must be on the same route or direct to a common fix, which is the CP used in a Cross clearance. In this case, direct to a common point means there can be no course changes between either aircraft's current position and the CP, though there may be intervening waypoints. The CP must be within a 40° cone of both aircraft tracks, meaning if either aircraft has been vectored or has course changes in the route, the IM operation should not be initiated until both aircraft are headed direct toward the CP. Prior to the CP, the equipment will cancel the operation and notify the flight crew if either aircraft in the pair fails this conformance check.

- During the Maintain stage (i.e., same route), the cross-track difference between the IM Aircraft current position and Lead Aircraft historical position must be within an 8 NM "swimlane" centered around IM Aircraft's instantaneous track projection. The "swimlane" is the area defined in the lateral plane of the aircraft +/-4 NM to either side, both ahead and behind, of its direction of movement.

- To initiate a Maintain clearance, the Lead aircraft must be ahead of the IM Aircraft and within a 6 NM swimlane centered around the IM Aircraft's instantaneous track projection; the IM Aircraft must be behind the Lead and within a 6 NM swimlane centered around the Lead's historical track; or the instantaneous tracks must have an intercept angle less than 90° and intersect between the two aircraft positions.

For more details on the limitations of the SafeRoute+ system as compared to the IM equipment compliant with RTCA DO-361A, refer to Appendix 9.1

Additionally, while Data Communications is envisioned as an enabler for future complex IM clearances, the I-IM operational evaluation utilized only verbal clearances and were limited to simpler clearances that allowed controllers to communicate them over voice communications.

An analysis by Priess and Weitz evaluated the benefits of improved spacing at the meter fixes (MFs), on the en-route/terminal airspace boundary, used to manage arrival flows to the terminal[8]. That analysis considered the relationship between delivery accuracy to Scheduled Times of Arrival (STAs) at the MFs and lateral conformance to Area Navigation (RNAV) arrival procedures. Improved delivery accuracy resulted in increased conformance to RNAV arrival procedures (i.e., a reduction in vectoring), which leads to aircraft efficiency benefits. Table 2 relates Meter Fix (MF) delivery accuracies to a maximum flow rate across an MF where ATC interventions to manage separation at the arrival meter fix is less than once every two hours (i.e., 0.5 interventions per hour). Flow rates exceeding these values will require more frequent ATC interventions.

Table 2. Relationship between Meter Fix Delivery Accuracy and Maximum Flow Rate

Category[3]	MF Accuracy (s, 95%)	Maximum Flow Rate (aircraft/hour)
Current Metering Performance	90	19
Improved Metering Operations	60	24
Flight-deck Tools (Conservative)	30	33
Flight-deck Tools (Expected)	10	47

The pie chart in Figure 5 shows the number of days in 2023 with the number of hours where the arrival flow rates, to at least one arrival meter fix, at Dallas Fort Worth International Airport (KDFW) exceeded 19 aircraft/hour. Current metering tools would be inadequate for keeping flights on their RNAV arrivals during these hours, and we expect increased rates of vectoring during these hours. Therefore, Figure 5 shows the benefits opportunity for improved delivery accuracy at KDFW. For example, in 16% of days (58 of 365 days in 2023), current metering tools are inadequate for 5 hours. In 19% of days (69 of 365 days in 2023), current metering tools are inadequate for 6 hours.

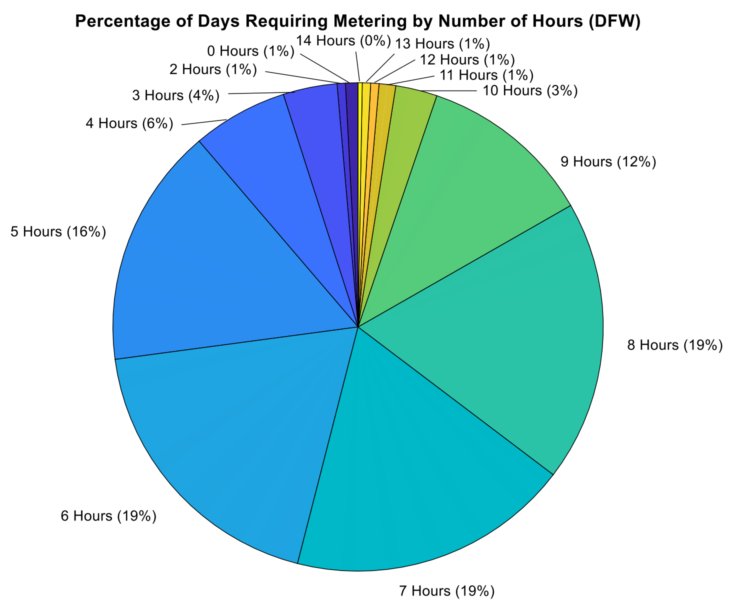


Figure 5 - Number of hours for which current metering operations are inadequate for flow rates at KDFW (over 2023)

[3] The category refers to air traffic capabilities and operations used to manage flights to STAs at the meter fix as defined in Priess and Weitz (Priess & Weitz, 2022). "Current metering performance" refers to the use of Time-Based Flow Management (TBFM) decision support tools at they exist today. "Improved metering performance" refers to the performance expected with improvements in TBFM adaptation and Performance-Based Navigation (PBN) procedure designs. "Flight-deck Tools" refers to the spacing performance possible with flight-deck capabilities like IM. While we expect flight-deck tools to yield delivery accuracies of 10 seconds, 95%, we have included a conservative assumption on the performance of 30 seconds, 95%.

The pie chart in Figure 6 shows the number of days in 2023 with the number of hours where the arrival flow rates, to at least one arrival meter fix, at KDFW exceeded 24 aircraft/hour. Improved metering operations – delivering flights to their STAs within 60 seconds, 95% – would be inadequate for keeping flights on their RNAV arrivals during these hours. Therefore, Figure 6 shows the benefits opportunity for improved delivery accuracies possible with flight-deck tools, like IM avionics, at KDFW.

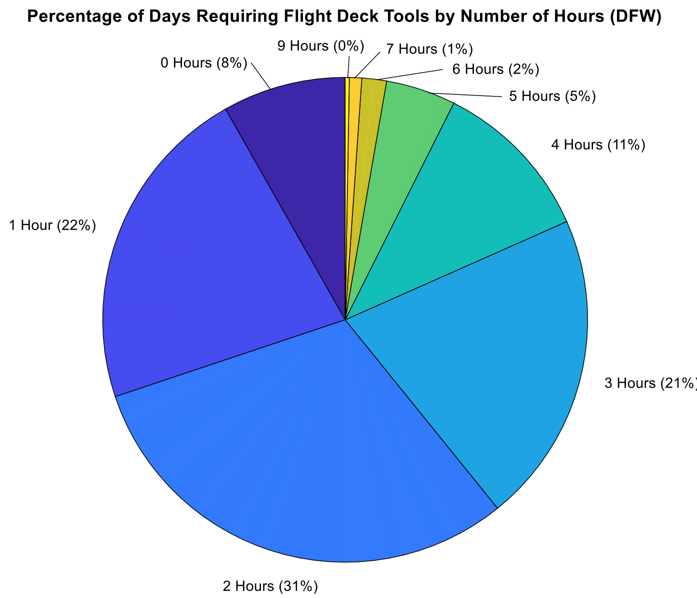


Figure 6. Number of hours for which improved metering operations are inadequate for flow rates at KDFW (over 2023)

These results highlight the flight efficiency benefits opportunity for IM operations ending in en-route airspace. As such, the I-IM operations being evaluated as part of the AIRS evaluation have the potential to provide significant benefits to airlines.

2.3 AIRS I-IM Trial Location

ZAB was selected as the preferred site for the AIRS I-IM operational evaluation, driven in part by AAL's interest in arrivals to their Phoenix hub and the relationship AAL had established with ZAB from defining Phoenix Sky Harbor International Airport (KPHX) Area Navigation (RNAV) arrival procedures and "descend via" procedures. ZAB also served as the key site for Ground-Based Interval Management – Spacing (GIM-S) and has relevant experience with the new operations/technologies. In addition, the capacity of Phoenix exceeds the demand, easing pressure of introducing the new operations.

The operational evaluation presented a unique opportunity to obtain knowledgeable feedback and recommendations from ZAB personnel with IM. Below are examples of key topics of interest:

- Controller subject matter feedback on IM operations
- Comparison of IM spacing to legacy spacing procedures

- Evaluation of IM in a mixed equipage environment (i.e., aircraft equipped with IM and those without the capability to conduct IM)
- Evaluation of IM controller workload impact
- Gain insights into minimum automation support required for IM implementation for national deployment
- Gain insight into phraseology requirements (including incorporating the use of third Party Flight ID in clearances)

I-IM operations were conducted in ZAB airspace (see Figure 7) with AAL A321 aircraft on the “PINNG” and EAGUL Area Navigation (RNAV) Standard Terminal Arrival Routes (STARs) into Phoenix Sky Harbor International Airport (KPHX), and overflight traffic subject to Miles-In-Trail (MIT) spacing (see Figure 8).

IM operations were conducted during either Visual Meteorological Conditions (VMC) or Instrument Meteorological Conditions (IMC) under Instrument Flight Rules (IFR) in airspace with Air Traffic Control (ATC) surveillance. For the operational evaluation, air traffic controllers used existing ATC automation.

There were no changes in separation or spacing criteria when using IM during the operational evaluation. ATC determines the time- or distance-based Assigned Spacing Goal (ASG) for each IM operation. The ASG will not violate ATC spacing or separation requirements in FAA Order 7110.65 and will conform to Letters of Agreement (LOAs) and other airport or runway constraints.

As part of the KPHX arrival operations, the controllers issue aircraft a descend via clearance. A descend via clearance is an abbreviated ATC clearance that requires compliance with a published procedure's lateral path and associated speed restrictions and provides a pilot-discretion descent to comply with published altitude restrictions. When performing an IM operation with a descend via clearance, flight crews were directed to follow the lateral and vertical path of the descend via clearance while following commanded IM speeds provided by the SafeRoute+ system.

The IM operation consists of a Lead Aircraft and an IM Aircraft equipped with the SafeRoute+ equipment and appropriately trained flight crew. Multiple IM Aircraft may perform an IM operation given the appropriate conditions, either as separate pairs of aircraft or as series of aircraft (i.e., an IM Aircraft in one pair is simultaneously the Lead Aircraft in a second pair).

Only AAL aircraft equipped with the SafeRoute+ equipment were approved to conduct IM operations. The operational environment included aircraft from several operators that are not equipped with the SafeRoute+ equipment. These aircraft operated in the same airspace, and arrived at the same airports, while equipped AAL aircraft were conducting IM. All aircraft equipped with ADS-B Out and broadcasting a valid ADS-B Out signal, regardless of operator, could serve the role of Lead Aircraft in an aircraft pair.

The following are representative of operations evaluated:

- Overflight operations:

- Dallas Fort Worth International Airport (KDFW) arrivals over INK (SE)
    - KDFW arrivals over MDANO (E)
    - San Diego International Airport (KSAN) arrivals over JUDTH (SW)
    - KSAN arrivals over GBN (NW)
    - Harry Reid International Airport (KLAS) arrivals over HAHAA (N)
- KPHX Arrival operations:
    - PINNG arrival (SW & SE)
    - EAGUL arrival (N & NW)

For overflight operations, typically a distance-based ASG (in nautical miles) was used. For the KPHX arrival operations, distance-based and time-based ASGs were used.

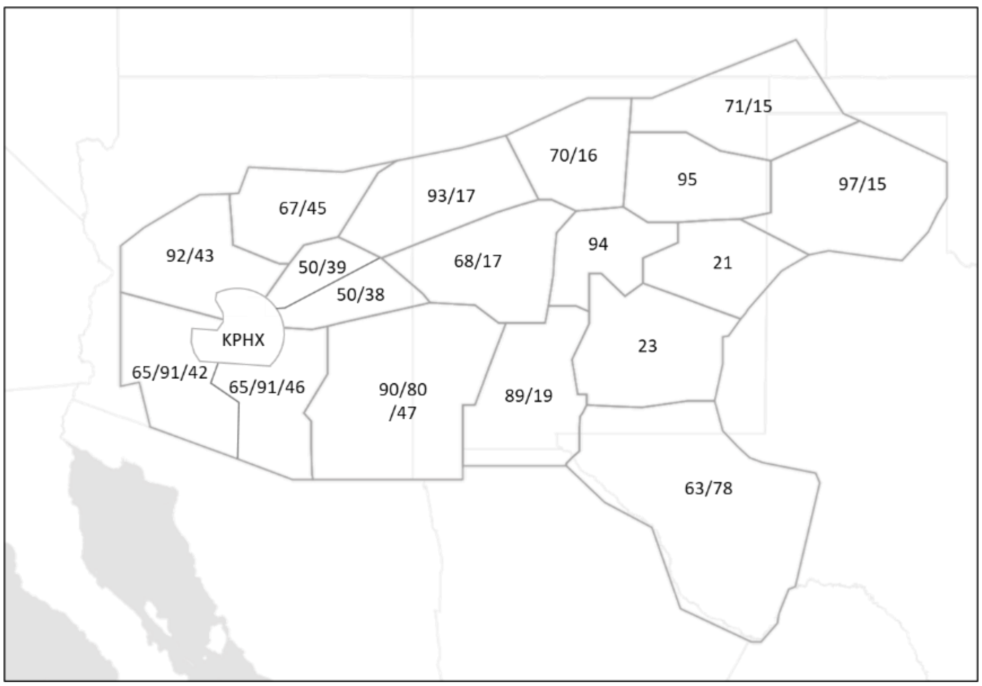
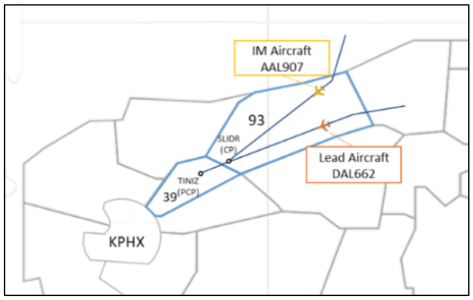
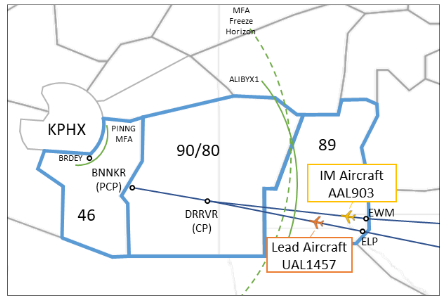


Figure 7 - Overview of ZAB airspace sectors

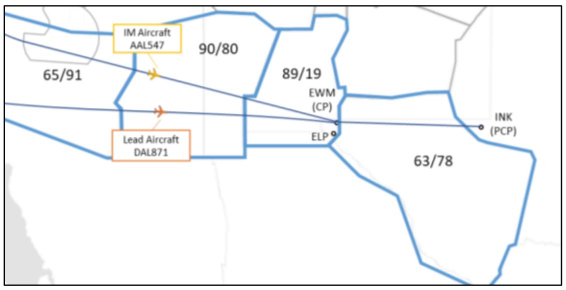
The following diagrams represent sample scenarios performed during the AIRS evaluation.



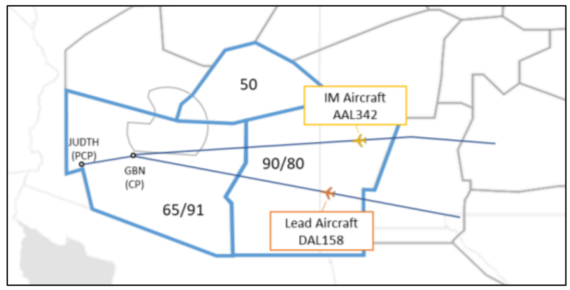
EAGUL Arrivals into KPHX



PINNG Arrivals into KPHX



Overflights to KDFW



Overflights to KSAN

Figure 8 - Sample scenarios of IM operations

2.4 ACSS SafeRoute+ Overview

As previously noted, American Airlines conducted a retrofit of their entire Airbus A321 fleet with the SafeRoute+ ADS-B In avionics suite. A retrofit option was chosen to evaluate the benefits of an avionics retrofit solution as a cost-effective approach for airlines to pursue when implementing ADS-B In applications.

The ACSS retrofit architecture supplements existing flight deck displays with a graphical ADS-B Guidance Display (AGD). The architecture includes the display of ADS-B traffic along with Traffic Alert and Collision Avoidance System (TCAS) traffic on the Navigation Display, flight crew data entry via the Multi-Purpose Control Display Unit (MCDU), and display of application-specific information on the AGD (see Figure 9).

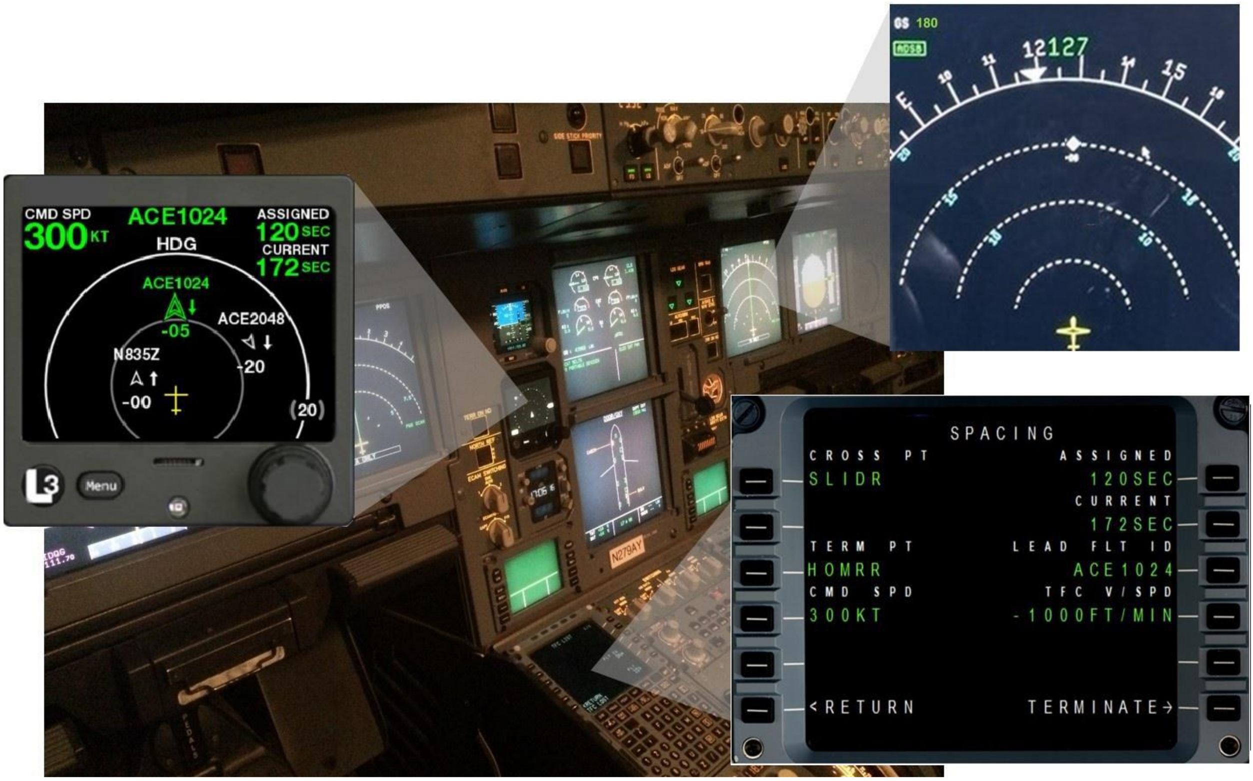


Figure 9 - ACSS SafeRoute+ avionics components

The AGD provides a graphical representation of surrounding traffic, similar to the existing TCAS display, but adds traffic directionality and traffic information provided by ADS-B. Relative traffic position for TCAS traffic is displayed on the AGD using typical TCAS symbology (i.e., Other, Proximate, and Traffic Alert (TA)). TCAS Resolution Advisory guidance is not displayed on the AGD.

After searching for the Lead aircraft flight ID, the flight crew utilizes the MCDU interface to the SafeRoute+ system to designate the selected aircraft. This prompts the flight crew to enter the IM clearance information from ATC in the MCDU, and speed guidance is then displayed on the AGD in the top left corner (CMD SPD), which the pilot monitors and adjusts as appropriate to achieve/maintain the ASG. The ASG (ASSIGNED) and current spacing interval (CURRENT) information are also displayed. Figure 10 is representative of information provided on the AGD and the MCDU.

Figure 10 - Representative AGD (left) and MCDU (right) displays

2.5 Assigned Spacing Goal (ASG)

Before issuing an IM clearance, the controller identifies an IM Aircraft and Lead Aircraft. The controller also determines the time-based or distance-based Assigned Spacing Goal (ASG) and a CP, if applicable. The ASG cannot violate ATC spacing or separation requirements in FAA Order 7110.65 and will conform to LOAs and other airport or runway constraints. Procedures and tools were developed to aid the controller in determining what ASG should be assigned.

2.5.1 Distance-Based ASG Determination

Distance-based Miles-in-Trail (MIT) ASG values used in IM operations were obtained from Traffic Management Initiatives (TMIs) developed and distributed by the Traffic Management Unit (TMU) at ZAB. One example of a distance based ASG was 15 NM over JUDTH for San Diego arrivals. These distanced-based ASG values were displayed on the Enhanced Status Information System (ESIS) boards.

2.5.2 Time-Based ASG Determination

Determining appropriate time-based IM clearances without automation support is difficult. Tools were provided to help the controller Subject Matter Experts (SMEs) and Traffic Management Coordinators (TMCs) determine time-based ASGs. The following sections describe these tools.

2.5.2.1 ASG Look-up Table

The ASG Look-up Table was created to provide a time-based ASG in relation to a desired distance-based spacing objective and aircraft groundspeed (see Figure 11). The TMC or supervisor determines the slowest groundspeed that a potential IM aircraft may fly during an IM operation and the desired distance-based spacing objective. Using this information, the TMC references the Look Up Table to find the time-based spacing value that complies with the distance-based spacing objective. If the ASG Look Up Table is used for operations, then the TMU would coordinate the time-based ASG with the area's supervisors.

		EXPECTED GROUNDSPEED AT P50 BOUNDARY						
		250 - 260	**270 - 280**	**290 - 300**	**310 - 330**	**340 - 360**	**370 - 390**	**400 - 420**
STREAM CLASS	7	110	100	95	90	85	75	70
	8	125	115	110	100	95	85	80
	9	135	130	120	110	105	95	90
	10	150	140	130	125	115	105	100
	11	165	155	145	135	125	115	105
	12	180	165	155	145	135	125	115
		ASG IN SECONDS						

Figure 11 – ASG Look Up Table

2.5.2.2 ASG Support Tool

As part of previous IM research, personnel from the FAA William J. Hughes Technical Center (WJHTC) developed a tool that could be used to calculate time-based ASG values for IM operations. This tool, known as the ASG Support Tool, uses Time-Based Flow Management (TBFM) System Wide Information Management (SWIM) data accessed via the SWIM tool to calculate applicable ASG values. The tool is a stand-alone external Java-based application that is run from a folder in a Windows environment. The tool is not integrated into the TBFM system, nor does it reside in the SWIM infrastructure.

Personnel from WJHTC made slight modifications to the Graphical User Interface (GUI) (see Figure 12) and pairing functionality to support the AIRS operational evaluation. The TBFM data is published via SWIM and consumed by the ASG Support Tool residing on an FAA computer located in the TMU.

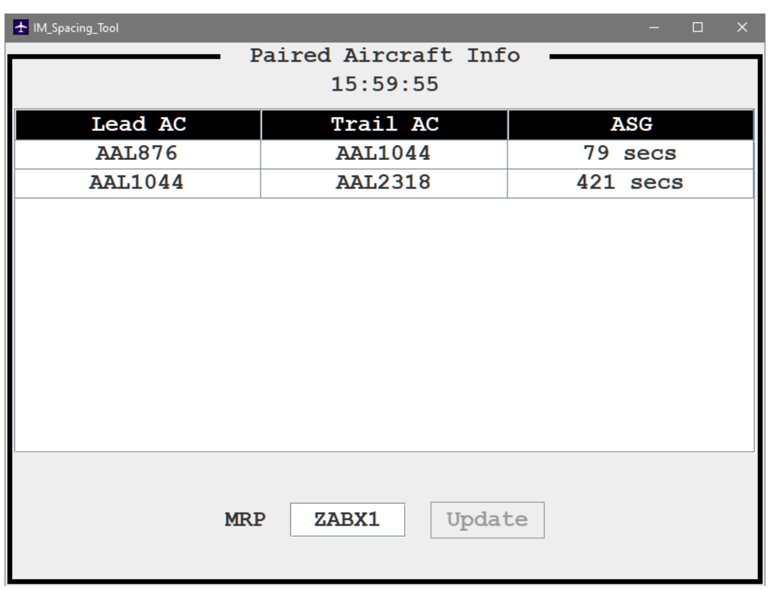


Figure 12 - ASG support tool GUI

The tool takes in a user-entered Meter Reference Point (MRP) and filters all aircraft from the TBFM messages to the given MRP. If aircraft filtered are frozen in the TBFM schedule and identified as an American Airlines A321 aircraft type, the tool then looks at the next earliest aircraft in the TBFM sequence for a potential pairing. The difference in TBFM STAs for both aircraft is then calculated and displayed in seconds on the tool as the ASG.

The ASG Support Tool was utilized briefly during Time-Based Metering (TBM) operations, but a recurring issue was identified quickly thereafter. The tool was pairing the appropriate IM aircraft reflected in the TBFM-generated sequence, but the ASGs calculated for some pairs were too small. Multiple recorded examples were displayed in the 30 second range, an illegal spacing value, and TMU did not believe the tool was working properly.

However, after analysis of the TBFM data, it was shown that the TMC was manually changing TBFM STAs upstream in the Extended Metering (XM) environment. This manual scheduling overrides the TBFM-generated schedule, and the aircraft are no longer deconflicted by the system as designed. As the ASG Support Tool consumes the scheduling information from TBFM, this was correctly reflected in the ASGs calculated by the tool. Even though the tool was verified to be working properly, after these occurrences, the tool was no longer used by TMU as it was not compatible with their metering operations.

Training may be one means to mitigate this to allow the ASG Support Tool to support AIRS again. If either aircraft in a potential pair identified by the tool is manually scheduled in TBFM, then the pair should not be utilized, even if the ASG appears valid.

2.6 Aircraft Identification

Since IM operations are initiated by a controller, the controller needs to know which American Airlines (AAL) A321 aircraft are capable of performing IM prior to issuing an IM clearance. Ideally the En Route Automation Modernization (ERAM) automation platform used by en route controllers would be able to provide an indication of which aircraft have the capability to perform an ADS-B In operation. The FAA has developed automation upgrades for ERAM that include providing the controller with what is known as an ADS-B Capability Indicator. Unfortunately, the planned upgrade was not available during the first year of the AIRS operational evaluation. Additionally, while American Airlines eventually equipped their entire A321 fleet with SafeRoute+ equipment, during most of the first year of the operational evaluation there was a mixture of SafeRoute+ equipped A321 aircraft and non-equipped A321 aircraft.

The lack of ground automation indicating ADS-B In equipage of aircraft during the AIRS evaluation led the team to define a "workaround" method (known as the "A321 Workaround") for indicating to controllers which aircraft were capable of conducting IM operations. It was determined all aircraft that were equipped with SafeRoute+ avionics would be filed using the "A321" International Civil Aviation Organization (ICAO) aircraft type designator in flight plans. Conversely, American Airlines A321ceo and A321neo aircraft that were not equipped would use the "A21N" ICAO aircraft type designator. This allowed air traffic controllers displaying the aircraft type on ERAM to quickly identify eligible American Airlines participants in the evaluation.

The A321 Workaround can be summarized as follows:

- Equipped A321ceo → file as A321 (no change)
- Equipped A321neo → file as A321
- Unequipped A321ceo → file as A21N
- Unequipped A321neo → file as A21N (no change)

Once all the American Airlines A321 were fully equipped with SafeRoute+ avionics, the A321 Workaround was no longer needed or used. At that point, AAL could file the correct ICAO designation for the A321 aircraft and controllers were able to issue IM clearances to all American Airlines A321 aircraft (aircraft type indicators of A321 and A21N).

A Safety Risk Management Panel (SRMP) of FAA, NATCA, Professional Aviation Safety Specialists (PASS), ACSS and American Airlines stakeholders convened in July 2021. The panel evaluated an ADS-B In Capability Indicator workaround for the STARS and ERAM automation systems. The SRMP reviewed the proposed change and identified three low-risk hazards that could occur because of the A321 workaround. Results of this SRMP are documented in "ADS-B In Retrofit Spacing Evaluation (AIRS Eval) A321 Workaround, Safety Risk Management (SRM) document (SBS-187, Rev 0.1, SMTS2021091700410)" which was approved in February 2022.

2.7 IM Operational Phases

2.7.1 Pre-Initiation

The initial step to begin an IM operation is for ATC to identify an appropriately equipped AAL A321 aircraft. Once the IM Aircraft is identified, ATC evaluates other aircraft to determine if a candidate Lead Aircraft exists. When TBFM metering is turned on, TBFM data is used to determine the Lead Aircraft in the sequence. When TBFM is not in use, this determination is made considering several factors, such as initial spacing and operational goals. ATC will monitor the position of the candidate IM Aircraft and will identify potential IM Aircraft pairs based on their projected arrival times or controller-determined sequence at a shared fix on their flight plans.

2.7.2 Initiation

The Initiation phase begins when ATC issues, via voice, the IM clearance to the flight crew of the IM aircraft. The clearance includes the type of clearance (Cross or Maintain), Lead Aircraft ID, ASG, CP (when issuing a Cross clearance), and, optionally, a PCP. The flight crew receives the IM clearance and reads back the clearance to the controller confirming the information.

The Lead aircraft, IM aircraft and ASG are coordinated in the fourth line of the ERAM data block. The controller enters the following information on the ERAM display:

- The Lead aircraft is identified by an “L” in the fourth line. IM Aircraft is identified by a “T” in the fourth line.
- If an aircraft is both a Trail and Lead, the fourth line will contain both a “T” and “L”.
- The fourth line is used to denote the assigned ASG in use unless indicated on the ESIS boards. An ASG of less than 70 will be considered mileage (e.g., T10). An ASG of 70 or more seconds will be considered seconds (e.g.,T120)

The flight crew enters the clearance elements into the SafeRoute+, performs a cross-cockpit verification of the entry, and executes the clearance, which triggers the SafeRoute+ equipment’s Commanded Speed display (assuming initiation criteria are met).

In the case of a Cross clearance with a time-based ASG, the avionics performs a feasibility check to determine if the ASG can be met within a 15 second tolerance by the CP. The avionics will then notify the flight crew of the clearance feasibility. In the case of a failed feasibility check, the equipment will issue a message (e.g., BAD GEOMETRY) or if the flight crew determines that the operation is not acceptable for other reasons, the flight crew notifies ATC and awaits further instructions.

2.7.3 Execution

The Execution phase begins when the IM Aircraft flight crew begins implementing the IM Speeds by dialing the IM Speed displayed on the AGD into the Flight Control Unit (FCU). During the operation, if the SafeRoute+ system recognizes the need for a new commanded speed, the flight crew is notified of the new commanded speed on the AGD.

With the presentation of each IM Speed, the IM Aircraft flight crew ensures that the IM Speed is acceptable considering the current aircraft configuration, environmental conditions, and airspace speed restrictions. If the flight crew determines they are unable to fly the IM Speed, they will contact ATC and report “unable” and await instruction. Otherwise, the flight crew dials the new IM Speed displayed on the AGD into the Flight Control Unit (FCU) follows the IM Speeds to achieve and maintain the ASG. If at any time the flight crew does not feel comfortable with the commanded speeds or deems the operation to be unsafe, they may contact ATC, report “unable,” and await instruction.

ATC continues to monitor and is responsible for separation for all aircraft, including those involved in the IM operation, by using existing surveillance capabilities and procedures. If the controller requires spacing other than that provided by IM or is notified by the flight crew of an issue with the IM operation, the controller may cancel (formally or by way of speed instruction) or amend the IM operation. If the controller intends to provide vectors or re-routing to either the IM Aircraft or the Lead Aircraft, the controller instructs the flight crew of the IM Aircraft to cancel the IM operation. The flight crew or controller may cancel the operation at any time if they deem the operation unsafe.

Verbal coordination is required when:

- Lead and IM Aircraft are in different sectors including:

- Initiation or cancellation of IM
- Any vectors or deviations of the Lead aircraft

- Planned Cancellation Point (PCP) issued is not in the sector the IM clearance was initiated
- Cross Point (CP) is in a different sector

Assigned Spacing Goal (ASG), Cross Point (CP), and Planned Cancellation Point (PCP) may be modified if necessary.

2.7.4 Cancellation

For the AIRS Evaluation, the use of a PCP was deemed optional and was infrequently used. Therefore, the ZAB controllers canceled the IM clearance via voice instruction or by the issuance of another speed instruction to the IM Aircraft's flight crew. If the flight crew is given a speed instruction from ATC, they cancel the IM operation in the IM avionics at which point IM Speeds are no longer provided. The flight crew will then fly speeds issued by ATC.

For IM Clearances that include a PCP, the SafeRoute+ equipment automatically cancels the IM Application when the IM Aircraft reaches the PCP. After cancellation, the SafeRoute+ equipment no longer displays IM Speeds. To avoid any potential confusion concerning flight crew action after cancellation, the controller must issue specific control instructions for the flight crew to follow.

2.8 Phraseology

During the operational evaluation, specific phraseology was used by ATC and the IM Aircraft flight crew as part of the IM operation. Controllers used aircraft callsigns when identifying the Lead Aircraft in the IM clearance; however, controllers and fight crews had the option to use a phonetic version of the Lead Aircraft identification if desired (e.g., they may say "U-A-L" or "Uniform Alpha Lima" instead of "United"). Additionally, because the operational evaluation used waypoints commonly used for routing aircraft in ZAB, controllers used the waypoint name (e.g., Gila Bend) in IM clearances rather than phonetic versions of the identifier (e.g., G-B-N); however, flight crews were able to request clarification or confirmation if they were unfamiliar or uncertain about the intended waypoint. An example of phraseology used during the first year of the operational evaluation is provided below.

Cross clearance

- "AAL123 cross SLIDR at and maintain eight miles behind SWA2345"
- "AAL123 cross SLIDR at and maintain one hundred and twenty seconds behind SWA2345"

Maintain clearance

- "AAL123 Maintain eight miles behind SWA2345"
- "AAL123 Maintain eighty seconds behind SWA2345"

Descend Via Clearance during IM operations:

- "AAL755 descend via the EAGUL six arrival runway 26 transition except maintain spacing"

Descend Via to Cancel IM operation:

- "AAL123 [cancel spacing (optional)] descend via EAGUL six arrival runway 26 transition"

IM Clearance Amendment:

- "AAL755 [amend spacing (optional)] cross HAHAA one zero miles behind UAL345"
- "AAL755 cross SLIDR seventy-three seconds behind UAL345"

PCP Amendment:

- "AAL755 cancel spacing at SLIDR resume normal speed"

IM rejection by Flight Crew

- "Albuquerque center AAL123 unable spacing [and reason (optional)]"

<u>Optional Clearances:</u>

Maintain Clearance with PCP

- "AAL755 cross GBN 15 miles behind UAL345 cancel at JUDTH resume normal speed"

IM Clearance Readiness

- "AAL645 Spacing Clearance Advise ready to copy"

IM Status Reports:

- "AAL123 say assigned spacing"
- "AAL123 say current spacing"

2.9 Training

Training was required for both AAL pilots and ZAB controllers prior to being authorized to conduct IM. The sections below provide a summary of the training conducted.

2.9.1 Pilot Training

All AAL Airbus narrow body aircraft pilots (A321, A320, A319) completed distance learning computer-based training (CBT) specific for IM operations. The training material covered

- Description of IM and the IM operational evaluation
- Pilot roles and responsibilities during an IM Operation
- Phraseology used for IM Operations
- Pilot Flying (PF) and Pilot Monitoring (PM) duties
- How to use the CDTI for IM Operations
- What to do when something abnormal occurs during an IM Operation

Pilots also had access to an IM Quick Reference Guide (QRG) in the airplane on their company issued iPads.

During the IM operational evaluation, American Airlines published additional information to the flight crews in the form of Crew Check In (CCI) memos. These CCIs included messages to the pilots to reinforce training material and/or update them on areas of special emphasis crews to be aware of. One example of this was a CCI that was used to clarify the proper way to enter Cross clearances in the SafeRoute+ system.

2.9.2 ATC Training

All ZAB controllers completed four hours of IM training before the start of the AIRS I-IM operational evaluation. This training was provided as a combination of classroom training (i.e., lectures) and time spent conducting simulated operations with representative scenarios in the Test and Training Laboratory (TTL). The scenarios included all clearance types, the A321 Workaround, and both distance-based and time-based ASGs. It took six weeks for all ZAB controllers to be trained.

The training materials were developed primarily by the ZAB controllers who also served as IM SMEs during the operational evaluation. Topics covered in the lecture portion of the training included:

- IM Overview
- AIRS Overview
- Training Objectives
- Identifying IM Capable Aircraft
- IM Clearance Elements
- Procedures
  - Initiating IM Operations
  - Monitoring IM operations
  - Coordinating IM operations
  - Terminating IM Operations
- Phraseology
- Pilot Responsibility
- Scenarios

Additionally, during the operational evaluation, members of the ZAB AIRS team updated the ZAB work force on status and updates of the operational evaluation during monthly team briefings.

2.10 Safety Risk Management

Safety Risk Management (SRM) work was conducted before starting the operational evaluation. An SRM panel was convened May 24-25, 2022 to identify and assess hazards associated with the proposed I-IM operational evaluation in ZAB airspace including overflight aircraft and arrival aircraft to Phoenix. The panel comprised stakeholders representing the FAA Flight Standards Service (AFS), FAA Air Traffic Services (AJT), FAA Mission Support Service (AJV), Albuquerque Air Route Traffic Control Center (ARTCC) (ZAB), National Air Traffic Controllers Association (NATCA), AAL management and flight operations, the Allied Pilots Association (APA), and subject matter experts (SMEs) in air traffic operations, flight operations, and safety. The assessment was conducted in accordance with the FAA Air Traffic Organization (ATO) Safety Management System (SMS) manual dated April 2019.

The SRM panel identified five hazards, three of which had two effects, resulting in a total of eight effects. Several controls were identified that minimized the severity of impacts leading to all effects having a severity rating of 5 (Minimal). Even with various likelihoods of these effects, all eight effects were found to be Low risk. Table 3 below summarizes the identified hazards.

Table 3. Summary of identified hazards

No.	Hazard Title	Initial Risk	Predicted Residual Risk
I-IM-1	**Designate the wrong lead aircraft**	5C (Low) 5B (Low)	5C (Low) 5B (Low)
I-IM-2	**Wrong ASG input into MCDU and used for IM Operation**	5D (Low) 5B (Low)	5D (Low) 5B (Low)
I-IM-3	**Controller uncertain about speed adjustment during IM operation**	5D (Low) 5B (Low)	5D (Low) 5B (Low)
I-IM-4	**Mismatch between IM state and controller awareness (whether internal to ZAB or external facilities) regarding IM Operation in effect**	5B (Low)	5B (Low)
I-IM-5	**Additional coordination necessary for IM Operation across multiple sectors**	5A (Low)	5A (Low)

The SRM panel reviewed the Operational Description as part of the hazard assessment and provided input to assist the operational evaluation site in finalizing their Standard Operating Procedures (SOPs) and phraseology.

The SRM panel results were documented in a Safety Risk Management Document (SRMD) which was reviewed and approved in October 2022. The scope of the SRMD included the coordinated use of IM by the en route controllers in ZAB airspace and the American Airlines pilots operating ACSS-equipped A321 aircraft in-trail (or direct to same route) of an ADS-B Out aircraft.

2.11 Project Implementation Details

This project is a public-private partnership that includes collaboration between the FAA, AAL, ACSS, NATCA and APA. Due to the collaborative and multi-organizational nature of this work, significant coordination and communication was required to successfully conduct the operational evaluation.

Since the operational evaluation is being conducted using certified aircraft operating in revenue service, all equipment and procedures had to be coordinated within the team and approved by the proper FAA organizations prior to the start of the operations. Additionally, significant data collection and analysis efforts were required by all parties to achieve the primary AIRS evaluation goal of demonstrating the operational feasibility and value of ADS-B In capabilities.

The following sections highlight some of the coordination and communication efforts during the operational evaluation. This information provides context for how results were obtained and analyzed and is also documented to support future operational evaluations.

2.11.1 Project Schedule

Figure 13 is a high-level depiction of the key activities with durations for accomplishing the operational evaluation. The list does not account for the time required to certify and install equipment on aircraft used in the evaluation.

The amount of effort and associated timelines required to accomplish those activities, can vary significantly depending on the level of the certification required, how much retrofit effort is required per aircraft (e.g., overnight updates versus multiple weeks in a maintenance hangar), and the number of aircraft that must be modified to support the operational evaluation.

	Task Name	Duration
1	**Pre-Operational Evaluation**	**260 days**
2	**Program Office (PO)**	**255 days**
3	Site Selection	50 days
9	Ops Description	135 days
17	SRMD	211 days
32	Execution Planning	80 days
35	**Airline**	**125 days**
36	Pilot Training	125 days
41	Operational Approval	91 days
49	Flight Crew Bulletin	20 days
53	**Facility**	**120 days**
54	Controller Procedures	30 days
58	Controller Training	80 days
64	Amend Letters of Agreement	30 days
67	Trial Notice (7110.65 Temp. Addition)	75 days
71	NOTAM	45 days
75	**Operations Begin**	**0 days**
76	**Evaluation Period**	**260 days**
77	Full Team Activities	257 days
91	PO Data Collection and Analysis	260 days
98	**PO Final Report**	**275 days**

Page 1

Figure 13 – Key activities with nominal task durations

The AIRS project timeline was significantly impacted by the COVID-19 pandemic. Avionics certification and installation activities were particularly stalled due to the in-person nature of that work. While telecons and remote work were employed to accomplish the tasks listed in the schedule and keep the work moving forward, the lack of in-person meetings and discussions in some cases affected the quality of communication and collaboration and impacted the progress of the project.

2.11.2 Project Review and Coordination

AIRS project reviews were held to identify any operational safety concerns, gain insights into the operations from data collected and analyzed throughout the operational evaluation, and determine if any changes could be made that would improve IM operations. These reviews included insights from controllers, flight crews, and experts in avionics systems, procedures, and aspects of the IM concept.

These reviews were conducted through weekly telecons, and in-person meetings hosted by ZAB. Weekly meetings provided a status of the past week’s IM usage and timely insights into any issues that had arisen during the week. The in-person meetings were nominally held monthly and were used to provide a more comprehensive review of the data. During these meetings, team members had the opportunity to examine trends in the data, conduct detailed reviews of key operations, and develop solutions for any observed issues.

2.11.3 Phased Approach

Initially, all IM operations (Maintain and Cross) were permitted in all areas within ZAB to maximize the use of IM at ZAB. This included overflight operations as well as arrival operations into KPHX.

During reviews conducted during the first months of the operational evaluation, the team noted a significant drop in IM operations after the first month of operations. Team members determined it would be more effective to use a structured approach for introducing IM operations.

Led by the team at ZAB, a phased approach was proposed and accepted. The phased approach gradually introduced different operations and clearances with support from ZAB controller SMEs. These phases were defined as follows:

- **Phase 0 (11/7/2022 through 11/20/2022)** – This was the period during the first two weeks of the operational evaluation. During this time, there was a substantial amount of support from ZAB controller SMEs who were in the control room providing guidance to controllers. These controllers, referred to as “floor walkers,” aided controllers in identifying, initiating, and monitoring IM operations. They also supported the trial by collecting feedback from controllers (in the form of handwritten feedback forms).
- **Phase 1 (11/21/2022 through 3/15/2023)** – During this phase there was very little support from ZAB floor walkers. There was a significant drop in operations and controller feedback forms. This phase motivated a more structured and SME floor walker, supported phased approach.

- **Phase 2 (3/16/2023 through 11/6/2023)** – During this period SME floor walkers focused on providing and helping controllers issue and monitor Cross clearances. Controllers were still able to issue Maintain clearances, but SME floor walkers focused on initiating and monitoring Cross operations for the purpose of gathering more data.
- **Phase 2N (3/16/2023 through 11/6/2023)** – This phase was concurrent with Phase 2 and captures the use of Maintain clearances during Phase 2.

3 Data Sources & Collection

The following data collection plan was developed to support the AIRS operational evaluation objective to quantify ADS-B In benefits. The following sections outline the data sources and data collection methodology.

3.1 Instrument Flight Procedures (IFP), Operations, and Airspace Analytics (IOAA)

The Instrument Flight Procedures (IFP), Operations, and Airspace Analytics (IOAA) Tool provides analysis capabilities to study flight operational metrics and use of IFPs. IOAA provides an interface to MITRE's Threaded Track data, which fuses FAA radar, Airport Surface Detection Equipment Version X (ASDE-X), and ADS-B data to create a smoothed, end-to-end trajectory for each flight. This trajectory data was used to examine metrics beyond those archived as part of Performance Data Analysis and Reporting System (PDARS). Threaded Track data is correlated with a specific flight using a track key, which allows multiple data sets to be referenced for a given flight using the same track key. The Threaded Track data goes through multiple quality checks before being published and so exhibits a lag of one to three months before it can be accessed via IOAA.

3.2 FAA Voice Transcript Data

The MITRE Transportation Data Platform (TDP) receives and transcribes voice tapes on a periodic basis for most NAS facilities. The voice transcript data is gathered by facility and parts of the transcript are assigned to specific flights using the callsign information. The flight identifier uses the same track key used by Threaded Track data so the two data types can be easily correlated. Because voice transcripts can be complicated, garbled, and use non-standard phrasing, the process to attach transcripts to specific flights is not perfect but does provide a wealth of information that is not available from other sources.

For the AIRS project, the data collection team uses the transcript information as a step to confirm if a flight in ZAB is receiving an IM clearance from a controller (as opposed to the pilot self-testing the equipment). More specifically, the ZAB transcripts are queried for relevant phrases containing:

A. *"spacing clearance"*
B. *("seconds"* OR *"miles"* OR *"second"* OR *"mile")* AND ("Additional Controller Input") AND *"behind"*

Note: Additional controller input is not required, but included here to illustrate the possible additional information provided by the controller, if needed.

Generally, the transcript query casts a wide net that is later filtered to match ACSS traffic computer events and times as further steps to indicate IM operations.

3.3 FAA TBFM Data

The FAA Performance Analysis Group (AJR-G) manages an online Tableau archive of TBFM information. The archive includes airborne metering usage at an airport, Constraint Satisfaction Point (CSP) delay, and compliance for specific aircraft and fixes. The AIRS project used this data to evaluate CSP compliance, including Meter Fixes (MFX) and Extended Metering Points (XMP), for flights into ZAB. Furthermore, this data was used to examine aircraft receiving and accepting speed advisories using the GIM-S capability. While GIM-S is not a focus of the AIRS project, the data allows a comparison of CSP compliance between IM and another method of spacing being used in ZAB.

3.4 SafeRoute+ Data

SafeRoute+ data refers to parameters recorded by the aircraft's TCAS surveillance processor including parameters related to surrounding ADS-B traffic, Ownship, and the SafeRoute+ applications. SafeRoute+ data was used to identify flights where target designation for IM was used and provided useful metrics.

ACSS developed a process to obtain SafeRoute+ data from the aircraft using Compact Flash (CF) cards placed in traffic computer (see Figure 14). American Airlines maintenance retrieved the flash cards from the TCAS periodically, typically once a month, and replaced it with a blank CF card. AAL maintenance then uploads the CF card data to an ACSS server for processing.

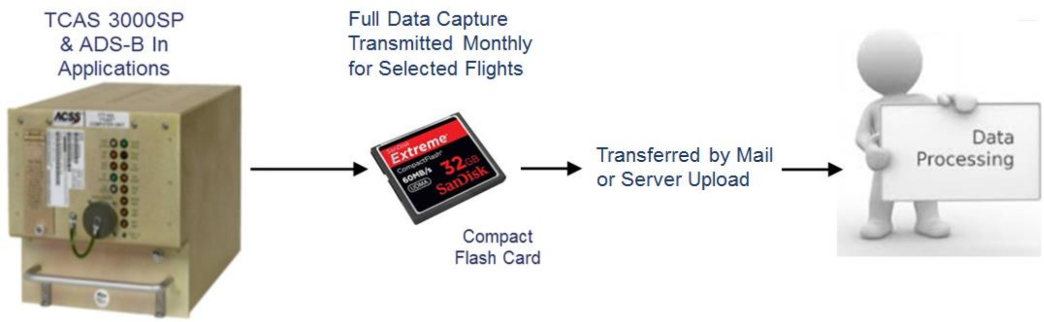


Figure 14 - Processes to obtain SafeRoute+ data from the aircraft

Upon receiving the CF card data, ACSS followed the following process:

1. Download the raw data files for storage and processing
2. Identify flights with ADS-B In equipment, those using target designation, and those using IM parameters
3. Calculate SafeRoute+ data parameters

4. Provide the SafeRoute+ data to the FAA semi-monthly

Based on the data extraction process, there is a lag in when a complete monthly set of data for all flights is available. The delay depends on when the data can be physically downloaded from each aircraft. In general, a complete set of data for a particular month is available three months after the operations occurred.

For flights using the IM application, ACSS provides a set of data with 68 elements recorded every second. Table 4 describes the data elements.

Table 4. ACSS provided data per second for IM flights

ACSS IM Data Elements	Definition
UTC Time	UTC time in hours, minutes, seconds
UTC Date	UTC date in year, month, day
Crossing Point ID	The alphanumeric identifier of IM Crossing Point
Planned Termination Point ID	The alphanumeric identifier of Planned Termination Point
Required Time Spacing	The Assigned Spacing Goal entered by the flight crew for a time-based spacing operation
Required Distance Spacing	The Assigned Spacing Goal entered by the flight crew for a distance-based spacing operation
IM Interval Type (Time/Distance)	A flag to indicate the interval type
Ownship Flight ID	The alphanumeric flight identifier of ownship's flight (e.g. "AAL1234")
Ownship Latitude	The latitude of ownship, as received from the aircraft navigation system
Ownship Longitude	The longitude of ownship, as received from the aircraft navigation system
Ownship Pressure Altitude	The pressure altitude of ownship, as received from the aircraft air data system
Ownship Mach	The Mach number of ownship, as received from the aircraft air data system
Ownship CAS	The calibrated airspeed of ownship, as received from the aircraft air data system
Ownship TAS	The true airspeed of ownship, as received from the aircraft air data system
Ownship SAT	The static air temperature of ownship, as received from the aircraft air data system
Ownship Windspeed	The calculated windspeed of ownship, as received from the aircraft flight management system
Ownship Wind Direction	The calculated wind direction of ownship, as received from the aircraft flight management system
Ownship Groundspeed	The groundspeed of ownship, as received from the aircraft navigation system
Ownship Selected CAS	The pilot selected airspeed of ownship, as received from the aircraft automatic flight control system
Ownship Selected Mach	The pilot selected Mach of ownship, as received from the aircraft automatic flight control system
TTF Flight ID	The alphanumeric flight identifier of traffic to follow, as received over ADS-B (e.g. "UAL43")

TTF Latitude	The latitude of traffic to follow, as received over ADS-B
TTF Longitude	The longitude of traffic to follow, as received over ADS-B
TTF Pressure Altitude	The pressure altitude of traffic to follow, as received over ADS-B
TTF Groundspeed	The groundspeed of traffic to follow, as received over ADS-B
Range from Ownship to Traffic	The horizontal distance between ownship and the traffic to follow
IM Command CAS	The CAS command calculated by the I-IM algorithm and displayed to the flight crew
IM Command Mach	The Mach command calculated by the I-IM algorithm and displayed to the flight crew
IM Command CAS/Mach Flag	A flag to indicate if the IM Command is a CAS value or a Mach value
Feasibility Result	An indication if the I-IM algorithm believes the entered spacing goal can be achieved by the time ownship reaches the crossing point or if the entered spacing goal is too large or too small to be obtained. The feasibility result is only calculated for time-based crossing operations.
IM Time Spacing	The current time spacing, in seconds
IM Distance Spacing	The current distance spacing, in nautical miles
IM Mode	The operational mode of the I-IM algorithm. The mode indicates when I-IM is executing, when it waiting for pilot data entry, and so forth.
Suggested Groundspeed	An internal I-IM parameter that indicates the groundspeed ownship would need to meet the spacing goal based on the current conditions
IM Computed IAS	An internal I-IM parameter that is the CAS-equivalent of the Suggested Groundspeed
Estimated TAS of TTF	An internal I-IM parameter that is an estimate of the traffic to follow's true airspeed, based on the groundspeed and pressure altitude of the traffic to follow as received over ADS-B and the atmospheric conditions of ownship.

3.5 Controller Feedback and Observations

Controllers provided objective and subjective feedback on IM operations, including any issues and recommended changes. The feedback was gathered using controller feedback forms and directed discussions.

3.5.1 Controller Feedback Forms

ZAB and project personnel developed a specific set of controller feedback forms for collecting information on IM operations conducted by ZAB controllers. They recorded which aircraft were part of the operation, where the operation was initiated (i.e., which sector), the type of clearance (Cross or Maintain), and the ASG issued to the flight crew. The form also included an area where controllers could provide observations during the operation. A sample controller feedback form used for the first year of the operational evaluation is shown in Figure 15.

These forms were made available at the Traffic Management Unit (TMU) Supervisors desks in the various traffic areas (e.g., North and Northwest areas) and at controller positions. These forms were filled out by ZAB SMEs, area supervisors, or controllers issuing the clearance. In general, most forms were filled out by ZAB SMEs (i.e., “floor walkers”) who were supporting the operational evaluation.

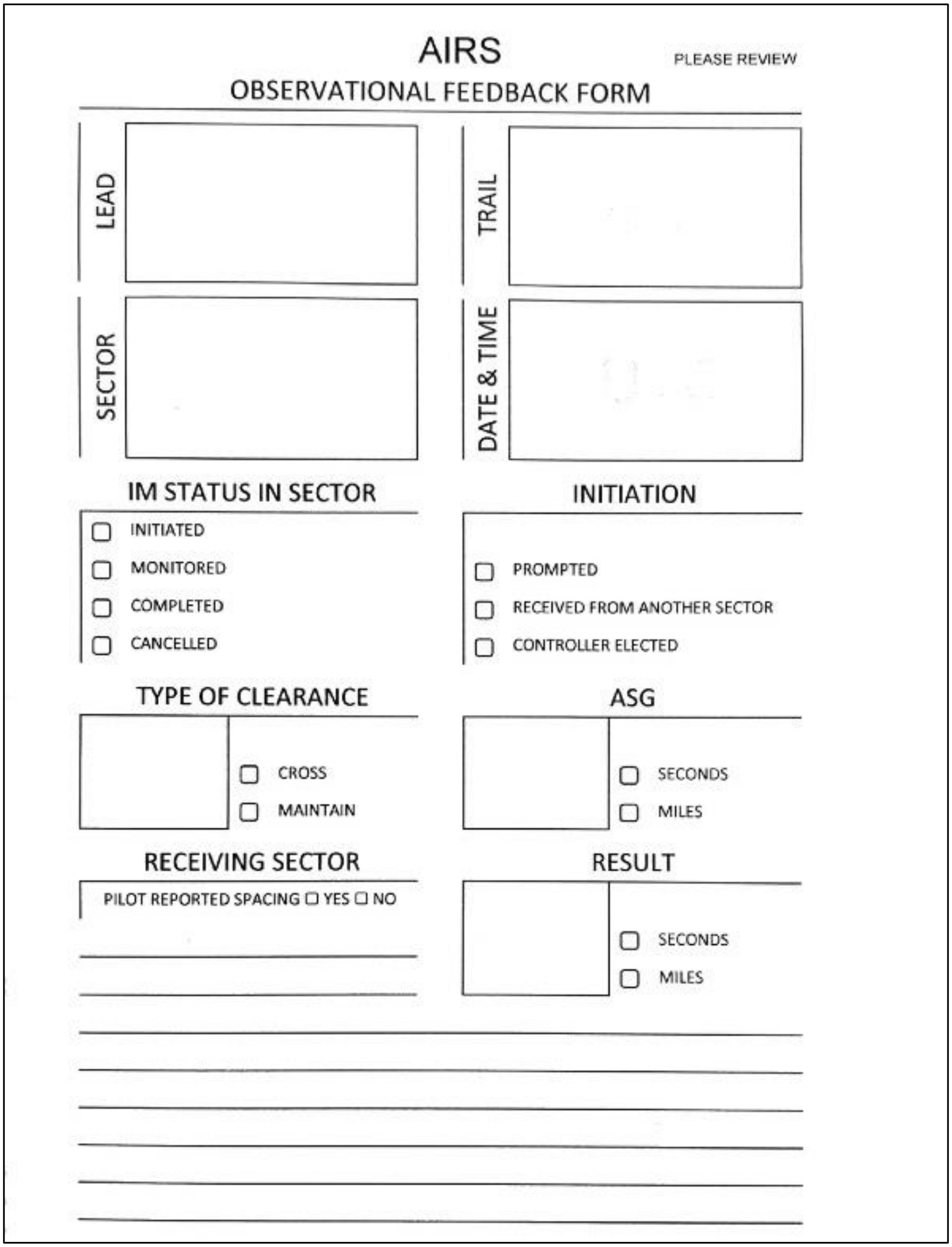
The forms were used to capture timely feedback on the operations. The data on the forms were also correlated with the ACSS traffic computer data to confirm pilot inputs to the avionics.

3.5.2 Directed Discussions

Controller feedback was also obtained by ZAB SMEs through informal discussions (i.e., “directed discussions”) with line controllers during team briefings. These discussions started approximately nine months after starting operations. By that time, most controllers were familiar with IM, and many had issued several IM clearances.

While there were no prescribed questions used, the goal of the discussions was to obtain feedback on the following topics:

- Overall impression of IM
- Usefulness of IM
- Identify any issues with the IM procedures
- Identify any issues with the IM phraseology
- Identify any ideas for improving IM


AIRS
PLEASE REVIEW
OBSERVATIONAL FEEDBACK FORM

LEAD
TRAIL
SECTOR
DATE & TIME

IM STATUS IN SECTOR
- ☐ INITIATED
- ☐ MONITORED
- ☐ COMPLETED
- ☐ CANCELLED

INITIATION
- ☐ PROMPTED
- ☐ RECEIVED FROM ANOTHER SECTOR
- ☐ CONTROLLER ELECTED

TYPE OF CLEARANCE
- ☐ CROSS
- ☐ MAINTAIN

ASG
- ☐ SECONDS
- ☐ MILES

RECEIVING SECTOR
PILOT REPORTED SPACING ☐ YES ☐ NO

RESULT
- ☐ SECONDS
- ☐ MILES

Figure 15 - Sample controller feedback form

3.6 Flight Crew Feedback and Observations

Subjective feedback was also sought from flight crews on their use of IM, whether they were encountering any issues, and whether any operational changes were required. Feedback was gathered through discussions conducted by AIRS APA SMEs with flight crews who had recently conducted IM operations and as part of AAL's Line Operations Safety Audit (LOSA) Program. Flight crew feedback obtained was correlated with other data sources including ZAB controller feedback and ACSS-supplied traffic computer data.

3.6.1 APA Discussions with Flight Crews

After an IM operation was identified (by controller feedback form or traffic computer data), APA Safety Representatives reached out to pilots that received the IM clearance. Discussions were primarily conducted by telephone and flight crews had the option of accepting or declining participation in the discussion. Most pilots were supportive of providing feedback and provided insights into the IM operation as well as identifying ways operations could be improved and how information could be clarified. These interviews were also used to reinforce or clarify AAL IM pilot training items.

3.6.2 Line Operations Safety Audit (LOSA)

The American Airlines' Line Operations Safety Audit (LOSA) Program is based on Advisory Circular (AC) 120-90 and is part of American Airlines' Safety Management System (SMS). It is one of the few LOSA programs that operates on a continuous basis. LOSA Observers are line-qualified pilots who are trained to identify both threats (external) and errors (internal) using the AAL Threat and Error Management model. LOSA data is objective in nature. It allows a unique third-person flight-deck perspective of line flights, and how the crew interacts with and manages threats and errors that occur.

To assist the AIRS project, AAL's LOSA Program conducted targeted observations of A321 flights where IM clearances could potentially have been issued. Since this was being conducted as a part of the continuous LOSA program, flight crews were unaware that observers were observing IM operations in addition to the other data LOSA observers were collecting. This provided unique, unbiased information on the use of IM avionics and IM operations.

The targeted LOSA activity began in March 2023.

3.7 Falcon Replay Videos

AIRS team members created video replays of IM operations identified as being of interest to the project using the FAA Falcon replay toolset. Falcon allows users to replay events and sessions from up to 45 days ago to near real time. These replays consist of a replay of the ERAM display video as well as audio of controller and pilot communications. Falcon uses track data offloaded from the National Offload Program (NOP) and ASDE-X data from SWIM.

Once an IM operation was identified through a controller feedback form or noted by an AAL flight crew member, an AIRS team member would access the data from the event in the Falcon system, replay the operation and capture the audio and video using video capture software such as Camtasia. Beginning in March 2023 and through November 2023 (the latter portion of the first year of the operational evaluation), a video was made of all identified IM operations.

These videos helped the team understand various aspects of the IM operations. AIRS team members representing various disciplines (e.g., controllers, pilots, avionics developers, concept SMEs) would view the replays together to develop a comprehensive understanding of the operations. The team used this interactive approach to establish what was working well and what could be improved.

3.8 Data Repository

Due to the many types of data collected and the dispersed nature of AIRS team members, a secure, central data storage system was used. AIRS was able to maintain security and configuration control of the data while at the same time making it easy to upload and download various data types.

A spreadsheet of all the data was used to organize all the data by IM operation. A sample of some of the columns used to capture the data follows:

- IM OP ID – unique operation identifier
- Sector – sector or sectors where the operation took place
- Date (Z) – date of operation in UTC
- Time (Z) – UTC time of operation
- Trail Flight ID
- Trail Aircraft Registration Number – used to help understand any issue associated with a particular airframe
- Lead Flight ID
- ASG – ASG assigned by the controllers
- IM Clearance Type – Cross or Maintain
- Cross Point – if a Crossing operation
- Controller Feedback Comments
- SME and FAA Team Comments
- Data Analysis Team comments
- SME Data Review Requested – noted by a controller or SME indicating additional analysis was required
- ACSS Deep Dive Requested - noted by a controller or SME indicating additional analysis was required by ACSS (questions about algorithm behavior)
- Data Card Data received
- Third Party aircraft ID query / issue?
- Controller Reported Issue
- Link to Falcon video file

4 Analysis and Results

The goal of the AIRS I-IM Operational Evaluation is to determine and evaluate the benefits associated with IM operations. Section 4 provides a summary of the results and analyses obtained during the first year of the operational evaluation.

4.1 Safety Hazard Assessment

During the Safety Panel for this operational evaluation, five hazards were identified by the various stakeholders (see Table 3). These hazards were monitored and assessed throughout the operational evaluation. A definition of each safety hazard and results are provided below.

During the operational evaluation, all issues and concerns were discussed weekly with ZAB Controller SMEs and monthly with all SMEs (which was more frequently than what was defined in the AIRS I-IM SRMD monitoring plan). During the first year of the operational evaluation, there were no IM operations that led to an effect of a loss of separation. During the safety panel, this effect was identified for hazards I-IM-1, I-IM-2, and I-IM-3 and had a low risk which was confirmed for the first year of the operational evaluation.

I-IM-1 "Designate the wrong lead aircraft" is when either the flight crew or the controller mistakenly identifies or designates an incorrect lead aircraft for the IM operation or there is a call sign mismatch where the lead aircraft is broadcasting the incorrect call sign. The safety panel determined there were two possible effects of this hazard: a loss of separation and additional workload. The safety panel determined these were both low risk effects. During the first year of the operational evaluation, there was no data that indicated the incorrect lead aircraft was designated.

I-IM-2 "Wrong ASG input into MCDU and used for IM Operation" is when either the flight crew or controller mistakenly enters/provides an incorrect time-based or distance-based ASG and this ASG is used for the IM operation. The safety panel determined there were two possible effects of this hazard: a loss of separation and additional workload. The safety panel determined these were both low risks. During the first year of the operational evaluation, there were no discussions or data indicating this hazard occurred.

I-IM-3 "Controller uncertain about speed adjustment during IM operation" acknowledges the learning curve at the beginning of the operational evaluation when controllers may not be familiar or comfortable with the IM speeds that the IM aircraft is flying to achieve/maintain the ASG. This was especially a concern when using a time-based ASG. This hazard also covers the cases when the flight crew of the IM aircraft may intentionally or unintentionally enter an incorrect IM speed. The safety panel determined there were two possible effects of this hazard: a loss of separation and additional workload. The safety panel determined these were both low risks. During the first year of the operational evaluation, controller workload was only an issue when initially communicating the IM clearance, not while monitoring the IM operations. There were no feedback forms, observations, or complaints recorded from controllers that monitoring the IM operations led to additional workload.

I-IM-4 "Mismatch between IM state and controller awareness (whether internal to ZAB or external facilities) regarding IM Operation in effect" would occur if there was a failure to coordinate IM operations to adjacent sectors. This could be caused by, for example, improper use of the fourth line data block in the controller system, failure of the pilot to inform the controller at check-in, and communication failures. The safety panel determined there was only one possible effect of this hazard: additional workload. The safety panel determined that this was low risk. There was no data where the fourth line was deleted or modified when it should not have been. When discussing this hazard, the panel stated that pilots self-reporting when entering a new sector was one of the controls to prevent the hazard from occurring. During the safety panel, it was recognized that pilots do not always remember to do this; and this was found to be true during the operational evaluation (Figure 16). Even though this happened a number of times, it never led to increased workload. Throughout the operational evaluation there were floor walkers to aid the controllers in issuing the IM clearances and monitoring the IM operations. These floor walkers were an additional control but were not necessary for safety.

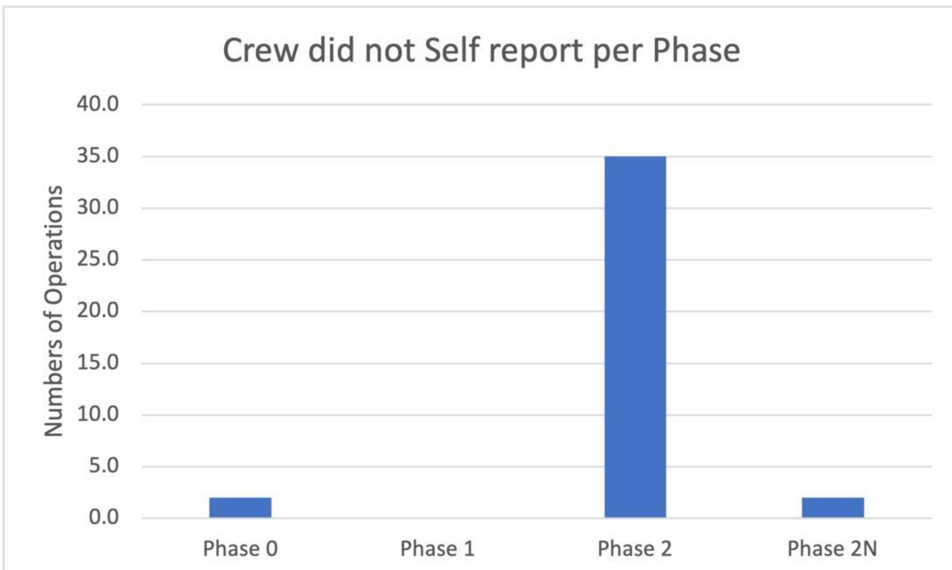


Figure 16 - Flight crew did not self-report IM operation

I-IM-5 "Additional coordination necessary for IM Operation across multiple sectors" is when there is one controller controlling a lead aircraft and another controller controlling the IM aircraft. This hazard is due to workload issues that could result from coordination between different sector controllers during these IM operations and the lack of technology to support this coordination. The safety panel determined there was only one possible effect of this hazard: additional workload. The safety panel determined this was a low risk. During the first year of the operational evaluation, IM operations were rarely conducted with aircraft in different sectors. When this did occur, it required floor walkers to coordinate with the controllers in the different sectors and aid in monitoring these operations between the different sectors. Due to this extra coordination and workload, controllers commented that any benefits from doing IM operations were lost because of the extra coordination. Controllers suggested that there would need to be additional tools and automation to aid the controller in initiating IM operations with an IM aircraft and lead aircraft in different sectors. These types of operations were not pursued after the initial attempts. As a result, this hazard was not realized.

4.2 Successful Operations

An important aspect of the operational evaluation was to assess how often IM was considered successful. If controllers were going to use IM operations on a routine basis, controllers needed to feel confident that when an IM clearance was issued, that clearance would result in a successful operation.

Over the course of the operational evaluation, criteria for defining successful or unsuccessful IM operations evolved. During Phase 0 and Phase 1, the success criteria were based on controller feedback that the IM aircraft met the assigned ASG. During the project team meetings, the ZAB SMEs noted that ASG alone was not sufficient to determine the success criteria. For example, the delay in the IM application speed changes were longer than controller expectations. Even if the ASG was met, the operations were not always consistent and predictable. Using the original success criteria, these operations were labeled successful, but they were not successful from the controllers' perspectives due to the lack of consistent, predictable behavior.

Starting in Phase 2, the success criteria evolved into considering whether the IM operation was acceptable to the controller by reviewing the operation. The controller perspective was based primarily on the controller feedback forms. If the feedback form did not provide enough information to determine success, the IM operation was flagged for additional analysis. When required or appropriate, a team review of the operation based on videos from the Falcon replays was conducted.

4.2.1 Methodology to Categorize IM Operations

Based on the feedback forms, several categories were formed and defined:

- **Successful**: For Phase 0 and Phase 1, the IM aircraft met the ASG. For Phase 2 and Phase 2N, the operation was acceptable from the controller's perspective (either via feedback form or through discussion with the ZAB SMEs).
- **Unsuccessful**: For all phases of year 1, the operation was unacceptable from the controller's perspective (either via feedback form or through discussion with the ZAB SMEs).
- **Infeasible**: Either the IM clearance did not pass the conformance check in SafeRoute+.[4]
- **No Operation**: A controller filled out the feedback form but never issued the IM clearance.
- **Flight Crew Unwilling**: The controller issued the IM clearance, but the flight crew was unwilling to conduct the IM operation. This could occur for operational reasons (e.g., commanded speed would be too fast for the given atmospheric conditions) or a crew that was not comfortable or ready to accept the clearance.
- **Controller Unwilling**: If a controller was unwilling to issue a clearance no feedback form was filled out.

[4] The "conformance check" related to "Infeasible" refers to the geometry, ownship position quality, and traffic position quality check.

These categories were used to determine the total number of IM operations attempted and the total number of completed IM operations. The total number of IM operations attempted is a sum of the successful, unsuccessful, and infeasible. The total number of completed IM operations is the sum of the Successful and Unsuccessful. This sum does not include the Infeasible operations since those were not executed. A Success Rate was calculated by dividing the Successful operations by the total number of completed IM operations.

4.2.2 Results of Categorizing IM Operations

Based on the feedback forms and the categories described in section 4.2.1, the following table was created (see Table 5.).

Table 5. Categorizing Feedback Forms for Phases 0 through 2N

	Phase 0	Phase 1	Phase 2	Phase 2N	All Phases
Successful	70	53	238	15	376
Unsuccessful	45	20	90	2	157
Infeasible	2	4	33	9	48
Flight Crew Unwilling	0	0	9	0	9
Controller Unwilling	0	0	5	0	5
Total Number of IM Operations Attempted	117	77	361	26	581
Total Number of Completed IM Operations	115	73	328	17	533
Success Rate	60.9%	72.6%	72.6%	88.2%	70.5%

Figure 17 shows the total number of operations that were attempted per phase, and Figure 18 shows the success rate in each phase. As the operational evaluation progressed from Phase 0 through Phase 2 and Phase 2N, the number of successful operations increased. Note that Phase 2 and Phase 2N overlap where Phase 2N includes the Maintain operations.

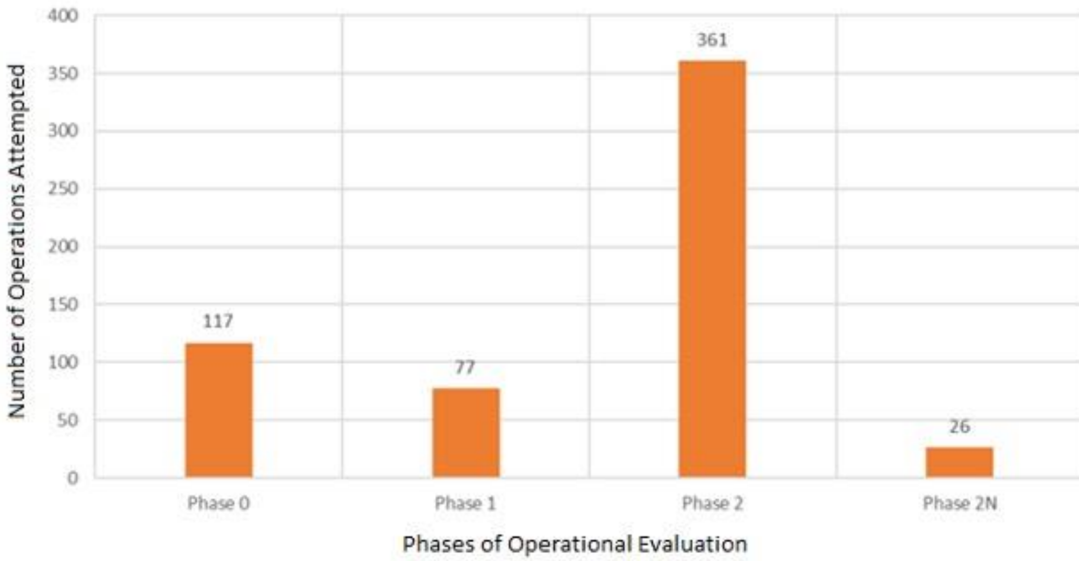


Figure 17 - The Total Number of Operations Attempted Per Phase of the Operational Evaluation

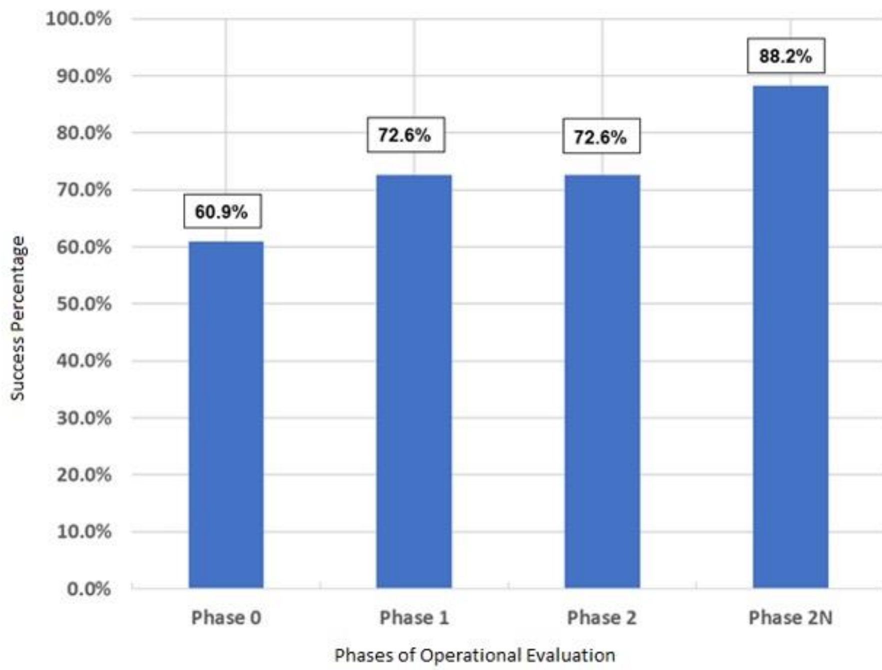


Figure 18 - Percentage of IM Operations that were Successful Per Phase of the Operational Evaluation

4.3 Tracking Concerns and Issues

Over the operational evaluation and through the controller feedback forms and SME discussions, several issues and concerns were categorized and tracked. Issues are defined as problems that arose from unsuccessful operations. Concerns are defined as items that occurred during successful operations were worth noting and tracking.

4.3.1 Concerns and Issues

Figure 19 shows the total number of reported concerns/issues for all phases.

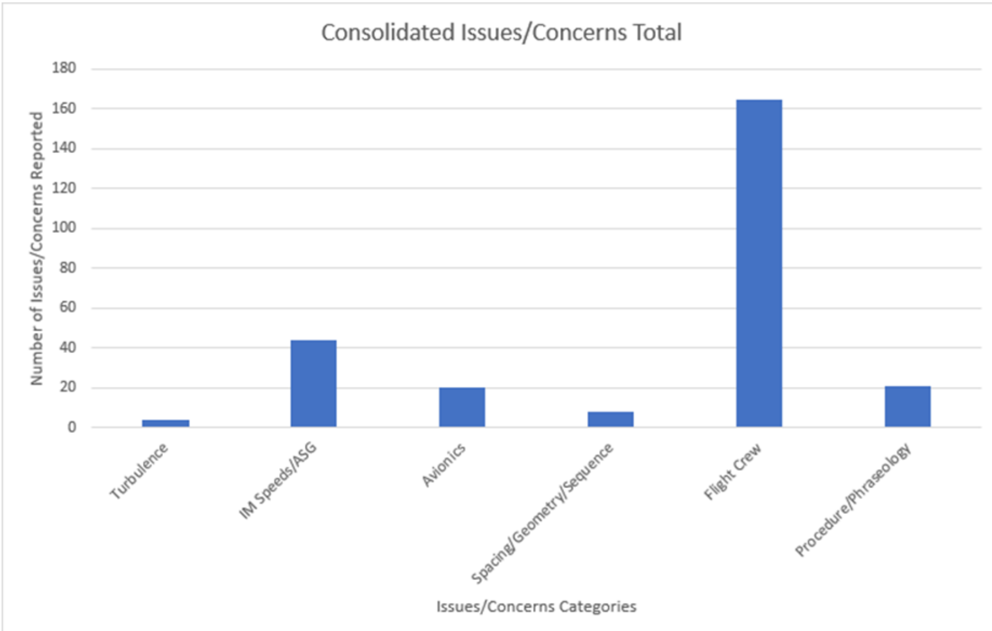


Figure 19 - Total Number of Reported Concerns/Issues for All Phases of the Operational Evaluation

Each category is defined as the following:

Turbulence

- Wake Turbulence – Pilot reported they had to adjust spacing due to wake.
- Atmospheric Turbulence – Pilot was unable to comply with IM Speeds due to atmospheric turbulence.
- Aircraft Weight – Pilot reported they could not comply with the IM Speed due to the aircraft weight or the weight displacement on the aircraft.
- Convective Weather – Pilot or controller reported issues with the operation due to convective weather.

IM Speeds/ASG

- Number of IM Speeds –Pilot reported there were too many IM Speeds implying the workload was higher than desired.
- IM or Descend Via Speeds –Pilot reported they could not apply the IM Speeds along with the "descend via" procedure.
- IM Speed Too Low or High – Pilot reported the SafeRoute+ commanded IM Speed was either too low or too high for the operation. This could have been due to flight crew comfort level or other operational constraints.
- ASG Too Small – Pilot received an "Interval Too Small" error from the SafeRoute+ feasibility check (the feasibility check is done for Cross clearances with time-based ASGs only).

Avionics

- Missing Waypoint – Pilot entered a waypoint for the CP (or the PCP) that was either not in the navigation database or was incorrect. At the beginning of the operational evaluation, the navigation database did not contain all the waypoints that were needed. A new database was loaded onto the aircraft that corrected this issue.
- Avionics Issues – Pilot reported the SafeRoute+ equipment was not working.
- Traffic Drop – Pilot reported the lead aircraft was dropped by SafeRoute+ for either a drop in surveillance or a drop in the quality of surveillance.

Spacing/Geometry/Sequence

- Traffic Sequence – Controller had concerns over traffic sequencing when using the IM operation. For example, the controller may have realized that the IM aircraft needed to be slowed down or sped up for the sequence. Another would have been if the controller did not realize the IM aircraft or lead aircraft had been given a "direct-to" instruction that took them off their course.
- Spacing Unavailable Message – Pilot received an "Unable Spacing" error from SafeRoute+. This was either due to a drop in the IM aircraft's surveillance quality, the lead aircraft's surveillance quality, or an unacceptable flight path geometry.
- Unable Cross but able Maintain – Pilot reported that they are unable to do the Cross clearance but could do a Maintain clearance.
- Bad Geometry – Pilot received a "Bad Geometry" error from SafeRoute+. This error message appeared when the lead or IM aircraft were not direct to the CP; IM aircraft had deviated from the lead aircraft's flight path during a Maintain IM operation; or lead aircraft was behind the IM aircraft.

Flight Crew

- Unable – Pilot was unable to conduct the IM operation.
- Not Following Commanded Speeds – Flight crew not following commanded speeds displayed on the AGD.
- Training – Pilot reported not having been trained.
- Pilot Did Not Self-Report – Pilot did not provide the IM operation information to the next sector.
- Entry Error – Pilot had entered the IM clearance incorrectly into SafeRoute+ and the equipment indicated there was an error. This includes pilot error when accidentally entering the CP into the PCP.
- Could Not Locate Traffic on Display – Pilot could not find and designate the Lead aircraft for the IM operation.
- Unequipped – Pilot reported they were not equipped with SafeRoute+.
- Distraction – Pilot reported the IM Speeds were becoming distracting and a nuisance.
- High Workload – Pilot reported the IM operation was too work intensive. This may have been due to the initial communication of the IM clearance and the length of the IM clearance or to the pilot not selecting the commanded IM Speed.
- Confidence in Outcome – Pilot reported that they are not confident of the outcome of the operation or avionics.

Procedure/Phraseology

- Procedural Misunderstanding – A misunderstanding of the IM operation occurred between the pilot and controller. This was typically caused by pilots misunderstanding the IM operation. As an example, during one operation the pilot thought they had to call the lead aircraft on the radio.
- Phraseology – Pilot was confused or did not understand the phraseology for the IM operation.

Figure 20 shows the number of concerns per a category for successful operations for Year 1, and Figure 21 shows the number of issues per a category for unsuccessful operations for Year 1.

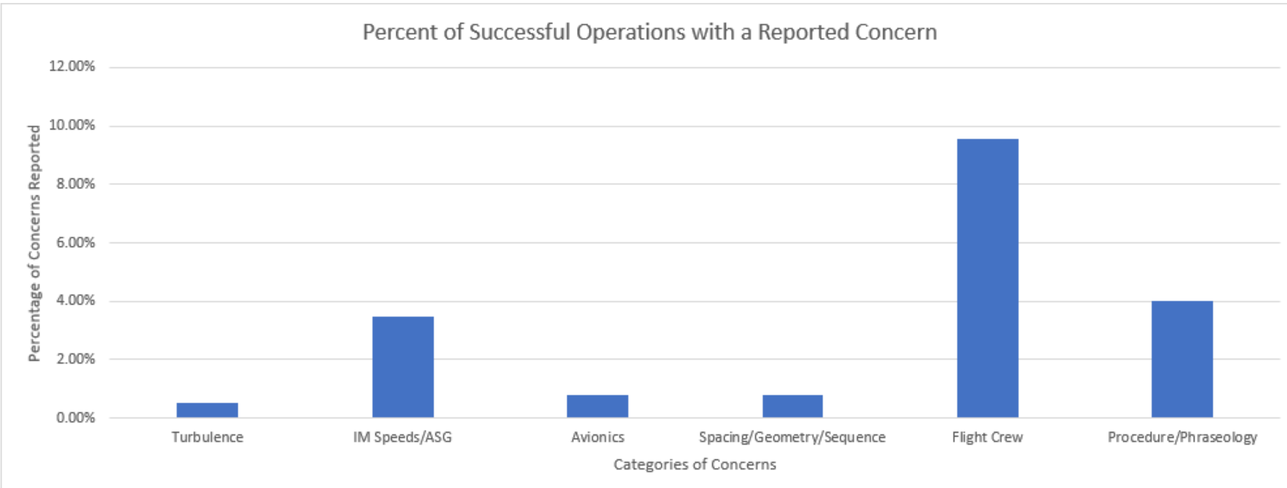


Figure 20 - Total Percent of Successful Operations with a Reported Concern

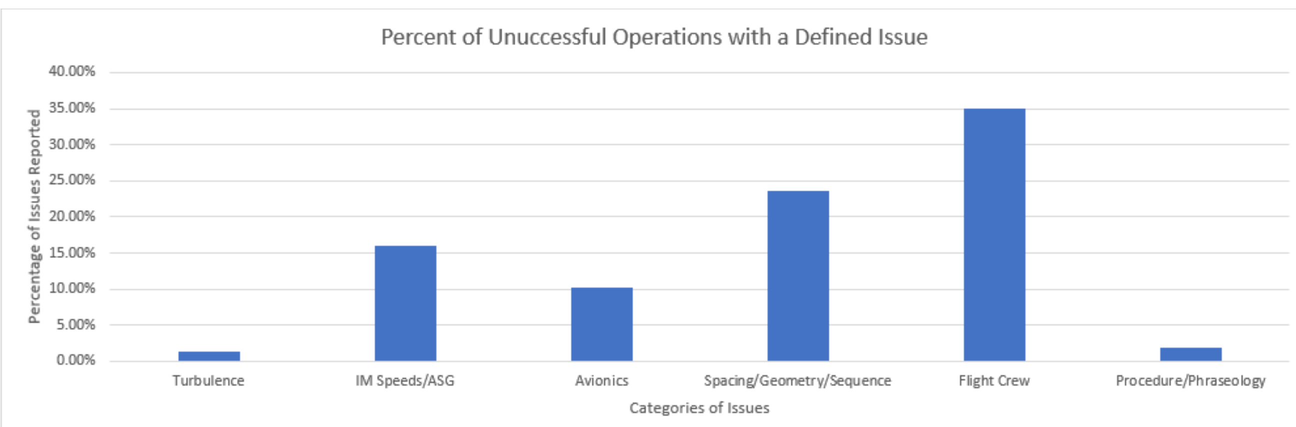


Figure 21 - Total Percent of Unsuccessful Operations with a Defined Issue

4.3.2 Tracking Concern and Issue Trends

These concerns/issues were tracked throughout the phases to determine trends in the data. Figure 22 shows the trends of key concerns and issues over the first year of the I-IM operational evaluation.

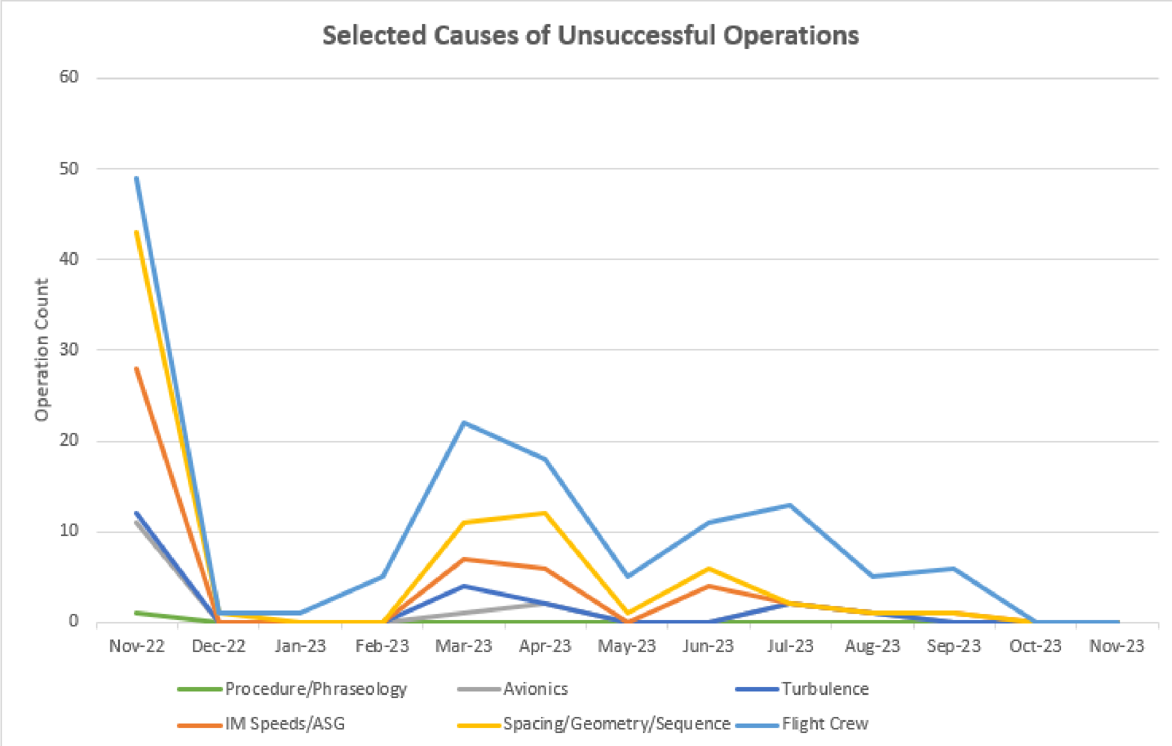


Figure 22 - Trends of Key Concerns and Issues over the First Year of the I-IM Operational Evaluation

The trends clearly show the number of unsuccessful operations diminishing as the flight crews became familiar with utilization of the avionics, and comfortable with the IM operations. As shown in Figure 22, many of the initial concerns were associated with flight crew issues as well as issues with spacing, relative geometries and sequence of aircraft.

4.4 Number of Relevant Operations

Data captured from the SafeRoute+ system included operations when the flight crews may have been experimenting with the equipment. This data had to be filtered to IM operations that were relevant to the scope of this operational evaluation. The SafeRoute+ data was correlated with controller feedback forms and other data sources for a complete picture of each IM operation.

There were a total of 537 relevant operations performed during year one. The methodology for counting the operations is as follows.

4.4.1 Methodology to Determine Relevant Operations

SafeRoute+ data is recorded for every second the IM application is in use. This data is provided to the AIRS data collection team semi-monthly. The data is processed and aggregated into "events" and "sub-events" to determine the relevant operations and performance metrics. The following steps are used in the process:

- An event is defined for each time range where the avionics mode is listed as "executing".
- Sub-events within each event include changes to commanded speed, changes to pilot-selected speed, and crossing the CP (denoted as the Achieve By Point (ABP) in the ACSS data but denoted as CP in this report).
- If a pilot enters a new Lead Aircraft, ASG, or CP, the SafeRoute+ is no longer "executing" so one event stops and a new one begins.
- An event is defined as concluded once the aircraft crosses into KPHX Terminal Radar Approach Control (TRACON), approximated by 50 NM radius around airport, because the operational evaluate is limited to ZAB.
- Only events with a duration of five minutes or longer are used in the analyses.
- The ACSS event data is correlated with the voice transcript data and the operational feedback form data to verify the controller's interaction with the flight crew of the IM Aircraft (the IM operation requires actions by both the pilot and controller). To qualify as an IM operation, the ACSS event needs to correlate with at least one of the other data sources available to confirm controller interaction.
- The event data was also correlated with IOAA trajectory data to determine distance from specific fixes and the TRACON boundary.

After processing, the number of qualifying IM events were gathered and aggregated using multiple factors including:

- IM clearance type (Maintain, Cross only, Cross-Maintain)
- ASG type (Time or Distance)
- Cross Point (CP)
- Planned Cancellation Point (PCP) (this is denoted as the Planned Termination Point (PTP) in the ACSS data but as PCP in this report).

4.4.2 Results of Analysis to Determine Number of Relevant Operations

Table 6 compares the ACSS event data to the feedback forms by month. Each row contains results for each month of the first year of the operational evaluation. Since multiple controllers may have interacted with the IM Aircraft over an IM operation or there may be a pilot and controller feedback form for the same IM operation, the feedback forms were consolidated for each IM operation or feedback event. They were further consolidated into those IM operations that were considered successful as described in Section 4.2 and then matched to the ACSS data. There is also a column of Missing ACSS events where there is a feedback form, but the ACSS data could not be correlated to it due to lack of data on the data card.

Table 6. ACSS Events Compared to Feedback Forms

Month	Feedback forms	Feedback events	Matching ACSS events	Successful feedback events	Matching ACSS events to Successful	Missing ACSS events
11/2022	157	137	114	82	78	4
12/2022	3	3	3	2	2	0
1/2023	5	5	4	3	3	0
2/2023	28	28	23	21	19	2
3/2023	113	87	65	52	43	9
4/2023	119	89	65	61	50	11
5/2023	16	15	9	10	8	2
6/2023	39	37	25	22	18	4
7/2023	106	74	61	51	48	3
8/2023	75	50	43	33	32	1
9/2023	69	47	41	34	32	2
10/2023	13	9	5	4	3	1
Total	**743**	**581**	**458**	**375**	**336**	**39**

Table 7 ACSS Events Compared to Transcript Data relates the ACSS events to the transcript data. After the initial phrase query of the transcript data, the transcript data is filtered to match ACSS events using the date, time, and relevant information from the IM operation (as described in Section 4.4.1). Each row of the table is a month during the first year of the operational evaluation. The “Selected Transcripts” column is the number of transcripts that match the phrase query and the “ACSS Events with Transcript Data” column is the transcript data that matches with ACSS events.

Table 7 ACSS Events Compared to Transcript Data

Month	Selected Transcripts	ACSS Events with Transcript Data
11/2022	502	146
12/2022	140	6
1/2023	124	6
2/2023	197	22
3/2023	385	63
4/2023	334	71
5/2023	312	10
6/2023	287	19
7/2023	366	62
8/2023	432	40
9/2023	238	29
10/2023	294	9
Total	**3,611**	**483**

Based on Table 6 and Table 7, Table 8 is a summary of ACSS events that match either feedback form or transcript data. The data are presented by IM Clearance Types. The "Either Match" column is the number of ACSS events used for the analyses described in Sections 4.5, 4.6, and 4.7.

Table 8. ACSS Events by IM Clearance Types

Clearance Type	ACSS Events	Feedback Form Match	Transcript Match	Either Match
Cross	128	73	90	101
Cross-Maintain	271	208	238	260
Maintain	816	133	155	176
Total	**1215**	**414**	**483**	**537**

Table 9 shows the same data from the "Either Match" column in Table 8 by month and for each IM Clearance type.

Table 9. ACSS events based on IM Clearance type and by month

By Month	Cross	Cross-Maintain	Maintain	Total
11/2022	32	54	66	152
12/2022	2	2	5	9
01/2023	2	1	4	7
02/2023		9	14	23
03/2023	14	38	15	67
04/2023	16	40	18	74
05/2023	2	7	1	10
06/2023	2	14	4	20
07/2023	13	37	18	68
08/2023	9	29	9	47
09/2023	8	26	17	51
10/2023	1	3	5	9
Total	**101**	**260**	**176**	**537**

For year 1 of the AIRS I-IM operational evaluation, there were 537 events where the ACSS data events match either the controller feedback form or the transcript data entries. Most of these events were Cross-Maintain or Cross events. This is a result of the route structure of the traffic flows in ZAB airspace (i.e., there are several merge points in ZAB airspace). It is also a result of the decision to focus Phase 2 (3/16/2023 - 11/6/2023) operations on Cross clearances. During this period SME floor walkers focused on providing and helping controllers issue and monitor Cross clearances.

Results based on these 537 relevant operations are presented in Section 4.5 (Speed Commands and Compliance), section 4.6 (Delivery Accuracy for IM A; and Section 4.7 (Inter-arrival Time and Inter-arrival Distance for IM and non-IM flights.

4.5 Speed Commands and Compliance

This section describes the analysis methodology and results on pilot compliance to IM speed commands displayed to flight crews on the AGD. This was analyzed for every ACSS event with duration greater than 5 minutes and which had some indication of controller interaction. These analyses led to some recommendations for future IM operations, which are described in Section 5.

4.5.1 Analysis Methodology for Number of Speed Commands and Compliance

Per the AAL training, the pilot should implement the speed commands as provided by the avionics in a timely manner. This should result in more predictable operational outcomes for flight crews and controllers. The metrics quantify the number of IM speed commands, pilot-selected speeds, and the compliance of selected speeds to the commanded speeds. The commanded speeds and selected speeds are expressed in either Mach or Calibrated Airspeed (CAS). The pilot has the option of selecting or changing the speed type during the operation and the avionics output mirrors the selection.

Both the number of commanded speeds and the number of pilot-selected speeds are computed. To account for the time a pilot needs to dial in a new speed, pilot-selected speeds with duration of less than 10 seconds are excluded. When a pilot switches from Mach to Calibrated Airspeed units this is counted as a new speed for both the commanded and selected speed totals.

Compliance is calculated as the percentage of time the pilot selected speed is within a certain tolerance of the commanded speed. For the IM effort, the following compliance criteria was chosen:

- CAS within ± 3 knots
- Mach with ± 0.01 Mach

In some cases, the compliance measurement was requested by the project team only for segments of the flight (i.e., during a Descend-Via). In these cases, the underlying data was limited to a subset using the trajectory information, and the metric was recalculated.

4.5.2 Results of Speed Compliance Analysis

Table 10 and Table 11 show the number of ACSS events when pilot-selected speed complied with the commanded speed by percent compliance in 10-percent increments. Table 8 summarizes results for all ACSS events over the first year. Table 10 is a subset of the data for segments where the IM operation occurs between the waypoints TINIZ and EAGUL. Typically, ZAB controllers will have issued a "descend via" clearance to flight crews during this portion of their flights into KPHX. These events were analyzed separately to analyze the compatibility of IM operations with a Descend Via operation.

Table 10. Compliance over entire 1st year data set

Percent compliance	Number of flights	Percent of flights
0%-10%	47	9%
10%-20%	17	3%
20%-30%	15	3%
30%-40%	26	5%
40%-50%	21	4%
50%-60%	35	7%
60%-70%	34	6%
70%-80%	70	13%
80%-90%	89	17%
90%-100%	183	34%

Table 11. Compliance over the 1st year data set with Descend Via only

Percent compliance	Number of flights	Percent of flights
0%-10%	6	6%
10%-20%	3	3%
20%-30%	8	8%
30%-40%	8	8%
40%-50%	5	5%
50%-60%	10	10%
60%-70%	14	13%
70%-80%	12	12%
80%-90%	26	25%
90%-100%	12	12%

A comparison of Table 10 and Table 11 reveals that compliance for the descend via operations appears to be lower than compliance for all operations over year 1. For example, only 37% of descend via flights exhibited high compliance (greater than 80%) while 51% of all flights exhibited high compliance.

An analysis was conducted of the pilot reaction times for selecting a new speed when a speed command was issued. This was done with the entire data set where speed compliance was greater than 80%. The results show a mean reaction time of 24.9 seconds and a median of 12 seconds. Figure 23 shows the distribution of pilot reaction time in seconds. Pilot reaction times greater than a minute appear to outliers in the data set and are grouped in the bar on the right-hand side of Figure 23.

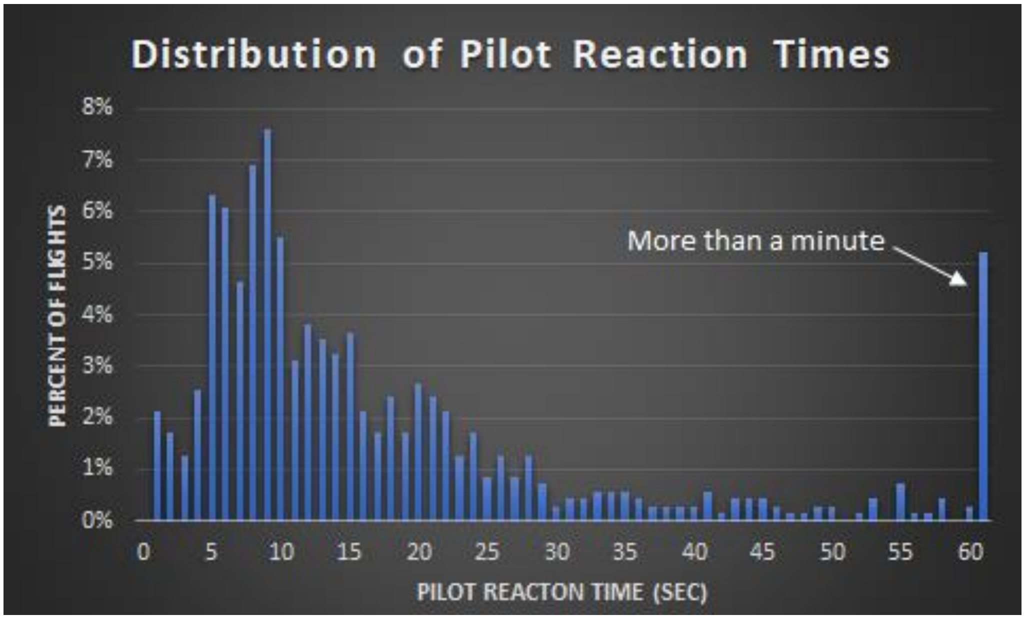


Figure 23 -Distribution of Pilot Reaction Times for the First Year

4.6 Delivery Accuracy for IM Aircraft

The following analysis was conducted to examine the achievable spacing accuracy of IM operations. The delivery accuracy describes the expected distribution of delivery errors – defined as the difference in the actual spacing and the ASG – for a population of IM operations. The resulting IM delivery accuracy was also compared to the delivery accuracy associated with current GIM-S controller tools.

4.6.1 Analysis Methodology for Delivery Accuracy

IM aircraft pairs are expected to achieve and maintain more accurate and precise spacing intervals than what is manageable by the controller alone.

The delivery error for an IM operation is defined as the difference between the actual spacing interval and the ASG in terms of seconds or distance depending on the type of ASG.

$$\text{Delivery Error} = \text{Actual Spacing} - \text{ASG}$$

For distance-based ASGs, the actual spacing is measured as the along-path distance between the Lead Aircraft and IM Aircraft. For time-based ASGs, the actual spacing is measured as the difference in the times the Lead Aircraft and IM Aircraft crossed the same location.

The delivery accuracy can be described by the mean and standard deviation for a population of delivery errors. The mean delivery error indicates the average difference in the actual spacing and the ASG, while the standard deviation of the delivery error is an indication of the spacing precision. The delivery accuracy can also be quantified as the percentage of delivery errors falling within a specified tolerance of the ASG (e.g., the percentage of operations with delivery errors within 10 seconds of their ASGs).

IM delivery accuracy was examined at two locations:

1. At the CP for Cross operations
2. At the End of the Procedure for all operations where this is defined as the time when SafeRoute+ stops executing the IM Application or when Aircraft crosses the KPHX TRACON boundary

The metrics were grouped into sets and examined in a variety of ways including direct examination of the distributions and associated statistics of the delivery error (i.e., mean, and standard deviation) as well as a presentation of the delivery accuracy in terms of percentages of operations with delivery errors within specified times and distances.

For the distribution, statistical testing, and trend analyses, the following restrictions were made to compare relevant sets:

1. All events were truncated at the KPHX TRACON boundary
2. Cross Point (CP) filter: For Cross operations, flights were removed if they terminated more than 2 NM before reaching the CP
3. Compliance filter: Flights were removed when speed compliance was less than 70%
4. Feasibility filter for time-based operations: Flights were removed if (Initial Predicted Time Spacing – ASG) divided by Initial Distance was greater than 0.5 seconds/NM. Separate feasibility calculations of initial distance were performed for the CP and the end of operation (see explanation in following paragraph).

Figure 24 relates delivery errors to the feasibility metric. The blue-shaded area is the desired delivery accuracy range (i.e., 95% of the delivery errors should fall within 10 seconds); the red-shaded area is an area where there is higher variation in the delivery error than desirable (outside the delivery accuracy envelope). When the feasibility metric is less than zero, the aircraft's predicted time spacing is less than the required time and the IM Aircraft must slow down to meet the goal. Conversely, when the feasibility metric is greater than zero, the predicted spacing is greater than the required spacing and the IM Aircraft must speed up to meet the goal. The distance to meet the ASG (either at the CP or at the end of the operation) affects the distance from zero along the horizontal axis. If the distance to fly is relatively large compared to the difference in time spacing needed, then the aircraft can be reasonably expected to achieve the ASG within the desired tolerance (10 seconds); this will produce a value close to zero on the horizontal axis. However, if the distance to fly is relatively short compared to the difference in time spacing needed, then it may not be feasible for the aircraft to achieve the ASG within the desired tolerance; this produced a value farther from zero on the horizontal axis. While it is easier to slow an aircraft down quickly to meet the ASG (left side of Figure 24), it is not as easy to speed up. This resulted in several IM Aircraft not meeting the delivery accuracy goal (right side of Figure 24). The value of 0.5 for the threshold was determined by visual inspection of the data in Figure 24. The results show the value of including the feasibility check in the ACSS IM application to identify those IM operations unlikely to meet the ASG within the 10-second tolerance.

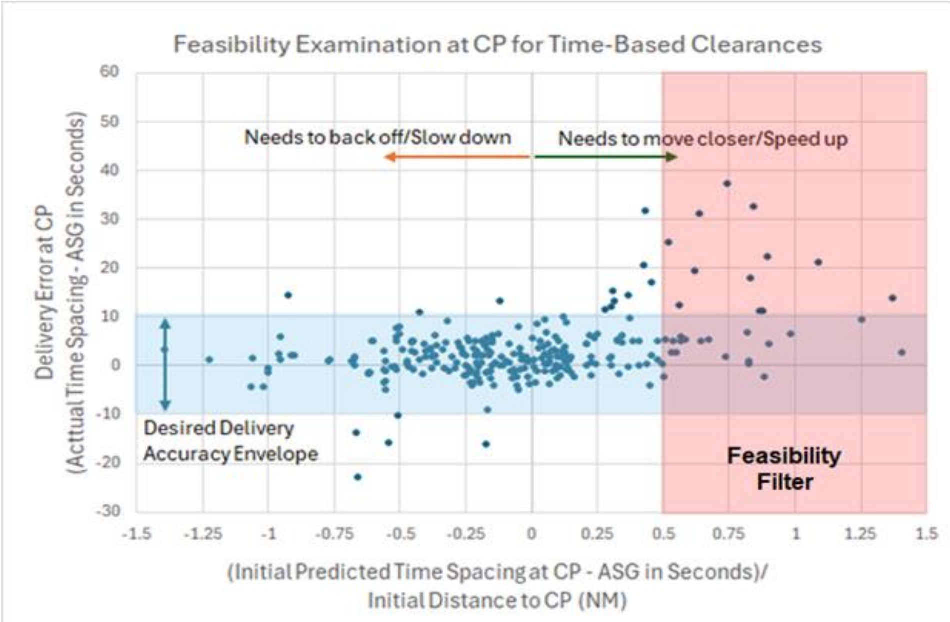


Figure 24 - Delivery Error vs. Feasibility Factor at the CP

4.6.2 Delivery Accuracy Analysis Results for IM Aircraft with Distance-Based ASGs

This section applies to IM events where a distance-based ASG was used. Table 12 provides the total number of distance-based events, the impact of the filters from Section 4.6.1 on those events, and the remaining events after filtering. Note the feasibility filter discussed in Section 4.6.1 only applies to time-based ASG and does not apply to distance-based events. The additional analyses in this section are performed on the remaining events only. Note that in Table 12, the filtering removed all Cross-only events.

Table 12. Number of IM Events with Distance-Based ASGs after each Filter and all Filters are applied

Distance-Based		Filtered Out			
IM Clearance Type	**Events**	**CP filter**	**Compliance filter**	**Both filters**	**Remaining Events**
Cross	44	44	12	44	0
Cross-Maintain	171	20	47	57	114
Maintain	79	0	26	26	53
Total	294	64	84	126	167

Using the remaining events from Table 12, delivery accuracies for distance-based IM events were examined at two points in each of the events: at the CP (when used) and at the End of Procedure. Figure 25 shows the delivery error distributions; the blue line shows the delivery error distribution at the CP, and the orange line shows the delivery error distribution at the End of Procedure. Both lines suggest a normal distribution, which means the delivery accuracies may be sufficiently described using the means and standard deviations of the delivery errors.

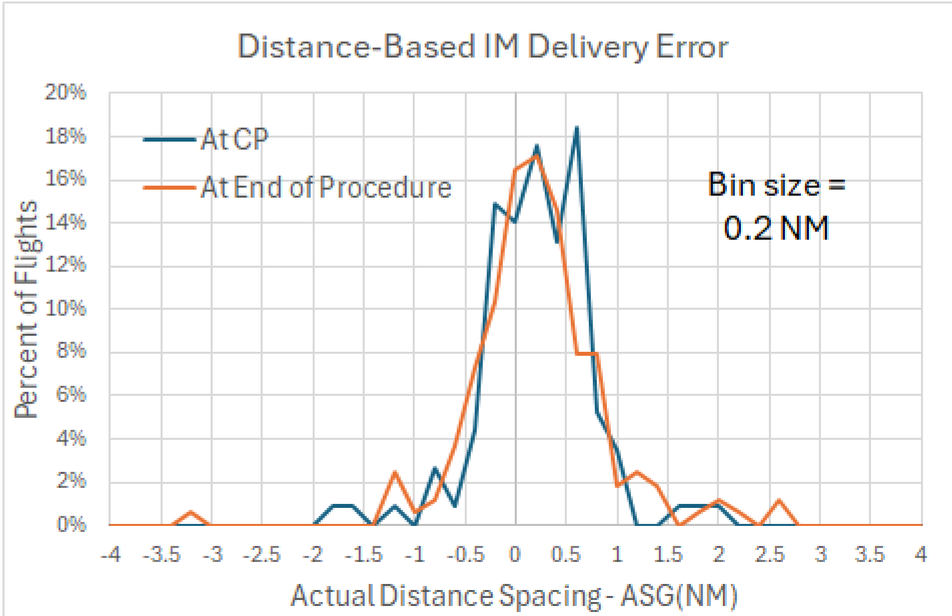


Figure 25 - Distance-based IM delivery errors

Table 13 provides the mean, standard deviation, and two standard deviations for the delivery errors at the CP of all remaining distance-based IM events in Table 12. One standard deviation from the mean bounds 68% of the data and two standard deviations bounds approximately 95% of the data assuming a normal distribution. The results in Table 13 only include Cross-Maintain operations since these operations use a CP (no Maintain events). Table 14 presents the delivery accuracy at the CP aggregated by 0.5 NM increments from the ASG.

Table 13. Normal Distribution Statistics for Distance-based IM Delivery Errors at the CP

	Delivery Error Statistics at the CP			
Operation	**Filtered Observations**	**Mean (NM)**	**StnDev (NM)**	**2*StnDev (NM)**
Cross				
Cross-Maintain	114	0.2	0.6	1.2
Maintain				
Total	114	0.2	0.6	1.2

Table 14. Distance-based IM Delivery Accuracy at the CP

Distance from ASG	Delivery Accuracy at CP (Year 1 only, CP filter, Speed Compliance ≥70%)	
	Number	Percent
Within 0.5 NM	74	65%
Within 1.0 NM	108	95%
Within 1.5 NM	109	96%
Within 2.0 NM	114	100%

Table 15 provides the mean, standard deviation, and two standard deviations for the delivery errors at the End of Procedure for all remaining distance-based IM events in Table 12. Table 16 presents the delivery accuracy at the End of Procedure aggregated by 0.5 NM increments from the ASG.

Table 15. Normal Distribution Statistics for Distance-based IM Error at the End of Procedure

	Delivery Error Statistics at the End of Procedure			
Operation	**Filtered Observations**	**Mean (NM)**	**StnDev (NM)**	**2*StnDev (NM)**
Cross				
Cross-Maintain	114	0.3	0.8	1.6
Maintain	53	0.2	1.1	2.2
Total	167	0.3	0.9	1.8

Table 16. Distance-based IM Delivery Accuracy at the End of Procedure

Distance from ASG	Delivery Accuracy at End of Procedure (Year 1 only, CP filter, Speed Compliance ≥70%)	
	Number	Percent
Within 0.5 NM	108	65%
Within 1.0 NM	145	87%
Within 1.5 NM	157	94%
Within 2.0 NM	159	95%

Comparing Table 14 and Table 16 results suggest that 95% of IM events using a distance-based ASG are within 1 NM of the ASG. At the End of Procedure, 95% of the events are within 2 NM of the ASG.

4.6.3 Delivery Accuracy Analysis Results for IM Aircraft with Time-Based ASGs

Table 17 and Table 18 provide the number of events remaining after the filters from Section 4.6.1 were applied to IM operations with time-based ASG. There are two tables because there were different feasibility filters depending on whether the measurement was taken at the CP (Table 17) or at the End of Procedure (Table 18). For both tables, the Remaining Events column provides the number of events remaining after all filters were applied; this is the number of events used in the delivery accuracy analyses.

Table 17. Number of IM Events with Time-Based ASGs after each Filter where Filters are applied at the CP

Time-Based		Filtered Out				
Operation	**Events**	**CP Filter**	**Compliance Filter**	**Feasibility Filter at CP**	**All Filters**	**Remaining Events**
Cross	57	41	15	15	47	10
Cross-Maintain	91	0	44	43	51	40
Maintain	N/A					
Total	148	41	59	58	98	50

Table 18. Number of IM Events with Time-Based ASGs after each Filter where all filters are applied at the end of Procedure

Time-Based		Filtered Out				
Operation	**Events**	**CP Filter**	**Compliance Filter**	**Feasibility filter at End of Operation**	**All Filters**	**Remaining Events**
Cross	57	41	15	16	47	10
Cross-Maintain	91	0	44	4	47	44
Maintain	98	0	52	7	54	44
Total	246	41	111	27	68	98

Using the remaining events from Table 17 and Table 18, delivery accuracies for time-based IM events were calculated at two points in each of the events: at the CP (when used) and at the End of Procedure. Figure 26 shows the delivery error distributions; the blue line shows the delivery error distribution at the CP, and the orange line shows the delivery error distribution at the End of Procedure. Like the results for distance-based ASGs, both lines suggest a normal distribution.

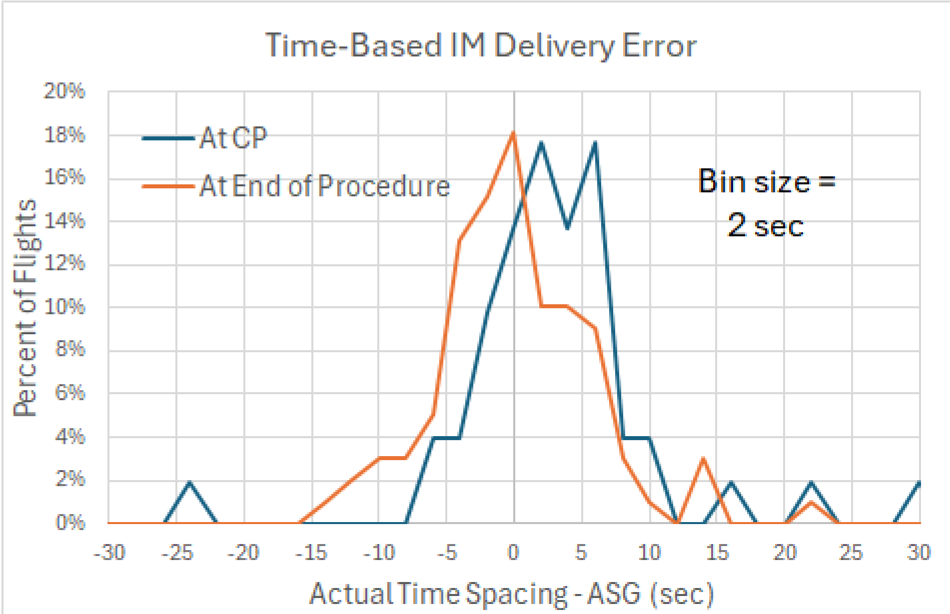


Figure 26 - Time-based IM Delivery Error

Table 19 provides the mean, standard deviation, and two standard deviations for the delivery error of the time-based IM events (the remaining events in Table 17) at the CP. The results in Table 19 only include Cross and Cross-Maintain operations since these operations use a CP (no Maintain events).

Table 20 presents the delivery accuracy at the CP aggregated by 5 second increments from the ASG.

Table 19. Normal Distribution Statistics for Time-based IM Delivery Errors at the CP in seconds

	Delivery Error Statistics at the CP			
Operation	**Observations**	**Mean**	**StnDev**	**2*StnDev**
Cross	10	0	3	6
Cross-Maintain	40	5	12	24
Maintain				
Total	50	4	11	22

Table 20. Time-based IM Delivery Accuracy at the CP in seconds

Time from ASG	Delivery Accuracy at CP (Year 1 only, CP filter, Speed Compliance ≥70%, Feasibility filter at CP)	
	Number	Percent
Within 5 seconds	34	68%
Within 10 seconds	45	90%
Within 20 seconds	46	92%
Within 30 seconds	50	100%

Table 21 provides the mean, standard deviation, and two standard deviations for the delivery errors of the time-based IM events (the remaining events in Table 18) at the End of Procedure. Table 22 presents the delivery accuracy at the End of Procedure aggregated by 5 second increments from the ASG.

Table 21. Normal Distribution Statistics for Time-based IM Delivery Error at the End of Procedure in seconds

	Delivery Error Statistics at the End of Procedure			
Operation	**Observations**	**Mean**	**StnDev**	**2*StnDev**
Cross	10	0	3	6
Cross-Maintain	44	2	10	20
Maintain	44	-2	6	12
Total	98	0	8	16

Table 22. Time-based IM Delivery Accuracy at the End of Procedure in seconds

Time from ASG	Delivery Accuracy at End of Procedure (Year 1 only, CP filter, Speed Compliance ≥70%, Feasibility filter at End of Procedure)	
	Number	Percent
Within 5 seconds	69	70%
Within 10 seconds	89	91%
Within 20 seconds	96	98%
Within 30 seconds	97	99%

The results in

Table 20 and Table 22 suggest that 90% of IM events using a time-based ASG are within 10 seconds of the ASG both at the CP and the End of Procedure. In addition, between 99% and 100% of the IM events are within 30 seconds of the ASG.

The time-based IM results can also be compared to other FAA capabilities that assist controllers when time-based metering. Figure 27 shows a comparison between the delivery accuracy for time-based IM operations at the CP and the delivery accuracy using GIM-S speed advisories to manage flights to their Scheduled Times of Arrival (STAs) at the Extended Meter Point (XMP). For the GIM-S data, only the flights that accepted speed advisories and had a non-zero TBFM delay were used. The delivery error for a flight using GIM-S speed advisories was calculated by subtracting the STA from the actual cross time.

GIM-S Delivery Error = Actual Cross Time – STA

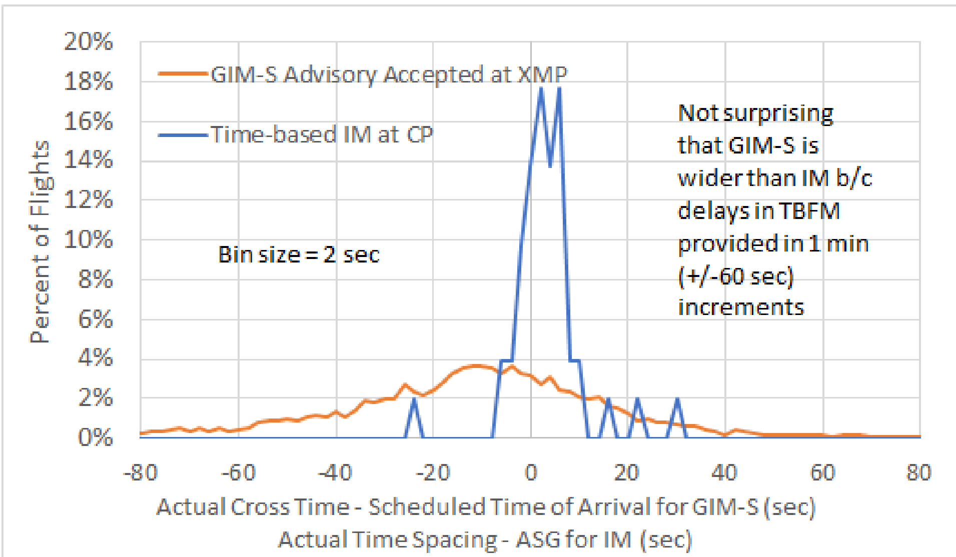


Figure 27 – Delivery Errors for Time-based IM operations and metering operations using GIM-S speed advisories

Figure 27, Table 23, and Table 24 show the results from comparing GIM-S delivery accuracies with delivery accuracies for time-based IM operations.

Table 23. Normal distribution statistics for Time-based IM and GIM-S

		Actual Time Spacing – ASG (sec)		**Actual Cross Time – Scheduled Time of Arrival (ATA-STA))sec_**	
Operation	**Observations**	**Mean**	**StnDev**	**Mean**	**StdDev**
Time-based IM	50	4	11		
GIM-S	4266			-16	45

Table 24. Time-based IM Delivery Accuracy at the CP compared to GIM-S Delivery Accuracy at XMP in seconds

Time from ASG	Time-based IM Delivery Accuracy (Percent)	GIM-S Delivery Accuracy (Percent)
Within 5 seconds	68%	12%
Within 10 seconds	90%	23%
Within 20 seconds	92%	42%
Within 30 seconds	100%	56%
Within 60 seconds		80%
Within 90 seconds		92%

From Table 24, it can be concluded that time-based IM operations result in more precise spacing than GIM-S. This result is expected for several reasons. TBFM decision-support tools present the difference in an aircraft's Estimated Time of Arrival (ETA) and its STA only when that difference exceeds one minute. As a result, ATC does not typically issue instructions to the flight crew to meet the STA until larger errors have accrued. Furthermore, ATC is not (and cannot be) expected to issue speed changes to address this difference as frequently as IM speeds are presented to the flight crew to address operational uncertainties, such as those resulting from winds or Lead Aircraft changes.

4.7 Inter-arrival Time and Inter-arrival Distance for IM and Non-IM flights

The following analysis compares the spacing accuracy at meter points for IM operations and aircraft not doing IM operations. MITRE Threaded Track data, gathered using the IOAA tool, was the data source for the analysis.

4.7.1 Analysis Methodology for Inter-arrival Time and Inter-arrival Distance for IM and Non-IM flights

Based on prior analysis and the results in Section 4.6, we expect IM aircraft pairs to achieve or maintain more consistent and less variant spacing intervals at meter points as compared to non-IM aircraft.

Primary Metrics used:

- **Inter-arrival Time (IAT) at a fix**. The IAT is defined as the difference in times between when the IM Aircraft crossed, and the Lead Aircraft crossed the fix.
- **Inter-arrival Distance (IAD) at a fix**. The inter-arrival distance is defined as the distance between IM Aircraft and the Lead Aircraft when the Lead Aircraft crosses the fix.

Analysis Details

The intended spacing interval for IM operations is the ASG, which is recorded and known for this analysis. However, the intended spacing for non-IM flights can differ based on demand or other factors and is not known. For this reason, the analysis was limited to the SLIDR and EAGUL fixes on the EAGUL arrival where it is commonplace to use 8 miles-in-trail (8 NM) to meter aircraft into the TRACON.

The steps used to perform these analyses are as follows:

1. Calculate the IAT and IAD at SLIDR and EAGUL for all arrivals sequencing those fixes.
2. Filter data to flights where inter-arrival spacing was less than 15 NM to limit the analysis to higher-demand periods.
3. Identify relevant IM flights for comparison to non-IM flights:
    a. All flights where IM is active near a fix (see step 4)
    b. Subset of flights where the CP or PCP was entered as SLIDR or EAGUL
4. Apply operating time qualification checks for IM flights:
    a. IM operation must start prior to crossing the fix (ACSS Start time earlier than Actual fix cross time)
    b. IM operation with a time-based ASG must end no sooner than one minute prior to crossing the fix (ACSS End time later than Actual fix cross time for time-based IM events)
        i. IM operation with a distance-based ASG must end no sooner than 3 minutes prior to crossing the fix (ACSS End time later than Actual fix cross time for distance-based IM events). For distance-based events when the flight crew has entered the PCP as SLIDR or EAGUL, the operation ends when the Lead Aircraft crosses the PCP. Therefore, IM operations that end further from crossing the fix are allowed.

The resulting metrics were grouped into sets and examined in a variety of ways including direct examination of the distributions and associated statistics (e.g., mean, median, mode, standard deviation) and statistical tests on the differences in the means and standard deviations.

The IM and non-IM aircraft may be subject to different spacing objectives. To compare the spacing variability for IM and non-IM flights, the maximum inter-arrival distance was reduced until the mean IATs of the IM and non-IM flights were the same (for time-based IM). For distance-based IM, a similar approach was used where the maximum inter-arrival distance was reduced until the mean inter-arrival spacing of the IM and non-IM flights was the same. With both sets having the same mean spacing intervals, we analyzed the difference in the standard deviations.

An example of the types of events used for this analysis is shown in Figure 28. This figure shows a busy push on SLIDR for arrivals in KPHX on September 7, 2023. The top image shows a string of non-IM Aircraft where the numbers are the initial inter-aircraft spacing values between each pair. The middle image shows the initial string of non-IM aircraft as their spacing decreases as they enter the KPHX TRACON. This middle image also shows a string of IM Aircraft and their initial inter-aircraft spacing values. The bottom image shows the string of IM Aircraft as their spacing values decrease as they enter KPHX TRACON. From this example, the IM Aircraft inter-aircraft spacings are more consistent than the non-IM Aircraft inter-aircraft spacings as they sequence the waypoint HOMRR.

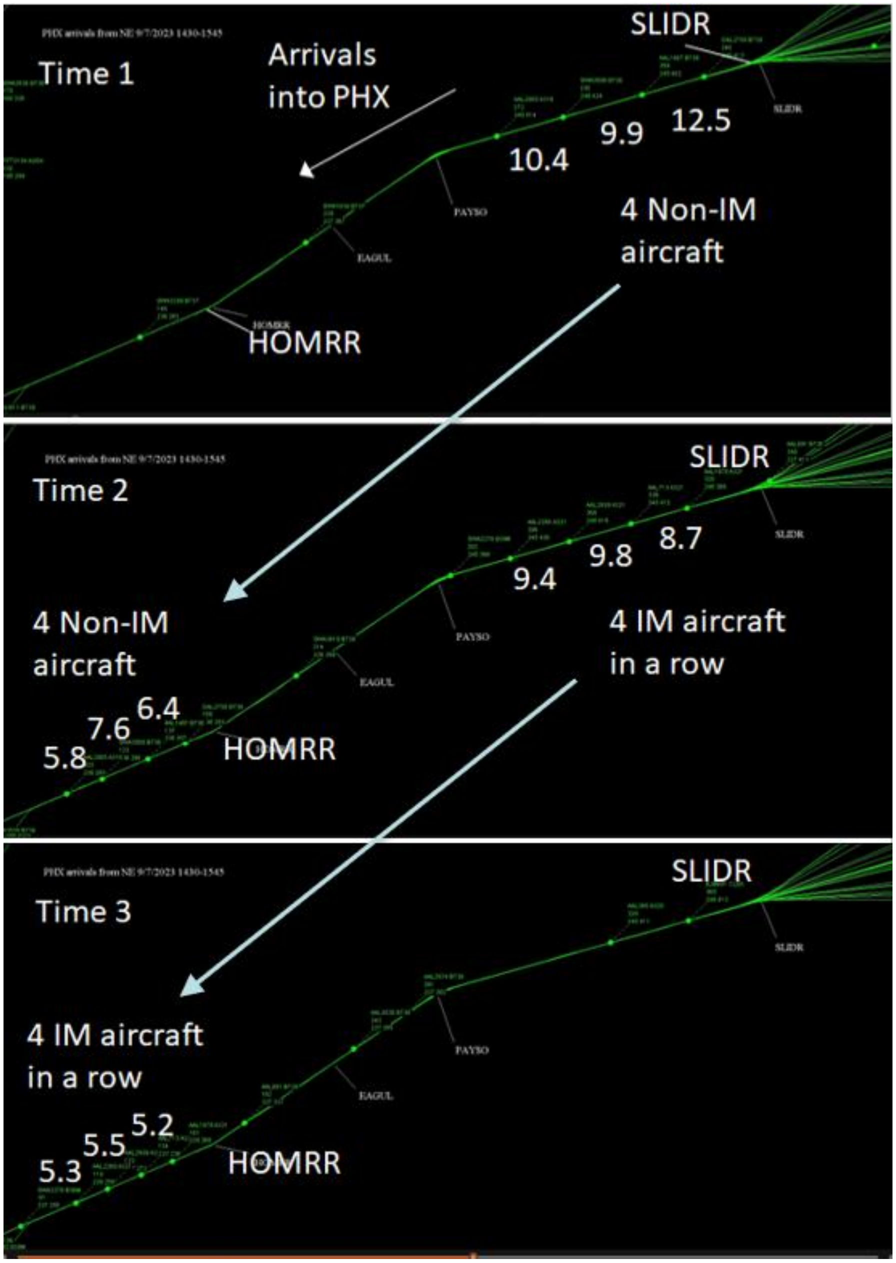


Figure 28 - Example of events used for analysis of Inter-arrival Time and Inter-arrival Spacing at SLIDR for IM and Non-IM Aircraft

Statistical results for IM and non-IM Aircraft spacings at SLIDR and EAGUL are presented in the next section.

4.7.2 Results for the Analysis for Inter-arrival Time and Inter-arrival Distance for IM and Non-IM flights

Figure 29 shows the IAT results for time-based IM and non-IM aircraft that crossed SLIDR. The data has been filtered for only those flights with inter-aircraft spacing values less than 15 NM to ensure the analysis is limited to high-demand periods, as described in Section 4.7.1. Table 25 contains a summary of the mean and standard deviation for the IAT. The first row – labeled as IM (time-based) – includes all aircraft that were executing an IM operation when they crossed SLIDR. The second row – labeled as IM (time-based) with CP or PCP at SLIDR – contains aircraft that were executing an IM operation that crossed SLIDR and entered SLIDR as the CP or PCP. The right two columns of Table 25 show the mean and standard deviation of the difference between the actual time spacing at SLIDR and the ASG.

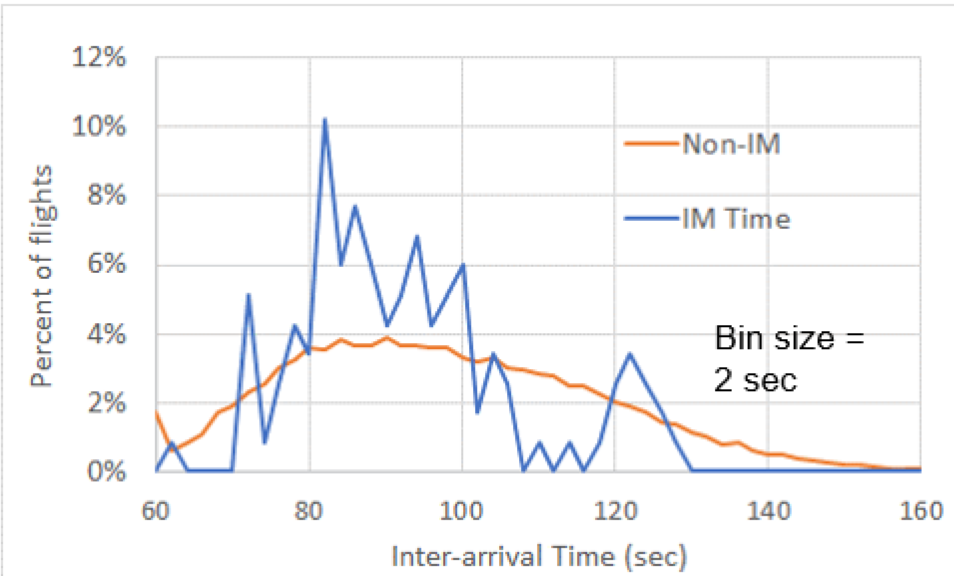


Figure 29 - IAT distributions for Time-Based IM and non-IM for flights crossing SLIDR

Table 25. IAT statistics for Time-Based IM and non-IM for flights crossing SLIDR

		Time Spacing (sec)		Actual Time Spacing – ASG (sec)	
Operation	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
IM (Time-based)	80	91	12	3	9
IM (Time-based) with CP or PCP at SLIDR	43	92	12	3	9
Non-IM	25209	97	21		

The time-based IM flights, in general, exhibit a smaller mean IAT and standard deviation of the IAT as compared to the non-IM flights. For the IM flights, the mean and standard deviation of the difference between actual and required time spacing is very small.

Figure 30 also shows the results for time-based IM and non-IM aircraft that crossed SLIDR. These results include a filter on the maximum inter-arrival distance until the mean IAT of the IM and non-IM flights was the same. Table 26 presents the mean and standard deviations for these events. The rows are defined as described previously.

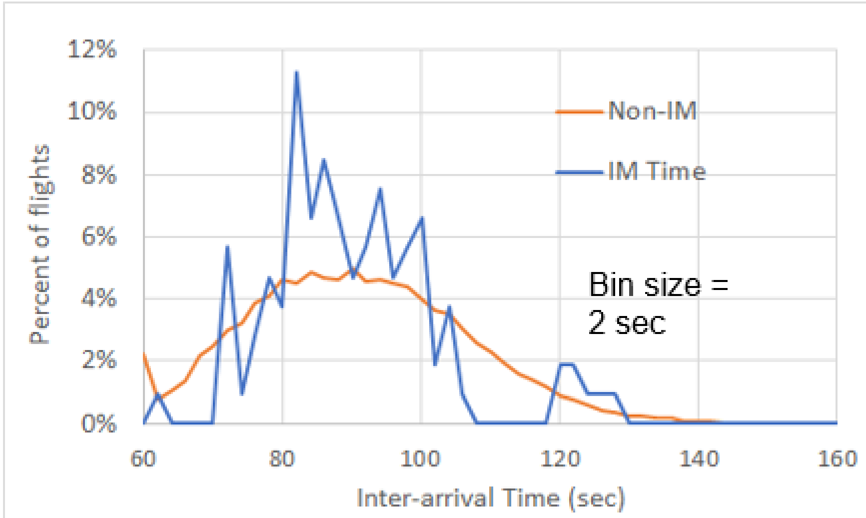


Figure 30 - Modified IAT distribution for Time-Based IM and non-IM for flights crossing SLIDR

Table 26. Modified IAT statistics on Time-Based IM and non-IM for flights crossing SLIDR

		Time Spacing (sec)		Actual Time Spacing – ASG (sec)	
Operation	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
IM (Time-based)	75	90	11	2	8
Non-IM	19694	90	17		
IM (Time-based) SLIDR	40	90	9	2	8
Non-IM	19694	90	17		

The results show that when controlling for the mean IAT, the IM aircraft still exhibit a smaller IAT standard deviation as compared to non-IM aircraft. These results show IM aircraft are more consistently delivered across fixes than without IM.

Figure 31 shows inter arrival distance (IAD) results from the distance-based IM and non-IM events across SLIDR that have been filtered for when spacing is less than 15 NM to ensure the analysis is limited to high-demand periods. Table 27 shows the means and standard deviations for the inter-arrival spacing values for these events.

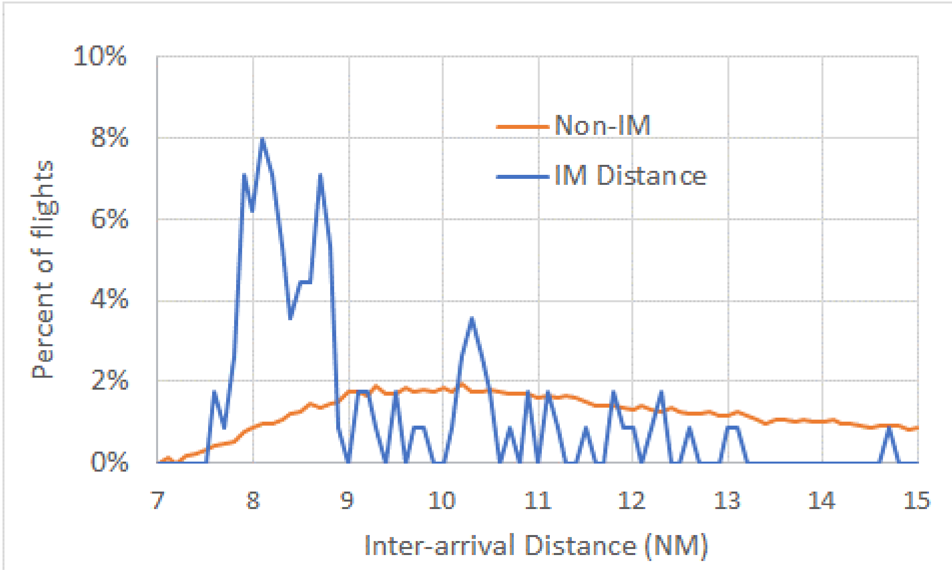


Figure 31 - IAD results for Distance-Based IM and non-IM for flights crossing SLIDR

Table 27. IAD statistics on Distance-Based IM and non-IM for flights crossing SLIDR

		Distance Spacing (NM)		Actual Distance Spacing – ASG (NM)	
Operation	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
IM (Distance-based)	109	9.1	1.5	0.5	1.3
IM (Distance-based) SLIDR	87	9.1	1.4	0.5	1.4
Non-IM	25209	10.9	2.2		

Like the IAT results for time-based IM operations, the IAD results for distance-based IM operations show smaller means and standard deviations for IM Aircraft as compared to Non-IM Aircraft.

The results in Figure 32 and Table 28 show the results when limiting the analysis to when IM and Non-IM Aircraft have the same mean inter-arrival spacing values. Again, the IM Aircraft exhibit a smaller standard deviation as compared to Non-IM Aircraft. Like the results for time-based IM operations, these results show IM flights are more consistently delivered across fixes than without IM.

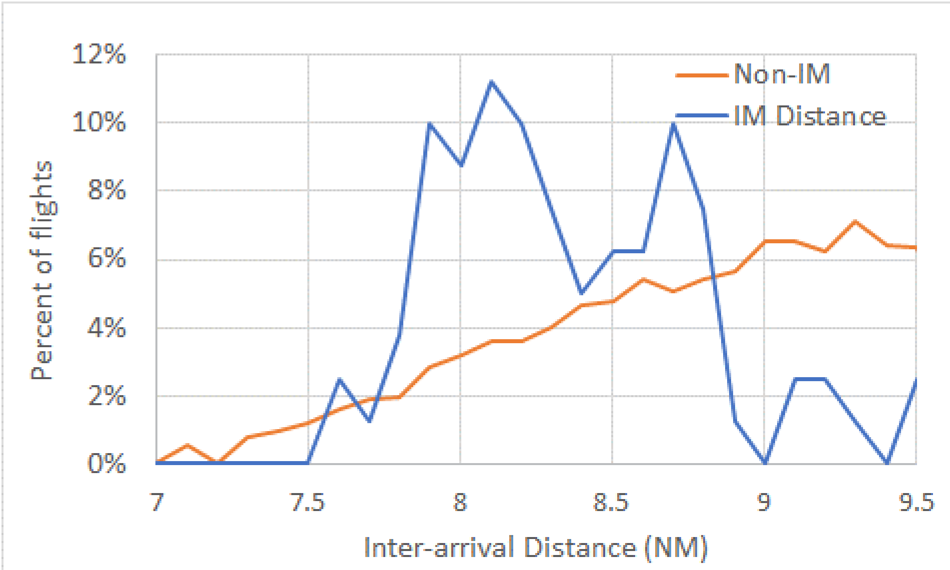


Figure 32 - Modified IAD results for Distance-Based IM and non-IM for flights crossing SLIDR

Table 28. Modified IAD statistics on Distance-Based IM and non-IM for flights crossing SLIDR

			Distance Spacing (NM)		Actual Distance Spacing – ASG (NM)	
Fix	**Operation**	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
SLIDR	IM (Distance-based)	76	8.3	0.4	0.3	0.4
	IM (Distance-based) SLIDR	60	8.3	0.4	0.3	0.4
	Non-IM	6527	8.3	1.3		

The prior analysis for flights crossing SLIDR was repeated for flights crossing EAGUL. One difference between SLIDR and EAGUL is that flight crews rarely entered EAGUL as a CP or PCP. EAGUL was only entered twice as the CP for Year 1 operations designated as events (i.e., operation was greater than 5 minutes and there was a feedback form or transcript match). Therefore, the results were not separated, as done previously.

Figure 33 and Table 29 present IAT results for EAGUL (for time-based IM operations); Figure 34 and Table 30 present the results when comparing standard deviations given the same mean IAT values for IM Aircraft and non-IM Aircraft.

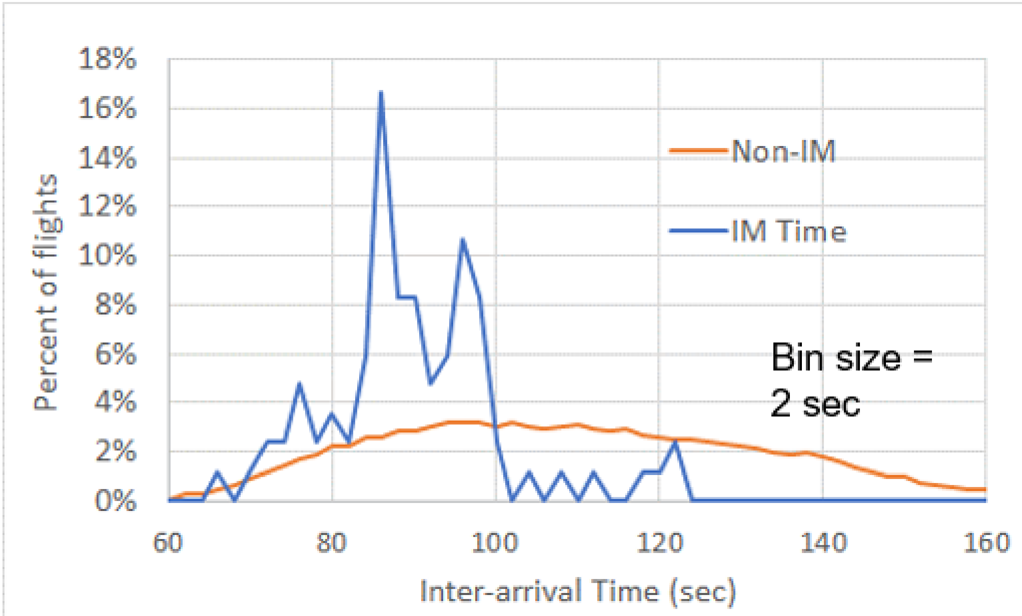


Figure 33 - IAT distributions for Time-Based IM and non-IM for flights crossing EAGUL

Table 29. IAT statistics on Time-Based IM and non-IM for flights crossing EAGUL

			Time Spacing (sec)		Actual Time Spacing – ASG (sec)	
Fix	**Operation**	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
EAGUL	IM (Time-based)	84	89	11	0	6
	Non-IM	28871	109	26		

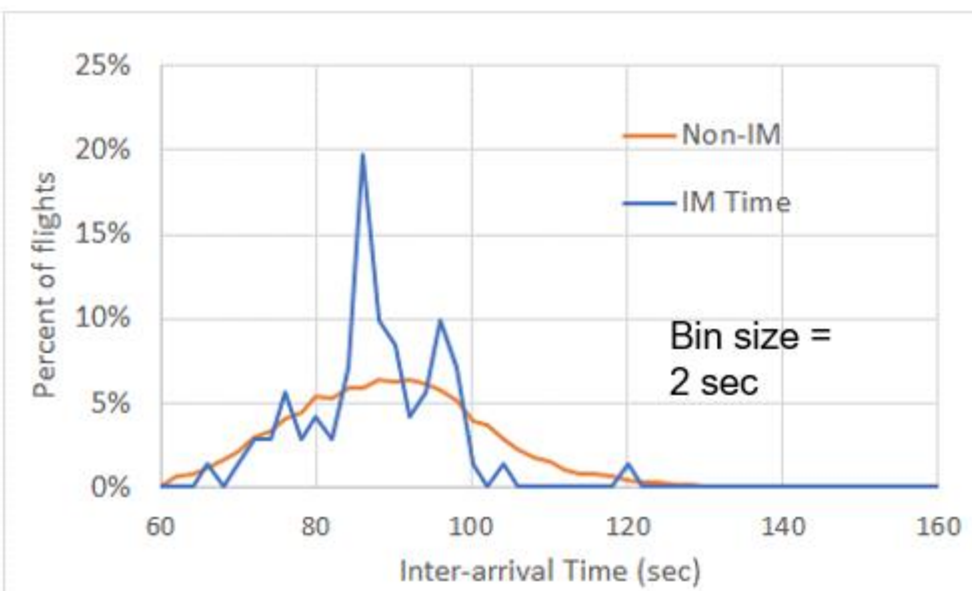


Figure 34 - Modified IAT distributions for Time-Based IM and non-IM for flights crossing EAGUL

Table 30. Modified IAT statistics on Time-Based IM and non-IM for flights crossing EAGUL

			Time Spacing (sec)		Actual Time Spacing – ASG (sec)	
Fix	**Operation**	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
EAGUL	IM (Time-based)	71	87	9	0	6
	Non-IM	12172	87	17		

Figure 35 and Table 31 present inter-arrival spacing results for EAGUL (for distance-based IM operations); Figure 36 and Table 32 present the results comparing standard deviations given the same mean inter-arrival spacing values for IM Aircraft and non-IM Aircraft.

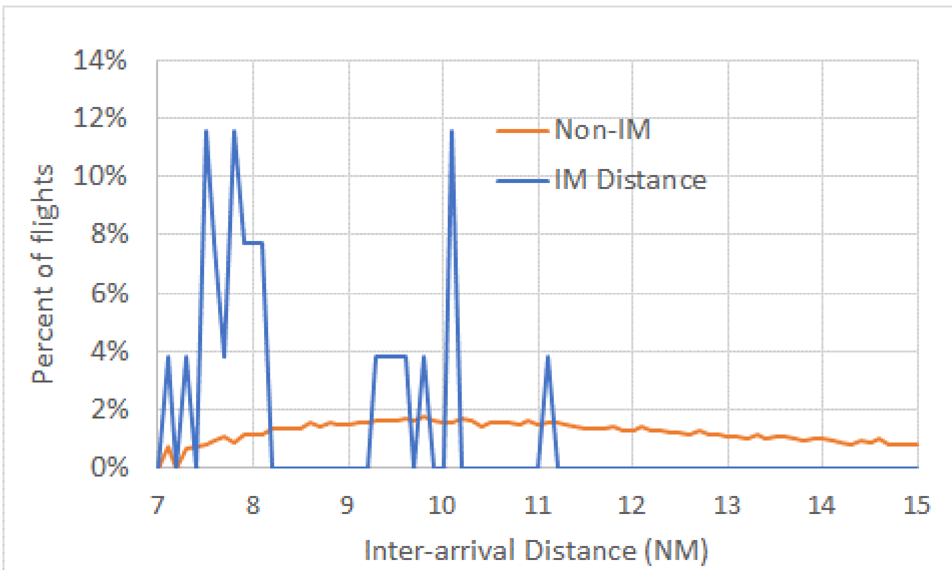


Figure 35 - IAD distributions for Distance-Based IM and non-IM for flights crossing EAGUL

Table 31. Modified IAD statistics on Distance-Based IM and non-IM for flights crossing EAGUL

			Distance Spacing (NM)		Actual Distance Spacing – ASG (NM)	
Fix	**Operation**	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
EAGUL	IM (Distance-based)	26	8.4	1.1	0.1	1.0
	Non-IM	28871	10.6	2.4		

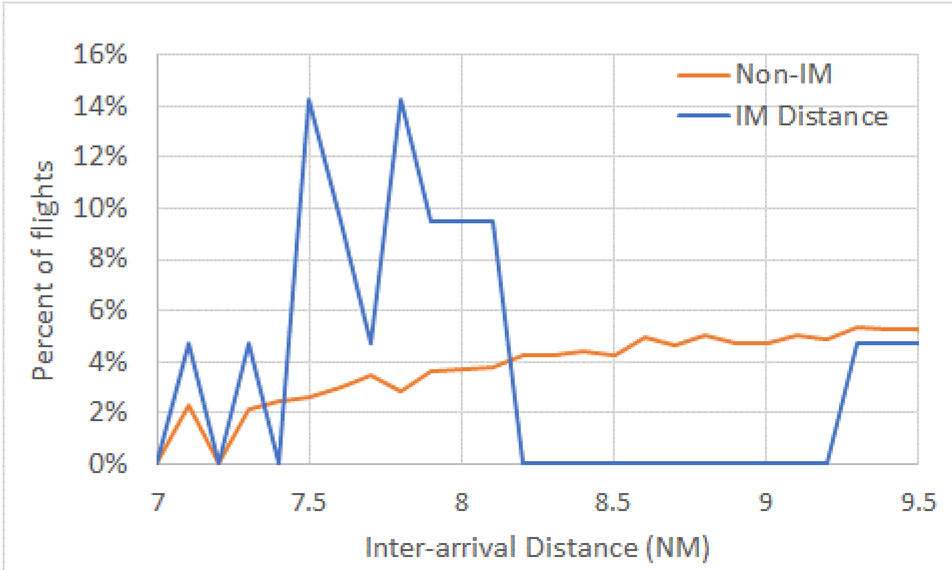


Figure 36 - Modified IAD for Distance-Based IM and non-IM for flights crossing EAGUL

Table 32. Modified IAD statistics on Distance-Based IM and non-IM for flights crossing EAGUL

			Distance Spacing (NM)		Distance Spacing – ASG (NM)	
Fix	**Operation**	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
EAGUL	IM (Distance-based)	21	8.0	0.7	-0.2	0.6
	Non-IM	9950	8.0	1.4		

The results at EAGUL show similar trends to those at SLIDR. In each case, the mean and standard deviation of the IAT and inter-arrival spacing are smaller for IM Aircraft compared to non-IM Aircraft. When the data is modified to limit the analysis to when the IM Aircraft and non-IM Aircraft have the same mean spacing value, the standard deviations for the IM Aircraft are always less than the standard deviations for the non-IM Aircraft. This shows IM operations can provide more consistent spacing values along the arrival path and more consistent flows.

4.8 CP and PCP Issues

The data entry page on the MCDU for a spacing operation includes a field where the flight crew can enter a PCP if a PCP is included in the spacing clearance. Controllers did not routinely issue PCPs during the operational evaluation. There were times when IM operations ended earlier than expected. The AIRS team investigated if flight crews entering a PCP was impacting operations. When analyzing the ACSS traffic computer data to determine the number of relevant operations for analysis (as described in Section 4.1), we also analyzed the number of events when a flight crew entered a PCP. Additionally, we analyzed the number of events when a flight crew entered the ATC-issued CP as both the CP and PCP.

Table 33 shows the number of events with PCPs entered in the IM application and the number of events with PCPs that are the same as the CPs by IM clearance type (the "Operation" column).

Table 33. Number of events that have a PCP and the CP is the same as the PCP

IM Clearance Type	Total	PCP count	PCP same as CP
Cross	101	32	32
Cross-Maintain	260	29	28
Maintain	176	44	0
Total	**537**	**105**	**60**

Table 34 shows the same data from Table 33 by month.

Table 34. A month-by-month comparison of the number of events that have a PCP and the CP is the same as the PCP

By Month	Total	PCP	PCP same as CP
11/2022	152	23	13
12/2022	9	0	0
01/2023	7	0	0
02/2023	23	1	1
03/2023	67	15	9
04/2023	74	25	16
05/2023	10	2	2
06/2023	20	2	0
07/2023	68	18	8
08/2023	47	5	3
09/2023	51	10	8
10/2023	9	4	0
Total	**537**	**105**	**60**

This led to evaluating the SafeRoute+ display and whether it created confusion on where the flight crews needed to enter the CP. During the operational evaluation, flight crews were reminded through memos on where to enter IM clearance information.

4.9 Current Spacing and Speed Compliance Issues

Based on the speed compliance analysis (see Section 4.5) and feedback from pilots and controllers, we analyzed whether flight crews were using the Current Spacing displayed on the AGD and their own discretion to determine speed instead of following displayed IM speed.

Table 35 compares the mean (median) number of commanded speeds from the IM application versus the mean (median) number of pilot selected speeds.

Table 35. Mean (Median) of commanded speeds versus Mean (Median) of pilot-selected speeds

Type of IM Operation	Number of IM Operations Analyzed	Mean (Median) of Command Speeds	Mean (Median) of Pilot-Selected Speeds
Maintain	176	5.0 (4)	6.3 (5)
Cross	101	2.3 (2)	4.3 (3)
Cross-Maintain	260	4.7 (4)	6.7 (5)
Combined	537	4.3 (3)	6.1 (5)

The disparity shown in Table 35 shows flight crews are not always following the commanded speeds. Through further investigation, it was determined that flight crews may be using their own discretion on speeds and the current spacing information on the AGD to meet the ASG instead of the commanded speeds. This is discussed in detail in section 4.11.

Some pilots provided feedback that the IM operations were too workload intensive (see Section 4.12). The frequency of commanded speeds was analyzed versus pilot-selected speeds by IM operation. Figure 37 shows the distribution of commanded speeds (blue bars) skews further to the left than the selected-speed distribution (orange bars), suggesting a lower number of commanded speeds per operation than selected speeds.

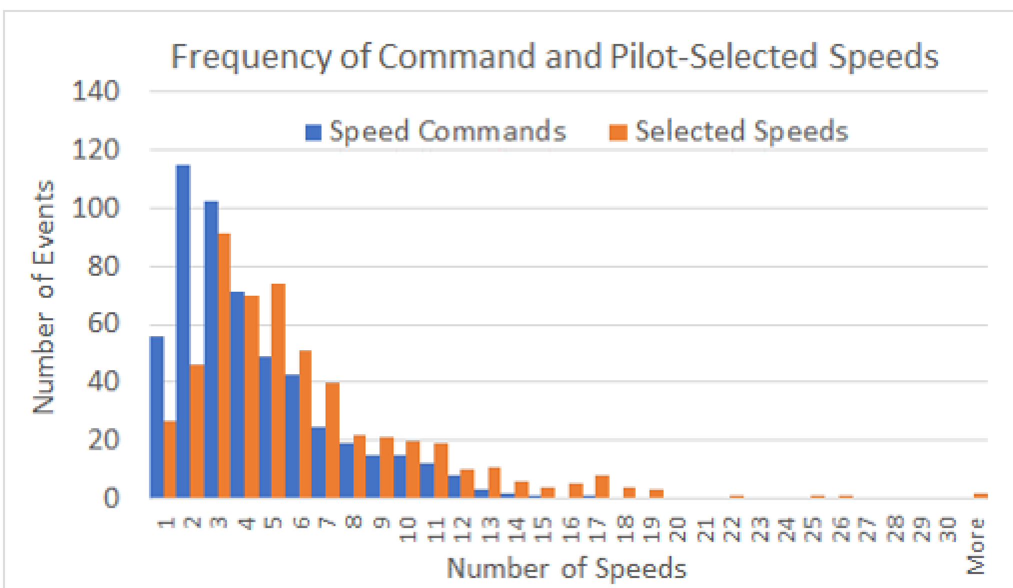


Figure 37 - Frequency of command or pilot-selected speeds

Figure 38 shows the duration of the IM operation and the number of commanded speeds versus pilot-selected speeds. Again, this seems to suggest that the flight crews may not be following the commanded speeds but trying to use their own discretion to meet the ASG. The traffic computer data event analysis, in Section 4.12, also showed several IM operations where the pilot-selected speed deviated from the commanded speed.

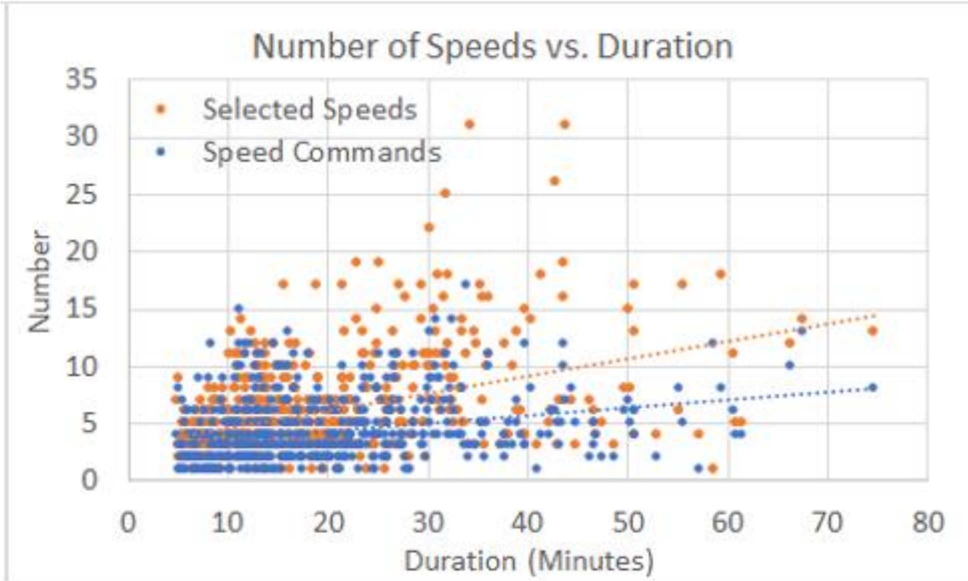


Figure 38 - Number of speeds (pilot selected or commanded) versus Duration

4.10 Controller Feedback

4.10.1 ZAB SME Feedback

Controller feedback forms were used to collect information on IM operations conducted by ZAB controllers (see Figure 15). These forms were used to record which aircraft were part of the operation, in which sector the operation was initiated, the type of clearance (Cross or Maintain) and the ASG. The data from these forms were correlated with the ACSS traffic computer data. The data were used to confirm the IM avionics inputs being made by pilots and were used to capture timely feedback on the operations.

These forms also included a section where controllers could provide subjective feedback on their observations during the operation. This information was reviewed by ZAB SMEs and discussed by the AIRS team members during weekly telecons and monthly meetings. Additionally, during monthly meetings, ZAB SMEs were asked to provide feedback on IM operations. This information was often used to determine what, if any, changes needed to be made to the operational evaluation. Some of the key findings are discussed below.

ZAB SMEs noted that, in general, ZAB controllers could be grouped into the following categories:

- **Enthusiastic** – They could see the potential of how IM operations could help the NAS and they conducted IM operations when possible.
- **Neutral** – They were happy to do the operation if SMEs pointed out feasible IM aircraft pairs and provided necessary coordination.

- **Negative** – They did not see the benefit of IM for their operation.

ZAB SMEs noted that many ZAB controllers had a neutral opinion of IM. ZAB SMEs reported these controllers stated they would be more inclined to use IM if the information needed to conduct IM operations was displayed on their ERAM displays. Even those who expressed a negative view of IM suggested they would be more apt to use IM if the information they needed to conduct IM was provided on their displays.

Some of the information controllers stated would be needed included:

- Indication of which aircraft can conduct IM
- Identification and display of IM aircraft pairs
- Determination of an ASG determined from the TBFM schedule
- Display of ASG on ERAM screen
- Coordination across sectors

The floor walkers provided a good workaround for the lack of automation, but without the floor walkers or automation upgrades, they stated the operational benefit did not outweigh the effort to use IM.

Controllers pointed out that it was difficult to use IM when dealing with significant weather in the area. Significant weather disrupts all operations and prevents the use of PBN procedures. If controllers had to vector traffic for weather, they would cancel IM and revert to traditional ATC techniques.

There were other factors that, at times, impacted controller acceptance of IM. Early in the evaluation, some pilots were hesitant to accept IM clearances. Some reasons for this reluctance included a lack of familiarity with the operation, confusion over the use of the SafeRoute+ system, and the time between when they were trained and when the operational evaluation began. Flight crew reluctance to accept clearances meant controllers could not always count on flight crews accepting clearances. This meant that controllers had to be prepared to offer non-IM clearances. Other times flight crew lack of familiarity resulted in controllers spending extra time guiding flight crew through the operation (including instructing flight crews on how to enter the IM clearance into MCDU), which controllers were willing to do when they had time. This resulted in extra time for controllers to issue IM clearances. Both situations would sometimes lead to a reluctance to offer an IM clearance.

Over the course of the year, AAL provided additional briefings and information to flight crews that added clarity. Proficiency also improved as more pilots received IM clearances and gained experience. As a result, the need for controllers to guide flight crews decreased. It was noted that while controllers may see a few IM opportunities a day, flight crews could go months before receiving an IM clearance. This resulted in a longer learning curve for the flights crews than for the ZAB ATC personnel.

Another concern expressed was the lack of opportunities to use IM operations. Even though AAL had equipped over 300 aircraft with the SafeRoute+ system, most aircraft in the airspace were not equipped to perform IM operations. There were times when there were pairs of aircraft that would benefit from IM, but the equipped aircraft was in front of the unequipped aircraft. In other cases, the sequence was appropriate, but the aircraft were spaced so far apart that IM was not needed.

Phraseology was another topic discussed often throughout the first year of data collection. Pilot and controller use of non-standard phraseology slowed down the issuance of clearances and made them less likely to be issued. The use of non-standard phraseology was reduced as controllers and pilots became more familiar with IM operations.

Initially, as described in Section 2.8, only one communication was required to initiate an IM clearance. A typical Cross clearance would be phrased as follows: “American one two three, cross SLIDR at and eight miles behind Southwest two three four five”. Halfway into the first year of the operational evaluation, it was noted this single clearance would sometimes catch flight crews off guard; particularly if they were dealing with other situations in the cockpit.

After discussions with APA Safety Representatives and controller SMEs during team meetings, it was decided that alerting flight crews that an IM clearance was coming would improve the operation. Controllers were instructed to inform flight crews “Expect spacing clearance, advise when ready to copy”. Once the flight crew acknowledged they were ready to copy, the clearance was given. This reduced the “startle factor” discussed in Section 4.11.

Toward the end of the first year of the operational evaluation, ZAB SMEs recommended an additional modification to the initial phraseology. After discussions with the AIRS team, controllers instructed the IM aircraft to first designate the traffic they were to follow. Once designated, controllers would provide the rest of the IM clearance. A typical IM Cross clearance would then be given as follows:

- Controller: “American one two three, designate Southwest two three four five”
- Pilot: “American one two three has Southwest two three four five designated”
- Controller: “American one two three cross SLIDR at and maintain eight miles behind designated traffic”

This approach improved the flow of the operations by further reducing the “startle factor” and confusion about the clearance. This approach has the additional benefit of mimicking the phraseology used in the AIRS CAS-A operational evaluation being conducted in partnership with the Dallas TRACON (D10) since both involve A321 flight crews.

As noted in Section 4.1, the first year of the operational evaluation was broken into phases. The primary reason for phase 2 was to overcome some of the hurdles described in this section. Floor walkers improved controller understanding by helping them recognize opportunities to use IM operations, which led to greater acceptance of IM. The use of floor walkers and focusing primarily on Cross clearances and areas where Cross clearances occurred, resulted in more consistent, successful IM operations and increased controller proficiency and acceptance of IM.

4.10.2 Directed Discussions

In addition to controller feedback collected through discussions with ZAB Subject Matter Experts, controller feedback was also obtained by ZAB SMEs through informal discussions ("directed discussions") with line controllers during team briefings. These discussions were conducted approximately nine months into the start of operations. By that time, most controllers were familiar with IM, and many had issued several IM clearances. These discussions occurred in the five different areas that comprise ZAB airspace: Southwest, Southeast, Northwest, North and East. Copies of the feedback from those discussions are contained in Appendix 9.2.

Below is a summary of key results from the directed discussions.

- Overall impression of IM
    - When the pilots are proficient with the SafeRoute+ system, the operation works well.
    - Most controllers have had a positive experience with IM operations.
    - Several controllers stated they had experienced no issues with IM.
    - AIRS operations have been primarily prompted by floor walkers (ZAB SMEs).
    - Controllers were not aware of controllers issuing clearances without floorwalker support.
    - Some controllers indicated they are still required to monitor, which means the workload would not truly decrease (i.e., they are not sure what the benefit is to the controller).
    - Other controllers stated that it does not seem like more work than what they normally do with KPHX sequencing.
    - AIRS is out of sight, out of mind, until a floorwalker asks for it (this was stated several times).

- Additional automation requests
    - Additional automation would encourage utilizing AIRS on a regular basis and reduce the need for floorwalkers.
    - Fourth line coordination is sometimes inadequate when dealing with multiple clearances or altitude stratums[5].
    - There needs to be a more efficient method of nonverbal coordination.
    - Some type of AIRS reminder directly on data block is needed.
    - The extra work that goes into the operation does not result in any added efficiency. Perhaps once Controller-Pilot Data Link Communications (CPDLC) is up and running, and AIRS clearances can be issued via a quick keyboard command, it would negate the negative cost-benefit.

[5] Stratums are differences in altitude that are large enough to be in different sectors/areas that are stratified by altitude.

- Controllers have experienced difficult or unsuccessful operations due to some of the following reasons:
    - Pilots reporting the SafeRoute+ system is giving them a "bad geometry" message.
    - Pilots have reported unacceptable speed commands.
    - Receiving an unable response by the pilot due to workload.
    - Receiving an unable response by the pilot due to lack of training.
    - Pilots unexpectedly speeding up and slowing down several times.
    - The pilots need better equipment that is easier to use. It seems like pilot error is the only reason it does not work.
    - Pilots do not always use the correct phraseology

- Suggestions for follow-on modifications to the operational evaluation
    - Controllers felt they would have more opportunity to use IM if it was available going into Fort Worth ARTCC (ZFW) rather than being forced to terminate at the ZAB boundary
    - Controllers requested a more focused effort that was airport specific. This will help controllers look for more opportunities to use it without prompting by floor walkers
    - Focus on terminal phase of flight
- Controllers wished they had more opportunities to utilize it (i.e., low number of equipped aircraft in their sector)
- Many stated that during bad weather, it is not a practical solution due to deviating aircraft.

4.11 Flight Crew Feedback

4.11.1 APA Interviews

Members of the APA National Air Traffic and Procedures Safety Team conducted numerous voluntary phone interviews with pilots who had received IM clearances from ZAB controllers. The purpose of these interviews was to gather subjective feedback from flight crews regarding their overall experience with the IM operation; phraseology; avionics interface; speed commands and the number of speed changes encountered.

The interviews were particularly focused on operations highlighted by ZAB controllers for additional study. Some operations were highlighted because they were particularly successful, and others were highlighted to help the AIRS team understand a concern or issue that had been raised.

The results of these interviews were briefed to and discussed with the entire AIRS project team during monthly, in-person meetings. These discussions, in combination with reviews of the Falcon replay videos, allowed the team to fully analyze the IM operations and lessons that could be learned from the events. The interviews provided valuable information that resulted in improvements and enhancements to pilot training, avionics interface, phraseology, and the overall IM operation.

It was noted by AIRS team members that it was particularly effective to have controllers, pilots, avionics manufacturers and concept SMEs all participating in these discussions and sharing their individual points of view. Not only did the collaboration result in a greater understanding of the operations but it also enabled the representatives to communicate back to their organizations regarding some of the lessons learned, ways to improve operations and the perspectives of the other organizations. Transparency and collaboration were the keys to this success.

For example, early in the operational evaluation, there was some confusion with the phraseology being used and how it was being interpreted by pilots and controllers. The analysis and discussions resulted in effective changes to the phraseology used for the rest of the operational evaluation.

Throughout the first year of obtaining flight crew feedback, there were several consistent, repeated themes were noted and discussed. A summary of those themes is documented below.

- **Startle Factor**
    - Numerous pilots were initially surprised and somewhat unprepared when they received their first IM clearance.
    - Comments included "I read the material a couple of months ago and sort of forgot about it," and "Since we aren't exposed to it daily, you're not thinking about it."
    - It was noted that this diminished significantly over the course of the operation evaluation as flight crews received additional clearances.

- **Stare Factor**
    - Some pilots report that it takes both pilots to monitor the AGD for speed commands and spacing accuracy.
    - Attention spent on the AGD increases workload and distracts from other duties.
    - The APA interviewers were able to point out this was a new piece of avionics and is not yet in every pilot's basic scan. Additionally, they were told there was no need to stare at the display and respond instantaneously to commanded speed changes.
    - As the flight crews became more familiar with the display, reports of the stare factor decreased significantly.

- **Automation**
    - Pilots would prefer the Commanded Speed be implemented via the Flight Management System of the aircraft instead of manually adjusting the speed.
    - Flight crews were informed this capability is not currently available but was included in the list of recommendations in Section 5.

- **Bad Geometry Message on the AGD**
    - Some crews have been confused with the interface; particularly when inserting the crossing point into the system (also noted in Section 4.3). Section 5.3 provides a detailed explanation of the problem and the proposed resolution.
    - The "Bad Geometry" message leads pilots to believe there is a problem with the system.

- AAL provided additional training material during the evaluation to address this problem.

- **Compliance with Assigned Spacing Goal**
  - The display of the ASG and Current Spacing on the AGD contributed to confusion for the pilots.
  - A high percentage of pilots believed they were responsible for achieving the ASG and would manipulate the aircraft's speed to expeditiously achieve the spacing goal.
  - This often resulted in increased workload for the pilots as it required numerous speed changes.
  - The company issued several communications to clarify that the only responsibility the pilot had was to comply with the Commanded Speed on the AGD or advise ATC if the speed could not be flown.
  - Over the course of several months, understanding and compliance improved dramatically.

- **Characteristics of Successful Operations**
  - Recent review of the training material
  - Familiarization with the SafeRoute+ avionics
  - Use of the pilot Quick Reference Guide
  - Appropriate behavior from avionics
    - Minimal speed commands
    - No excessive speed changes
  - Anticipated the IM clearance and pulled up Quick Reference Guide and reviewed prior to receiving the clearance
  - Experimenting with the system the entire flight and already had an aircraft designated

- **Characteristics of Unsuccessful Operations**
  - Have not recently reviewed the training material
  - Desire for simulator training
  - Lack of training tools that provide "button pushing"
  - Attempting to manually meet the ASG
  - Avionics interface confusion
  - Entering the CP incorrectly

Many pilots commented they found the IM operation to be straight forward, easy, and intuitive. They found the quick reference guide to be particularly effective and helpful. While pilots found the operation to be intuitive, they did comment they thought there would be more automation involved. The initial setup in the MCDU for IM was challenging for some pilots, but most found the actual operation to be easily manageable once established.

Many pilots initially commented about their concerns and perceptions with IM training. It was not feasible to install the system in the Airbus flight simulators. Training was limited to bulletins, videos, and iPad-based Distance Learning modules, as well as briefing from instructors and check airmen. Several pilots voiced their concerns with this approach. Many noted pilots "learn by doing" and not just reading about the system. As a result of this comment and other similar comments, an interactive training device was proposed and discussed in Section 5.

Another frequent observation was pilot confusion with the display on the AGD where both the ASG and the current spacing were displayed during a Crossing operation (see Figure 39). Pilots reported concerns that the current spacing does not always match the ASG. For a Crossing operation, prior to reaching the CP, the current spacing value is the current value of the spacing the aircraft would have at the CP if there were no speed changes made by the flight crew. Current spacing information was provided to flight crews for informational purposes only. This information was never intended to be used as guidance information or something that the pilots needed to match with the ASG.

Figure 39 - ADS-B In Guidance Display

APA and American took steps to clarify how the assigned spacing is achieved by the avionics and the pilots' responsibility is to set the aircraft's speed to match the current commanded speed. Human factors played a role in this error, as pilots are conditioned to expeditiously comply with ATC instructions. When assigned a spacing goal, most pilots expected the avionics to achieve the spacing sooner than what was being observed. This resulted in the manipulation of speeds to try and achieve the spacing goal in less time. This action usually resulted in a higher workload than necessary due to multiple self-induced speed changes. This was confirmed by examining traffic computer data shown and discussed in section 4.12.

Through AIRS Project Team discussions on this topic, it was determined displaying the Assigned and Current spacing values on the AGD was not needed or beneficial. As a result, a new pilot interface has been proposed (see Section 5.3).

Some pilots reported that the AGD would display frequent and/or excessive numbers of speed commands. At times the commanded speeds would change dramatically (e.g., jump from Mach .72 to Mach .76). Other times the AGD would display several speed changes over a short period of time. Some of these effects were caused by the previously described tendency for pilots to manipulate aircraft speeds to achieve the ASG rather than following the commanded speeds. On a few occasions, the cause of the behavior was caused by assumptions within the algorithm. These cases are discussed in Section 4.12.

Many pilots reported several benefits with the CDTI as part of their flight deck technology. The primary advantage is increased Situational Awareness. The CDTI brings this element to flight crews which has increased the level of safety in both the terminal and en route environments.

Pilots have noted they are more aware of what is going on with the traffic around them and feel they are more in sync with the Air Traffic Controller. This occurs in both the terminal and en route airspace. By having the flight identification of other traffic, they are more aware of what frequency changes are coming and the next instructions they can expect to receive from the controller. This can help to prevent read-back hear-back errors and missed or repeated frequency changes.

Pilots have avoided areas of turbulence when they can pinpoint a specific flight or aircraft that has reported a turbulence encounter and locates them on their navigation display. They can also call aircraft directly to ask specific flight-related questions.

As the flight crews gain experience with IM operations, some have observed the benefit of less vectoring and speed assignments from controllers. This has reduced their workload and gives them more predictability during their arrival into KPHX.

Many pilots have been vocal that they would like to see the CDTI in all aircraft and do not want it to go away.

4.11.2 LOSA Observations

In addition to flight crew feedback collected through APA interviews, AAL's LOSA Program captured flight crew feedback by conducting targeted observations of A321 flights where IM clearances could potentially have been issued. Since this was being conducted as part of the continuous LOSA program, flight crews were unaware that observers were observing IM operations in addition to the other data LOSA observers were collecting.

AIRS focused LOSA observations began in March of 2023. During the first nine months of the targeted LOSA activity, several challenges became apparent. The first was finding CDTI equipped A321s. In March 2023, few AAL A321s were equipped with the SafeRoute+ system. This challenge became less of an issue as over the course of 2023 the A321 fleet was fully fitted.

The next challenge was finding flights that would operate on EAGUL and PINNG STARs into KPHX (where most of the IM operations were being performed). Once that was solved with the help of AAL dispatch, it became apparent that not any flight would do. Only a certain number of flights would work as there was also a requirement to have traffic close enough on the STAR that would allow an IM clearance to be issued.

During 2023, 12 LOSA observations were successfully conducted for IM clearances. Even with the limited number of observations, the LOSA data proved valuable as it gave the AIRS Project team members the “pilot’s perspective” of what is seen from the flight deck during IM operations. The LOSA data helped identify the necessity for improved crew training as well as flight crew interface improvements that were needed. It also drove improvements in communications and phraseology.

Similar to feedback received during the APA interviews, LOSA observed flight crew interaction discussing why the SafeRoute+ system commands speeds that seem counterintuitive to either the ASG or an upcoming published STAR speed restriction. Flight crews did not understand why the system would still command a slower speed when the distance or time is larger than what is required. Crews would also question the system when they observed the Lead Aircraft slowing down for a published STAR speed restriction, while the IM system still commanded a faster speed than published when the distance or time requirement was met.

The observed data also helped the FAA and air traffic controllers who participate in issuing clearances understand what does and does not work during IM operations. Overall, the lessons learned will contribute to establishing more efficient IM operations.

4.12 Traffic Computer Data Event Analysis

As previously noted, ACSS developed a process to obtain SafeRoute+ data from the IM aircraft using CF cards placed in the traffic computer (see Figure 14). American Airlines maintenance retrieved the flash cards from the SafeRoute+ system periodically and then transmitted the data recorded on the CF cards to ACSS. This data was then processed by ACSS and made available for post-event analyses.

This data provided insight into how the pilots used the SafeRoute+ system, what information was being displayed to the pilots, and how the algorithm was performing. The AIRS team used this data, along with the other data sources previously mentioned, to obtain in-depth understanding of specific IM operations. Initially this data was used to investigate operations that had been flagged for further study through the other data sources. Later in the year, an automated process was developed to allow the team to review all IM operations.

This data provided an increased understanding of how the algorithm was performing given a variety of initiation conditions (e.g., the initial spacing, the relative altitudes between the Lead and IM Aircraft) and wind conditions. While the algorithm was thoroughly tested and certified prior to the start of the operational evaluation, analyzing the algorithm performance given different environmental conditions and IM aircraft pair geometries, provided insight into the algorithm robustness and any potential modifications that developers might consider exploring.

Figure 40 through Figure 44 are examples of the type of analyses the team was able to examine for each operation. The results in these figures are for a Cross operation with the waypoint ZUN as the CP (denoted as Achieve By Point (ABP) in the ACSS data). The ASG assigned by the controller was 80 seconds and no Planned Cancellation Point (denoted as Planned Termination Point (PTP) in the ACSS data) was issued.

Figure 40 shows the lateral path of the operation. The Lead Aircraft is denoted by the red line and the IM Aircraft is denoted by the blue line. When both aircraft are on the same path, only the red line is visible. The black line shows the IM Aircraft's lateral path after the IM operation has ended (i.e., the IM application is no longer executing in the SafeRoute+ system). KPHX is indicated by the black star in the lower left and the operation ended as the aircraft entered KPHX's airspace.

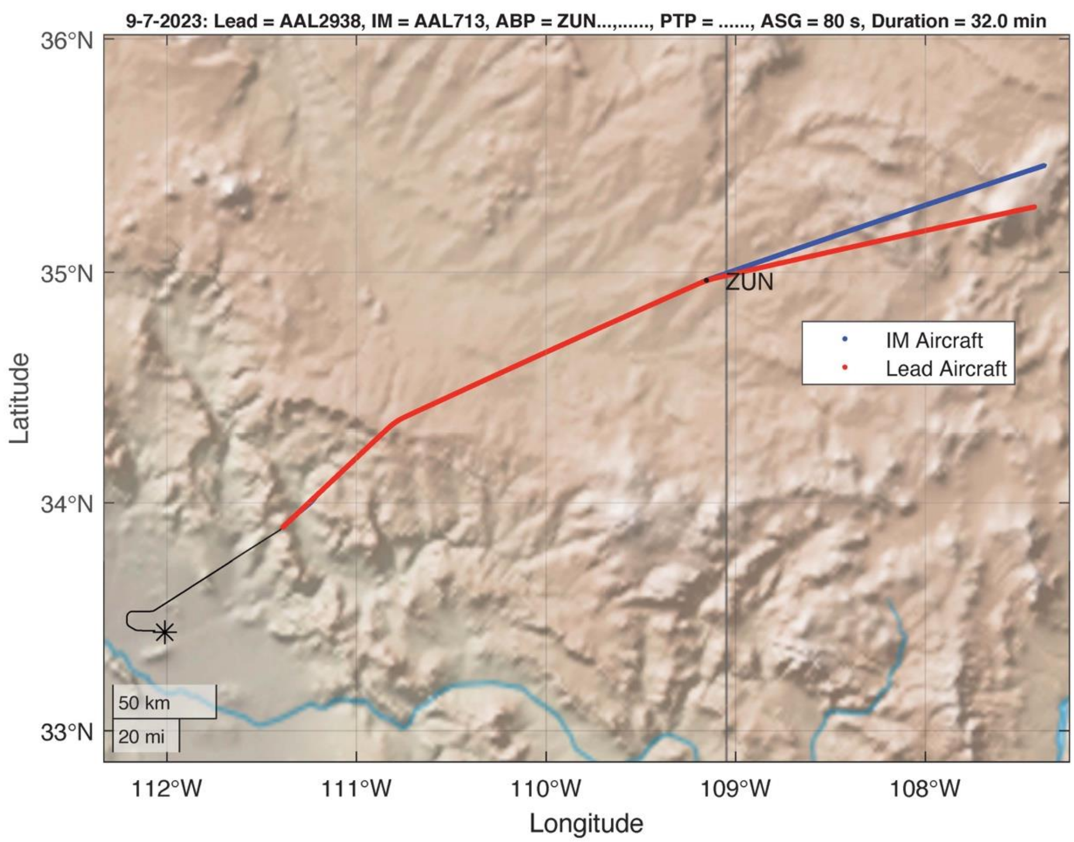


Figure 40 - Lateral Path

This data allowed the team to evaluate cases when the SafeRoute+ system displayed "bad geometry," and the IM operation could not be executed. For example, there were some instances when the Lead Aircraft was further from the CP than the IM Aircraft but due to a faster ground speed would get to the CP before the IM aircraft. This geometry is not allowed in the current algorithm. There were other cases when the aircraft were not within the required tolerance of 3 NM to be considered on the same route for a Maintain IM clearance.

Figure 41 contains plots of the vertical profiles and ground speeds of each aircraft along with the wind speeds and directions experienced by the IM aircraft. For this example, both aircraft started out at 34,000 feet (the Lead Aircraft descended to 34,000 feet shortly after the IM operation started). The Lead Aircraft began its descent about 19 minutes into the IM operation, and the IM Aircraft began its descent about 3 minutes later (both aircraft started their descent in approximately the same geographic location). Both aircraft had similar ground speeds during the operation (including similar decelerations in the descent portion of the flight). The data also show the windspeed was relatively constant until the IM Aircraft was in the descent phase of flight.

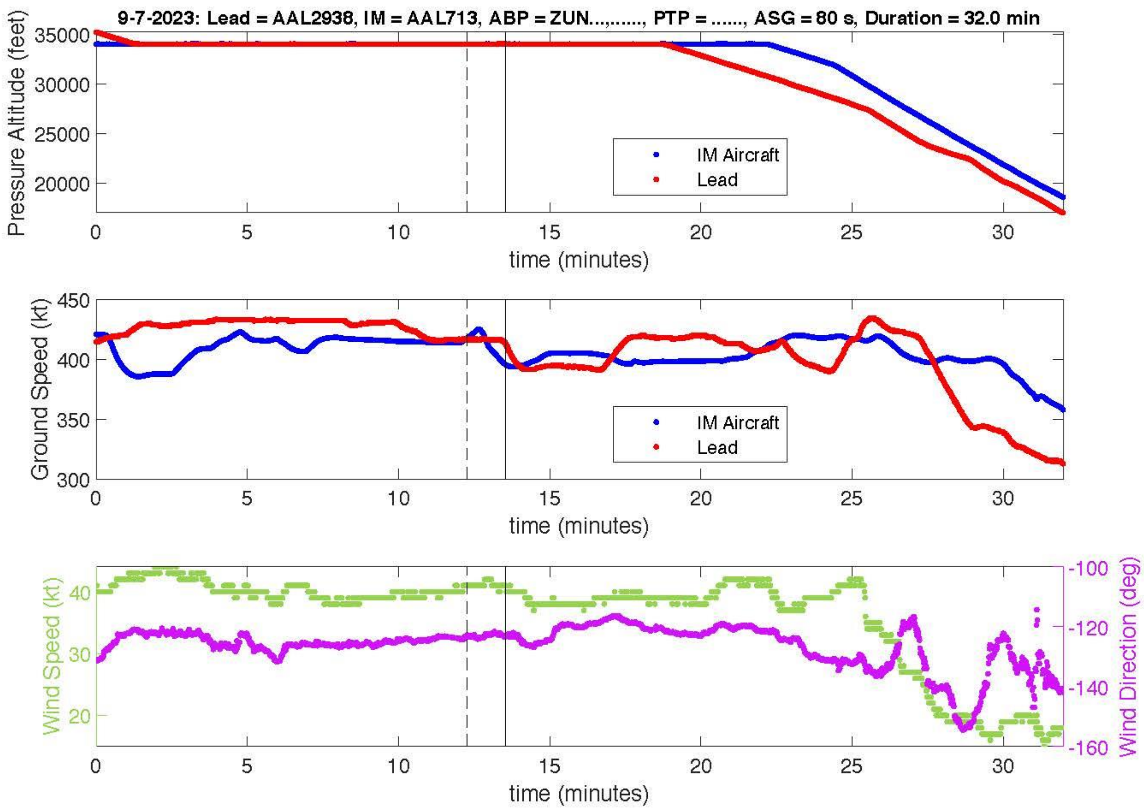


Figure 41 - Vertical profile, ground speed and wind information

Over the year of the operational evaluation, this information proved to be valuable in understanding some of the characteristics of the SafeRoute+ algorithm. For example, there were some operations conducted where the IM aircraft was at a significantly different altitude than the Lead Aircraft. In one case, there was a difference of 10,000 feet. In many cases, this was not an issue but occasionally the wind field could vary significantly between the two altitudes. As aircraft descended and experienced different wind fields, there could be significant differences in ground speed causing large IM speed changes.

The IM algorithm in the SafeRoute+ system was intentionally designed so that it would not respond too quickly to sudden changes in groundspeed. This was incorporated to minimize sudden commanded speed changes and to ensure the system was not too sensitive to temporary atmospheric changes. Most of the time this design approach provided predictable, smooth speed changes. However, on a few occasions with significant differences in wind fields and corresponding ground speed changes, the IM algorithm appeared to slightly delay commanded speed changes. This never resulted in an operational issue, but it was noticed by flight crews and controllers. It is something to be considered in recommended changes (see Section 5).

Additionally, the SafeRoute+ algorithm has no information on the Lead Aircraft's airspeed (Mach or CAS) and must estimate this value. For this conversion, the algorithm assumes both aircraft are flying in air of the same temperature. When the temperature difference is significant, this can lead to an erroneous estimate of the Lead Aircraft's airspeed that would result in a commanded speed that was either too low or too high. Reviewing the vertical profile, ground speed, and wind information, as depicted in Figure 41, were helpful for understanding these cases.

When executing a Maintain clearance, the SafeRoute+ algorithm provides speed guidance designed to achieve the ASG within 5 minutes from the start of the operation. For a Cross clearance, the algorithm provides speed guidance that attempts to achieve the ASG by the time the IM aircraft reaches the CP and then maintains that spacing until the operation is cancelled. The algorithm will adjust the IM Speed as soon as the spacing error (i.e., the difference in the current spacing and ASG) exceeds 5 seconds and attempts to keep the spacing error within +/-10 seconds of the ASG.

For a Maintain clearance, the spacing error is the difference between the current spacing and the ASG. For example, if the current spacing between the Lead Aircraft and the IM aircraft is 105 seconds and the ASG is 90 seconds, the spacing error would be 15 seconds. For a Cross clearance, prior to reaching the CP, the spacing error is the difference in the IM and Lead Aircraft ETAs at the CP and the ASG.

Figure 42 contains plots of the calculated spacing error during the example operation and the ground speeds of each aircraft. The vertical dashed line in Figure 42 is the time when the Lead Aircraft crossed the CP, the solid vertical line is when the IM aircraft crossed the CP, and the solid horizontal line is the value of the ASG. The spacing error is significant at the beginning of the operation but quickly falls within the +/- 10 second tolerance. At the point where the IM Aircraft reaches the CP, the spacing error appears to be around 3 seconds (well within the allowed tolerance).

Generally, once the ASG is achieved, it is maintained within +/- 10 seconds of the ASG after that point. However, in this case, around the 18-minute mark, there appears to be some oscillation around the ASG. At that point the Lead Aircraft experiences a rapid, noticeable increase in speed followed by a decline followed by another significant increase and then finally a steady decrease. One potential explanation for the spacing error oscillation is the delay built into the algorithm. The algorithm will not provide new speed commands until the spacing error exceeds 5 seconds or it has been at least 15 seconds since the last commanded speeds. This logic results in fewer speed changes but can allow the spacing error to grow.

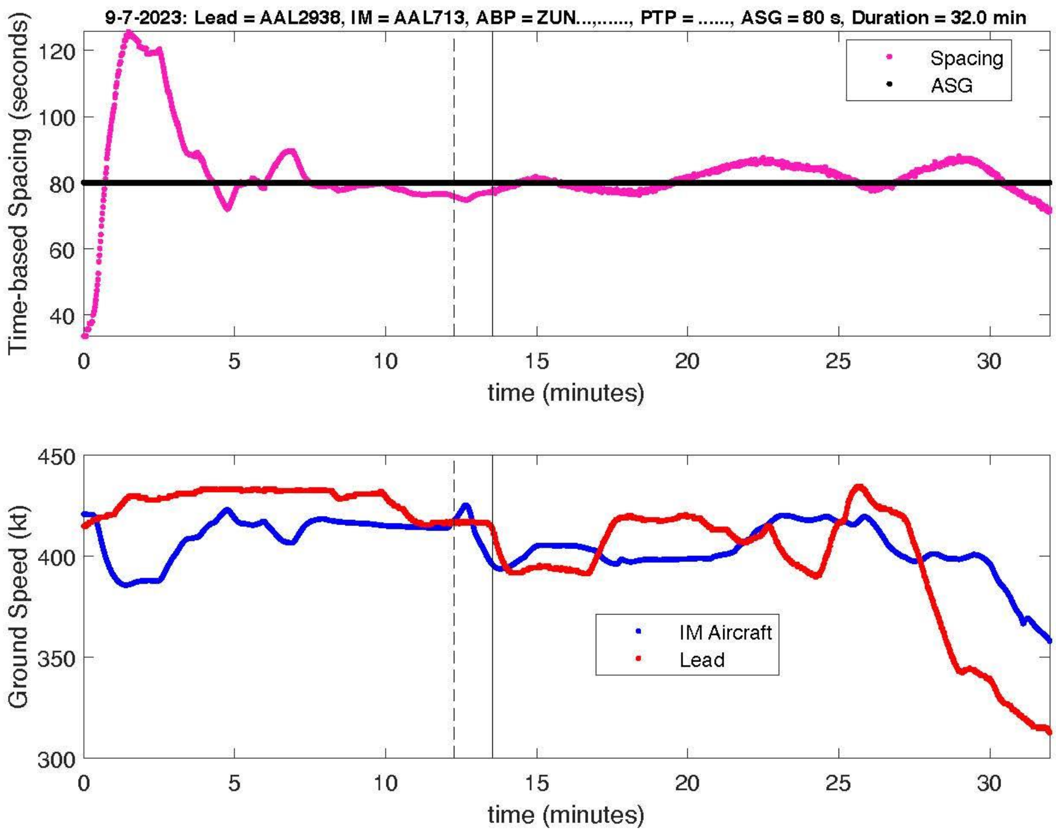


Figure 42 - Spacing Error, Ground Speed

In this case, it appears the spacing error oscillations were caused or exacerbated by the flight crew. Figure 43 shows a plot of the speeds and feasibility check that were part of the operation. The top plot shows the IM aircraft's Mach number (blue), the SafeRoute+ commanded Mach (red), and the flight crew-selected Mach (yellow). The middle plot shows the IM aircraft's CAS (blue), the commanded speed (red), the selected speed (yellow), and the unfiltered CAS command (purple). The Mach and CAS are shown as a function of the execution time. The speeds are only shown when the IM application was operating in that mode. For example, the IM application was in Mach from the start of execution until 22 minutes into the operation. At that time, the IM application switched to CAS. In this case, the transition from Mach to CAS was triggered by descending through the Mach/CAS transition altitude. The bottom plot shows the feasibility check results (blue) and the selected speed validity (solid red for CAS and dashed red for Mach).

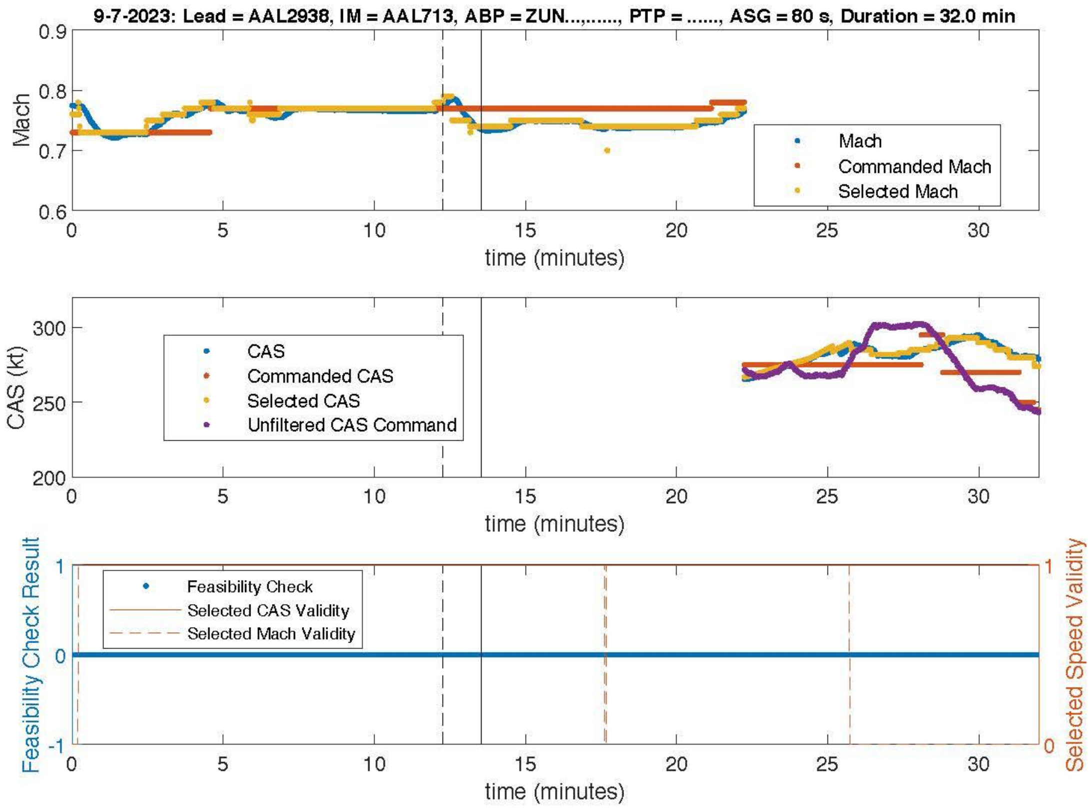


Figure 43 - Speeds and Feasibility Check

As shown in Figure 39, the AGD displays the commanded speed (CMD SPD), the ASG (ASSIGNED) and the current spacing (CURRENT). When in the Maintain mode, the current spacing is the current spacing that exists between the Lead Aircraft and the IM aircraft. When in the Crossing mode, the current spacing is the spacing that would exist between the two aircraft when they will arrive at the CP if nothing changes with the aircraft speeds. It is not the current spacing between the two aircraft at that time (both aircraft must be on a common route to calculate spacing).

The top plot of Figure 43 highlights a case when the flight crew selected different speeds than the commanded speeds (shown by the difference in the red and yellow lines). The commanded speed and selected speed were the same for the first few minutes of the operation. Approximately three minutes into the IM operation, the flight crew dialed in five different speeds over a 2 to 3-minute period. The flight crew left the speed constant until the Lead Aircraft reached the waypoint at ZUN and started to slow down. The flight crew then made four speed changes over one minute to slow down. They gradually increased the speed to the commanded speed (possibly due to the speed up of the Lead Aircraft). Once the IM application switched to displaying speeds in CAS, they were changing speeds frequently. It is likely the flight crew saw the effects of the changes in the Lead Aircraft's ground speed and were trying to manage the spacing manually to meet the ASG. As previously noted, the corresponding oscillation in the spacing error can be seen in Figure 42. While the commanded speed only changed six times over the entire operation (approximately 32 minutes), the flight crew ended up entering over 30 different speed changes.

Figure 44 is a display of the IM Aircraft's speed (Mach in the top plot and CAS in the middle plot), the commanded speed, and the Lead Aircraft's speed (Mach and CAS) as estimated by the IM application. Also shown in Figure 44, as indicated by the dark black lines, is a calculated limit for the IM speed. IM speeds are limited by these values. This limit was developed to approximate the DO-361 requirement to limit speeds to within 15% of the IM Aircraft's airspeed profile[6] and is based on the Lead Aircraft's estimated CAS.

The AIRS team tracked the impact of the limit, and it appears this situation occurred a few times during the operational evaluation. ACSS is recommending a possible change to the IM speed limit calculation (see Section 5).

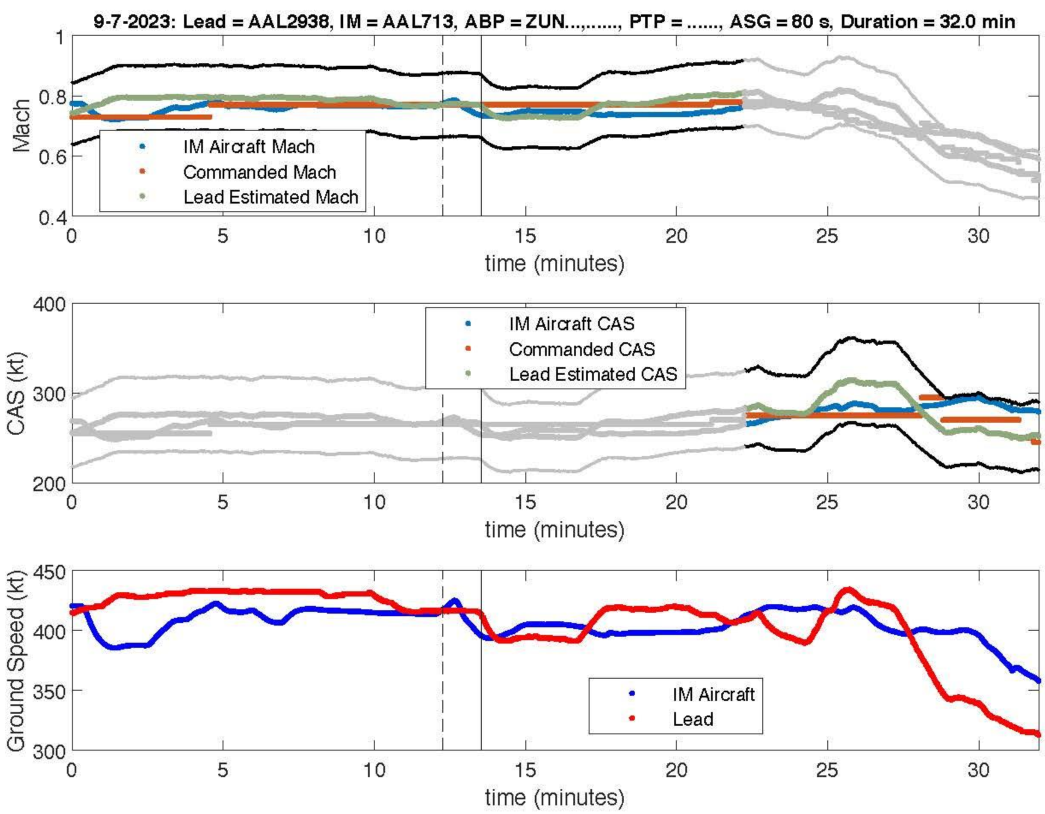


Figure 44 - Speed Limits and Ground Speeds

5 Recommendations

During the operational evaluation, issues and concerns were uncovered. These issues were often resolved operationally or were fixed through SafeRoute+ equipment changes. Some require more significant changes beyond the scope of this operational evaluation. Additionally, during investigations of the operations, a few ideas were proposed that could be pursued in the future to

[6] DO-361A reduced the speed limits to 10% of the IM Aircraft's airspeed profile, which is the IM Aircraft's nominal airspeed profile over the operation and is based on its airspeed at initiation and the navigation procedure.

improve IM operations. The following subsections document recommendations that were noted during the first year of the operational evaluation.

5.1 Controller Recommended Changes to Support IM Operations

Controllers suggested IM operations would be significantly improved, and controllers would be more inclined to use IM, if the information they needed to conduct IM was presented on ERAM displays. The floor walkers provided a workaround for the lack of automation but without the floor walkers or automation upgrades, it was believed the benefits of IM would not be realized.

Controllers recommended the following information be provided on their displays for supporting the initiation and execution of IM operations:

- Indication of aircraft capable of conducting IM
- Identification and display of IM aircraft pairs
- Determination of an ASG based on the TBFM schedule
- Display of the ASG
- Methods to coordinate IM operations across sectors
- Methods to coordinate IM operations across facility boundaries

Controllers also suggested the use of datalink would improve the issuance of IM clearances, particularly for Cross clearances. If datalink is not a near term option, another suggestion would be to create one, straight forward clearance that would support both Maintain and Cross clearances.

Additionally, controllers stated they would like to see more aircraft equipped with IM systems. It was pointed out that the number of IM operations were limited since only AAL A321s were equipped.

5.2 Flight Crew Recommended Changes to Support IM Operations

Flight crews frequently stated training materials should be improved. Specifically, pilots requested hands-on, interactive training. One proposed solution is to require IM simulator training. Another suggestion was to develop an interactive, individual training module that could be installed on a tablet.

AAL leveraged an L3Harris computer-based training application that is used as a training aid on the American fleet types and coordinated with ACSS to develop a CDTI training module. This tablet-hosted training module was deployed during the second year of the AIRS operational evaluation and data is being collected on the effectiveness of the training module.

5.3 Recommended SafeRoute+ Pilot Interface Changes to Support IM Operations

The AIRS team recommended the removal of current spacing information on the AGD (value under "CURRENT" in Figure 39). Many pilots misunderstood the definition of this information, found this information compelling and rather than following the commanded speed presented on the AGD, they tried to manage the spacing manually. Removal of the current spacing information should reduce the likelihood of pilots from selecting different speeds than the commanded speeds.

Data collected during the first year of the operational evaluation indicated that many flight crews had difficulty using the MCDU interface to correctly enter required information for Cross operations. This situation often occurred for two reasons: the default state of the equipment and confusion over how to enter the CP.

The default page for entering data supports Maintain clearances (see Figure 45). To get to the page for entering the Cross clearance, flight crews would have to select the button adjacent to the arrow by the word CROSS (line select key L2). The arrow proved to be difficult to see and the word CROSS is much larger and more compelling. Without entering information on the CROSS page, the SafeRoute+ system left the system in the default state of a Maintain operation. Unless both aircraft were on the same route to the CP, the aircraft relative positions would not be acceptable for a same route, Maintain clearance. As a result, pilots would receive a “BAD GEOMETRY” message and not conduct an IM operation. This proved to be frustrating to pilots and controllers.

Figure 45 - Default MCDU IM spacing page

Additionally, flight crews noticed that there was a place to enter a value under CROSS using line select key L3. Many pilots interpreted this to mean they should enter the Cross Point in this location. Unfortunately, line select key L3 is for entering the Planned Cancellation Point (PCP) (called termination point in this version of the display software). Pilots thought they were entering the CP for the operation when instead they were entering the PCP.

The AIRS project team recommended the MCDU interface be redesigned to avoid these confusions. By the end of the first year of the operational evaluation, ACSS had already developed, but not implemented, an alternative MCDU interface shown in Figure 46.

For this design, the Cross operation is chosen as the default operation and the interface defaults to the appropriate page for entering information to support a Cross operation. Next to line select key R1, there is an indication clarifying which page the pilot is on highlighted in blue. For the display on the left “CROSS” is highlighted in blue. To enter information for a Maintain clearance, the flight crew must push line selection key R1. The word “MAINT” is highlighted in blue, and the pilot can enter information that would support a Maintain operation. Also note that “TERM PT” has been replaced with the updated term “CANCEL PT”. We expect this new interface will be deployed during the second year of the AIRS operational evaluation and data will be collected on the effectiveness of interface change.

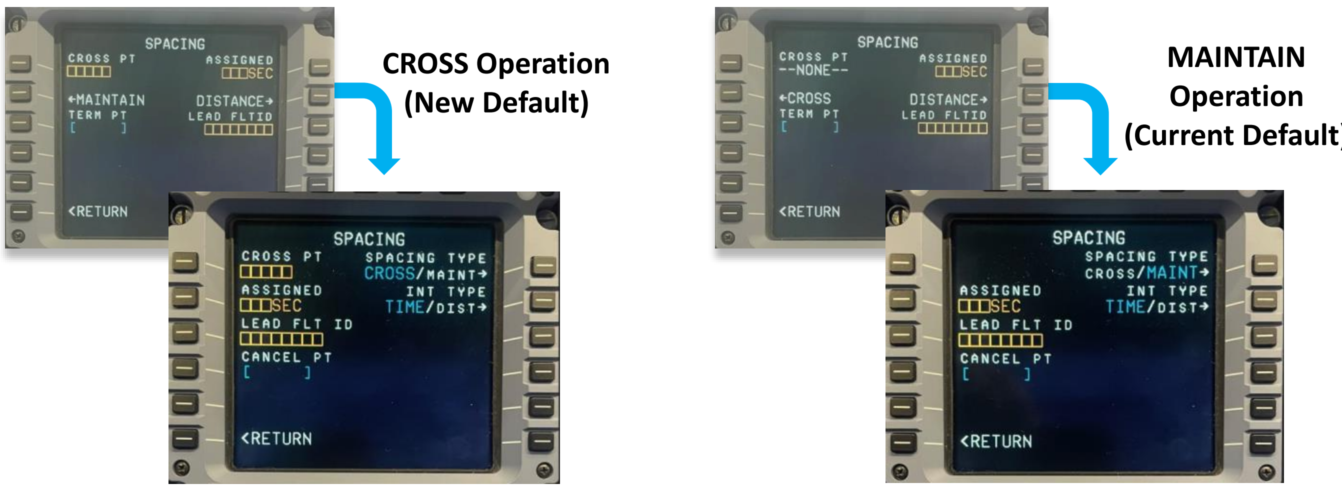


Figure 46 - Proposed MCDU interface

6 Summary

The first year of the AIRS Initial-Interval Management (I-IM) operational benefits evaluation was conducted in partnership with the Albuquerque Air Route Traffic Control Center (ZAB), Federal Aviation Administration (FAA) headquarters organizations, American Airlines (AAL), and Aviation Communication & Surveillance Systems, LLC (ACSS). Other partners on the project include representatives from the National Air Traffic Controllers Association (NATCA) and the Allied Pilots Association (APA). Operations began in November 2022, and data collection for the first year was completed in November 2023.

American Airlines conducted a retrofit of their entire Airbus A321 fleet, consisting of A321ceo (current engine option) and A321neo (new engine option) aircraft, with the commercially available SafeRoute+ ADS-B In avionics suite. In total, 298 aircraft were equipped, of which 218 were A321ceos and 80 were A321neos.

The primary goal of the AIRS operational evaluation was to demonstrate the operational feasibility and value of ADS-B In capabilities using a more cost-effective approach for airlines to implement ADS-B In applications via a retrofit solution.

Data was collected and analyzed from several sources as a part of the operational evaluation. FAA data sources included trajectory data; Instrument Flight Procedures (IFP), Operations, and

Airspace Analytics (IOAA); Aviation System Performance Metrics (ASPM); Voice Transcript Data, and TBFM Data. Other data sources included SafeRoute+ traffic computer data, ZAB controller feedback forms and observations, and AAL/APA flight crew feedback and observations.

During the first year of the operational evaluation, a total of 581 IM operations were attempted resulting in 533 completed IM operations. Of the 533 completed IM operations, 376 were categorized as successful and 157 were categorized by controllers as unsuccessful by controllers resulting in a success rate of 71. Operations were considered unsuccessful if the operation exhibited a concern or issue that was tracked by the project. Examples of issues and concerns included phraseology problems, flight crews deviating from the commanded speeds, and avionics issues. These concerns and issues were tracked and studied throughout the year. Some of these issues and concerns resulted in procedural changes (e.g., phraseology modifications) and others led to recommendations for future changes to procedures and the SafeRoute+ system.

Analyses of IM distance-based operations data indicate that at a Crossing point (CP), the difference between the measured distance and the distanced-based Assigned Spacing Goal (ASG) is an average of 0.2 NM with 95% of the flights within 1 NM of the mean. Similarly, analyses of IM time-based operations data indicate that at a CP, the difference between the observed time and the time-based spacing goal is an average of four seconds with 95% of the flights being within 24 seconds of the mean.

Analyses were conducted to compare the accuracy of the aircraft conducting IM spacing at meter points versus the accuracy of the spacing of those aircraft that were not doing IM operations. Aircraft conducting time-based IM operations demonstrated a smaller mean inter-arrival time (IAT) and standard deviation of the interarrival distance as compared to the non-IM flights. Similar to the IAT results for time-based IM, interarrival distance analyses demonstrate that distance-based IM spacing operations achieve a smaller mean and standard deviation for IM flights as compared to non-IM flights.

Discussions with ZAB subject matter experts and ZAB line controllers indicated that most controllers found that when there were no previously mentioned issues with the operation, the IM operation worked very well, and controllers could see the potential benefits of IM. However, controllers indicated they would be more inclined to use IM if the information they needed to conduct IM was displayed on their ERAM displays.

Initially during the first year of the operational evaluation, some flight crews took a while to become familiar with the SafeRoute+ system and IM operation. However, as flight crews became more familiar with the operation, they found IM to be straight forward, easy, and intuitive. They found the quick reference guide to be particularly effective and helpful. While pilots found the operation to be intuitive, they did comment that they thought there would be more automation involved.

During the operational evaluation, issues and concerns were uncovered. These issues were often resolved operationally or were fixed through SafeRoute+ equipment changes. Some improvements would require more significant changes that were beyond the scope of the first year of the operational evaluation. A list of these potential improvements is included in this report.

7 Acronyms

ACSS	Aviation Communication & Surveillance Systems
AAL	American Airlines
APA	Allied Pilots Association
ADS-B	Automatic Dependent Surveillance - Broadcast
AGD	ADS-B Guidance Display
AIRS	ADS-B In Retrofit Spacing
AJR-G	FAA Performance Analysis Group
ARTCC	Air Route Traffic Control Center
ASDE-X	Airport Surface Detection Equipment Version X
ASG	Assigned Spacing Goal
ASPM	Aviation System Performance Metrics
ATC	Air Traffic Control
CAS	Calibrated Airspeed
CAS-A	CDTI Assisted Separation on Approach
CAVS	CDTI Assisted Visual Separation
CBT	Computer-Based Training
CDTI	Cockpit Display of Traffic Information
CEO	Current Engine Option
CF	Compact Flash
CP	Cross Point
CSP	Constraint Satisfaction Point
D10	Dallas-Fort Worth TRACON
ERAM	En Route Automation Modernization
ESIS	Enhanced Status Information System (ESIS)
FAA	Federal Aviation Administration
GIM-S	Ground-based Interval Management - Spacing
GUI	Graphical User Interface
ICAO	International Civil Aviation Organization
IFP	Instrument Flight Procedures
IOAA	IFP, Operations, and Airspace Analytics
IAT	Inter-arrival Time
I-IM	Initial-Interval Management
IMC	Instrument Meteorological Conditions
IM	Interval Management
KDFW	Dallas-Fort Worth International Airport
KLAS	Harry Reid International Airport (Las Vegas)
KSAN	San Diego International Airport
MCDU	Multi-Function Control and Display Unit
MFX	Meter Fix
MOPS	Minimum Operational Performance Standards
MRP	Meter Reference Point
ND	Navigation Display
TDP	Transportation Data Platform
NEO	New Engine Option

NOP	National Offload Program
P50	Phoenix TRACON
PF	Pilot Flying
PCP	Planned Cancellation Point
PDARS	Performance Data Analysis and Reporting System
PM	Pilot Monitoring
RNAV	Area Navigation
RTCA	Radio Technical Commission for Aeronautics
SBS	Surveillance Broadcast Services
SME	Subject Matter Expert
SRM	Safety Risk Management
STA	Scheduled Time of Arrival
STARS	Standard Terminal Automation Replacement System
SWIM	System Wide Information Management
TBFM	Time-Based Flow Management
TBM	Time-Based Metering
TCAS	Traffic Alert and Collision Avoidance System
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
TTF	Traffic to Follow
TTL	Test & Training Laboratory
VMC	Visual Meteorological Conditions
WJHTC	William J. Hughes Technical Center
XM	Extended Metering
ZAB	Albuquerque ARTCC

8 Reference Documents

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[3] RTCA (2020). *Safety, performance, and interoperability requirements document for Airborne Spacing – Flight Deck Interval Management (ASPA-FIM) (DO-328B).* Washington, DC: RTCA

[4] RTCA (2020). *Minimum Operational Performance Standards (MOPS) for Flight-Deck Interval Management (FIM) Change 1(DO-361A Change 1).* Washington, DC: RTCA

[5] D. Howell, R. Dean and G. Paull, "Benefits and Costs of ADS-B In Efficiency Applications in US Airspace," in *USA/Europe Air Traffic Management Research and Development Seminar*, 2019.

[6] ADS-B Equip2020, Working Group 4, "ADS-B In Strategy Document: Closing the Loop on the Flight Deck," Washington, DC, 2019.

[7] *ADS-B In Retrofit Spacing (AIRS), Initial–Interval Management (I-IM) Operational Description, Version 2*, June 1, 2022. Located at https://www.faa.gov/air_traffic/technology/adsb/documents.

[8] S. Priess and L. A. Weitz, "Benefits of Required Time of Arrival (RTA) and Interval Management (IM) Operations," The MITRE Corporation, McLean, VA, 2022.

9 Appendices

9.1 SafeRoute+ Impact on IM Operations

Impact of ACSS SafeRoute+ Equipment on Interval Management (IM) Operations with Limited IM Air Traffic Control (ATC) Automation Support

Greg Comstock, The Belmont Group
Joe Kotula, Federal Aviation Administration (FAA)
With the FAA Automatic Dependent Surveillance-Broadcast In (ADS-B In)
Systems Engineering Work Group (SEWG)
2023/12/31

Summary
This paper presents operational limits on the use of ACSS SafeRoute+ equipment as compared to equipment compliant with the Flight-deck Interval Management (FIM) Minimum Operational Performance Standard (MOPS), DO-361A/ED-236A. These operational limitations were observed during the FAA ADS-B In project's effort to define IM operations in an environment with limited to no new ATC automation support.

Background

FAA and industry have been pursuing ADS-B In applications to improve the safety and efficiency of the National Airspace System (NAS). Interval Management (IM) is an application where the IM Aircraft's Flight-deck IM avionics (FIM Equipment) uses ADS-B Out reports from a specified Lead Aircraft to generate speed guidance (IM Speeds) for the flight crew to support the performance of a relative spacing task. An air traffic controller issues an IM clearance, and the IM Aircraft is to achieve an assigned spacing goal (ASG; e.g., 90 seconds or 5 Nautical Miles [NM]) behind the Lead Aircraft. This spacing can be achieved as soon as possible or at a specified downstream Crossing Point (CP)[7]. The IM Aircraft continues to manage its spacing from the Lead Aircraft until the operation is cancelled by the controller or the IM Aircraft reaches a Planned Cancellation Point (PCP)[8]. Example IM clearances are depicted in Figure 1.

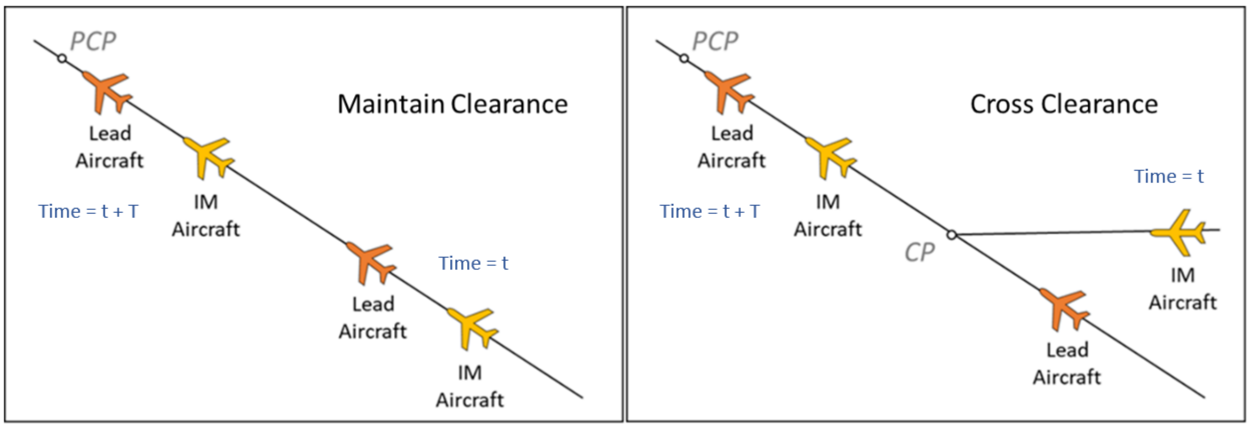

Figure 1: Example IM clearances, from AIRS IM Operational Description

Standards for ADS-B In applications have been published through the joint government/industry RTCA and European Organisation for Civil Aviation Equipment (EUROCAE) committee process. General requirements for ADS-B In avionics are contained in DO-317C/ED-194B (RTCA/EUROCAE 2020) and requirements specific to the FIM application are contained in DO-361A/ED-236A as modified by Change 1 (RTCA/EUROCAE 2021, hereafter referred to as the FIM MOPS).

Aviation Communications & Surveillance Systems (ACSS) has developed an ADS-B In product which, among other features, includes a first-to-market limited IM capability. This product is called SafeRoute+™. Though SafeRoute+ meets the requirements for other ADS-B In applications, it was developed many years prior to the publication of the FIM MOPS. As a result, SafeRoute+ does not meet the full set of requirements within the FIM MOPS and, therefore, will not satisfy the full set of documented test procedures. As such, the ACSS SafeRoute+ product is not 'MOPS-compliant.'

[7] The CP is called the Achieve-by Point (ABP) in the FIM MOPS.
[8] The PCP is called the Planned Termination Point (PTP) in the FIM MOPS.

The ADS-B In Retrofit Spacing (AIRS) Evaluation project is a joint effort between the FAA, American Airlines (AAL), and ACSS to conduct air traffic operations using SafeRoute+ to evaluate the benefits of various ADS-B In capabilities. The AIRS Evaluation project will conduct year-long operational trials of Cockpit Display of Traffic Information (CDTI)-Assisted Separation (CAS) and Initial-IM (I-IM) to gather data on operational benefits and provide lessons learned for deployment of future ADS-B In applications in the National Airspace System (NAS). The AIRS CAS operations are being conducted at the Dallas Terminal Radar Approach Control Facility (TRACON) (D10). The AIRS IM operations are being conducted at the Albuquerque Air Route Traffic Control Center (ARTCC) (ZAB).

Simultaneously, the FAA ADS-B In Systems Engineering Working Group (SEWG) is developing operational descriptions of IM operations that can be deployed with fewer changes to Air Traffic Control (ATC) automation. The SEWG is considering these IM operations for use in both ARTCCs and TRACONs. In this effort, a range of operations have been defined, supported by SafeRoute+ equipment, and are captured in the Tactical Terminal IM Operational Description document and the Tactical En Route IM Operational Description document. These operations may be supported with only ADS-B In capability indicators being deployed in en route automation and potentially available in the future in Terminal automation. They include:

1) En Route Miles in Trail (MIT) Operations,
2) En Route to Oceanic Time-based Restriction Operations,
3) Various Time-based Arrival Operations, and
4) Independent Runway Spacing Operations.

However, in both the SEWG and the AIRS activities, the limitations of the SafeRoute+ equipment to perform IM as part of today's ATC operation have been observed. While the generalized IM benefit of more precise spacing in the aforementioned operations can be achieved with both SafeRoute+ and MOPS-compliant FIM Equipment, the operational applicability of IM is reduced when assuming the more limited SafeRoute+ IM functionality. The intent of this paper is to enumerate the functional differences between MOPS-compliant FIM Equipment and SafeRoute+, as those differences impact, limit, or restrict IM operations. It is important to note that these differences and limitations are independent of the level of ATC automation available, and all of the operations discussed herein would be otherwise achievable with MOPS-compliant FIM Equipment in an environment with limited ATC automation. The timeline for these ATC automation investments remains to be determined.

Avionics Differences that Limit Operations

Three major areas of functionality, integral to MOPS-compliant FIM Equipment, are not supported by the SafeRoute+ equipment and present limitations and restrictions on the types of IM operations that can be performed. The three major technical differences impacting operations are: 1) a lack of planned trajectory information for the IM and Lead Aircraft, 2) an incomplete set of IM Special Point functions, and 3) a lack of specific IM clearances. The operational impact of each of these are summarized in Table 1 and described in detail in the remainder of this section.

Table 1: Summary of Operational Limitations

SafeRoute+ difference from MOPS	Operational Limitations
Lack of Planned Trajectory Information	Limits to establishing IM on arrival Limits on initating IM operations to continue into a terminal merge Limits on use of IM en route Inability to support EoR IM opperations
Incomplete set of IM Special Points Funtionality	Inability to support multiple flow operations ending at TRACON boundary Inability to support metering operations ending between ARTCC sectors
Incomplete set of IM Clearance Functions	Inability to perform Final Approach Spacing

Lack of Planned Trajectory Information

The most fundamental and significant difference between SafeRoute+ and MOPS-compliant FIM Equipment is how spacing is estimated. MOPS-compliant FIM Equipment follows the following basic steps for spacing calculation and correction:

1) Interpret IM Aircraft (Ownship) and, if needed, Lead (Designated Traffic) Intended Flight Path Information (IFPI) to generate a four-dimensional (4D) trajectory or trajectories.
2) Compare aircraft state data (e.g., position and velocity vector) and reference 4D trajectories to establish either current spacing or predicted spacing at a specified downstream point (the CP).
3) Generate IM Speeds to correct differences between the current or predicted spacing and the ASG.

The first of these steps requires controller communication and flight crew input of IFPI, as well as access to Navigation Database with navigation procedure information. These can be burdensome to implement, both operationally and technically. While SafeRoute+ does have a waypoint database it does not have procedure data nor a means to input IFPI for the traffic to follow. Thus, it cannot build a planned reference trajectories for the aircraft. As a result, SafeRoute+ follows these basic steps for spacing calculation and correction:

1) Compare aircraft state data (e.g., position and velocity vector) and along-track distance (between aircraft on a common route or each aircraft to the CP) to establish current spacing (on a common route) or predicted spacing at a specified downstream point (the CP).
2) Generate IM Speeds to correct differences between the current or predicted spacing and the ASG.

For the SafeRoute+ spacing calculation to be accurate, it must reflect the true flight paths of the aircraft. Any turn or descent between the IM Aircraft's or Lead's current position and the CP is not captured in the along-track estimate. As a result, both the IM Aircraft and the Lead must be direct-to the CP for a SafeRoute+ Cross clearance, and the CP must be located prior to the aircrafts' respective top of descent. This limits the use of Cross clearances given present-day published procedures. An example of this limitation can be seen in a southwest arrival flow into Chicago O'Hare International Airport (ORD), depicted in Figure 2.

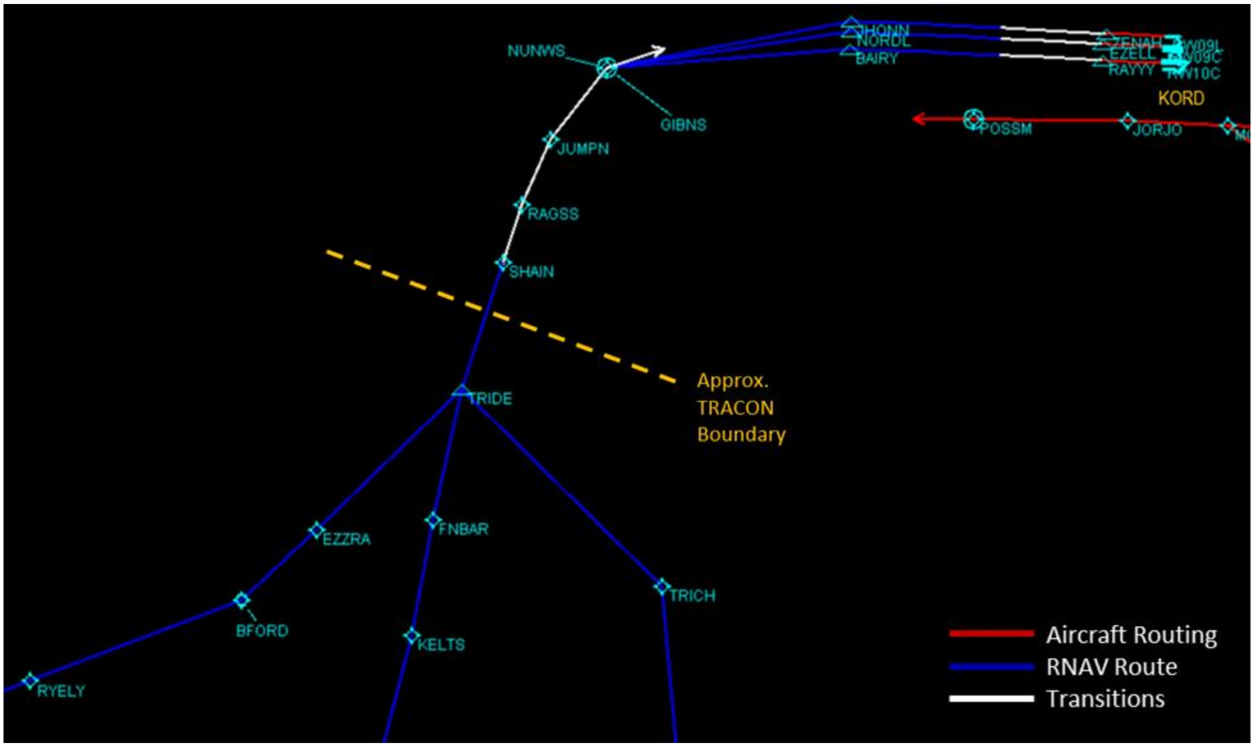

Figure 2: SHAIN2 RNAV Transitions and Arrival

The first common point on the TRIDE Standard Terminal Arrival (STAR), across all en route transitions, is the first possible and a likely CP for a Cross Clearance. This clearance type will allow ARTCC controllers to use IM to sequence and space aircraft across all flows to meet their operational objective for delivery to the TRACON, whose boundary lies between TRIDE and SHAIN (depicted by the dashed yellow line). Due to the SafeRoute+ straight-line distance calculation, such a Cross operation could not be initiated until after both aircraft have passed either BFORD, KELTS, or TRICH; leaving around 25 NM to the natural CP. Looking at the full arrival procedure prior to SHAIN (Figure 3) shows the extent of this limitation.

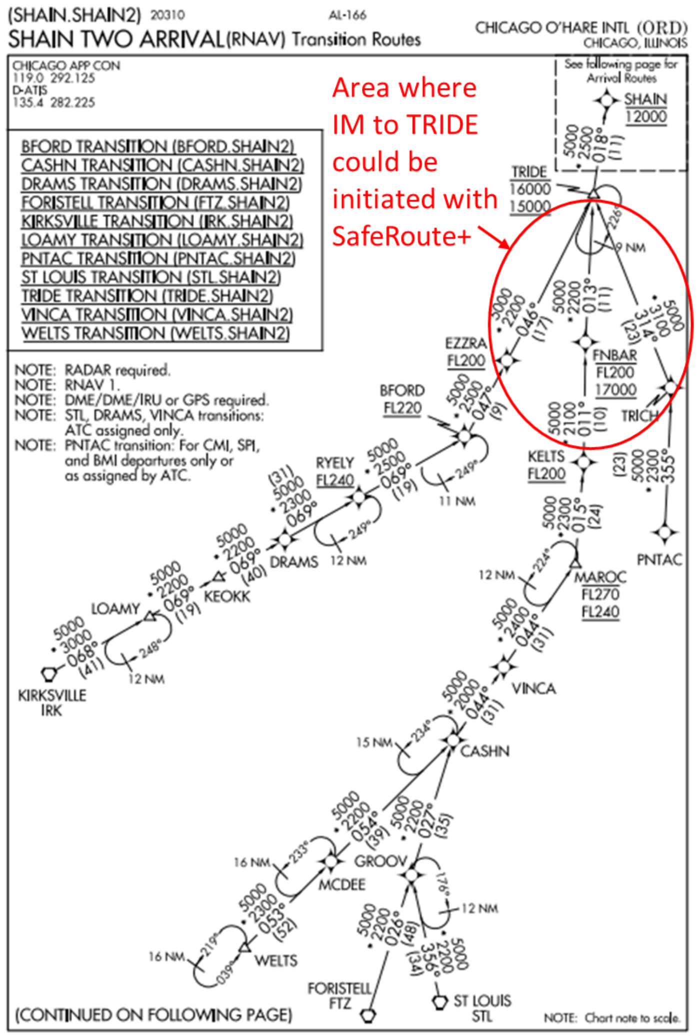

Figure 3: Full SHAIN2 RNAV Transitions and Arrival prior to SHAIN

SafeRoute+ therefore excludes 100+ NM of the Are Navigation (RNAV) Arrival from a potential IM operation when compared to MOPS-compliant FIM Equipment, which is able to initiate at any point on these RNAV Arrivals. This reduces the total amount of time for spacing corrections prior to TRIDE and requires the IM clearance to be entered during a period of higher pilot and ATC workload. In high traffic demand conditions, where IM would potentially provide the most benefit, establishing an IM operation on this segment of the arrival may not be operationally feasible.

A similar example was identified during the AIRS project and can be seen in en route airspace prior to the PINNG arrival. As depicted in Figure 5 - Number of hours for which current metering operations are inadequate for flow rates at KDFW (over 2023) Sector 78 in ZAB is largely excluded from IM operations supporting the arrival flow as both aircraft need to pass EWM or ELP to ensure a direct route to the CP (DRRVR). With extended metering being conducted in this sector to the extended meter point (XMP), an appropriate sequence has already been established for delivery all the way to the KPHX runways. The possibility to issue a single IM clearance upon the aircraft's entry into ZAB airspace and have that same IM operation continue to the TRACON boundary cannot be accomplished without the trajectory estimation provided in MOPS-compliant FIM Equipment. This exact same issue is also experienced in overflight operations where aircraft on different jet routes turn before merging into a single flow.

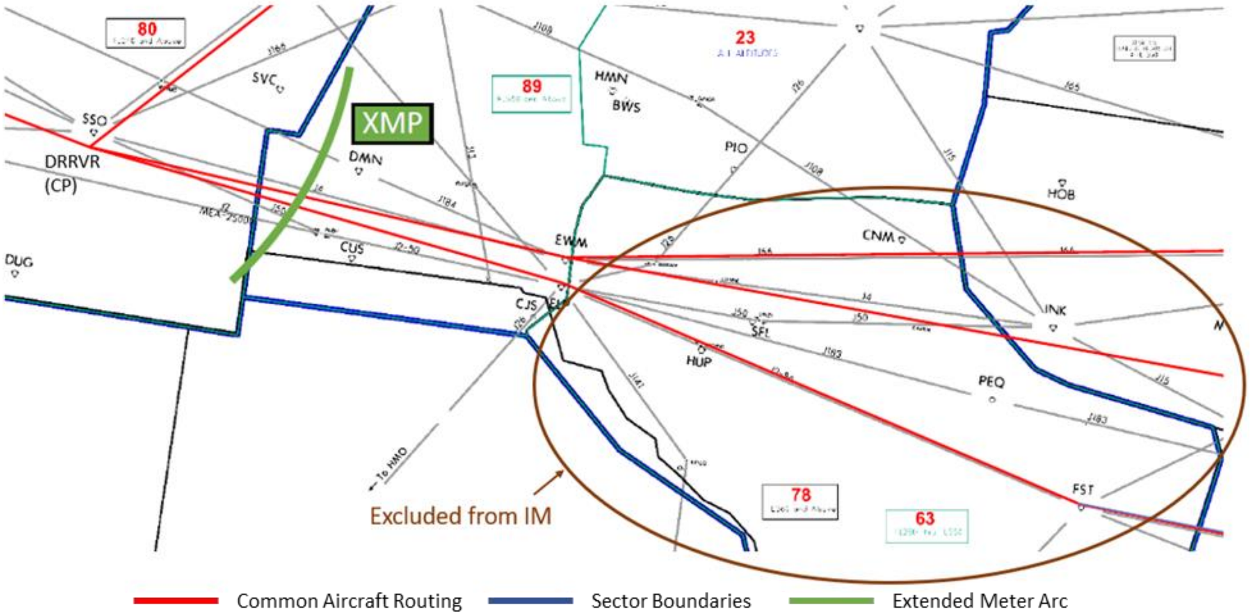

Figure 5: ZAB sectors prior to PINNG arrival, aircraft flows right to left

The inability for SafeRoute+ to accommodate CPs on descent segments precludes any ability for a Cross clearance to be initiated once the aircraft are in the terminal environment. Two terminal-initiated IM scenarios developed by the SEWG, one at Denver International Airport (DEN) and one at Los Angeles International Airport (LAX), were not achievable by SafeRoute+. The DEN operation, depicted in Figure 6, has dual arrivals from the same corner-post merging in the Feeder controller's airspace prior to hand-off to Final. With IM, this could be a standardized delivery to Final. The LAX operation, depicted in Figure 7, similarly has dual arrivals and continues to the Final Approach Fix (FAF). MOPS-compliant FIM equipment would support any of these operations, including the route short-cutting depicted for the LAX flow.

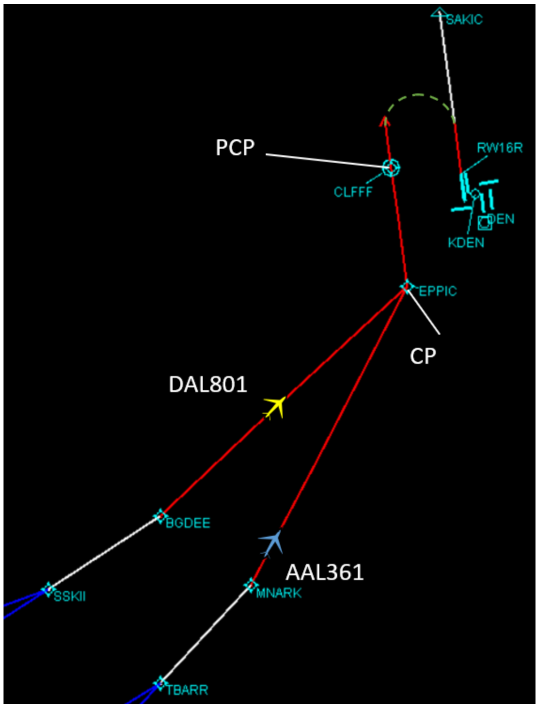

Figure 6: Dual Arrival Merge at DEN

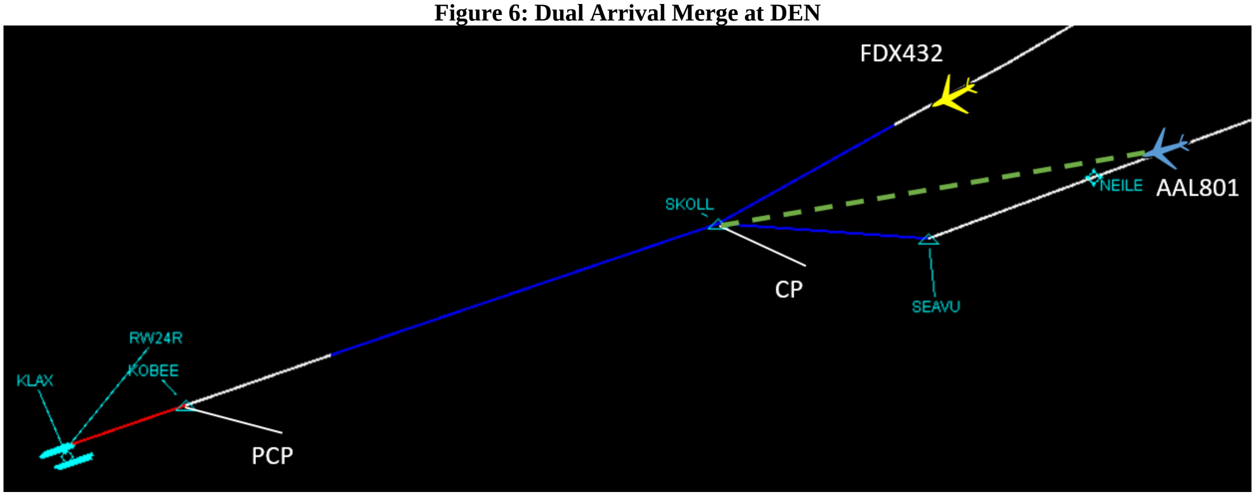

Figure 7: Dual Arrival to FAF Merge at LAX, with Trail Aircraft shortcut to SKOLL

A final example describes how the lack of trajectory predictions for the IM and Lead Aircraft restricts possible operations during an Established on Required Navigation Performance (RNP) (EoR) operation when using SafeRoute+. EoR operations include a Radius-to-Fix (RF) turn onto final approach that can produce efficiency and fuel saving benefits by avoiding a long downwind segment prior to approach. Such an operation at LAX can be seen in Figure 8. RNP-equipped aircraft coming in from VAALE or GADDO can take the RF turn(s) to MUBME to avoid otherwise longer routes.

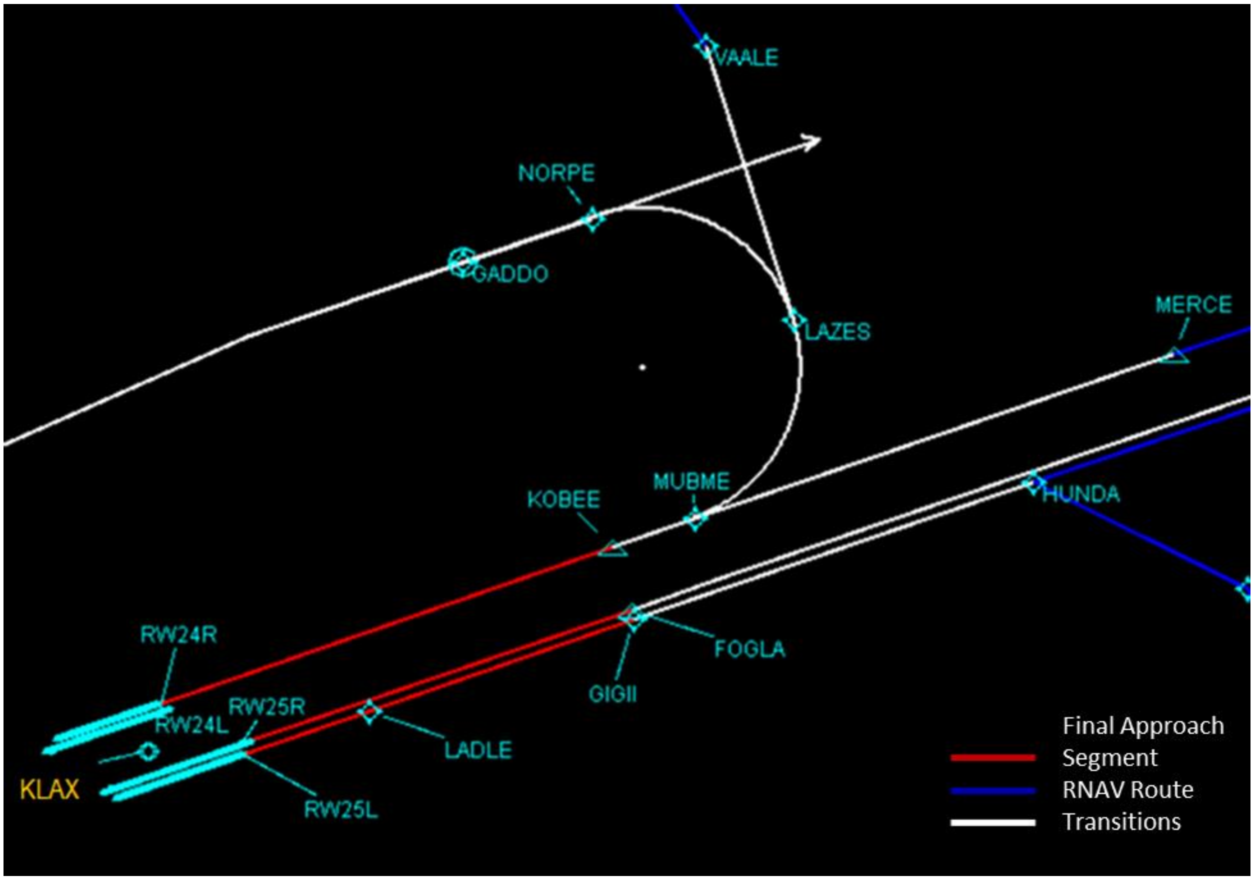

Figure 8: LAX RF turn to final approach

It can be difficult, however, to merge aircraft utilizing EoR with aircraft using a traditional, straight-in approach (MERCE to KOBEE in Figure 8). At the cost of communicating the Lead's IFPI to the IM Aircraft, MOPS-compliant FIM Equipment can assist controllers in this spacing task by managing spacing of aircraft on each flow by a Cross clearance with a CP of MUBME. If the IM Aircraft is using an EoR routing, a controller can have confidence that the IM Aircraft will fill a pre-planned gap behind its Lead on the approach. If the IM Aircraft is using the straight-in approach, the controller can have confidence that the IM Aircraft will leave enough space behind its Lead using the EoR routing. Neither case is supported by the SafeRoute+ avionics, which is unable to accommodate any noticeable turn, let alone an RF leg, prior to a CP.

Incomplete Set of IM Special Points Functionality

Functionality to support non-coincident routes (i.e., routes that do not merge or intersect) was a substantial addition to DO-361A/ED-236A from the original MOPS. Non-coincident routes require a new IM Special Point called the Traffic Reference Point (TRP). In most operations, this point could be defaulted by the FIM Equipment. However, a controller could communicate a TRP to use a Cross clearance with the Lead and IM Aircraft on separate, non-coincident routes. These types of operations occur throughout the NAS and especially at ATC sector boundaries whenever a Traffic Management Initiative (TMI) is in effect.

Further complicating matters, ATC sector boundaries are often not aligned with Named Fixes available in a Navigational Database. MOPS-compliant FIM Equipment can accept IM Special Points (CP, TRP, PCP) defined as an along-path distance before or after any Named Fix. Thus, a MOPS-compliant IM operation can be defined on a route to the relevant sector boundary regardless of whether there is a Named Fix in that location.

SafeRoute+ is unable to support these non-coincident route operations as it does not include TRP functionality, nor can it estimate IM Special Point locations before or after Named Fixes.

An example application of this cross-boundary IM operation can be seen at the southwest corner arriving into Charlotte TRACON (CLT) from Atlanta ARTCC (ZTL), depicted in Figure 9.

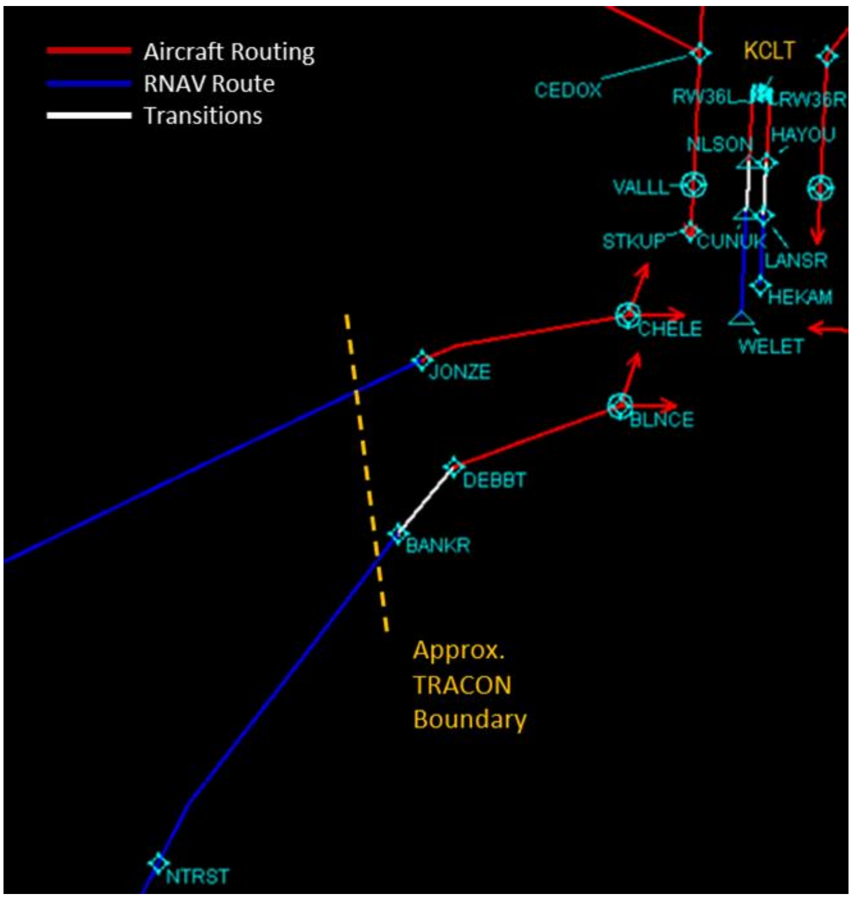

Figure 9: Southwest arrivals from ZTL into CLT

On the JONZE2 and BANKR2 arrivals, the ZTL/CLT boundary is just prior to JONZE and BANKR, respectively. Whether ZTL is performing Miles-in-Trail (MIT) or metering into CLT, the ideal IM operation is a Cross clearance to this ZTL/CLT boundary. Each aircraft crossing into the TRACON would be appropriately spaced regardless of the arrival route being used by the Lead or Trail. With MOPS-compliant FIM Equipment, this could be achieved with IM Aircraft on either JONZE2 or BANKR2 regardless of the Lead Aircraft's route. With SafeRoute+ equipment, the only IM operation available is when the Lead Aircraft is directly in front of the IM Aircraft on the same arrival. Even if named waypoints existed on every procedure at every sector boundary, SafeRoute+ could not perform such an operation as the CP and TRP would be on different routes (i.e., the routes do not merge).

The AIRS project identified an equivalent operation between ZAB sectors. The east area, shown in Figure 10, typically runs an extended metering operation to the XMP just prior to the north area (left). Just as the ZTL/CLT example, no Named Fixes are available at this boundary and it was understood that SafeRoute+ would only be capable of performing same route operations, despite metering being applied to aircraft on all aircraft routes (in red on Figure 10) crossing the XMP. These limitations could not be overcome operationally and thus IM was not pursued in the combined northwest sector.

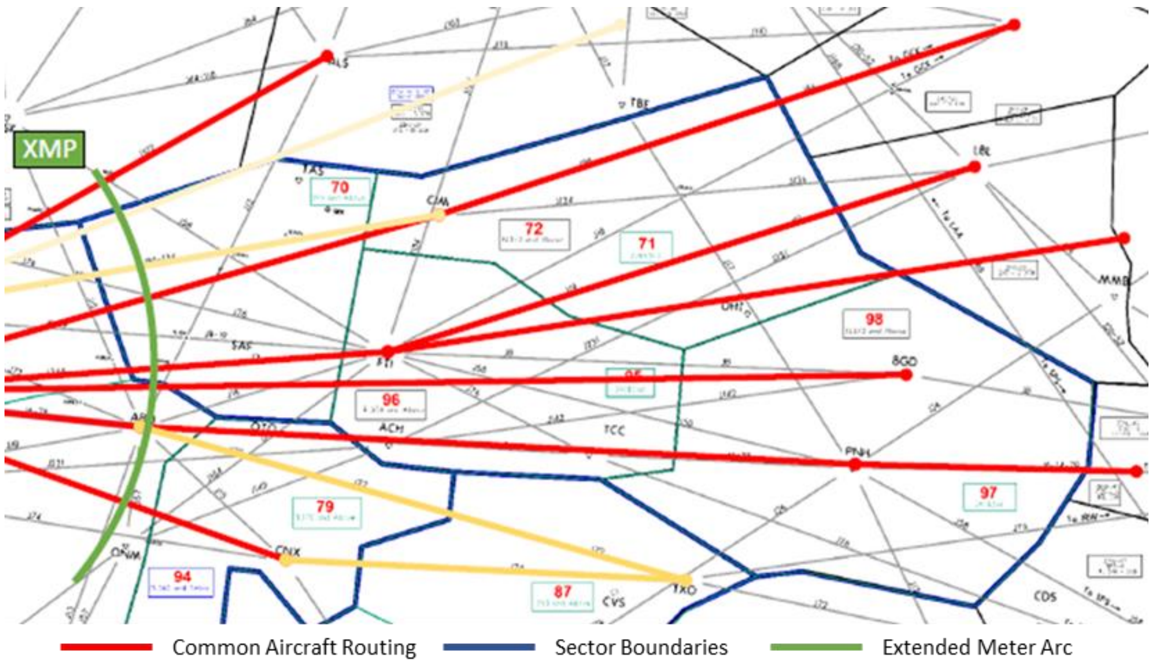

Figure 10: Combined east area sector at ZAB, aircraft flows right to left

Incomplete Set of IM Clearance Functions

The FIM MOPS specifies five IM clearance types. These are:

1) Achieve-by then Maintain (i.e., 'Cross' clearances)
2) Capture then Maintain (i.e., 'Maintain' clearances)
3) Maintain Current,
4) IM Turn, and
5) Final Approach Spacing.

Each of these five clearance types have unique requirements and functionality. SafeRoute+ supports its version of the most broadly applicable clearances (Cross and Maintain), but none of the unique requirements of Maintain Current, IM Turn, and Final Approach Spacing are addressed. Of these three unsupported clearance types, Final Approach Spacing would benefit early IM operations in the NAS. The Final Approach Spacing clearance was designed to be a short, tactical clearance issued to aircraft established on or vectored to the final approach course. Functionality associated with the Final Approach Spacing clearance includes:

- Defaulted PCP,
- Defaulted CP (unique to Final Approach Spacing clearance),
- IFPI can be simply a runway assignment, and
- Automatic calculation of a Merge Point (unique to Final Approach Spacing clearance).

An air traffic controller can issue a Final Approach Spacing clearance (sample phraseology for example: “American two eighty-three Space 2.6 NM[9] behind UAL435”) to an IM Aircraft vectored to final and be confident that the spacing between the IM Aircraft and the Lead Aircraft will be captured prior to the Final Approach Fix (FAF). An example of this operation on the PHL RW26 approach is shown in Figure 11.

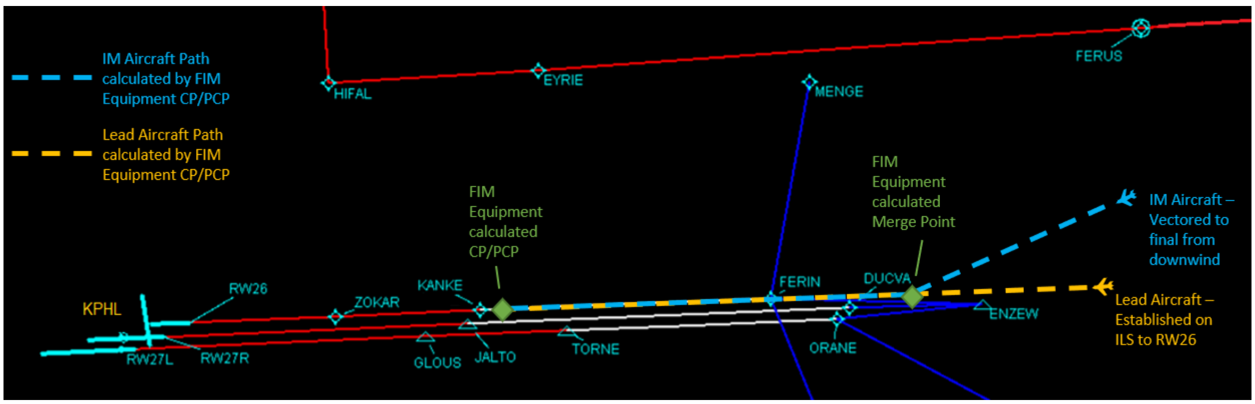

Figure 11: Example Final Approach Spacing clearance at PHL

The applicability of the Final Approach Spacing clearance is universal, with the usability and benefit of the operation being improved by longer approach distances to the FAF (when EoR is either not possible or not available). Further, these clearances cannot be emulated by either the SafeRoute+ Cross or Maintain clearances[10]. If SafeRoute+ equipment was used for such approaches, the clearance could only be initiated when both aircraft are established on approach, limiting utility. Additionally, as SafeRoute+ lacks specific IM Speed functionality detailed in the FIM MOPS for when the Lead Aircraft passes the PCP, any distance-based clearance going to the FAF is untenable as the SafeRoute+ equipment is likely to suggest speeds prior to the FAF that mirror the Lead aircraft’s groundspeed as it slows to its final approach speed.

Consequential Behavioral Differences

Several other functional differences between SafeRoute+ and MOPS-compliant FIM Equipment do not directly limit which IM operations can be performed but may pose operational

[9] SafeRoute+ is also currently unable to support distance-based spacing goals at a resolution less than whole nautical miles. This resolution is expected to improve to 0.1 NM in a future release.

[10] Even if the unique Final Approach Spacing functionality is ignored, the specific geometries supported by this clearance would, in some cases, not be able to be initiated due to checks performed by SafeRoute+. See the Appendix.

consequences for controllers. In an operational environment with both SafeRoute+ and MOPS-compliant FIM Equipment, these differences will result in different observed behaviors that may reduce ATC acceptance of and trust in IM operations.

IM Speed Limiting

The difference in speed limiting would be the most recognizable difference between SafeRoute+ and MOPS-compliant behavior. Both implementations respect airspace speed restrictions (e.g., 250 knots [kt] below 10,000 feet [ft]), but the difference in nominal IM Speed limiting can be significant and is presented in Table 2. These differences in IM Speed limiting behavior also effect how an IM Aircraft would react to speed limits defined as part of a navigational procedure, referred to here and in the FIM MOPS as procedural airspeed limits.

Table 2: SafeRoute+ and MOPS-compliant Speed Limiting Difference

SafeRoute+ Speed Limiting	MOPS-compliant Speed Limiting
IM Speeds cannot exceed +/-15% of Lead Aircraft's estimated airspeed history at Ownship's current location.	IM Speeds cannot exceed +/-10% relative to Ownship's nominal Airspeed Profile.

The most obvious difference is that 15% is greater than 10%.[11] More significantly, the basis of the percent airspeed is entirely different. SafeRoute+ uses the Lead Aircraft's groundspeed reports and Ownship's sensed winds and temperature to estimate the Lead Aircraft's airspeed. If the Ownship and Lead Aircraft are at different altitudes and/or experiencing very different winds, this estimate will be wholly inaccurate and will result in over constraining the Ownship's speeds. In some situations, this would result in an Ownship being unable to make any progress towards the assigned spacing despite any real limitations of the aircraft or operation. This was observed during the AIRS evaluation and operations were subsequently limited to those where the aircraft were in roughly the same wind conditions (i.e. close together). This type of limiting is problematic and will likely be removed in a future version of SafeRoute+.

MOPS-compliant FIM Equipment, having built a 4D trajectory for Ownship, has an expected speed profile (i.e., the Airspeed Profile) for the entirety of the IM operation to the PCP. This Airspeed Profile incorporates any procedural airspeed limits that may exist along the path, so the IM Aircraft will not deviate from these procedural airspeed limits by more than 10%. For SafeRoute+, any procedural airspeed limit protection would be indirect by way of the Lead Aircraft's groundspeed when crossing procedural waypoints. Again, the allowed deviation would be 15% of the Lead Aircraft's estimated airspeed instead of 10% around the procedural constraint. Additionally, since MOPS-compliant FIM equipment uses Ownship's airspeed as a limiting factor, the initial speed changes from such equipment would be in a predictable range (likely +/- 30 kts from current groundspeed). SafeRoute+ equipment can generate initial speed changes in excess of 70 kts. It is expected that controllers will notice these differences between implementations.

[11] In DO-361, the required speeds limits relative to the aircraft's nominal speed profile were ±15%. Through simulation and testing, it was decided that ±10% was sufficient, and the requirement was revised in DO-361A. The bound itself is required to be configurable at installation for a MOPS-compliant system.

Beyond the IM Speed limiting that SafeRoute+ performs, MOPS-compliant FIM Equipment implementations have additional requirements for speed limiting during RF turns. However, this difference would not be noticed operationally as SafeRoute+ equipment does not support IM during RF turns.

Initiation Checks Beyond MOPS Requirements

SafeRoute+ performs several checks upon IM initiation that are not required by or described in the MOPS. These checks are meant to confirm the correct geometric configuration of aircraft at the beginning of an operation. For both the Maintain and Cross clearances, the SafeRoute+ equipment verifies that the Trail aircraft is behind the Lead aircraft at the start of the IM operation. This has the unintended consequence of prohibiting ATC from using an IM operation to sequence the Trail aircraft behind the Lead aircraft at a future point. For a Cross or Maintain clearance with aircraft on different flight levels, this forces ATC to ensure the Trail is already behind the Lead (or further away from the CP) before issuing an IM clearance, which could require additional ATC action (such as manually slowing the Trail or delaying IM initiation) to accomplish the same outcome given a single IM clearance with MOPS-compliant FIM Equipment.

These and other differences between SafeRoute+ and MOPS-compliant FIM Equipment that may be noticeable to controllers working both types of equipped aircraft are described in detail in the Appendix.

Conclusions

The ACSS SafeRoute+ equipment is the first, and currently only, certified avionics available with IM functionality. There are numerous, beneficial IM operations achievable with SafeRoute+. However, there are several operationally feasible scenarios not supported by SafeRoute+ that limit the overall IM benefit to the NAS. SafeRoute+ can only be used in the geometries presented in Figure 1, which limit the overall applicability of IM operations as compared to those supported by the FIM MOPS. Additionally, behavioral differences between SafeRoute+ and MOPS-compliant FIM Equipment may cause confusion and ATC distrust in IM generally without significant training and setting expectations based on implementations. ATC Subject Matter Experts have warned against adding operational complexity due to varying avionics implementations. Joint governmental and industry standards, such as DO-361A/ED-236A, try to prevent proliferation of varying avionics operational capabilities and behaviors. There is an expectation that all FIM equipment going forward will meet the requirements specified for that application in TSO-C195c.

The operations presented in this paper which SafeRoute+ cannot support are not dependent on a large investment in ATC automation and are missed opportunities to perform IM operations should MOPS-compliant FIM Equipment implementations become available. The SafeRoute+ avionics as they stand do provide a present-day spacing capability and helps move the NAS towards an IM future, but do not represent the full capability of IM as intended in regulatory standards and their supporting operational concept documents.

Horizontal Path Conformance

The Horizontal Path Conformance checks within the FIM Equipment are designed to ensure that the IM and Lead Aircraft positions at any time are consistent with the FIM Equipment trajectories used to generate speed guidance. The Horizontal Path Conformance check differs based on whether the aircraft are in an achieve stage (prior to the CP) or in a Maintain stage (after the CP or for a Maintain clearance). Prior to the CP, the horizontal path conformance checks for SafeRoute+ and MOPS-compliant FIM Equipment are as depicted in Figure 12 (note the IM Aircraft is referred to as the "Trail" in this figure).

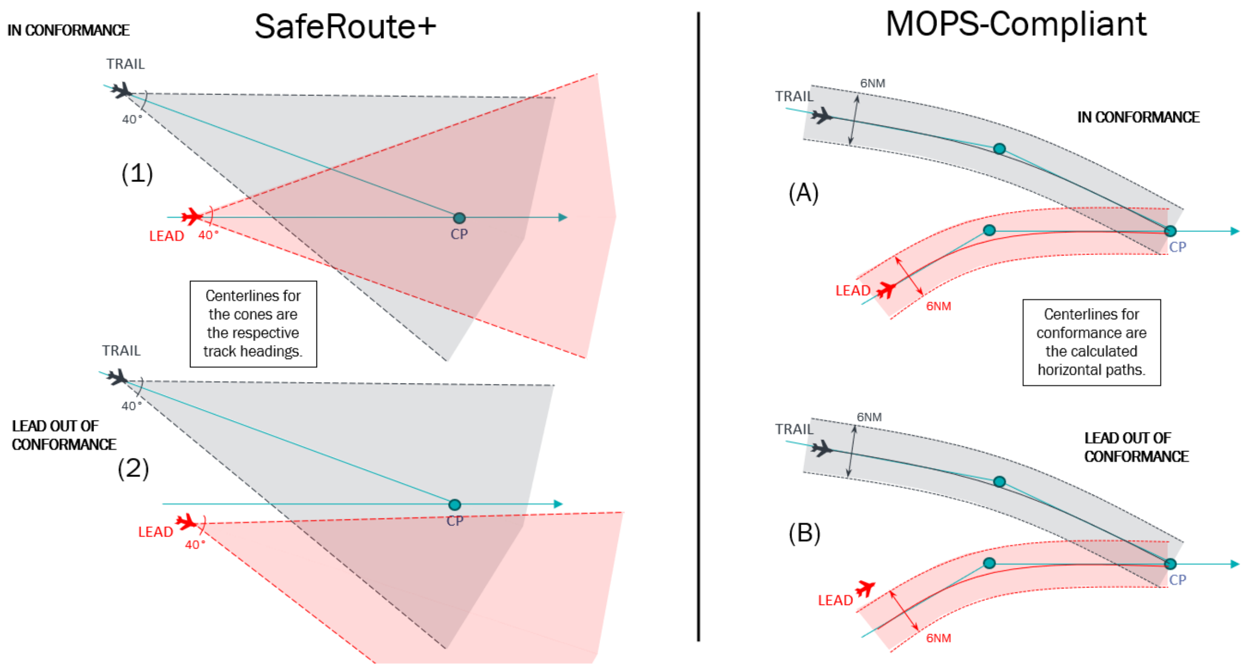

Figure 12: Horizontal Path Conformance checking prior to CP

Despite this functional difference, the operational limitations for SafeRoute+ previously discussed may limit differences in behavior prior to the CP. Therefore, ATC may not observe these differences.

After the CP or during a Maintain clearance, the horizontal path conformance checks are as depicted in Figure 13 (again, the IM Aircraft is referred to as the "Trail" in this figure).

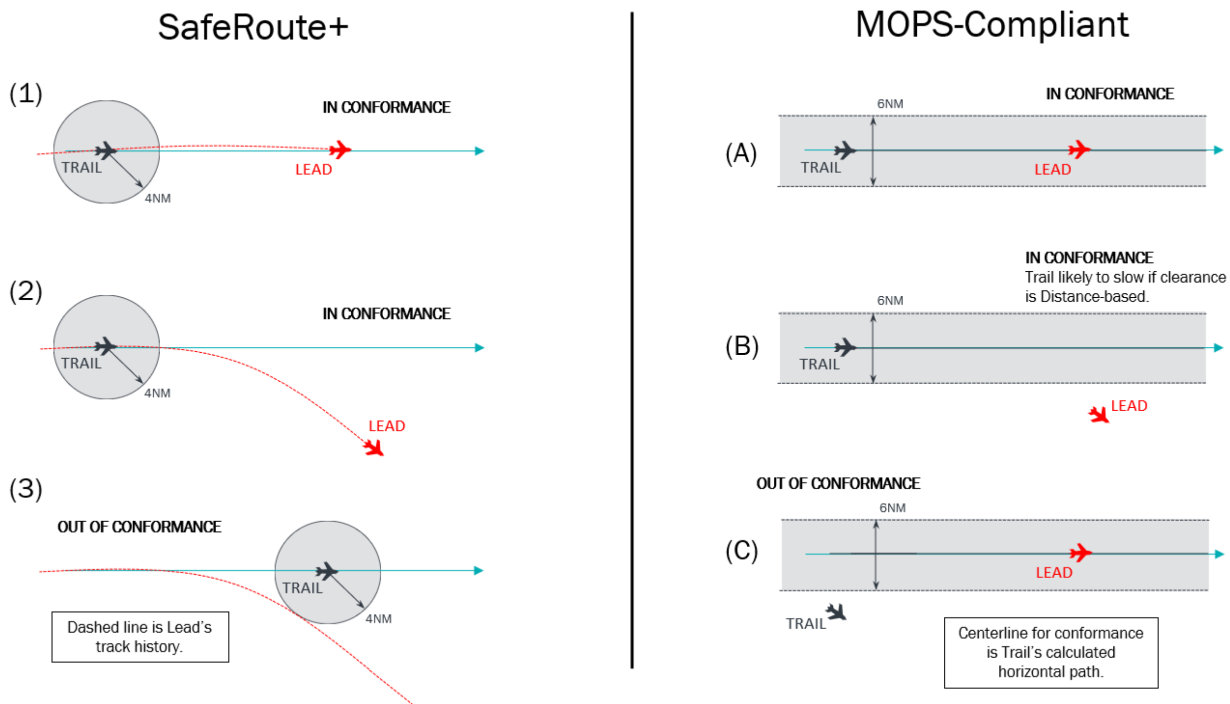

Figure 13: Horizontal Path Conformance checking during Maintain

Conformance checking is not performed on the Lead Aircraft for MOPS-compliant FIM Equipment, as MOPS-compliant FIM Equipment accommodates parallel or near-parallel Maintain regimes. Conversely, SafeRoute+ monitors the magnitude of the difference between the IM Aircraft's position and the Lead's track history to validate that they are flying the same route. This again limits the use of the SafeRoute+ equipment during IM operations to parallel or near-parallel operations, but the degree of operational impact is unclear. Parallel or near-parallel operations may be supported by SafeRoute+ if the routes were sufficiently close, but the applicability would need to be assessed on a case-by-case basis.

For operations where the Lead and IM Aircraft are on the same route, it is not known whether or not the differing conformance behavior would be noticeable to controllers.

Follow-on Clearance Information

MOPS-compliant FIM Equipment includes functionality that would allow a flight crew to input IM clearance information for a future operation while conducting a current IM operation. An example of this is depicted in Figure 14, in which LEAD2 will come sequentially between the IM Aircraft (TRAIL) and LEAD1 on approach. The controller can give an IM clearance with respect to LEAD1 for an upstream spacing objective (such as the depicted meter arc, merge point, or approach spacing needed to allow LEAD2 to be inserted) and then also communicate the information that will be needed for the IM clearance with respect to LEAD2 on approach. This greatly simplifies the task of initiating the IM clearance on approach, which is generally a very busy time for ATC and the flight crew.

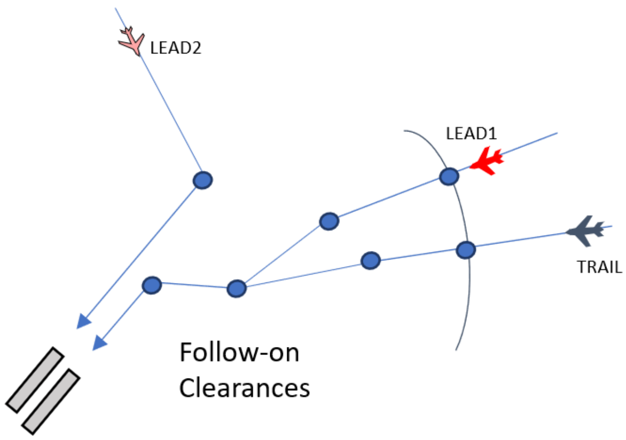

Figure 14: Follow-on IM Clearance Example

SafeRoute+ does not have this functionality and thus cannot support these operations. However, given the complexity and aircraft sequence certainty needed for these types of operations to be beneficial, IM "follow on clearance" operations are not likely to be fielded until simpler IM operations are well established.

Initiation Criteria and Traffic Alignment

There are unique behaviors for SafeRoute+ and MOPS-compliant FIM Equipment during the initiation of a Maintain Clearance. SafeRoute+ attempts to validate its assumption that the IM Aircraft (or 'Trail') and the Lead Aircraft are on the same route by requiring that any of the following be true (with graphical examples in Figures 15a and 15b):

1) The Lead is ahead of the Trail and within a 6 NM swimlane centered around Trail's instantaneous track projection[12],
2) The Trail is behind the Lead and within a 6 NM swimlane centered around Lead's historical track, or
3) The intersection of the Trail's instantaneous track projection and the Lead historical track is located between the Lead and Trail, with intercept angle less than 90 degrees.

[12] The "swimlane" is the area defined in the lateral plane of the aircraft +/-3 NM to either side, both ahead and behind, of its direction of movement.

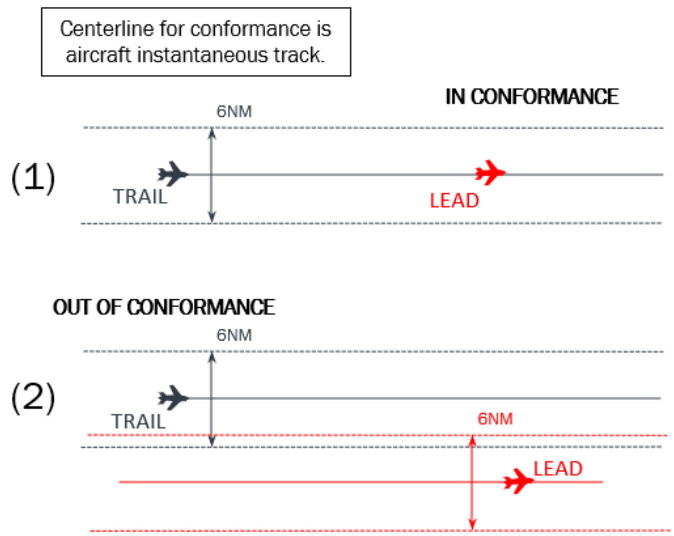

Figure 15a: SafeRoute+ Maintain clearance initiation criteria - swimlane

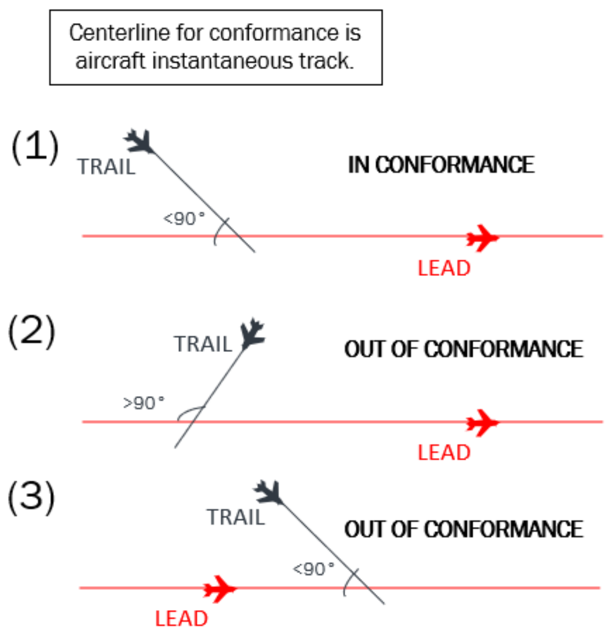

Figure 15b: SafeRoute+ Maintain clearance initiation criteria – intercept angle

These checks adequately confirm that the IM Aircraft and the Lead Aircraft are flying the same route, but limit the ability to use a Maintain clearance with SafeRoute+ on parallel or near-parallel routes. As MOPS-compliant FIM Equipment is expected to support such operations, no such checks are performed. The operational impact of this difference may only be noticeable if a controller attempted to initiate a Maintain clearance with SafeRoute+ on parallel jet routes or in geometries similar to those presented for Final Approach Spacing, both of which are not likely.

Similarly, when initiating a Cross clearance, the SafeRoute+ equipment performs a check to verify that the Lead aircraft has less distance to fly to the CP than the Trail aircraft (i.e., the Lead aircraft is closer to the CP). This would prevent initiation of a Cross clearance where a controller could re-sequence the Lead/Trail pair, using IM to ensure the Lead gets ahead of the Trail over the course of the achieve stage prior to the CP. No such limitation is imposed by the FIM MOPS.

Lastly, part of the updates included in DO-361A/ED-236A covered a unique situation where the Lead Aircraft was performing a turn prior to the initiation of a Maintain clearance with a time-based ASG. In these cases, the use of traffic history may prove unsuitable for IM Speed generation, and thus additional requirements were added. These generally require checks for traffic alignment with the IM Aircraft's reference trajectory and include explicit definitions for spacing unique to this scenario. SafeRoute+ does not perform these functions and thus may present undesirable IM Speeds for a brief time at the beginning of such an operation.

9.2 Directed Discussions Controller Feedback Results

9.2.1 North Area

- Most controllers agree that it "works fine," but we also noted that when weather gets involved it's no longer practical.
- One controller asked if we could vector the leading aircraft, or they can deviate and maintain the spacing. We discussed why that would not work.
- While many agree that we've proven that it works, none can find any benefit to ATC as of yet.
- The pilots need better equipment that's easier to use. It seems like pilot error is the only reason it doesn't work.
- The extra work that goes into the operation does not result in any added efficiency. Perhaps once CPDLC is up and running, and AIRS clearances can be issued via a quick keyboard command, it would negate the negative cost-benefit.
- Some don't like that it adds to their workload in that it's now something else they have to monitor and add to their scan.
- Someone stated that "it needs to work with more than 2 aircraft."
- It's frustrating that pilots are not reading the phraseology back correctly. Often times they do not read back the "maintain" portion, which now requires another transmission.
- A controller stated that there is only so much it can do in the limited amount sector 93's airspace. Also, over that short span, there is a limit of available speed adjustments at altitude. i.e. upper and lower limits of mach number capability.
- It was asked what the ultimate goal of AIRS is.
- Difficult to do when you need perfect conditions. i.e., No bad WX, smooth rides, same altitudes, no deviations.
- Recommend pilots get more hands-on training with AIRS so they know what to do on their side when AIRS is issued.
- Most controllers in the North seem willing to do it when reminded they can do it but it sounds like it creates more of a workload for them.

Briefing today with AIRS went well. Had a little bit different feedback compared to the rest of the week.

- Controllers feel that they have been getting less pushback from the pilots when giving the pilots the AIRS clearance.
- Most of the controllers are willing to do AIRS when there is a floor walker or some indicator to remind them to do it.
- A few of the controllers stated that it doesn't seem like more work than what they normally do with KPHX sequencing.

I feel this discussion was one of the most positives that I have taken notes on this week. They all would like to see this continue as time goes on with improvements made and more airlines/aircraft being able to participate in the program.
Controllers admitted that they do AIRS when asked to do it but that they tend to forget about it on a daily basis or 60-70% of the time, when they do remember it, the aircraft are not in a position to use it.

9.2.2 Northwest Area

- The controllers in the Northwest Area are on board using this. They wish we would have more opportunities. For instance, using it descend via on the EAGULs. Most of them haven't really been able to use it.
- Controllers in the Northwest area are not looking for opportunities to use it unless prompted by floor walkers because they don't have as many options to use it.
- Controllers requested a more focused test that is airport specific. They believe this will help controllers look for more opportunities to use it without prompting by floor walkers.

9.2.3 East Area

- All AIRS testing was prompted by floor walkers and not aware of any controllers testing on their own.
- In a test conducted last week the floor walker had to walk a pilot through an issue with nose trajectory, explaining termination fix vs enroute fix I believe. Even after all this was sorted out when shipped to the next sector, one pilot in the test checked on correctly and the following A/C did not.
- When the pilots are up to speed, we have seen the system work well in the past.
- Everyone's experience with AIRS has been positive in general and all had experienced the "bad geometry" issues in the beginning.
- One controller experienced a time when the pilot unabled the clearance due to an unreasonable speed increase to M.92.
- Reasons they had for not utilizing AIRS clearances were perceived conflicts with extended metering to KPHX, and wondering if it would be beneficial for Sector 93 when blending in ZDV stream.
- The group agreed that additional automation would encourage utilizing AIRS on a regular basis and make it more tangible.

- They mentioned a couple times when a floorwalker wanted to do some testing, they requested the floorwalker leave the area as the floor was too busy.
- They are aware they can do AIRS testing if they find a good opportunity.
- Two instances appeared to work very well.
- The crew feels they would have a lot more opportunity to test if it was available going to DFW. Being forced to terminate at the ZAB boundary makes it not worth it.
- The crew also brought up that with constant deviations the last few months it makes it very hard to test.
- A clearance was successful up to PNH at which point the lead aircraft made a hard turn to MDANO picking up a substantial amount of speed due to wind angle. At this point the trail aircraft was unable to catch up and continue the desired miles in trail.
- A clearance was unabled by the pilot due to “workload”.

9.2.4 Southeast Area

Feedback / opinions:

- The potential is there but haven’t used it much.
- Metering and IM clearances conflict, not easy to use together, and metering is daily.
- AIRS is out of sight, out of mind, until a floorwalker asks for it.
- Fourth line coordination is sometimes inadequate, when dealing with multiple clearances or stratums
- Pilot lack of training, ability, or willingness (instances of multiple attempts of the clearances, pilot didn’t understand or couldn’t execute).
- During weather season, isn’t a practical solution for deviating aircraft.
- As it stands, adds more complexity than it alleviates.

Ideas:

- Focus on terminal phase of flight
- Some type of AIRS reminder directly on datablock
- Specific operations pre-coordinated to test IM clearances, where pilots and controllers are expecting it
-
- Feedback / opinions:
- Have only attempted IM clearances when prompted
- No desire to use independently, complicates things
- Controller with three prompted attempts, one unable due to equipment, one unable due to pilot untrained, one success
- Adds to pilot workload
- Frustration that there are resources allocated to this project when other issues in the agency are more impactful (poor frequencies, low staffing, airport issues, etc.)

- Even if IM clearances worked as intended, controller is uncomfortable with trusting the pilot to maintain the separation. More comfortable with personally controlling the situation with current methods.
- Controllers are still required to monitor, which means the workload wouldn’t truly decrease. Complacency could lead to missing the one time it doesn’t work.

A reminder directly on datablock was widely regarded as a good idea.

- "it's in my toolbox, but still hidden away in the corner."
- both controllers present today participated only when it was floor walker initiated.
- Fourth line coordination should be adequate, a phone call should not be required (same reasoning behind headings, speeds, WX deviations in the fourth line).
- an indicator in the datablock showing eligible aircraft may help to encourage participation
- one controller has tried to perform an IM procedure six times with "we can't do that" from the pilots all six times
- a fourth line indicator denoting an IM eligible aircraft might encourage more participation from the controllers
- unlikely to participate without floor walkers, especially with weather, volume, bad rides, etc... impacting the sector

9.2.5 East Area

Questioned asked by ZAB SME:

- “Have you been utilizing AIRS?” Answer: “Only when prompted by the floor walkers.”
- “Have you had any issues?” Answer: No issues.
- “Have the pilots been accepting it?” Answer: “Not all the time. Some pilots say bad geometry.” Also, “in the beginning pilots were unfamiliar with AIRS but now they are more receptive and knowledgeable.”
- “Who has done an IM?” Answers: “Everyone said yes but only when prompted to by a floor walker.”
- “Were there any issues giving the clearances?” Answers: “Not on our end. Some pilots don’t like to do it.”

Feedback from the crew in attendance:

- “Why would we not do it outside of weather season?”
- “It’s not a tool I would use.”
- “With only American airlines A321’s capable it is not useful right now.”
- “How is this not a conflict of interest since American Airlines is the only one doing it?”
- “Why are we doing it here at ZAB since our staffing is so bad?”

- “Coordination between sectors is not adequate. There needs to be a more efficient method of nonverbal coordination.”

Other feedback noted:

- They don’t understand the significance of the program.
- Unsure if there is an advantage over the metering or miles-in-trail.
- Would like to see the Phoenix TRACON (P50) involved to see the full potential of the clearances.
- No issues with the pilots accepting the clearances.
- They appreciate the floor walkers cards with the phraseology because they don’t remember it on their own.
- The controller remembers a time when the pilots were unable to comply with the speeds to make the clearance work.
- The pilots don’t like the number of speed changes on the descend via clearances.
- They were confused with TBFM on an AIRS at the same time.
- Complained about the pilots speeding up and slowing down several times.
- Why focus on AIRS when we have CPDLC coming soon?