Surveillance and Broadcast Services (SBS) Group

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

Final Project Review Report (2022-2024)

Version 1.0

August 2025

Federal Aviation Administration
600 Independence Avenue, SW
Washington, DC 20591

Revision History for

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

Final Project Review Report (2022-2024)

Record of Revisions

Revision	Description	Document Date
	AIRS I-IM Operational Evaluation Year 1 Project Review Report (2022-2023)	September 6, 2024
Version 0.2	Added results from Year 2; reorganized and revised the report for improved clarity; added new sections explaining the data collection process, plotting of SafeRoute+ data, and illustrative examples of major issues encountered [Initial Draft of AIRS I-IM Final Project Review Report (2022-2024)]	April 18, 2025
Version 0.3	Revised throughout per comments received from AIRS team review of v0.2 between April 18 – May 29, 2025 [AJM-42 Communications Team Review Draft of AIRS I-IM Final Project Review Report (2022-2024)]	June 20, 2025
Version 0.4	Revised per AJM-42 Communications Team Review [AJM Review Draft of AIRS I-IM Final Project Review Report (2022-2024)]	July 7, 2025
Version 1.0	Revised per AJM management review [Baseline release of AIRS I-IM Final Project Review Report (2022-2024)]	August 20, 2025

Executive Summary

Global demand for air travel continues to rise, with 3.8% year-over-year increases projected over the next 20 years. To address this increased demand, new capabilities and procedures are needed to increase air traffic safety and throughput.

Improvements in aircraft communication, navigation, and surveillance systems in the National Airspace System (NAS) have led to the development of multiple concepts to enhance safety and improve throughput. These include the deployment of Automatic Dependent Surveillance-Broadcast (ADS-B) and expanded use of Trajectory-Based Operations (TBO). Aircraft 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 flight crew.

Interval Management (IM) is a new capability that was designed to realize TBO and NextGen objectives by improving aircraft speed management in a flow of traffic along planned flight paths. This would lead to throughput benefits and help mitigate growth in airborne delays as the number of flights continue to increase.

IM 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 maintain an assigned spacing goal relative to a specified Lead aircraft. Relative spacing from the Lead aircraft is managed on the IM aircraft using an ASA which provides IM speed guidance to the flight crew. The relative spacing goal may be issued as a distance or time value to support time-based metering operations. IM speed guidance yields more precise inter-aircraft spacing intervals than possible when speed instructions are issued by air traffic controllers, even when using Air Traffic Control (ATC) 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, yielding 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 fuel burn.

In 2012, the ADS-B In Aviation Rulemaking Committee (ARC) was tasked by the FAA with defining “a strategy for incorporating ADS-B In technologies into the NAS”. Two key recommendations were made by the ARC. The first was to prioritize “five key ADS-B In applications with the greatest potential to positively affect the ADS-B In business case.” Most of these applications were IM-related which motivated the development of RTCA/EUROCAE standards for IM avionics. The ARC also requested that the FAA conduct “flight trials for a sufficient number of ADS-B In applications to validate the utility of operational concepts and validate the business case…”

The ADS-B In Retrofit Spacing (AIRS) project was established for the purpose of conducting a large-scale operational evaluation of certain ASAs during revenue service flights using a retrofit solution. The AIRS Initial-Interval Management (I-IM) operational 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 included representatives from the National Air Traffic Controllers Association (NATCA) and the Allied Pilots Association (APA). Operations began in November 2022 and data collection was completed in November 2024. All listed partner organizations participated in the "AIRS team" referred to in this report.

A sub-group of the complete set of IM operations described in RTCA/EUROCAE avionics standards, termed Initial-IM (I-IM), were studied as part of the AIRS operational evaluation. ACSS certified their SafeRoute+ avionics suite in 2020, which included a spacing application that supported I-IM operations. AAL installed the SafeRoute+ avionics suite in their entire Airbus 321 fleet.

Data sources for the operational evaluation included FAA trajectory data, FAA Aviation System Performance Metrics (ASPM), FAA voice transcript data, and FAA Time-Based Flow Management (TBFM) data. Other data sources included SafeRoute+ data, ZAB controller feedback forms and observations, AAL/APA flight crew feedback and observations, and FAA Falcon replay videos.

During the operational evaluation, over 1475 I-IM clearances were issued, with most resulting in completed I-IM operations. Concerns or issues were identified via controller and flight crew feedback and were tracked by the AIRS team. Examples of concerns and issues noted included phraseology interpretation and understanding, flight crews deviating from IM speeds, and use of the flight crew interface to the aircraft Multi-purpose Control and Display Unit (MCDU). These concerns and issues were tracked and studied throughout the operational evaluation. Some of these issues and concerns resulted in procedural changes (e.g., phraseology modifications) and others led to changes in the SafeRoute+ software. Lessons learned were also documented for future activities.

Discussions with ZAB controllers indicated that most of them found that when none of the previously mentioned issues occurred, 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 operations was displayed by En Route Automation Modernization (ERAM).

AAL pilots received their initial I-IM training through bulletins, PowerPoint-like briefing materials, and basic videos. AAL pilots did not have an opportunity to practice an IM operation before 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+ Spacing application and IM operations. However, as flight crews became more familiar with the operation, most found IM to be straightforward 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. ACSS also developed interactive procedural training software that was hosted on a tablet or accessed via laptop/desktop computer. This provided AAL pilots with an interactive tool simulating data entry and displays associated with the SafeRoute+ Spacing application using a virtual interface to mimic the MCDU and ADS-B Guidance Display (AGD) interfaces. ACSS also modified the SafeRoute+ Spacing application's MCDU interface to enable more intuitive use by flight crews; however, the operational evaluation concluded before this could be evaluated.

Analyses of IM distance-based operations data indicated that at a common point (known as the Cross Point (CP)), the difference between the observed inter-aircraft distance and the spacing goal was a mean value[1] of 0.2 nautical miles (NM), with 95% of the flights being within ± 1 NM of this mean. Similarly, analyses of IM time-based operations data indicated that at the CP, the difference between the observed time and the time-based spacing goal was a mean value of -1 second (early), with 93% of the flights being within ± 10 seconds of this mean (very close to the assumed performance for benefits estimation).

Analyses were conducted to compare the delivery accuracy of the aircraft conducting IM operations over meter points versus the delivery accuracy of those aircraft that were not conducting IM operations. Aircraft conducting IM operations demonstrated smaller mean values and standard deviations in both inter-arrival time (IAT) for time-based IM operations and inter-arrival distance (IAD) for distance-based IM operations, as compared to non-IM operations. The improved delivery accuracy demonstrated with IM operations in this operational evaluation supports future TBO that minimize vectoring from Performance-Based Navigation (PBN) arrival routes.

The results showed the spacing precision claimed in prior work was achieved in a real-world environment including operational uncertainties, such as winds and unexpected speed changes from the Lead aircraft. The IM spacing performance was significantly better than what can be achieved using time-based metering decision support tools and controller-issued speed instructions alone. Prior studies showed that increased spacing precision at arrival meter fixes, like those operations studied as a part of this operational evaluation, can lead to flight efficiency benefits because flights are better able to remain on their planned arrival procedures. 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 travel.

[1] The term mean value is equivalent to the word "average."

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 personnel
    - The Belmont Group, Inc.
    - Blue Mountain Aero, LLC
    - The MITRE Corporation
    - The Regulus Group

Contents

1 INTRODUCTION 3

1.1 AIRS PROJECT OVERVIEW 3
1.2 AIRS PROJECT OPERATIONAL EVALUATION APPROACH 4
1.3 DOCUMENT SCOPE 4

2 INITIAL-INTERVAL MANAGEMENT OPERATIONAL BENEFITS EVALUATION 5

2.1 INTERVAL MANAGEMENT OVERVIEW 5
2.2 INITIAL-INTERVAL MANAGEMENT OVERVIEW 8
2.3 AIRS I-IM OPERATIONAL EVALUATION LOCATION 12
2.4 ACSS SAFEROUTE+ AND SPACING APPLICATION OVERVIEW 15
2.5 ASSIGNED SPACING GOAL 18
2.5.1 Distance-Based ASG Determination 18
2.5.2 Time-Based ASG Determination 18
2.6 IDENTIFYING AIRCRAFT ELIGIBLE FOR AN IM CLEARANCE 20
2.7 IM OPERATIONAL PHASES 21
2.7.1 Pre-Initiation 21
2.7.2 Initiation 21
2.7.3 Execution 22
2.7.4 Cancellation 23
2.8 PHRASEOLOGY 24
2.8.1 Initial Phraseology 24
2.8.2 Descend Via Operations 27
2.8.3 Phraseology Changes 28
2.9 TRAINING 29
2.9.1 Pilot Training 29
2.9.2 Controller Training 30
2.10 SAFETY RISK MANAGEMENT 30
2.11 PROJECT IMPLEMENTATION DETAILS 31
2.11.1 ACSS SafeRoute+ Equipage 32
2.11.2 Project Reviews and Coordination 33
2.11.3 Evolution of the Operational Evaluation 33
2.11.4 Controller/Pilot Exposure to IM Operations 34

3 DATA SOURCES AND COLLECTION 35

3.1 OVERALL APPROACH TO DATA COLLECTION AND USE OF DATA 35
3.2 DATA REPOSITORY 37
3.3 CONTROLLER FEEDBACK AND OBSERVATIONS 38
3.3.1 Controller Feedback Forms 38
3.3.2 Directed Discussions 41
3.4 FLIGHT CREW FEEDBACK AND OBSERVATIONS 41
3.4.1 APA Discussions with Flight Crews 41
3.4.2 Line Operations Safety Audit Program Feedback 42
3.5 FALCON REPLAY RECORDINGS 42
3.6 INSTRUMENT FLIGHT PROCEDURES, OPERATIONS, AND AIRSPACE ANALYTICS 43
3.7 FAA VOICE TRANSCRIPT DATA 43
3.8 FAA TBFM DATA 43
3.9 SAFEROUTE+ DATA 44
3.10 TRAFFIC COMPUTER DATA EVENT ANALYSIS 46

4 ANALYSIS AND RESULTS 53

4.1 SAFETY HAZARD ASSESSMENT 53

4.2 Controller Feedback ... 55
4.2.1 ZAB Controller SME Feedback ... 55
4.2.2 Example of Improperly Entered IM Clearance (Bad Geometry) ... 58
4.2.3 First Example of IM Speed Limiting ... 60
4.2.4 Second Example of Speed Limiting ... 62
4.2.5 Example of IM Operation during Descend Via procedure ... 64
4.2.6 Directed Discussions ... 68
4.3 Flight Crew Feedback ... 70
4.3.1 APA Interviews ... 70
4.3.2 LOSA Observations ... 73
4.3.3 Flight Crew Interface Changes Resulting from the Operational Evaluation ... 74
4.4 Number of Attempted IM Operations from Controller Feedback Forms ... 76
4.5 Tracking Concerns and Issues ... 77
4.5.1 Concerns and Issues ... 77
4.5.2 Concern and Issue Trends ... 79
4.6 Number of IM Events from SafeRoute+ Data ... 81
4.6.1 Approach to Determine Relevant IM Events ... 81
4.6.2 Number of Relevant IM Events ... 82
4.7 IM Speeds, Pilot-Selected Speeds, and Speed Compliance ... 84
4.7.1 Approach to Count Speeds and Determine Speed Compliance ... 84
4.7.2 Results on Speeds and Speed Compliance ... 85
4.7.3 Example of Good Speed Compliance ... 88
4.7.4 Example of Poor Speed Compliance ... 89
4.7.5 Speed Compliance Issues Associated with Display of Current Spacing ... 91
4.8 Delivery Accuracy and Error for Relevant IM Events ... 91
4.8.1 Analysis Methodology for Delivery Accuracy and Error ... 91
4.8.2 Delivery Accuracy and Error Analysis Results for IM Aircraft with Distance-Based ASGs ... 93
4.8.3 Delivery Accuracy and Error Analysis Results for IM Aircraft with Time-Based ASGs ... 96
4.9 Inter-arrival Time and Inter-arrival Distance for IM and Non-IM flights ... 100
4.9.1 Analysis Methodology for Inter-arrival Time and Inter-arrival Distance ... 100
4.9.2 Results of Inter-arrival Time and Inter-arrival Distance Analyses for IM and Non-IM flights ... 102
4.10 CP and PCP Issues ... 106

5 LESSONS LEARNED ... 108

5.1 Operational Evaluation Approach and Focus ... 108
5.2 Phraseology ... 108
5.3 Lack of IM-Specific ATC Automation Tools ... 108
5.4 Pilot Training ... 109

6 CONCLUSION ... 110

7 ACRONYMS ... 112

8 REFERENCES ... 114

9 APPENDICES ... 116

9.1 SafeRoute+ Impact on IM Operations ... 116
9.1.1 Other Avionics Differences ... 130
9.2 Directed Discussions – Controller Feedback Results ... 135
9.3 AIRS A321 Workaround SRM Document ... 139
9.4 AIRS I-IM ZAB Operational Evaluation SRM Document ... 140

1 Introduction

1.1 AIRS Project Overview

Global air traffic demand continues to rise, with predicted year-over-year increases of 3.8%[1]. To address this increased demand, new capabilities and procedures are needed to increase air traffic throughput without compromising safety.

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, throughput, 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 to mitigate the growth of NAS-wide delays and projected airport throughput 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 airport throughput and realize TBO and NextGen objectives[2].

In 2012, the ADS-B In Aviation Rulemaking Committee (ARC) was tasked by the FAA with defining "a strategy for incorporating ADS-B In technologies into the NAS"[3]. Two key recommendations were made by the ARC. The first was to prioritize "five key ADS-B In applications with the greatest potential to positively affect the ADS-B In business case." Most of these applications were Interval Management as defined in RTCA/EUROCAE standards[4][5] (see Section 2.1). The ARC also requested that the FAA conduct "flight trials for a sufficient number of ADS-B In applications to validate the utility of operational concepts and validate the business case…"[3].

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 operational evaluation enabled the FAA and the aviation industry to:

- Evaluate and confirm operational benefit assumptions
- Evaluate the use of an ADS-B Guidance Display (AGD) as a retrofit solution in the flight deck forward field of view
- Validate ADS-B In avionics performance in 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
- Gain experience on phraseology and procedures for future NAS-wide implementation
- Further the development and deployment of ADS-B In technology

1.2 AIRS Project Operational Evaluation Approach

The AIRS operational evaluation involved a unique approach to managing the risks associated with introducing new technologies and operations into the NAS. The operational evaluation was conducted using certified aircraft operating in revenue service but was limited to specified airspace regions for a period of two years. The evaluation did not include significant, potentially costly, ATC automation enhancements necessary for all envisioned operations. This operational evaluation was not a flight test series involving experimental aircraft, nor was it a NAS-wide implementation. The operations and certified avionics were intended to be representative of solutions that could be deployed NAS-wide.

The operational evaluation approach allowed the FAA and industry to make modifications based on data obtained during the evaluation. For example, based on feedback obtained during the operational evaluation, 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, from mid-2020 until the end of 2023, AAL retrofitted their entire Airbus A321 fleet, comprised of A321ceo (current engine option) and A321neo (new engine option) aircraft, with the commercially available ACSS SafeRoute+ avionics suite. This flight deck system and applications enabled Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS), CDTI Assisted Separation on Approach (CAS-A), and Initial-Interval Management (I-IM) operations. When the operational evaluation began in November 2022, 224 AAL Airbus 321 aircraft were equipped. By the end of the operational evaluation, 298 AAL Airbus 321 aircraft were equipped.

1.3 Document Scope

The AIRS Initial-Interval Management (I-IM) operational evaluation was conducted in partnership with the Albuquerque Air Route Traffic Control Center (ZAB), with operations beginning in November 2022 and ending in November 2024. The purpose of this report is to document the results from the operational evaluation over this period. This document provides an overview of the operational evaluation, a description of the data collection process, analyses of the data obtained, and a summary of key lessons learned.

2 Initial-Interval Management Operational Benefits Evaluation

2.1 Interval Management Overview

Interval Management (IM) is an ADS-B-enabled operation that uses a combination of ground automation, flight-deck capabilities, and procedures to conduct relative spacing operations between aircraft. Relative spacing describes managing the position of one aircraft relative to another aircraft, as opposed to managing the aircraft to a static reference such as crossing a waypoint at a specified clock time. To initiate an IM operation, air traffic control instructs the flight crew of an equipped IM aircraft to achieve and then maintain a spacing goal, relative to a specified Lead aircraft (see Figure 1). The relative spacing goal may be issued as a distance value, supporting operations like Miles-in-Trail, or a time value, facilitating time-based metering operations.

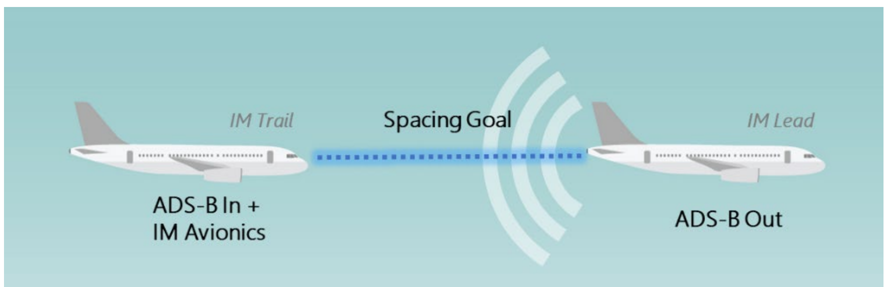


Figure 1 - Depiction of basic IM operation

Enabled by ADS-B reports from the Lead aircraft, the IM avionics onboard 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. IM operations result in consistent, low variance spacing between aircraft during level cruise or arrival phases of flight. Precise inter-aircraft spacing will allow reduced inter-aircraft spacing intervals, resulting in increased throughput at constraint points along the arrival path. Airport arrival throughput is expected to increase when IM operations are conducted in terminal airspace and end close to the arrival runway. Flight efficiency is also expected to increase, as IM aircraft are managing their spacing using speed changes alone and avoiding costly, low-altitude maneuvering[2].

In envisioned end-state IM operations, controllers will have automation support and procedures to identify eligible aircraft, along with the necessary information to issue IM clearances, including coordination across sectors. The IM clearance may include[2] the Lead aircraft's identification; the Assigned Spacing Goal (ASG); the Cross Point (CP) where the ASG must be achieved; the Planned Cancellation Point (PCP), where the IM operation is automatically cancelled; and the Lead aircraft's Intended Flight Path Information (IFPI), which describes the Lead aircraft's navigation clearance. Upon receiving an IM clearance, the flight crew enters the information into their IM avionics. The IM avionics calculates the IM speed (also referred to as the Commanded Speed in some documents) to achieve and/or maintain the ASG based on the IM clearance. Both

[2] The IM avionics standards describe different IM clearance types which may be used for different operational scenarios based on, for example, controller objectives, traffic flows, and route geometries. The IM clearance elements vary across the different IM clearance types as some information can be implied.

the flight crew and the controller are provided with situational awareness information to monitor the progress of an IM operation.

The full set of IM operations is described in RTCA/EUROCAE DO-328B/ED-195B "Safety, Performance and Interoperability Requirements Document for Airborne Spacing—Flight Deck Interval Management (ASPA-FIM)"[4][5]. The IM avionics requirements are specified in RTCA/EUROCAE DO-361A/ED-236A, Change 1, "Minimum Operational Performance Standards (MOPS) for Flight-Deck Interval Management (FIM)"[6][7]. The IM operations and the avionics requirements have been developed to support a 10-second spacing tolerance.[3]

The IM avionics determine the IM speeds to meet spacing objectives based on IM clearance elements. One key IM operational objective is to achieve the ASG at the CP. The CP can be any merge point on the Lead and IM aircraft's routes, including merge points late in the arrival procedure.[4] To support these types of IM operations, the IM avionics must determine the IM speeds based on a prediction of when the Lead and IM aircraft will cross the CP. The type of algorithm used is termed a trajectory-based algorithm due to its reliance on a prediction of each aircraft's four-dimensional (4D) trajectory between its current position and a downstream point. Trajectory-based algorithms are contrasted with state-based algorithms, which only involve calculations using Lead and IM aircraft current (or historical) positions and speeds.

A description of prior research that demonstrated the need for a trajectory-based algorithm using Lead and IM aircraft 4D trajectories can be found in DO-328B/ED-195B, Appendix B-6[4][5]. The referenced study evaluated whether an algorithm using the Lead aircraft's current state[5] and its assumed horizontal path could meet the 10-second spacing tolerance at the CP when the Lead and IM aircraft are on different routes prior to the CP[8]. The state-based algorithm used in the referenced study defined the spacing interval based on the distances to the CP for the Lead and IM aircraft. The IM speeds were calculated to linearly reduce the initial spacing interval to the ASG over the IM aircraft's remaining distance to the CP. Results showed that the state-based algorithm performed worse than a trajectory-based algorithm since the approach of correcting spacing error linearly over the IM aircraft's remaining distance to the CP does not account for differences in the ground speed profiles of the Lead and IM aircraft. Differences in ground speed profiles result from differences in speed and altitude restrictions on navigation procedures as well as wind conditions experienced by the Lead and IM aircraft along their routes of flight. This was illustrated using several IM operations with different wind conditions, where the initial positions of the Lead and IM aircraft were chosen such that the spacing was equal to the ASG at the CP when both aircraft flew their navigation procedures[8]. The spacing interval, as defined in the state-based algorithm,

[3] 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.

[4] The FIM MOPS also describes IM operations where the Lead and IM aircraft never merge. In those cases, the spacing is measured relative to a Traffic Reference Point (TRP) on the Lead aircraft's route and the CP on the IM aircraft's route. For simplification, this section describes the case when the Lead and IM aircraft's routes merge at the CP.

[5] The current state term means the current aircraft position in three dimensions (3D: latitude, longitude and altitude) as well as the current aircraft 3D velocity vector.

does not behave linearly with respect to the IM aircraft's distance to the CP and varies significantly based on the winds. Therefore, the assumption of a linear spacing error correction does not support the desired spacing performance. The state-based algorithm's inherent inability to anticipate aspects of the Lead aircraft's ground speed profile along its route leads to significantly worse spacing performance than trajectory-based algorithms, especially over longer IM operations where initial IM speeds could lead to an infeasible operation with spacing performance well outside the 10-second tolerance.

As previously noted, IM operations enable more precise inter-aircraft spacing than otherwise possible, which allows smaller inter-aircraft spacing intervals, on average, resulting in increased throughput. Several studies have quantified IM benefits given the assumed 10-second spacing tolerance. Howell et al.[9] 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. That study assumed IM operations ending at the Final Approach Fix (FAF). Table 1 shows the maximum arrival throughput increases under various weather conditions[6] for different IM operations[7] (from Table II in [9]). The different IM operations in Table 1 are described in more detail in the ADS-B In Strategy document developed by the Equip 2020 ADS-B In Working Group[10].

Table 1. Maximum Arrival Throughput Increases by Airport and For Different IM Operations (Table II in [9])

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%	

[6] Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC) are as defined by the FAA for airports; the Marginal Meteorological Conditions (MMC) definition can be found in [9].
[7] The IM operations shown are Same Runway (SR), Dependent Crossing and Converging Runways (DCCR), Dependent Staggered Approaches (DSA), and Paired Approach (PA). See DO-328B/ED-195B for details on these IM operations.

Airport	SR VMC, MMC, IMC	SR + DCCR	SR + DCCR + DSA/PA
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%		

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 should address 29.9% of those airborne delays, and the use of flight-deck (ADS-B In) applications should address 19.7% of those airborne delays.

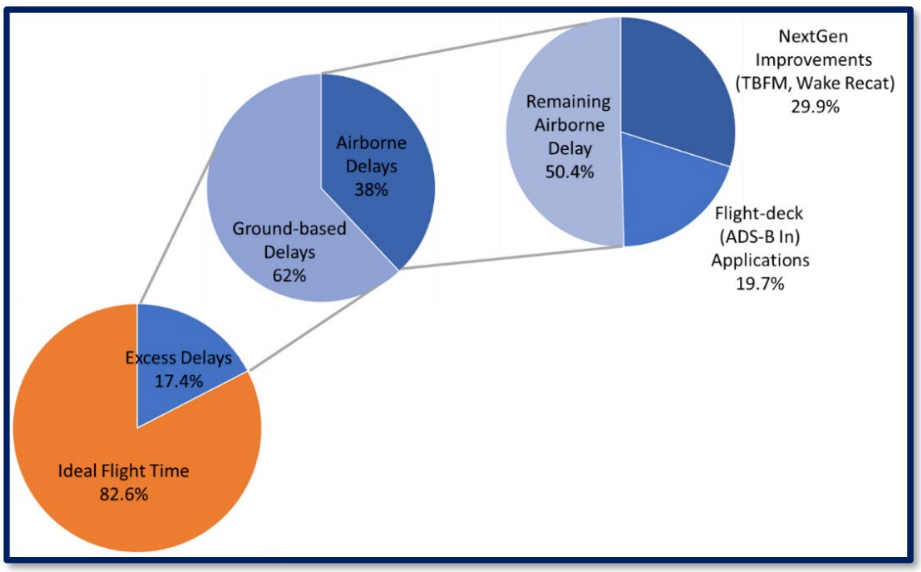


Figure 2 - Remaining shortfalls in airborne delays addressed by ADS-B In applications (see Figure 11 in [11])

2.2 Initial-Interval Management Overview

I-IM is a subset of the capabilities described in DO-328B/ED-195B. This subset consists of two IM clearance types, Cross (a constrained geometry subset of Achieve-by then Maintain in DO-328B/ED-195B) and Maintain (Capture then Maintain in RTCA DO-328B/ED-195B), 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 operational concept is contained in the FAA document entitled "ADS-B In Retrofit Spacing (AIRS) Initial–Interval Management (I-IM) Operational Description"[11].

As stated in Section 1.2, the ACSS SafeRoute+ avionics suite was installed on AAL A321 aircraft to conduct this operational evaluation. Specifically, the SafeRoute+ Spacing application was used by AAL flight crews in the conduct of operations. See Section 2.4 for an overview of the SafeRoute+ Spacing application.

A Maintain clearance was used when the IM aircraft and Lead aircraft were on a common route (see Figure 3). The SafeRoute+ Spacing application provided IM speeds that, when flown, would cause the IM aircraft to achieve the ASG as soon as possible and then maintain the ASG (within a tolerance) until the controller cancelled the operation or the IM aircraft reached the PCP (if assigned).

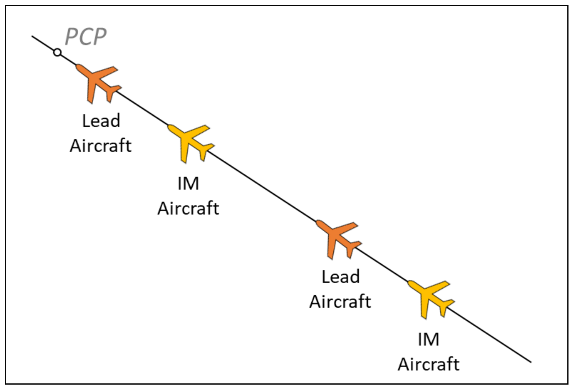


Figure 3 - IM Maintain Operation

A Cross clearance was used when the IM aircraft and Lead aircraft needed to achieve a spacing goal by the CP, which had to be a common point on their respective routes. Typically, this was used when a Lead aircraft and IM aircraft were initially on different routes that merged and continued along a common route (see Figure 4). The aircraft routes had to be direct to the CP with no turns. The SafeRoute+ Spacing application provided IM speeds that, when flown, would cause the IM aircraft to achieve the ASG (within a tolerance) at or before the CP. Once the CP was reached, the flight crew continued to fly IM speeds until the controller cancelled the operation or the IM aircraft reached the PCP (if assigned).

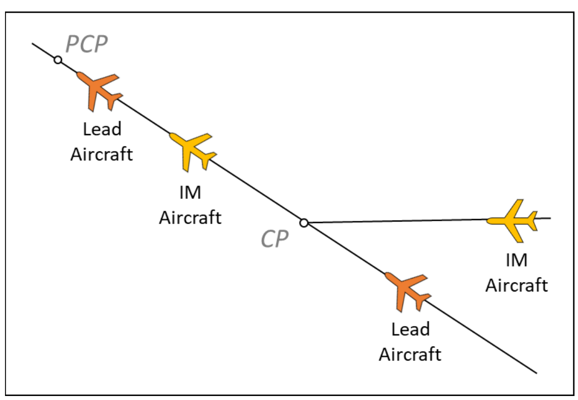


Figure 4 - IM Cross Operation

While Data Communication is envisioned as an enabler for future complex IM clearances, the operational evaluation utilized only simpler IM clearances that allowed controllers to use voice communications.

In Section 2.1, the benefits of IM operations to a FAF (the envisioned end-state IM operations) were discussed. The AIRS team also conducted an analysis of benefits from improved spacing at arrival metering fixes, which reflected the IM operations that were conducted during this operational evaluation.

An analysis by Priess and Weitz evaluated the benefits of improved spacing at the meter fixes (MFs) at the terminal airspace perimeter, used to manage arrival flows to the terminal[12]. 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 led to aircraft efficiency benefits. Table 2 relates Meter Fix (MF) delivery accuracies to a maximum flow rate across an MF where controller 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 controller interventions.

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

Category[8]	MF Accuracy (seconds, 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

Figure 5 shows the percentage 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 (DFW) exceeded 19 aircraft/hour. Current metering tools would be inadequate for keeping flights on their RNAV arrivals during these hours, and increased rates of vectoring are expected. Therefore, Figure 5 shows the benefits opportunity for improved delivery accuracy at DFW. For example, in 19% of days (69 of 365 days in 2023), current metering tools were inadequate for six hours.

[8] 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[10]. "Current metering performance" refers to the use of Time-Based Flow Management (TBFM) decision support tools as they existed in 2022. "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 flight-deck tools should yield delivery accuracies of 10 seconds, 95%, a conservative assumption on the performance of 30 seconds, 95%, was used.

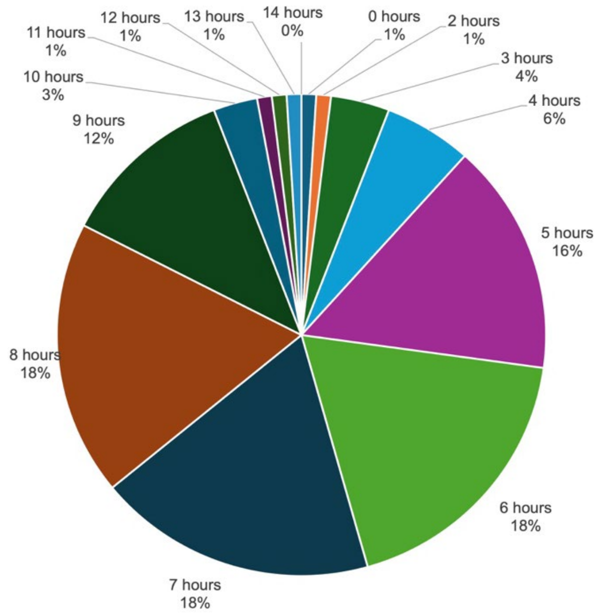


Figure 5 - Number of hours for which current metering operations are inadequate for flow rates at DFW (in 2023)

Figure 6 shows the percentage of days in 2023 with the number of hours where the arrival flow to at least one DFW arrival meter fix exceeded 24 aircraft/hour. Improved metering operations – delivering flights to their STAs within 60 seconds, 95% of the time – 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 DFW.

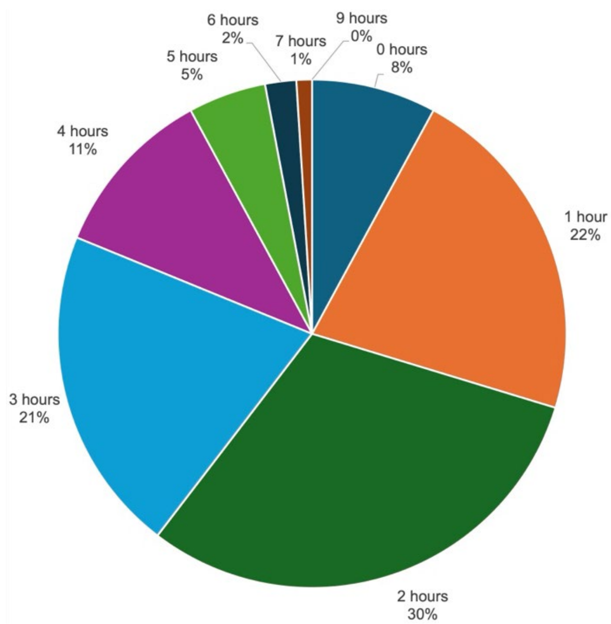


Figure 6 - Number of hours for which improved metering operations are inadequate for flow rates at DFW (in 2023)

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

2.3 AIRS I-IM Operational Evaluation 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 along with the relationship AAL had established with ZAB from defining Phoenix Sky Harbor International Airport (PHX) Area Navigation (RNAV) arrival procedures and "Descend Via" procedures. ZAB also served as the key site for Ground-Based Interval Management – Spacing (GIM-S)[13] and had relevant experience with the new operations and technologies. In addition, the arrival capacity of Phoenix normally exceeds the arrival demand, lowering the risk of introducing the new operations.

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

- Controller feedback on I-IM operations
- Comparison of I-IM spacing to legacy spacing procedures
- Evaluation of I-IM in a mixed equipage environment (i.e., aircraft equipped with the capability to conduct I-IM and those without the capability to conduct I-IM)
- Subjective evaluation of I-IM controller workload impact
- Insights into minimum ATC automation support required for national IM deployment
- Insight into phraseology requirements (including the method of providing the call sign of the Lead aircraft to the aircraft conducting I-IM in ATC instructions on a shared VHF frequency)

Figure 7 is a depiction of ZAB's airspace including the various sectors.

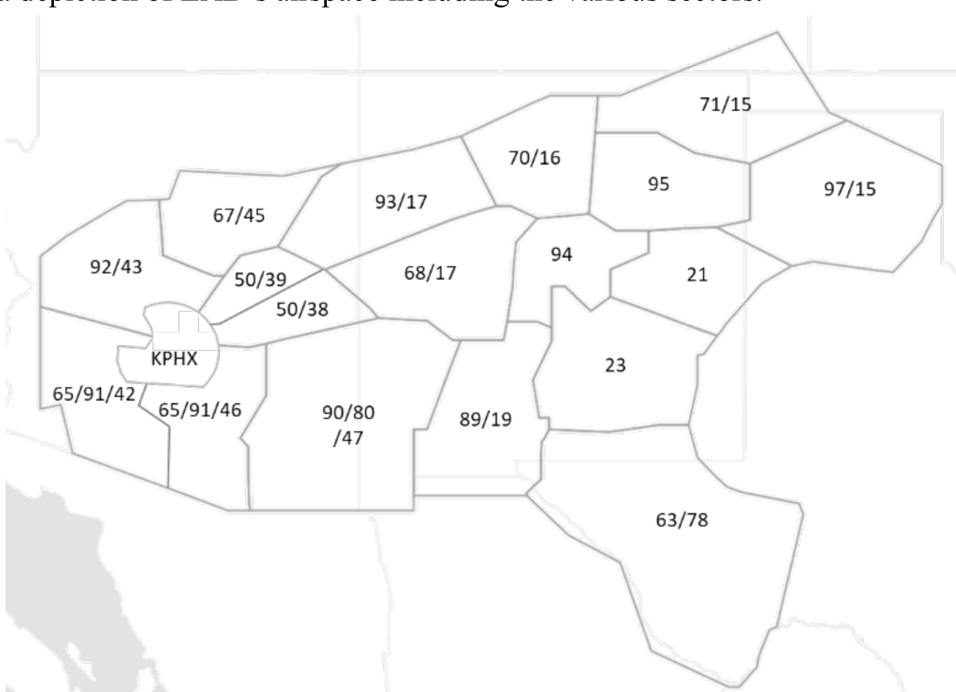


Figure 7 - Overview of ZAB airspace sectors

An area is a region of airspace made up of multiple sectors that are staffed by a team of controllers who specialize in that region of the airspace. Figure 8 shows a map of the ZAB areas[9]. Since aspects of operations often vary by area, the AIRS team included at least one controller Subject Matter Expert (SME) from each area. This provided the AIRS team insight into the use of I-IM operations for variety of operational conditions. This approach also ensured that there was someone associated with each ZAB area who could answer questions raised by controllers.

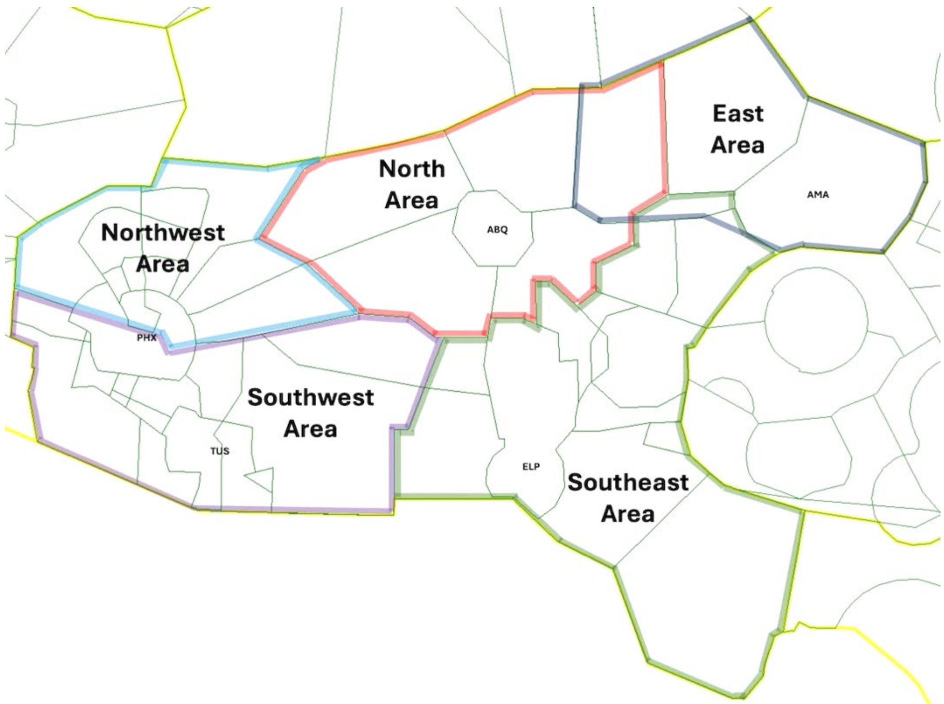


Figure 8 - Overview of ZAB areas

I-IM operations were conducted by AAL A321 aircraft on the PINNG and EAGUL RNAV Standard Terminal Arrival Routes (STARs) into PHX, and overflight routes through ZAB's airspace (see Figure 9). For overflight operations, typically a distance-based ASG in nautical miles (NM) was used. For PHX arrival operations in ZAB's airspace, both distance-based (NM) and time-based (seconds) ASGs were used.

I-IM operations were conducted in ZAB airspace with ATC surveillance, and largely in Class A airspace (only I-IM operations between EAGUL and HOMRR went below Class A airspace). For the operational evaluation, ZAB controllers used existing ATC automation.

There were no changes in separation or spacing criteria when using I-IM during the operational evaluation. Controllers determined the time- or distance-based ASG for every I-IM operation. The ASG could not violate ATC spacing or separation requirements in FAA Order 7110.65 and was required to conform to Letters of Agreement (LOAs) with other ATC facilities.

[9] The East Area has a larger horizontal extent above FL290 than below FL290 due to the sector structure of ZAB. Conversely, the North and Southeast Areas have a larger horizontal extent below FL290 than above FL290. This graphic shows the horizontal extent of the East Area at FL290 and above since AAL aircraft participating in the AIRS operational evaluation were usually operating in this airspace.

As part of PHX arrival operations, ZAB controllers issued a Descend Via clearance to arriving aircraft, which is an abbreviated ATC clearance that requires compliance with a published STAR's lateral path and associated speed/altitude restrictions. When performing an I-IM operation with a Descend Via clearance, flight crews were directed to follow the lateral path and comply with the altitude restrictions of the Descend Via clearance while complying with IM speeds provided by the SafeRoute+ Spacing application.

An I-IM operation consisted of a Lead aircraft and an IM aircraft with the SafeRoute+ Spacing application and an appropriately trained flight crew. Note that ZAB controllers typically referred to the IM aircraft as the Trail aircraft. Multiple IM aircraft could perform I-IM operations given the appropriate conditions, either as separate “pairs” of aircraft or as a continuous series of aircraft (i.e., an IM aircraft could also simultaneously be a Lead aircraft with another IM aircraft behind).

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

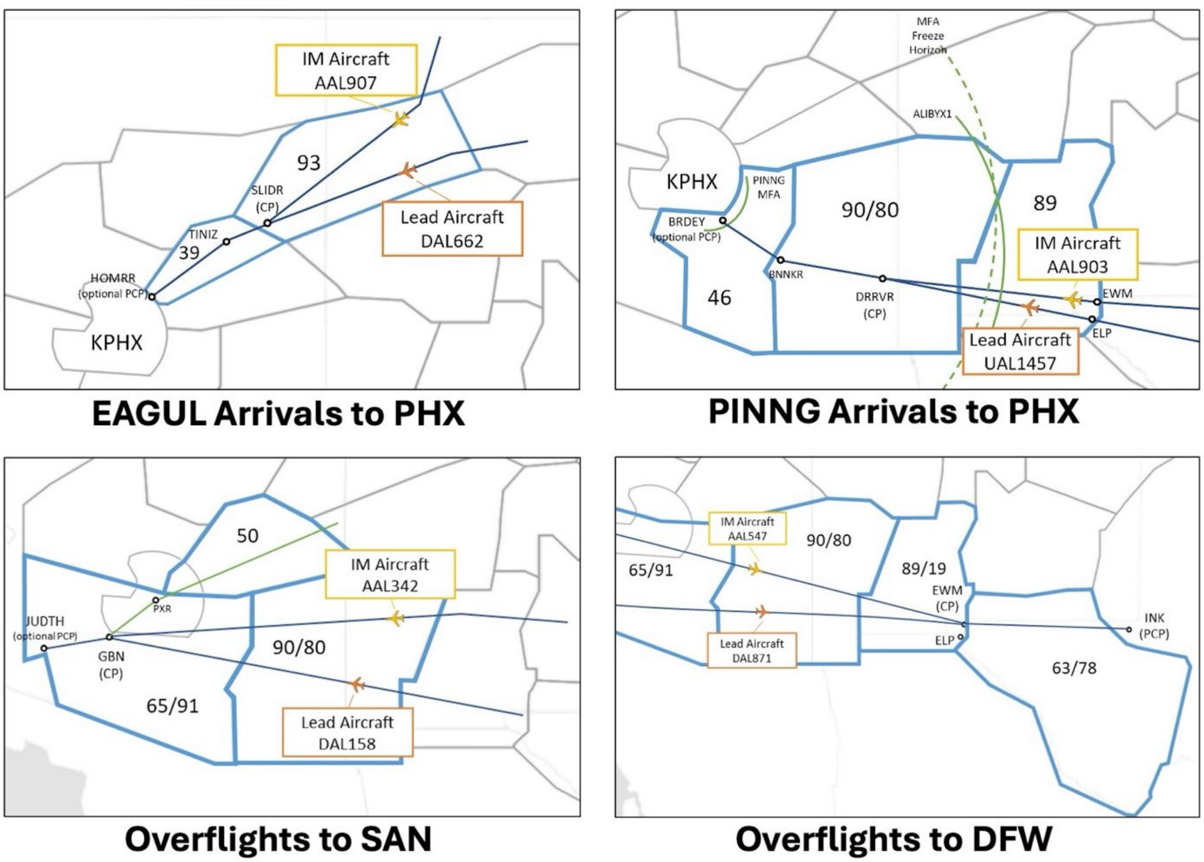


Figure 9 - Sample scenarios of I-IM operations

In the remainder of this report, for convenience, any reference to Interval Management or Initial Interval Management (IM or I-IM) will be called “IM” and must be considered in the context of a sentence. In this operational evaluation, all operations were I-IM operations (but will appear in the text below as “IM operations”). Other generic IM references or references to RTCA/EUROCAE standards do not refer to this operational evaluation.

2.4 ACSS SafeRoute+ and Spacing Application Overview

The original SafeRoute system was developed in the early 2000s, before any RTCA/EUROCAE standards for IM existed. SafeRoute+ was an update of the original SafeRoute system, with a goal that the SafeRoute+ Spacing application would appear more like a MOPS-compliant IM system. However, the SafeRoute+ Spacing application is not compliant with the RTCA/EUROCAE FIM MOPS[6][7], which limits the IM operations for which the SafeRoute+ Spacing application may be used. Some of the major differences between the SafeRoute+ Spacing application and a MOPS-compliant IM avionics system are documented in Appendix 9.1.

AAL retrofitted their entire Airbus A321 fleet with the SafeRoute+ ADS-B In avionics suite. A retrofit option was chosen to evaluate the benefits of such an avionics solution as a cost-effective approach for airlines to pursue when implementing ADS-B In applications. The ACSS retrofit architecture supplemented existing flight deck displays with a graphical AGD. The architecture included 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 10).

Figure 10 - ACSS SafeRoute+ avionics components

The AGD provided a graphical representation of surrounding traffic, like the TCAS information on the ND, but added traffic directionality and traffic information provided by ADS-B. Relative traffic position for TCAS traffic was displayed on the AGD using typical TCAS symbology (i.e., Other, Proximate, and Traffic Alert [TA]). TCAS Resolution Advisory guidance was not displayed on the AGD.

The flight crew utilized the MCDU interface to the SafeRoute+ system to search for the Lead aircraft flight ID and designate[10] that aircraft. The flight crew then entered the IM clearance information from the controller into the MCDU's Spacing application interface. After successfully accomplishing that, an IM speed was displayed on the AGD in the top left corner (under CMD SPD). The pilot flying would monitor and adjust aircraft speed (typically by selecting a speed in the aircraft's autoflight system) to match the IM speed (to achieve and/or maintain the ASG). The ASG (ASSIGNED) and current spacing (CURRENT) information were also displayed. Figure 11 shows representative information provided on the AGD and Figure 12 shows representative information provided on the MCDU when the SafeRoute+ Spacing application was active.

Figure 11 - Representative AGD for SafeRoute+ Spacing application

Figure 12 - Representative MCDU for SafeRoute+ Spacing application in Maintain stage

Current spacing information was provided on the AGD for informational purposes only. This information was not intended to be used as guidance information or something that flight crews

[10] See RTCA/EUROCAE DO-317B/ED-194A, section 1.7.1 for more information about the meaning of this term in ADS-B In systems complying with [E]TSO-C195b; the SafeRoute+ system was certified to this TSO (which does not address IM functionality) but the Designate feature was also used by the SafeRoute+ Spacing application.

needed to align with the ASG. The meaning of current spacing on the AGD was different depending on whether the SafeRoute+ Spacing application was in Cross or Maintain stage. In the Maintain stage, current spacing was a direct measure based on the Lead aircraft's ADS-B report history. However, in Cross stage, the current spacing displayed was an estimated value[11] of spacing from the Lead aircraft at the CP if there were no speed changes made by the flight crew.

One of the design goals for the SafeRoute+ Spacing application was to minimize the number of IM speed changes provided to a flight crew. In a Cross operation where the IM aircraft was not directly following the Lead aircraft, the Spacing application would estimate the predicted spacing error at the CP based on relative groundspeeds and distance to the CP. If the predicted spacing error would be eliminated before the CP, the Spacing application would delay any IM speed change until needed (zero predicted spacing error at CP) and then an IM speed would be selected to have the IM aircraft match the Lead aircraft's groundspeed. Otherwise, the Spacing application would adjust the IM speed to achieve the ASG at the CP.

Some other limitations of the SafeRoute+ Spacing application that impacted operations included the following:

- Both the IM and Lead aircraft had to be on the same route or direct to a common fix (the CP in a Cross clearance). Direct to a common point meant there could be no course changes (within a tolerance) between the current position of either the Lead or IM aircraft and the CP, though there could be intermediate waypoints. The CP had to be within a 40° cone of both aircraft tracks, meaning if either aircraft was vectored or had a course change in their route, the IM operation would not be initiated until both aircraft were headed direct toward the CP. Prior to the CP, the SafeRoute+ Spacing application would not provide IM speeds (and would notify the flight crew) if either the Lead or IM aircraft had failed this path conformance check.
- During the Maintain stage (i.e., both Lead and IM aircraft on same route), the cross-track difference between the IM aircraft's current position and Lead aircraft's historical position had to be within an 8 NM wide "swimlane" centered around the IM aircraft's instantaneous position and track projection.
- To initiate a Maintain clearance, one of the following three cases existed: (1) the Lead aircraft had to be ahead of the IM aircraft and within a 6-NM wide swimlane centered around the IM aircraft's instantaneous position and track projection; (2) the IM aircraft had to be behind the Lead aircraft and within a 6-NM swimlane centered around the Lead aircraft's historical track; or (3) the instantaneous tracks must have an intercept angle less than 90° and intersect in front of the IM aircraft and behind the Lead aircraft (see Figure 13 for a depiction of the third case).

[11] The estimated value was calculated by the SafeRoute+ Spacing application based on the Lead and the IM aircraft's current groundspeeds and distances to the CP.

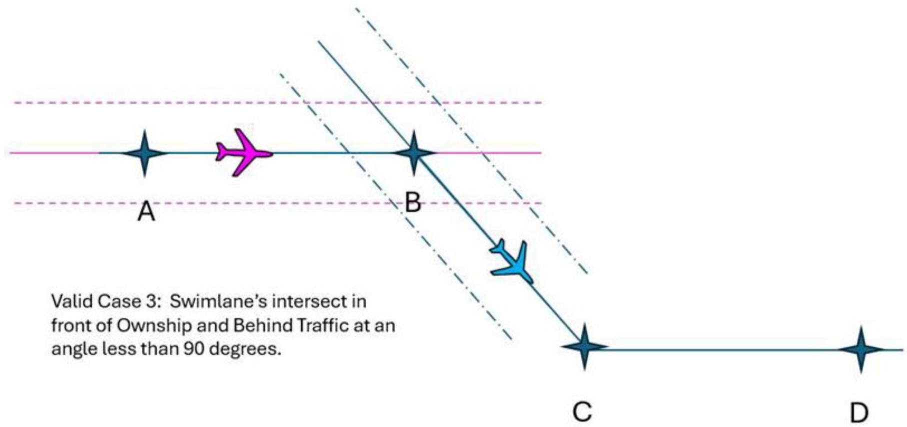


Figure 13 – Valid Geometry to Initiate a Maintain Clearance

For more details on the limitations of the SafeRoute+ Spacing application as compared to systems compliant with DO-361A/ED-236A, refer to Appendix 9.1.

2.5 Assigned Spacing Goal

Before issuing an IM clearance, the controller identified an IM aircraft and Lead aircraft. The controller also determined the time-based or distance-based Assigned Spacing Goal (ASG) and a CP, if applicable. The ASG could not violate ATC spacing or separation requirements in FAA Order 7110.65 and had to 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. At ZAB, the TMU publishes MIT restrictions on the Enhanced Status Information System (ESIS) boards.

2.5.2 Time-Based ASG Determination

Determining appropriate time-based IM clearances without automation support was 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 14). The TMC or supervisor determined the expected groundspeed of a potential IM aircraft and the desired distance-based spacing objective at the ZAB airspace boundary with the Phoenix Terminal Radar Approach

Control Facility (TRACON), known within the FAA as P50. Using this information, the TMC referenced the Look Up Table to find the time-based spacing value that complied with the distance-based spacing objective. If the ASG Look-up Table was used for operations, then the TMC would coordinate the time-based ASG with the area's supervisors.

		Expected Groundspeed (knots) at ZAB boundary with P50						
		250-260	270-280	290-300	310-330	340-360	370-390	400-420
Desired inter-arrival distance (NM) at ZAB boundary with P50	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	120	110	105	100
	11	165	155	145	135	125	115	105
	12	180	165	155	145	135	125	115
		ASG in seconds						

Figure 14 – ASG Look-up Table

2.5.2.2 ASG Support Tool

As part of previous IM development activities, 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, used Time-Based Flow Management (TBFM) System Wide Information Management (SWIM) data to calculate applicable ASG values, as described below. The tool was a stand-alone external Java-based application that was run from a folder in a Windows environment. The tool was not integrated into the TBFM system, nor did it reside within the SWIM infrastructure.

Personnel from WJHTC made slight modifications to the Graphical User Interface (GUI) (see Figure 15) and pairing functionality to support the AIRS operational evaluation. TBFM data was published via SWIM (independent of this operational evaluation) and consumed by the ASG Support Tool residing on an FAA computer located in the TMU.

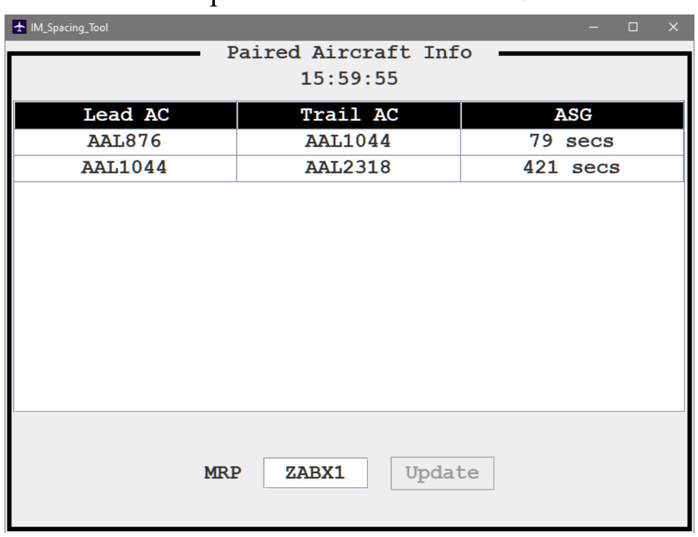


Figure 15 - ASG support tool GUI

The tool took in a user-entered Meter Reference Point (MRP) and filtered all aircraft from the TBFM messages to only those flying over the given MRP. If the filtered aircraft were frozen in the

TBFM schedule and identified as an AAL aircraft with an A321 type designator[12], the tool then looked at the next earliest aircraft in the TBFM sequence for a potential Lead aircraft. The difference in TBFM STAs for both aircraft was then calculated and displayed in seconds by the tool as the ASG.

The ASG Support Tool was utilized briefly during time-based metering operations, but a recurring issue was identified quickly thereafter. The tool was identifying the correct Lead aircraft for the appropriate IM aircraft in the TBFM-generated sequence, but the ASGs calculated were too small for some Lead-IM aircraft groupings. Multiple recorded examples were displayed at values around 30 seconds, an inappropriate spacing value, and TMU did not believe the tool was working properly.

However, after post-event analysis of the TBFM data, it was shown that a TMC was manually changing TBFM STAs upstream in the Extended Metering (XM) environment. This manual scheduling overrode the TBFM-generated schedule, and the aircraft were no longer deconflicted by the system. As the ASG Support Tool consumed 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 ZAB metering operations.

2.6 Identifying Aircraft Eligible for an IM Clearance

Since IM operations are initiated by a controller, the controller needs to know which AAL A321 aircraft can perform 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 most of the AIRS operational evaluation period. Additionally, while AAL 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 could conduct 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, AAL A321ceo and A321neo aircraft that were not equipped would use the "A21N" ICAO aircraft type designator. This allowed ZAB controllers displaying the aircraft type designator on ERAM to quickly identify eligible AAL participants in the evaluation.

[12] This was the IM aircraft, displayed as "Trail AC" by the tool.

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 operating AAL A321 aircraft 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 AAL A321 aircraft (aircraft type designators of A321 and A21N).

A Safety Risk Management Panel (SRMP) comprised of FAA, NATCA, Professional Aviation Safety Specialists (PASS), ACSS and AAL 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 were 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 March 2022 (see Appendix 9.3).

2.7 IM Operational Phases

An IM Operation consisted of four phases: pre-initiation, initiation, execution, and cancellation. A description of each phase is listed below.

2.7.1 Pre-Initiation

The first step to begin an IM operation was for a controller to identify an appropriately equipped AAL A321 aircraft. Once the IM aircraft was identified, the controller evaluated other aircraft to determine if a candidate Lead aircraft existed. When TBFM metering was turned on and the ASG Support Tool was in use, TBFM data was used to determine the Lead aircraft in the sequence. Otherwise, this determination was made considering several factors, such as initial spacing and operational goals. A controller monitored the position of the candidate IM aircraft and identified 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 began when a controller issued, via voice, the IM clearance to the flight crew of the IM aircraft. The elements of the clearance included the type (Cross or Maintain), Lead aircraft ID, ASG, CP (when issued a Cross clearance), and, optionally, a PCP. The flight crew received the IM clearance and read back the clearance to the controller to confirm the information.

The Lead aircraft, IM aircraft, and ASG were entered into the fourth line of the ERAM data block for cross-sector coordination purposes. The controller entered the following information on the ERAM display:

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

The flight crew entered the clearance elements into the SafeRoute+ Spacing application, performed a cross-cockpit verification of the entry, and executed the clearance, which triggered the SafeRoute+ Spacing application to provide an IM speed on the AGD (assuming initiation criteria were met).

In the case of a Cross clearance with a time-based ASG, the avionics performed a feasibility check[13] to determine if the ASG could be met within a 15 second tolerance by the CP. The avionics then notified the flight crew of the clearance feasibility as shown in Figure 16. In the case of a failed feasibility check or if the flight crew determined that the operation was not acceptable for other reasons, the flight crew notified a controller and awaited further instructions.

Figure 16 - SafeRoute+ Spacing application infeasibility notification on the MCDU

2.7.3 Execution

The Execution phase began when the IM aircraft flight crew began to implement the IM speeds by dialing the IM speed displayed on the AGD into the A321 Flight Control Unit (FCU). During the operation, if the SafeRoute+ system recognized the need for a new IM speed, the flight crew was notified of the new IM speed on the AGD.

When an IM Speed change occurred, the IM Speed value flashed on the AGD until the IM Speed was entered on the FCU or was acknowledged by pressing the AGD Control Knob button. When an IM Speed change was not followed for 15 seconds (i.e. the IM Speed was not entered on the FCU), an advisory message “ADJUST SPEED” was displayed in reverse white on the AGD. This message was removed when a new IM Speed was provided, the IM Speed was entered on the FCU, or when the AGD Control Knob button was pressed.

[13] The feasibility check was performed assuming the Lead aircraft would maintain its current groundspeed to the CP and considering a minimum and maximum airspeed/Mach profile for the IM aircraft, based on its current airspeed/Mach envelope (e.g. V_{min}, V_{max}) and assuming constant (current) winds.

With the presentation of each IM Speed, the IM aircraft flight crew ensured that the IM Speed was acceptable considering the current aircraft configuration, environmental conditions, and airspace speed restrictions. If the flight crew determined they were unable to fly the IM Speed, they would contact a controller, report “unable,” and then await instruction. Otherwise, the flight crew dialed the new IM Speed displayed on the AGD into the Flight Control Unit (FCU) and the aircraft followed the IM Speeds to achieve and maintain the ASG.

Flight crews were to follow IM Speeds until the IM operation was canceled by a controller. This could be accomplished by several different methods:

- A controller instructed the flight crew to cancel the IM operation
- A controller issued a speed instruction to the flight crew
- When controllers issued an IM Clearance, the clearance could include a controller-specified waypoint, the PCP, where the IM Operation should end.

If at any time the flight crew did not feel comfortable with the IM speed or deemed the operation to be unacceptable, they could contact a controller, report “unable,” and await instruction.

A controller continually monitored and was responsible for separation for all aircraft, including those involved in the IM operation, by using existing surveillance capabilities and procedures. If the controller required spacing other than that provided by IM or was notified by a flight crew of an issue with the IM operation, the controller could cancel (formally or by way of speed instruction) or amend the IM operation. If the controller intended to provide vectors or re-routing to either the IM aircraft or the Lead aircraft, the controller instructed the flight crew of the IM aircraft to cancel the IM operation. The flight crew or controller could cancel the operation at any time, if they deemed the operation unacceptable.

Verbal coordination among controllers within ZAB was required if:

- Lead and IM aircraft were in different ATC sectors, including when a controller initiated or cancelled an IM operation or when the Lead aircraft deviated from their planned route of flight (due to a controller-issued vector or pilot initiation)
- The PCP was not in the ATC sector where the IM clearance was initiated
- The CP was not in the ATC sector where the IM clearance was initiated

The ASG, CP, and PCP could be modified after the initial IM clearance, if necessary.

2.7.4 Cancellation

For the operational evaluation, the use of a PCP was deemed optional and was infrequently used. As a result, ZAB controllers cancelled 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 was given a speed instruction from a controller, they cancelled the IM operation in the SafeRoute+ Spacing application, at which point IM Speeds were no longer provided. The flight crew would then fly speeds issued by a controller.

For IM Clearances that included a PCP, the SafeRoute+ equipment automatically cancelled the IM Application when the IM aircraft reached the PCP. After cancellation, the SafeRoute+ equipment no longer displayed IM Speeds. To avoid any potential confusion concerning flight crew action after cancellation, the controller issued specific control instructions for the flight crew to follow.

2.8 Phraseology

During the operational evaluation, specific phraseology was used by controllers and IM aircraft flight crews as part of the IM operation. The phraseology used at the start of the operational evaluation was developed by the AIRS team and documented in an Operational Description[11]. This phraseology was based on material from the Operational Services and Environment Definition contained within DO-328B/ED-195B[4][5].

One concern in the development of phraseology for this operational evaluation involved the need to use a call sign of an aircraft that was being spoken about, versus spoken to, and the potential for that to cause confusion. This topic, called third-party call sign confusion, has been studied in detail in the past[14]. ZAB controllers used aircraft call signs when identifying the Lead aircraft in the IM clearance. The IM phraseology was structured to put the Lead aircraft's call sign at the end of any ATC instruction or clearance as much as possible. Another concern was that flight crews might not know an operator's three-letter designator – while "AAL" was obvious for "American", "RPA" may not be obvious for pilots as meaning "Brickyard". Therefore, controllers and flight crews had the option to use a phonetic version of the Lead aircraft identification if desired (e.g., they may say "J-I-A" or "Juliet India Alpha" instead of "Blue Streak").

The operational evaluation used waypoints commonly used for routing aircraft in ZAB and controllers used the waypoint name (e.g., Gila Bend) in IM clearances rather than phonetic versions of the identifier (e.g., G-B-N). As happens in standard operations, flight crews were able to request clarification or confirmation if they were unfamiliar or uncertain about the intended waypoint.

There was also concern during the development of phraseology about the length of an IM clearance, so every effort was made to keep such clearances as short as possible. The initial philosophy was that controllers and flight crews could be trained to understand the implied meaning behind some of the terms used (i.e., a Cross clearance means "Cross [waypoint] and maintain" the ASG until the flight crew is told to cancel IM).

During the operational evaluation, the initial phraseology was modified based on feedback received by controllers and flight crews as discussed below.

2.8.1 Initial Phraseology

The AIRS team assumed that flight crews may not be prepared for an IM clearance. It was decided that it would be prudent to have controllers advise the flight crew of an impending IM clearance using the following clearance:

ATC Message: "*[IM aircraft call sign],* SPACING CLEARANCE, ADVISE READY TO COPY"

- "American 755, spacing clearance, advise ready to copy"

Flight crews were expected to reply with:

<u>Flight deck message</u>: "*[ATC Facility], [IM aircraft call sign]* READY TO COPY*"*

- "Albuquerque Center, American 755 ready to copy"

Controllers would then issue either a Maintain clearance or a Cross clearance:

Maintain clearance

<u>ATC Message</u>: "*[IM aircraft call sign],* MAINTAIN *[Assigned Spacing Goal]* BEHIND *[Lead aircraft call sign]"*

- "American 123, Maintain eight miles behind Southwest 2345"
- "American 123, Maintain 80 seconds behind Southwest 2345"

Cross clearance

<u>ATC Message</u>: *"[IM aircraft call sign],* CROSS *[Cross Point] [Assigned Spacing Goal]* BEHIND *[Lead aircraft call sign]"*

- "American 123, cross SLIDR eight miles behind Southwest 2345"
- "American 123, cross SLIDR 120 seconds behind Southwest 2345"

Although it was rarely used during the operational evaluation, ZAB controllers had the option of including a PCP in an IM clearance. If a PCP was given as part of the clearance, the PCP was provided at the end of the clearance as shown below:

Cross Clearance with PCP

<u>ATC Message</u>: "*[IM aircraft call sign],* CROSS *[Cross Point] [Assigned Spacing Goal]* BEHIND *[Lead aircraft call sign],* CANCEL AT *[Planned Cancellation Point] AND [speed instruction after PCP]*"

- "American 755, cross GBN 15 miles behind United 345, cancel at JUDTH and resume normal speed"

Flight crews would indicate their acceptance of the clearance:

Maintain clearance acceptance

<u>Flight Deck Message</u>: "*[IM aircraft call sign],* MAINTAIN *[Assigned Spacing Goal]* BEHIND *[Lead aircraft call sign]*"

- "American 755, maintain 82 seconds behind United 345"

Cross clearance acceptance

<u>Flight Deck Message</u>: "*[IM aircraft call sign],* CROSS *[Cross Point] [Assigned Spacing Goal]* BEHIND *[Lead aircraft call sign]*"

- "American 755, cross SLIDR eight miles behind United 345"

Cross clearance acceptance if PCP provided

<u>Flight Deck Message</u>: "*[IM aircraft call sign],* CROSS *[Cross Point] [Assigned Spacing Goal]* BEHIND *[Lead aircraft call sign],* CANCEL AT *[Planned Cancellation Point] AND [speed instruction after PCP]*"

- "American 755, cross GBN 15 miles behind United 345, cancel at JUDTH and resume normal speed"

If a flight crew was unable to accept an IM clearance or if the flight crew was no longer able to comply with an existing IM clearance, the flight crew would indicate that to the controller:

IM rejection by Flight Crew

Flight Deck Message: *“[ATC Facility], [IM aircraft call sign]* UNABLE SPACING *[and reason (optional)]*”

- “Albuquerque Center, American 123 unable spacing due to equipment failure”

After notification of flight crew rejection, a controller was expected to assign a speed when acknowledging notification

ATC Message: *[IM aircraft call sign],* ROGER, *[instructions as necessary]*

- “American 755, roger, maintain Mach .78”

Controllers were allowed to amend an ongoing IM clearance as needed. This was done as follows:

IM Clearance Amendment:

ATC Message: “*[IM aircraft call sign],* AMEND SPACING, CROSS *[Cross Point] [New ASG]* BEHIND *[Lead aircraft call sign]*”

- “American 745, amend spacing, cross SLIDR eight miles behind United 345”

As mentioned previously, IM operations were canceled if controllers explicitly instructed a flight crew to cancel the IM operation or if controllers provided a new speed instruction to a flight crew:

ATC Message: “[IM aircraft call sign], CANCEL SPACING, {optional} [instructions as necessary]

- “American 755, cancel spacing, maintain 310 knots”
- “American 755, resume published speeds”
- “American 755, reduce speed to Mach .75”

Figure 17 and Figure 18 show Quick Reference Cards that were created and issued to ZAB controllers to support IM Operations.

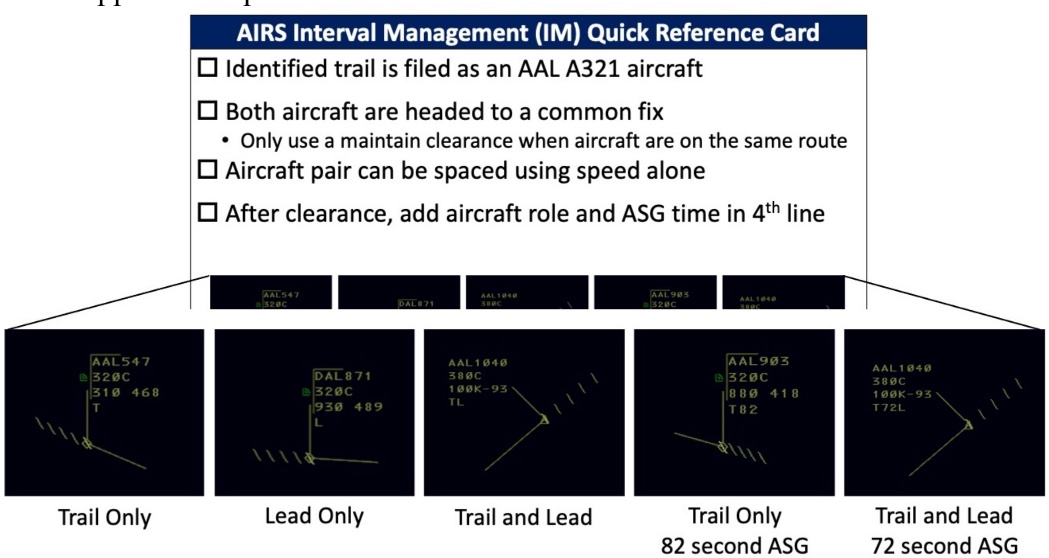


Figure 17 – ZAB Controller Quick Reference Card (1 of 2)

AIRS Interval Management (IM) Quick Reference Card

Optional Advisory
- "Spacing clearance advise ready to copy"

Maintain Clearance
- "Maintain (X Seconds) behind (Lead ID)"
- "Maintain (X Miles) behind (Lead ID)"

Cross-Then Maintain Clearance
- "Cross (Fix) (X Seconds) behind (Lead ID)"
- "Cross (Fix) (X Miles) behind (Lead ID)"

Descend Via Clearance during IM operations
- "Descend via the (Arrival) except maintain spacing"

Cancellation (e.g., if lead vectored or leaving ZAB)
- "Cancel spacing (speed instruction)"
- **Remove 4th line data prior to leaving ZAB airspace**

Lead ID options
"United" "U A L" or "Uniform Alpha Lima"

Figure 18 – ZAB Controller Quick Reference Card (2 of 2)

2.8.2 Descend Via Operations

ZAB controllers issue a "Descend Via" clearance to aircraft operating on the EAGUL SIX RNAV Arrival into PHX. The EAGUL SIX Arrival, shown in Figure 19, includes speed constraints at key waypoints in addition to altitude constraints. As an example, at waypoint TINIZ, aircraft are expected to be at or below flight level 330 (FL330) and be flying an airspeed of 270 knots (270K). When aircraft are issued a Descend Via clearance, flight crews are required to fly the lateral path and meet the altitude and procedural speed constraints listed on the arrival.

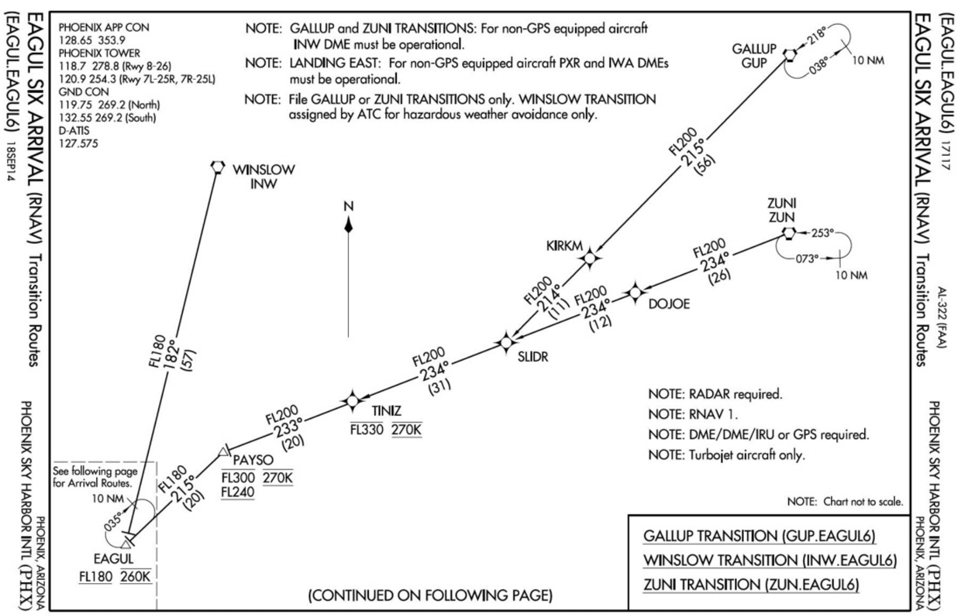


Figure 19 – EAGUL 6 Arrival to PHX (only segments to EAGUL shown)

When an IM aircraft conducting an IM Operation was issued a Descend Via clearance, it was recognized that flight crews needed to have a clear understanding about which speeds the IM aircraft was expected to follow. Therefore, ZAB controllers would issue one of two different clearances.

If a controller intended the IM aircraft to continue the IM Operation and follow IM Speeds, controllers would issue the following clearance:

Descend Via Clearance during IM operations:

<u>ATC Message</u>: "*[IM aircraft call sign],* DESCEND VIA *[STAR name],* EXCEPT MAINTAIN SPACING"

- "American 755, descend via the EAGUL6 arrival runway 26 transition, except maintain spacing"

If a controller intended the IM aircraft to cancel the IM Operation and follow procedural speeds, controllers would issue the following clearance:

Descend Via to Cancel IM operation:

- "American 123, cancel spacing, descend via EAGUL six arrival runway 26 transition"

2.8.3 Phraseology Changes

Throughout the operational evaluation, the AIRS team held periodic project reviews to discuss observations and data. Based on these discussions and feedback from controllers and flight crews, some of the phraseology was modified.

One change involved phraseology used in the Cross clearance. Feedback indicated some flight crews were asking what to do upon reaching the CP in a Cross clearance. Some flight crews thought the IM operation was complete once they reached the CP, even though the SafeRoute+ Spacing application automatically entered a Maintain stage after reaching the CP. As a result of these discussions, the phraseology for the Cross clearance was revised to include "and maintain" to clarify the operation after the CP. A sample is listed below:

<u>ATC Message</u>: "*[IM aircraft call sign],* CROSS *[Cross Point]* AT AND MAINTAIN *[assigned spacing goal]* BEHIND *[Lead aircraft call sign]"*

- "American 123, cross SLIDR at and maintain eight miles behind SWA2345"

Another change involved the initial communication from the controller to the flight crew. Most controllers used the optional "*[IM aircraft call sign]* SPACING CLEARANCE, ADVISE READY TO COPY". While this helped flight crews, feedback received from flight crews indicated that the IM Clearance was still a lot to capture in one voice transmission. Sometimes flight crews requested that the IM Clearance be repeated by the controller.

After team discussions, it was decided to first inform the flight crews of which aircraft they would be following. This would give them a chance to Designate the Lead aircraft before receiving the rest of the IM Clearance.

<u>ATC Message</u>: *"[IM aircraft call sign],* DESIGNATE *[Lead aircraft call sign]"*

- "American 456, designate Southwest 123"

\- or -

<u>ATC Message</u>: *"[IM aircraft call sign],* DESIGNATE *[Lead aircraft call sign]*, REPORT DESIGNATED".

- "American 456, designate Southwest 123, report designated"

Prior to issuing the IM clearance, a controller had to elicit a response from the flight crew to verify the correct traffic was designated (if this had not already occurred):

ATC Message: *"[IM aircraft call sign],* VERIFY TRAFFIC IS DESIGNATED".

- "American 456, verify traffic designated"

Flight crew Message: *"[IM aircraft call sign]* HAS DESIGNATED *[Lead aircraft]*".

- "American 456 has designated Southwest 123"

Once the Lead aircraft was designated, the rest of the IM Clearance was given with "designated traffic" replacing the Lead aircraft's call sign. For example:

- "American 123, maintain eight miles behind designated traffic"

This change also helped reduce the potential for third-party call sign confusion and aligned with the CAS-A clearances that were issued to AAL flight crews as part of the AIRS CAS-A operational evaluation conducted with the Dallas/Fort Worth (DFW) TRACON (D10) beginning in March 2023[15].

Another change involved an update to phraseology for Descend Via operations. In this case, "maintain spacing" was replaced with "maintain commanded speeds." It was felt that using "commanded speeds" would help emphasize to flight crews that they were supposed to follow IM speeds versus the published, procedural speeds listed on the chart. It was also felt that this updated phraseology better aligned with the flight crew task (see Section 4.3). The new message was:

ATC Message: "*[IM aircraft call sign],* DESCEND VIA *[STAR name] [Runway Transition]*, EXCEPT MAINTAIN COMMANDED SPEEDS".

- "American 456, descend via EAGUL6 arrival runway 26 transition, except maintain commanded speeds"

Similarly, phraseology for terminating an IM Descend Via operation was modified to emphasize to flight crews that they should stop using IM Speeds and use published speeds (or speeds provided by controllers).

ATC Message: "*[IM aircraft call sign],* RESUME PUBLISHED SPEEDS AT *[waypoint]*".

- "American 456, resume published speeds at HOMRR"

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 pilots of AAL Airbus single-aisle aircraft (A321, A320, A319) completed distance learning computer-based training (CBT) specific for IM operations. The training material covered:

- Description of IM and the operational evaluation
- Pilot and controller 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 aircraft on their company issued iPads.

During the IM operational evaluation, AAL 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 for flight crew awareness. One example of this was a CCI that was used to clarify the proper way to enter Cross clearances in the SafeRoute+ Spacing application.

As discussed further in Section 4.3.1, an interactive training device, known as ETHOS, was developed by ACSS for AAL pilots, and this was released about halfway through the operational evaluation.

2.9.2 Controller Training

All ZAB controllers completed four hours of IM training before the start of the 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
- Controller and pilot roles and responsibilities
- Scenarios

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

2.10 Safety Risk Management

Safety Risk Management (SRM) work was conducted prior to starting the operational evaluation. An SRM panel was convened May 24-25, 2022, to identify and assess hazards associated with the proposed 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), ZAB, NATCA, AAL management and flight operations, APA, and 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 and is Appendix 9.4 of this document. The scope of the SRMD included the coordinated use of IM by controllers in ZAB airspace and AAL flight crews operating ACSS-equipped A321 aircraft in-trail (or direct to same route) of an ADS-B Out Lead aircraft.

2.11 Project Implementation Details

The AIRS project was a public-private partnership that included 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 was 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 goal of demonstrating operational feasibility and evaluating the value of operations using certain 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 ACSS SafeRoute+ Equipage

AAL equipped their fleet of A321ceo and A321neo aircraft with ACSS SafeRoute+ avionics. The A321ceo aircraft were equipped with the ACSS TCAS 3000SP system and the A321neo aircraft were equipped with the ACSS T3CAS system. A Supplemental Type Certificate (STC) was obtained for the TCAS 3000SP system in November 2019 and an STC was obtained for the T3CAS system in August 2021.

Having enough IM-capable aircraft was viewed as a key factor in initiating the operational evaluation. For proficiency reasons, ZAB controllers desired enough IM-capable aircraft so that there was a chance for a controller working PHX arrivals to initiate at least one IM operation per shift. There was also a desire to have enough IM-capable A321s so that flight crews had at least a 1-in-3 chance of being in an equipped aircraft (measured as the number of equipped A321s divided by the total number of single-aisle Airbus aircraft being operated by AAL).

Figure 20 shows the history of AAL's retrofit of their combined fleet of A321ceos and A321neos. The first A321ceo aircraft was equipped in late 2019 for the certification flight. Due to COVID-19, there was no further equipage until July 2020 and the equipage rate increased significantly in the latter half of 2021. When the operational evaluation started in November 2022, 226 aircraft had been equipped with SafeRoute+ avionics. This was almost 80% of the total AAL Airbus A321 fleet at that time. By January 2024, all the original 288 aircraft were equipped[14]. After the period shown in Figure 20, AAL acquired 10 additional A321neo aircraft which were equipped with SafeRoute+ avionics between February and May 2024, bringing the total of equipped aircraft to 298 aircraft by the end of the operational evaluation.

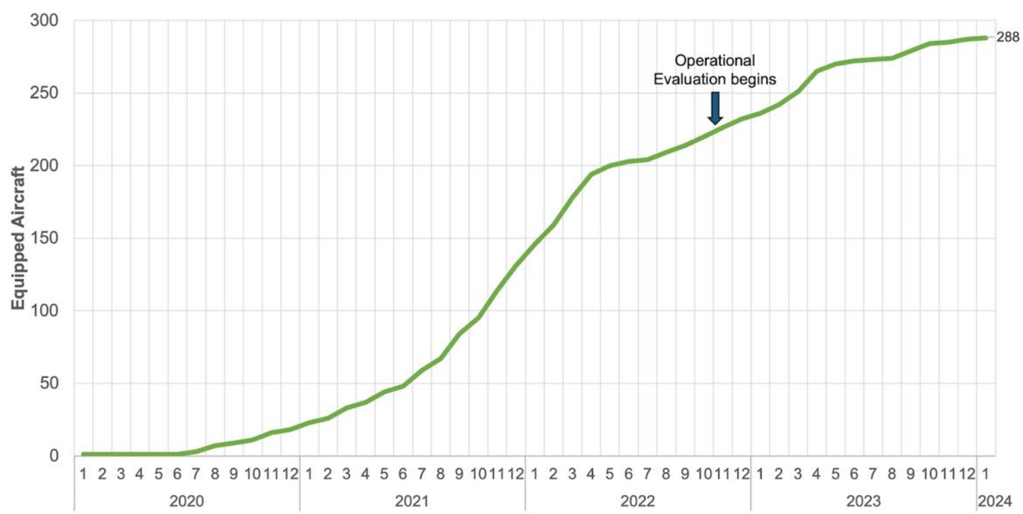


Figure 20 – AAL SafeRoute+ installation timeline

[14] Since SafeRoute+ avionics retrofits were performed during regularly scheduled heavy maintenance checks, all operating AAL A321 aircraft (with either engine option) were equipped with SafeRoute+ by mid-November 2023.

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.

2.11.2 Project Reviews 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 should 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.

Project 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. 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 Evolution of the Operational Evaluation

At the start of the operational evaluation, all IM operations (Maintain and Cross) were permitted in all areas within ZAB to maximize the use of IM. This included overflight operations as well as arrival operations into PHX.

Over the duration of the operational evaluation, the AIRS team focused on different aspects of IM operations. The different focus areas were driven by questions raised or trends noted during discussions of data analyzed by the team while the operational evaluation was underway (see Section 3.1). Some key focus areas and durations are listed below:

- **November 7–20, 2022** – During the first two weeks of the operational evaluation, there was a substantial amount of support from ZAB controller SMEs who were in the control room providing guidance to their colleagues working a sector. The ZAB controller SMEs aided controllers with identifying, initiating, and monitoring IM operations. The ZAB controller SMEs also supported the operational evaluation by collecting feedback from controllers (in the form of handwritten feedback forms).
- **November 21, 2022 – March 15, 2023** – During this period, there was less support from ZAB controller SMEs. There was also a corresponding drop in operations and receipt of controller feedback forms.
- **March 16, 2023 – November 6, 2023** – After AIRS team reviews and discussions with ZAB and NATCA management, it was decided that ZAB controller SMEs would provide a more active role in the implementation of the operational evaluation. One day per week, each ZAB controller SME was excused from their normal duties and served as dedicated support in the control room. They focused on providing and helping controllers issue and monitor Cross clearances. Cross clearances were chosen as a point of emphasis since there were usually more opportunities for such operations and there were more questions about

how those IM operations were conducted; both by controllers and flight crews. Controllers were still allowed to issue Maintain clearances, but there was less emphasis on those IM operations during this time. As before, the ZAB controller SMEs were instrumental in gathering and filling out controller feedback forms (a crucial data source).

- **November 7, 2023 – November 6, 2024** - During this period, the focus of IM operations shifted to EAGUL arrival descent operations. These operations were usually a combination of Cross and Maintain operations (e.g., Cross SLIDR or an upstream waypoint and Maintain after the CP to HOMRR or an earlier waypoint). Due to the focus on EAGUL arrival operations, only the Northwest and North areas of ZAB were involved.

2.11.4 Controller/Pilot Exposure to IM Operations

During the operational evaluation period, there were approximately 6,000 AAL pilots that flew Airbus single-aisle aircraft. These pilots were qualified to fly the A319, A320, and A321 (either engine option) and could be scheduled to fly any of these aircraft types. This slowed the exposure of some AAL Airbus single-aisle pilots to the SafeRoute+ avionics due to the various rates at which those pilots were scheduled to fly an equipped A321. Additionally, the frequency of conducting operations in ZAB airspace varied from pilot to pilot. As a result, some AAL Airbus single-aisle pilots were not exposed to an IM operation until months after the operational evaluation had started. On the other hand, almost all the ZAB controllers were exposed to IM operations within the first month of the operational evaluation and might see a few opportunities a day to initiate an IM operation. This resulted in a longer learning curve for the flight crews than for ZAB controllers.

3 Data Sources and Collection

A data collection plan was developed to support the operational evaluation and data collection methods were adapted, as needed, during the two-year period. The following sections outline the data sources, the collection methodology, and as applicable, how the data was used in monitoring the operational evaluation.

3.1 Overall Approach to Data Collection and Use of Data

The data collection process shown in Figure 21 was used to provide weekly monitoring of IM operations. In this figure and the ones that follow in this section, the numbers in parentheses refer to sections where more information can be found about each step in the process.

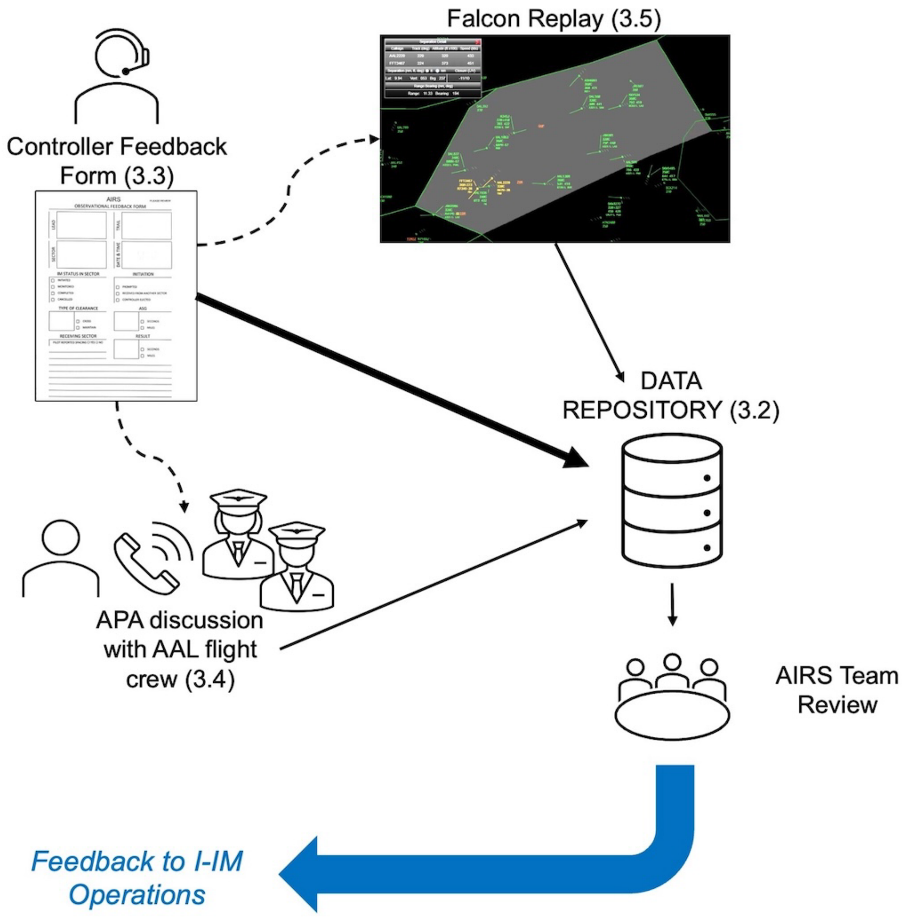


Figure 21 – Data Collection/Analysis process for providing weekly feedback to IM operations

The process was initiated by the controller feedback form developed for use by ZAB controllers (see Section 3.3). These forms were available daily and reviewed by the ZAB controller SME on duty; sometimes the ZAB controller SME would assist in completing these forms. Each controller feedback form would initiate a database record in the Data Repository with information from newly available forms loaded into the Data Repository at least once per week (see Section 3.2). During weekly AIRS team meetings, the ZAB controller SMEs would typically note IM operations of interest for further review and investigation. Particularly in the first year of the operational evaluation, this would trigger (indicated by the dashed curved line in the figure) the APA representative on the AIRS team to contact one or more members of the AAL flight crew[15] to discuss a given IM operation (see Section 3.4).

About halfway through the first year of the operational evaluation, the AIRS team began using the FAA Falcon replay tool to make audiovisual recordings of various IM operations (also indicated by the dashed curved line in the figure (see Section 0). All the key information gathered by these methods were recorded in the Data Repository to build a more complete picture of the identified IM operation, which was then discussed and reviewed by the AIRS team on a periodic basis and which provided feedback to the operational evaluation. Such feedback could lead to controller training updates, flight crew training updates, or even changes in the phraseology used by controllers and flight crews during IM operations.

The project collected additional data during the operational evaluation. The TCAS unit which hosted the SafeRoute+ software also contained the ability to record onboard data on a Compact Flash Card (see Section 3.9). AAL maintenance personnel replaced the Compact Flash Card on each equipped A321 approximately monthly and transmitted that data to a server at ACSS where the data was translated into a format that could be read by other software tools. ACSS would then provide this data approximately bi-weekly to AIRS team analysts. However, this process, which is outlined on the right half of Figure 22, could take up to 2-3 months from when the IM operation occurred until the data could be processed and analyzed by the AIRS team. For the second year of the operational evaluation, the AIRS team developed automated software tools which could plot the data from the Compact Flash Cards (see Section 3.10) more quickly and provide it to the AIRS team for review and potential action, though time lags of 1-2 months were typical.

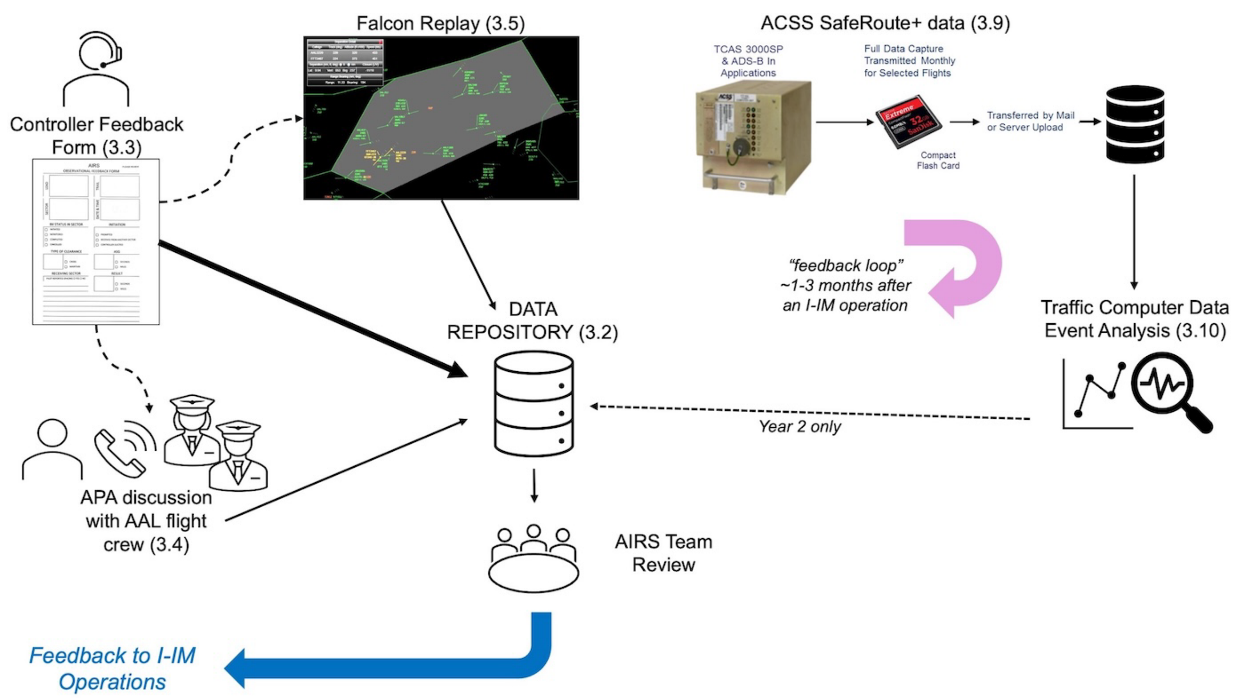


Figure 22 - Data Collection/Analysis process for providing longer-term feedback to IM operations

[15] With the AAL flight number and date from the Data Repository, APA could locate such personnel without any further involvement from the AIRS team.

From the aircraft data, "ACSS events" were identified as described in Section 4.6 and then correlated with either a Controller Feedback Form or FAA VHF Transcript data (see Section 3.7) as shown in Figure 23.

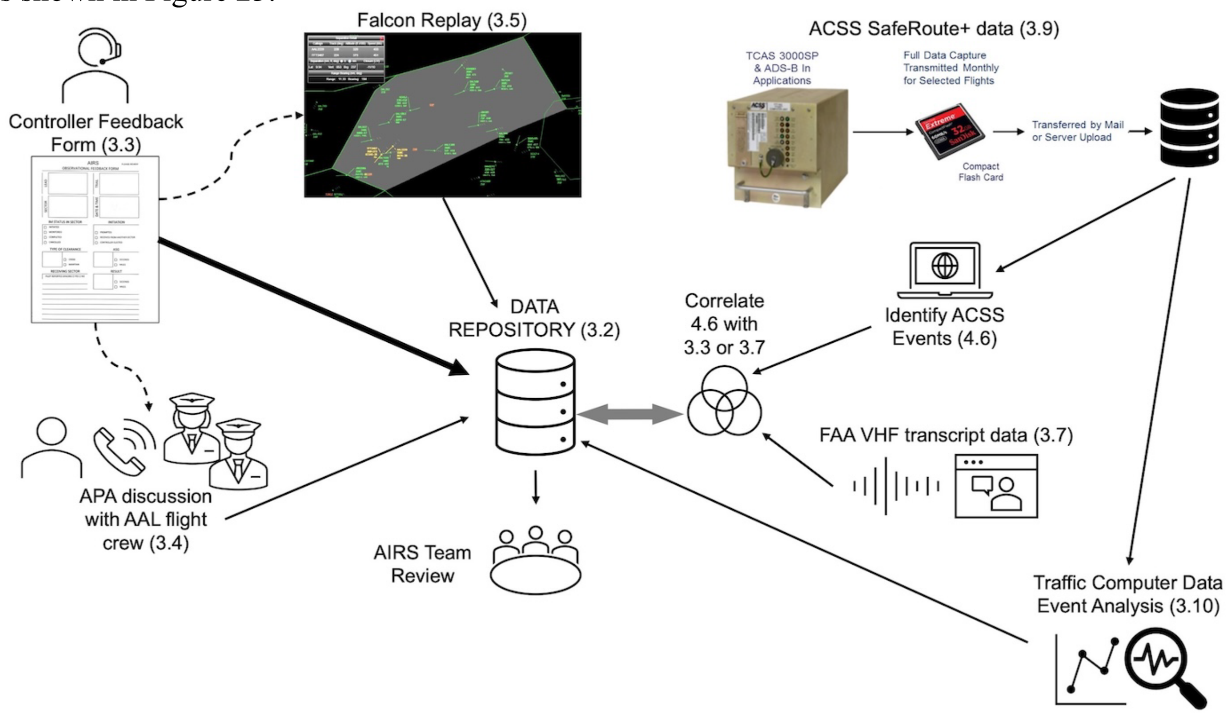


Figure 23 – Complete Data Collection/Analysis/Correlation process involving Aircraft Data

Note that the data collection process was subject to omissions and errors, particularly during the first year of the operational evaluation. During the entire operational evaluation, ZAB controllers were not required to complete controller feedback forms and some ZAB controllers were willing to conduct IM operations without any ZAB controller SME support – these IM operations were discovered by correlating ACSS events with FAA VHF Transcript data. There was also a period where one of the Compact Flash Card readers was faulty or misconfigured and some ACSS data was lost – when controller feedback forms existed, the AIRS team was able to detect the loss of such data. Finally, the FAA VHF Transcripts were imperfect, as expected, and the AIRS team was unable to obtain any transcripts after April 21, 2024, as described in Section 3.7.

3.2 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.

The Data Repository was managed using a spreadsheet to organize all the data by attempted IM operation. Table 4 shows many of the key data elements captured in the spreadsheet.

Table 4. Key Data for each Attempted IM Operation in the Data Repository Management Spreadsheet

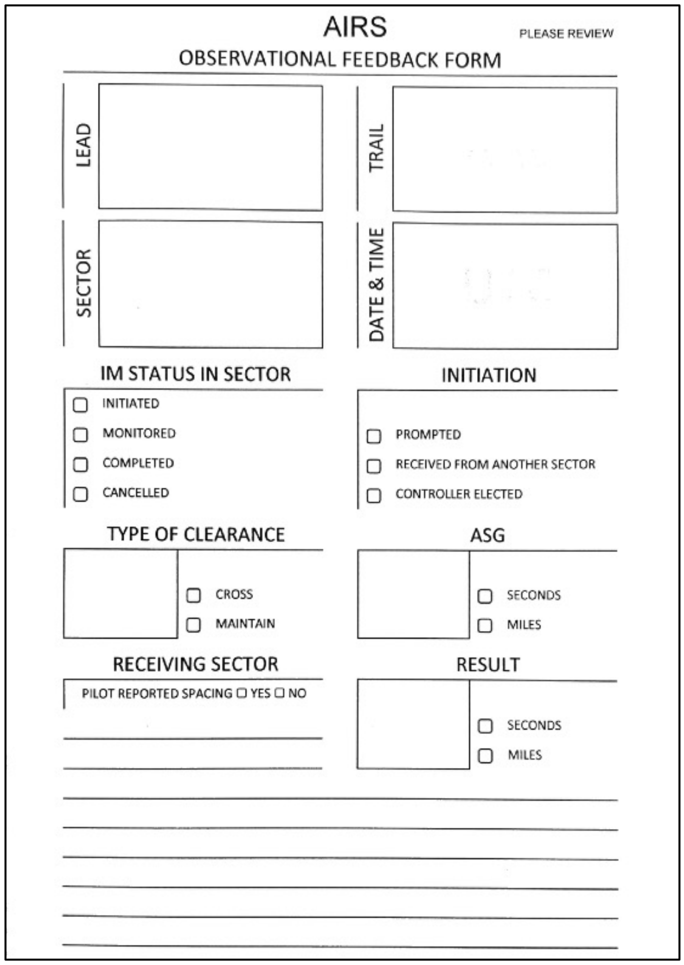
Column Title	Description	Sample Entry
IM OP ID	Unique operation identifier	05410-Y2
Sector	Sector or sectors where operation occurred	93
Date (Z)	Date of operation in UTC	2/20/2024
Time (Z)	UTC time of operation	1937
Trail Flight ID	IM aircraft Flight ID (Call Sign)	AAL123
Trail Reg	IM aircraft Registration – to track any airframe-specific issues	N105NN
Lead Flight ID	Lead aircraft Flight ID (Call Sign)	UAL123
ASG	ASG assigned by controller	90 Seconds
IM Clearance Type	Cross or Maintain	Cross
Cross Point	Waypoint name, only for a Cross operation	SLIDR
Direct Feedback (Comments)	Controller Feedback Comments	<Please review circled on form> Deep dive for DV data
SME and FAA Team Comments	Falcon Video Link, Pilot Feedback, Additional team comments	Falcon Video - <Falcon Video Link> Pilot Feedback Form: <Pilot Feedback Link>
Data Analysis Team comments	Comments from the team reviewing ACSS data card information	1 event over 5 min
ASG within 10 Sec of CP and/or HOMRR	Determination if ASG achieved spacing goal during Operation	Spacing Met
SME Data Review Requested	SME noting additional analysis was required	Deep Dive
ACSS Deep Dive Requested	Noting additional analysis requested of ACSS (question about SafeRoute+ Spacing behavior)	x
Data Card Data received	Either blank or provided a URL to the data for the operation	<Data Card Data Link>
Concern/Issue	Concern/Issue noted during operation or after data received	Bad Geometry

3.3 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.

3.3.1 Controller Feedback Forms

ZAB and project personnel developed a specific set of controller feedback forms for collecting information and timely feedback 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. The controller feedback form used for the first year of the operational evaluation is shown in Figure 24.


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

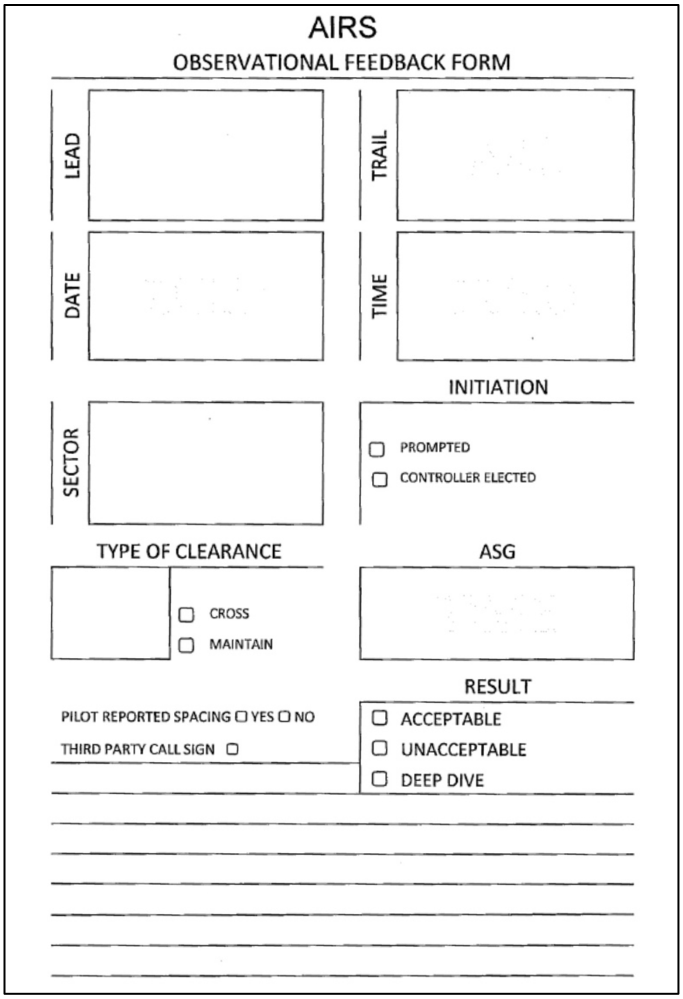
RESULT

- SECONDS
- MILES

Figure 24 - Original Controller Feedback Form

These forms were available at the TMU and supervisors' desks in the various ZAB areas (e.g., North, Northwest; see Figure 8) and at controller positions. The forms were filled out by ZAB controller SMEs, area supervisors, or controllers issuing the clearance. In general, most forms were filled out by ZAB controller SMEs who were supporting the operational evaluation. The data on the forms were also correlated with the ACSS SafeRoute+ data to confirm pilot inputs to the avionics, as described in Section 3.1 and Section 3.9.

Based on experience gained during the first year of the operational evaluation, the controller feedback forms were modified slightly for the second year, as shown in Figure 25. The major changes were on the lower half of the form.



AIRS

OBSERVATIONAL FEEDBACK FORM

LEAD | TRAIL

DATE | TIME

SECTOR

INITIATION

☐ PROMPTED
☐ CONTROLLER ELECTED

TYPE OF CLEARANCE

☐ CROSS
☐ MAINTAIN

ASG

PILOT REPORTED SPACING ☐ YES ☐ NO

THIRD PARTY CALL SIGN ☐

RESULT

☐ ACCEPTABLE
☐ UNACCEPTABLE
☐ DEEP DIVE

Figure 25 - Revised Controller Feedback Form

As part of the new form, controllers were asked to indicate if an operation was considered acceptable or unacceptable. Controllers were given some flexibility in this determination. An unacceptable operation did not necessarily mean the operation was not completed successfully. It did mean that there was something that occurred that was worth discussing as a team after the fact. Generally, if an operation was deemed to be unacceptable, a Falcon replay (see Section 0) was made of the operation and discussed by the team. There were several reasons why an operation could be viewed as unacceptable. Examples that came up periodically were when controllers ended up helping a flight crew understand an IM operation or how to properly enter the IM clearance information in the SafeRoute+ Spacing application. This would happen occasionally with flight crews who were unfamiliar with an IM operation or the SafeRoute+ Spacing application. Many times, such “unacceptable” IM operations ended up successfully meeting the spacing goal.

Another box that could be checked was if a controller was recommending a “deep dive” of the operation. This meant that the controller felt that it was important to examine the SafeRoute+ Spacing application data in detail. This could occur if the controller was unsure whether a flight crew was following the IM speeds or if a flight crew reported a problem with the avionics system.

The form also included a place where controllers could indicate if the flight crew did not report that they were conducting an IM operation to a downstream sector they were entering. This was a task flight crews were required to perform to ensure controller sector-to-sector communication was accomplished and was analogous to a flight crew reporting to a downstream controller when deviating, as approved, from a flight plan route for weather or if flying a controller-assigned vector for traffic from the prior controller.

Finally, there was a box that controllers could check if there was an issue with third-party call sign confusion. This was discussed in Section 2.8.

3.3.2 Directed Discussions

Controller feedback was also obtained by ZAB controller SMEs through informal discussions (i.e., "directed discussions") with their colleagues during team briefings. These discussions started approximately nine months after starting IM 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
- Any issues with IM operations
- Any issues with the IM phraseology
- Any ideas for improving IM

3.4 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 was correlated with other data sources including ZAB controller feedback and ACSS-supplied SafeRoute+ data.

3.4.1 APA Discussions with Flight Crews

After an IM operation was identified for follow-up, APA Safety Representatives would reach out to the flight crew that received that 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 operational insights, including ways IM operations could be improved and how information could be clarified. These interviews were also used to reinforce or clarify AAL IM pilot training items.

3.4.2 Line Operations Safety Audit Program Feedback

The AAL Line Operations Safety Audit (LOSA) program is based on FAA Advisory Circular (AC) 120-90 and is part of AAL 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 and it allows a unique, third-person flight-deck perspective of line flights and how the crew 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 be 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 the SafeRoute+ Spacing application and IM operations.

The targeted LOSA activity began in March 2023 and continued throughout the remainder of the operational evaluation.

3.5 Falcon Replay Recordings

Assigned FAA members of the AIRS team created replays of IM operations identified as being of interest to the project using the FAA Falcon replay toolset. Falcon allows users to replay operations from up to 45 days prior to near real time. These replays consisted of videos representing the surveillance data provided to ERAM, along with relevant ERAM data block information, and audio of controller and pilot communications. Figure 26 shows a screenshot from a sample Falcon replay recording of AAL2229 conducting an IM operation (with FFT3467 as the Lead aircraft).

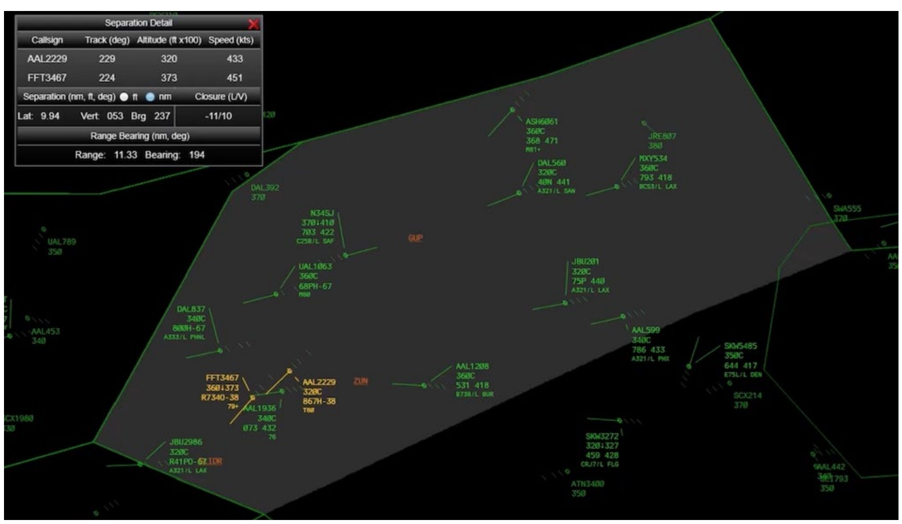


Figure 26 - Sample Falcon replay screenshot

Once an IM operation was identified through a controller feedback form, or noted by an AAL flight crew member, an assigned FAA employee would access the operation in the Falcon system, replay the operation, and capture a recording of the audio and video using audiovisual capture software.

These recordings helped the AIRS team understand various aspects of IM operations. AIRS team members representing various disciplines (e.g., controllers, pilots, avionics developers, concept SMEs) would view the recordings together to develop a comprehensive understanding of the operations. As described in Section 3.1, the team used this interactive approach to establish what was working well and what could be improved.

3.6 Instrument Flight Procedures, Operations, and Airspace Analytics

The FAA 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, FAA airport surface surveillance system data, and ADS-B data to create a smoothed, end-to-end trajectory for each flight. 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. The Threaded Track data goes through multiple quality checks before being published and therefore exhibits a lag of one to three months before it can be accessed via IOAA.

3.7 FAA Voice Transcript Data

The MITRE Transportation Data Platform (TDP) receives and transcribes voice tapes on a periodic basis for most FAA facilities. The voice transcript data is gathered by facility and parts of the transcript are assigned to specific flights using the call sign 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 it does provide a wealth of information that is not available from other sources.

For the AIRS project, the data collection team used the transcript information as a step to confirm if a flight in ZAB was receiving an IM clearance from a controller (as opposed to a pilot exercising the SafeRoute+ Spacing application on their own initiative to explore its features). More specifically, the ZAB transcripts were queried for relevant phrases containing:

A. *"spacing clearance"*
B. *{"seconds"* OR *"miles"* OR *"second"* OR *"mile"}* AND *"behind"*

Generally, the transcript query cast a wide net that was later filtered to match ACSS events and times to confirm that an IM operation occurred.

The transcript data was available from the beginning of the operational evaluation until April 20, 2024. After that time, the data feed from the FAA to the TDP experienced an issue that was not resolved by the data analysis cutoff period for this report (March 28, 2025).

3.8 FAA TBFM Data

The FAA Air Traffic Organization Performance Analysis Group (AJR-G) manages an online Tableau archive of TBFM information. The archive includes TBFM scheduled and actual meter point crossing times for each relevant aircraft. Furthermore, the data is segregated by different TBFM capabilities (e.g., arrival and extended metering). Roughly six percent of TBFM scheduled flights in ZAB are provided with TBFM-calculated speed advisories to meet the metering times. Controllers can decide to accept the speed advisory or not during the metering process.

The AIRS project used the TBFM metering data (both for flights that use and do not use speed advisories) to evaluate delivery errors and accuracy for TBFM metered flights in ZAB. TBFM data was gathered during the two-year operational evaluation period for two sets of data:

1. All TBFM scheduled flights with accepted speed advisories in ZAB bound for PHX (17,526 flights)
2. All TBFM scheduled flights without speed advisories in ZAB bound for either PHX or Los Angeles International Airport (LAX) (270,462 flights)

While TBFM was not a focus of the AIRS project, the data allowed a comparison of spacing accuracy between IM and another spacing method used by ZAB.

3.9 SafeRoute+ Data

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

ACSS developed a process to obtain SafeRoute+ data from aircraft using Compact Flash (CF) cards placed in the TCAS unit (see Figure 27). AAL maintenance retrieved the CF card from each aircraft's TCAS unit periodically, typically once a month, and inserted a blank CF card. AAL maintenance then uploaded the retrieved CF card data to an ACSS server for processing.

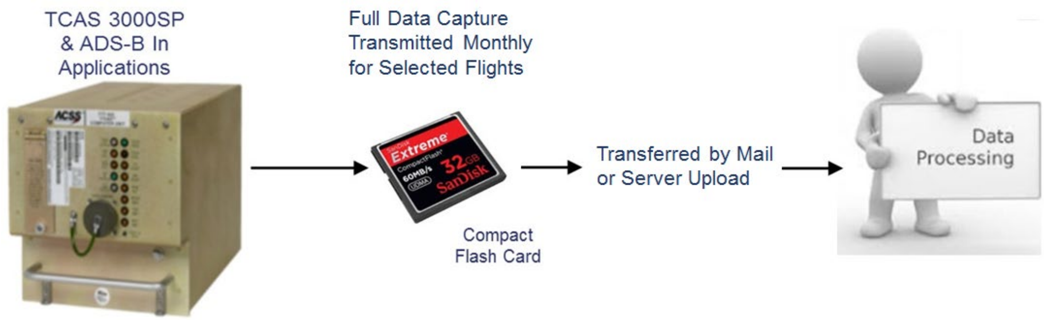


Figure 27 - Processes to obtain SafeRoute+ data from aircraft

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

1. Download the raw data files from CF cards for storage and processing
2. Identify flights using traffic 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 was a lag in when a complete monthly set of data for all flights was available. The delay depended on when the data could be physically downloaded from each aircraft. In general, a complete set of data for a particular month was available to the FAA three months after the operations occurred.

During the evaluation, there were some occurrences where data on flights from a specific aircraft was lost due to card handling and data transfer issues. Section 4.6.2 discusses the minimum number of IM operations which were lost in this manner. IM operations (indicated by a controller feedback form or voice transcript) that had no corresponding SafeRoute+ data were excluded from the delivery accuracy and error analysis.

For flights using the Spacing application within SafeRoute+, ACSS provided a set of data with 68 elements recorded every second. Table 5 describes a subset of these data elements.

Table 5. ACSS provided data per second for IM flights

ACSS IM (Spacing) Data Elements	Definition
UTC Time	UTC time in hours, minutes, seconds
UTC Date	UTC date in year, month, day
Cross Point ID	The alphanumeric identifier of IM Cross Point
Planned Cancellation Point ID	The alphanumeric identifier of Planned Cancellation Point (PCP)
ASG (time)	Assigned Spacing Goal entered by the flight crew for a time-based spacing operation
ASG (distance)	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	Alphanumeric flight identifier of ownship's flight (e.g. "AAL1234")
Ownship Latitude	Latitude from ownship's navigation system
Ownship Longitude	Longitude from ownship's navigation system
Ownship Pressure Altitude	Pressure altitude from ownship's air data system
Ownship Mach	Mach number from ownship's air data system
Ownship CAS	Calibrated airspeed from ownship's air data system
Ownship TAS	True airspeed from ownship's air data system
Ownship SAT	Static air temperature from ownship's air data system
Ownship Windspeed	Calculated windspeed from ownship's flight management system
Ownship Wind Direction	Calculated wind direction from ownship's flight management system
Ownship Groundspeed	Groundspeed from ownship's navigation system
Ownship Selected CAS	Pilot-selected airspeed from ownship's autoflight system
Ownship Selected Mach	Pilot-selected Mach from ownship's autoflight system
TTF (Lead aircraft) Flight ID	Alphanumeric flight identifier of traffic-to-follow (Lead), as received over ADS-B (e.g. "UAL43")
TTF (Lead aircraft) Latitude	Latitude of traffic-to-follow (Lead), as received over ADS-B
TTF (Lead aircraft) Longitude	Longitude of traffic-to-follow (Lead), as received over ADS-B
TTF (Lead aircraft) Pressure Altitude	Pressure altitude of traffic-to-follow (Lead), as received over ADS-B
TTF (Lead aircraft) Groundspeed	Groundspeed of traffic-to-follow (Lead), as received over ADS-B
Range from Ownship to Traffic	Horizontal distance between ownship and the traffic-to-follow (Lead)
IM Command CAS	CAS command calculated by the SafeRoute+ Spacing application and displayed to the flight crew
IM Command Mach	Mach command calculated by the SafeRoute+ Spacing application and displayed to the flight crew
IM Command CAS/Mach Flag	A flag to indicate if the IM Speed is a CAS value or a Mach value

ACSS IM (Spacing) Data Elements	Definition
Feasibility Result	An indication if the SafeRoute+ Spacing application calculates that the entered ASG can be achieved by the time ownship reaches the CP or if the entered ASG is too large or too small to be obtained. The feasibility result is only calculated for time-based Cross operations.
IM Time Spacing	Current time spacing, in seconds
IM Distance Spacing	Current distance spacing, in nautical miles
IM Mode	The operational mode of the SafeRoute+ Spacing application. The mode indicates when the Spacing application is executing, when it is waiting for pilot data entry, and so forth.
Suggested Groundspeed	An internal Spacing application parameter that indicates the groundspeed needed to meet the ASG based on the current conditions
IM Computed IAS	An internal Spacing application parameter that is the CAS-equivalent of the Suggested Groundspeed
Estimated TAS of TTF (Lead aircraft)	An internal Spacing application parameter that is an estimate of the traffic-to-follow's (Lead's) true airspeed, based on the groundspeed and pressure altitude of the traffic-to-follow (Lead) as received over ADS-B and the current atmospheric conditions from ownship's air data system.

3.10 Traffic Computer Data Event Analysis

The ACSS SafeRoute+ data, described in the previous section, were graphically depicted for each IM operation recorded in the controller feedback forms. The IM operational graphics provided insight into how the SafeRoute+ Spacing application performed given the starting conditions for the Lead and IM aircraft, the IM speeds and spacing intervals that were displayed to the pilots, and how the pilots responded to the IM speeds. The AIRS team used this data, along with the other data sources previously mentioned, to obtain in-depth understanding of specific IM operations.

Initially, the IM operational graphics were generated to investigate operations that had been flagged for further study by ZAB controllers or through other data sources. Around the end of the first year of the operational evaluation, ZAB controllers requested the analysis team generate the graphics for all IM operations for their review. By the end of the operational evaluation, graphics had been generated for 475 IM operations in the first year of data collection[16], and for 774 IM operations in the second year.

The graphics generated for each operation are explained using the following figures for an example IM operation that occurred on February 20, 2024.

The avionics mode and CP were plotted for each individual IM operation recorded in the ACSS SafeRoute+ data. Figure 29 shows the avionics mode (top) and CP (bottom) as a function of UTC time. The avionics mode can have five numerical values:

- 1 = IM not configured
- 2 = Awaiting Clearance Entry
- 3 = Ready for Execution
- 4 = Waiting for Environment
- 5 = Executing

[16] The graphics were retroactively generated for IM operations that occurred in the first year of data collection using the automated process developed and used during the second year of data collection.

The CP plot shows whether a CP has been entered. The "……" indicates no CP has been entered. The avionics mode and CP entry can be correlated with the clearance information recorded on the controller feedback forms to evaluate whether flight crews entered the information consistently with their clearances.

For the IM operation in Figure 28, the lateral paths of the Lead (red) and IM aircraft (blue) are shown when the avionics mode was equal to 5 (Executing). The Lead and IM aircraft were flying direct to the ZUN waypoint, which was the CP, and then flew the same route over HOMRR. The SafeRoute+ Spacing application transitioned out of mode 5 approximately 20 NM after the IM aircraft crossed HOMRR. Waypoints SLIDR and TINIZ are also shown.

The text above the graphic shows information about the IM operation input to the SafeRoute+ Spacing application by the flight crew. The date of the operation, Lead aircraft ID, and IM aircraft ID are included. The CP is shown as "ZUN…,……," which indicates a CP of ZUN followed by a maintain operation. The PCP was recorded as "……," which indicates the flight crew did not enter a PCP. The ASG was 120 seconds. The duration of the IM operation was calculated from the time the avionics mode was equal to 5. This IM operation lasted more than 45 minutes.

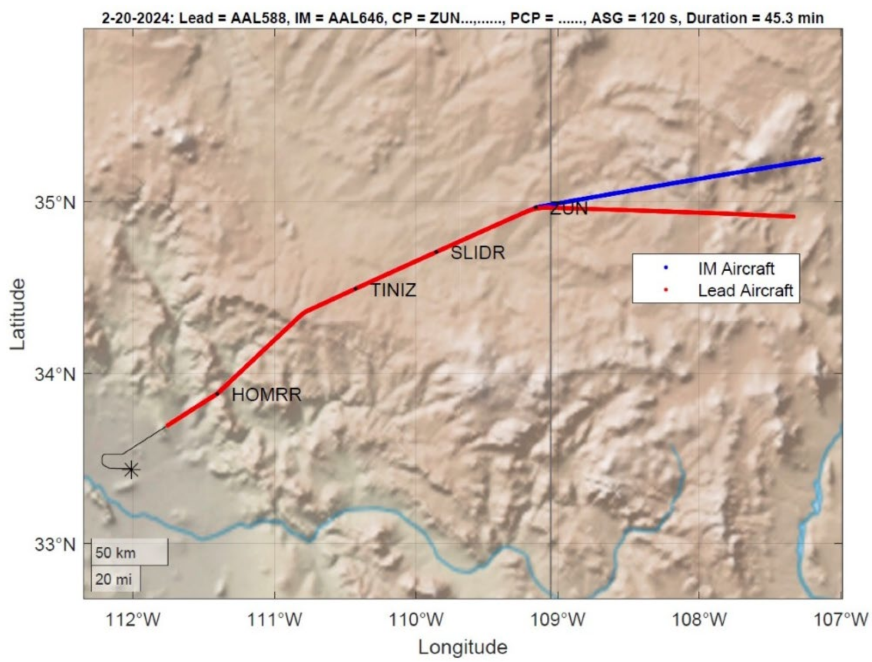


Figure 28 - Lateral Paths for Lead Aircraft (red) and IM Aircraft (blue)

As shown in Figure 28 and Figure 29, the flight crew entered the CP as ZUN. With the entry of the CP, the avionics mode transitioned from mode 4 (Waiting for Environment, which can indicate that the geometry between the Lead and IM aircraft is not appropriate for the information entered) to mode 3 (Ready for Execution). The flight crew then began executing the operation as indicated by the transition to mode 5. The CP later changed to "……," which indicated the IM aircraft had passed the CP and transitioned to the Maintain stage. The avionics mode later changed to mode 3 (Ready for Execution) as the flight crew cancelled the operation. The data continued to be recorded as the IM clearance information was still entered in SafeRoute+.

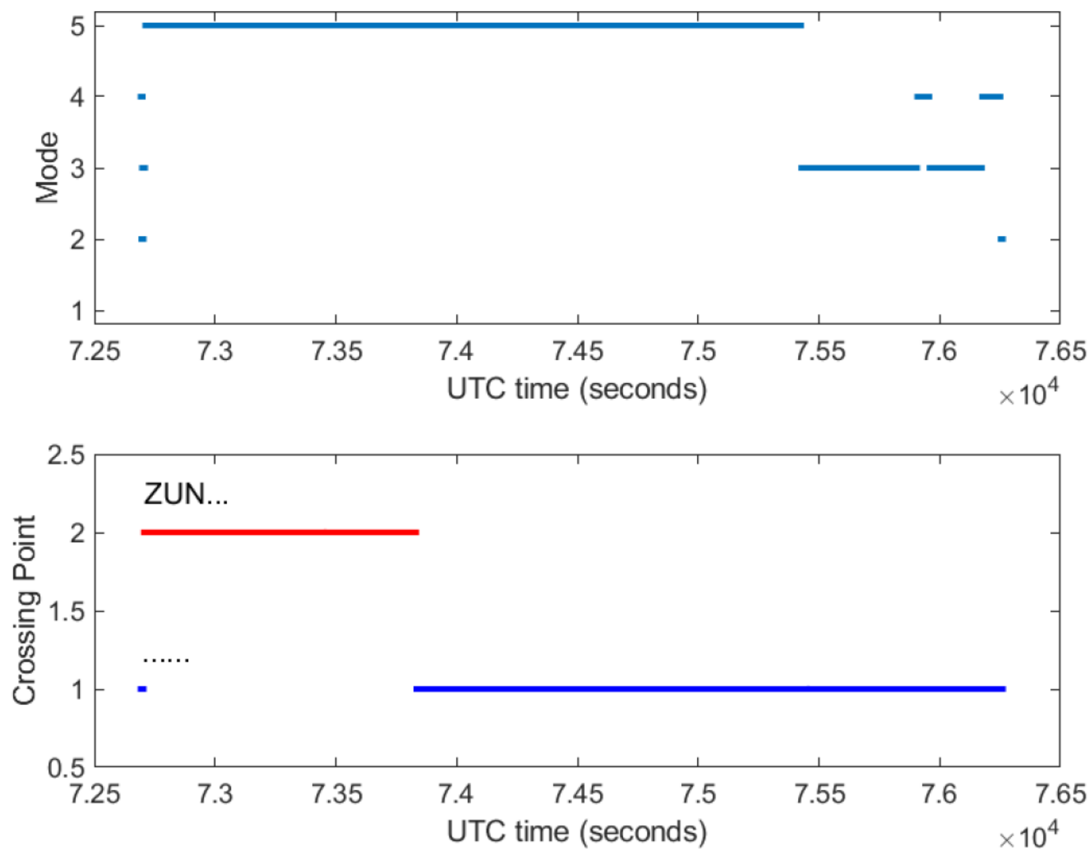


Figure 29 - Avionics mode (top) and Cross Point entry (bottom) as a function of time for IM operation

Figure 30 shows the pressure altitude (top) and ground speed (middle) for the lead (red) and IM aircraft (blue) as a function of time (the time scale is defined relative to when the SafeRoute+ Spacing application first transitioned to mode 5). The wind speed and direction, as measured by the IM aircraft, are shown in the bottom plot as a function of time. The vertical gray lines show when the Lead and IM aircraft crossed the CP (ZUN). The other vertical gray lines indicate when the IM aircraft passed over SLIDR, TINIZ, and HOMRR. Understanding when the aircraft passed these waypoints helped ZAB controllers evaluate the IM operations.

In this IM operation, the IM aircraft was at 34,000 feet and the Lead aircraft was at 30,000 feet when the IM operation was initiated. The IM aircraft began descending to 30,000 feet around 10 minutes into the IM operation, and both aircraft maintained 30,000 feet until the lead began its descent around 27 minutes into the operation. The IM aircraft began its descent around 32 minutes into the operation.

The ground speed profiles can help understand how the IM operation evolved, and the behavior can be correlated with the altitude profiles. As expected, the ground speed decreases for each aircraft when they began their descent.

The wind speed plot shows the IM aircraft experienced a significant headwind (the wind was blowing from a westerly direction) around 150 knots at the start of the IM operation. As the aircraft descended, the wind speed decreased to around 50 knots near HOMRR.

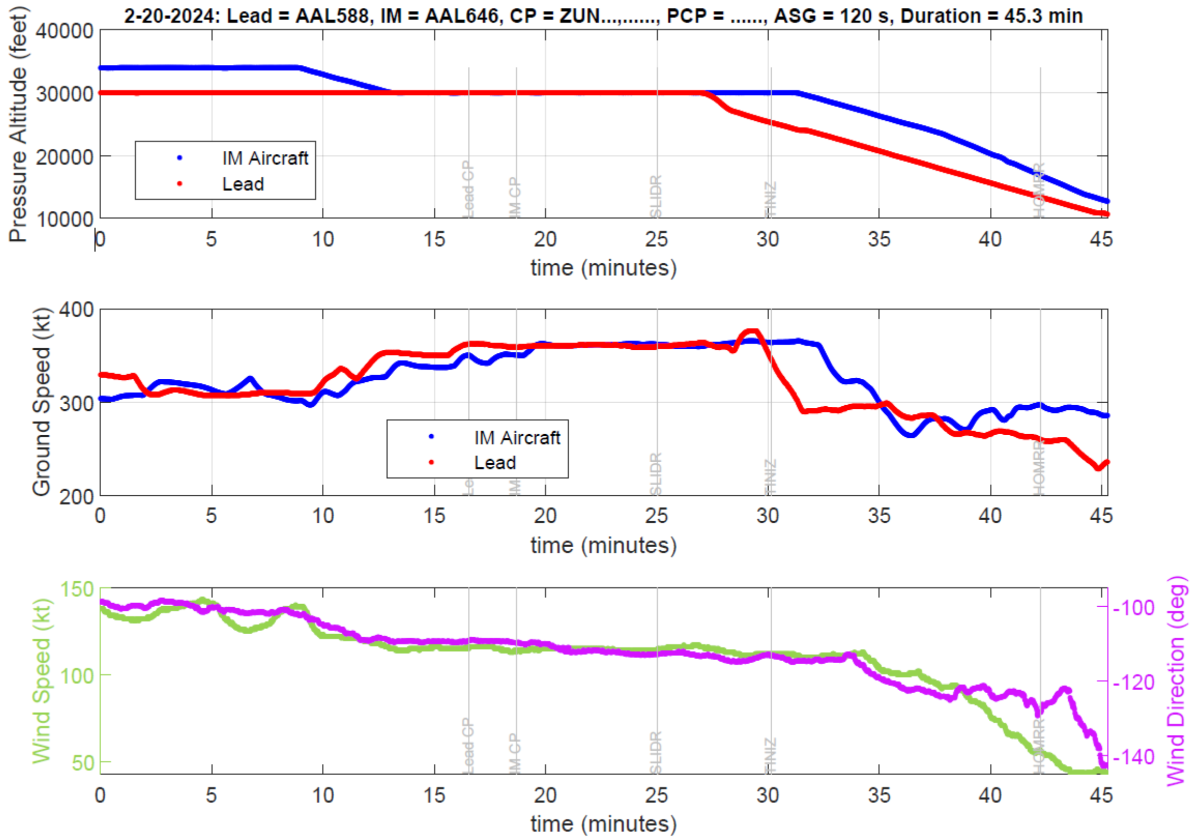


Figure 30 - Pressure Altitude (top) and Ground Speed (middle) for Lead and IM Aircraft and Wind Speed and Direction (bottom) for IM Aircraft

Figure 31 shows the IM speed calculations by the SafeRoute+ Spacing application as a function of time. The top plot shows when the IM speed was displayed to the flight crew in Mach. The orange line is the IM speed (or commanded Mach) displayed to the flight crew; the yellow line shows the pilot-selected Mach value; and the blue line shows the aircraft's actual Mach value. The middle plot shows the same information when the IM speed was displayed in CAS. The purple line shows IM Computed IAS (defined in Table 5), labeled as the unfiltered CAS command, which was computed by the SafeRoute+ Spacing application. This value was not subjected to rounding or limiting and indicated changes in the calculated spacing that would result in subsequent changes to the IM speed.

The bottom plot shows the Selected Mach (blue) and CAS (red) Validity as values of 0 or 1. SafeRoute+ assumed that a value of 1 indicated whether FCU speed selection was being used. For example, if the IM speed was displayed in CAS, but the Selected CAS Validity was equal to 0, this indicated the FMS was in managed speed mode, and the aircraft was following the speed profile in the FMS (i.e., the flight crew was not selecting speeds in the FCU).

In this IM operation, the IM speeds were initially displayed in Mach. The Selected Mach Validity value of 1 indicated the aircraft was using the FCU-selected speeds. The changes in the orange line indicated the IM speeds displayed to the flight crew were changing. The pilot-selected Mach speeds matched the IM speeds where the yellow lines overlap with the orange lines. However, there were instances where the pilot-selected speeds deviated from the IM speeds (e.g., starting around 10 minutes into the IM operation and until the IM speed started to be displayed in CAS). The IM speed switched to being displayed in CAS around 23 minutes into the IM operation, which related to when the Lead aircraft began its descent. The flight crew generally selected the IM speeds with some deviations. The IM operation was cancelled, and IM speeds were no longer displayed about 3 minutes after the IM aircraft crossed HOMRR.

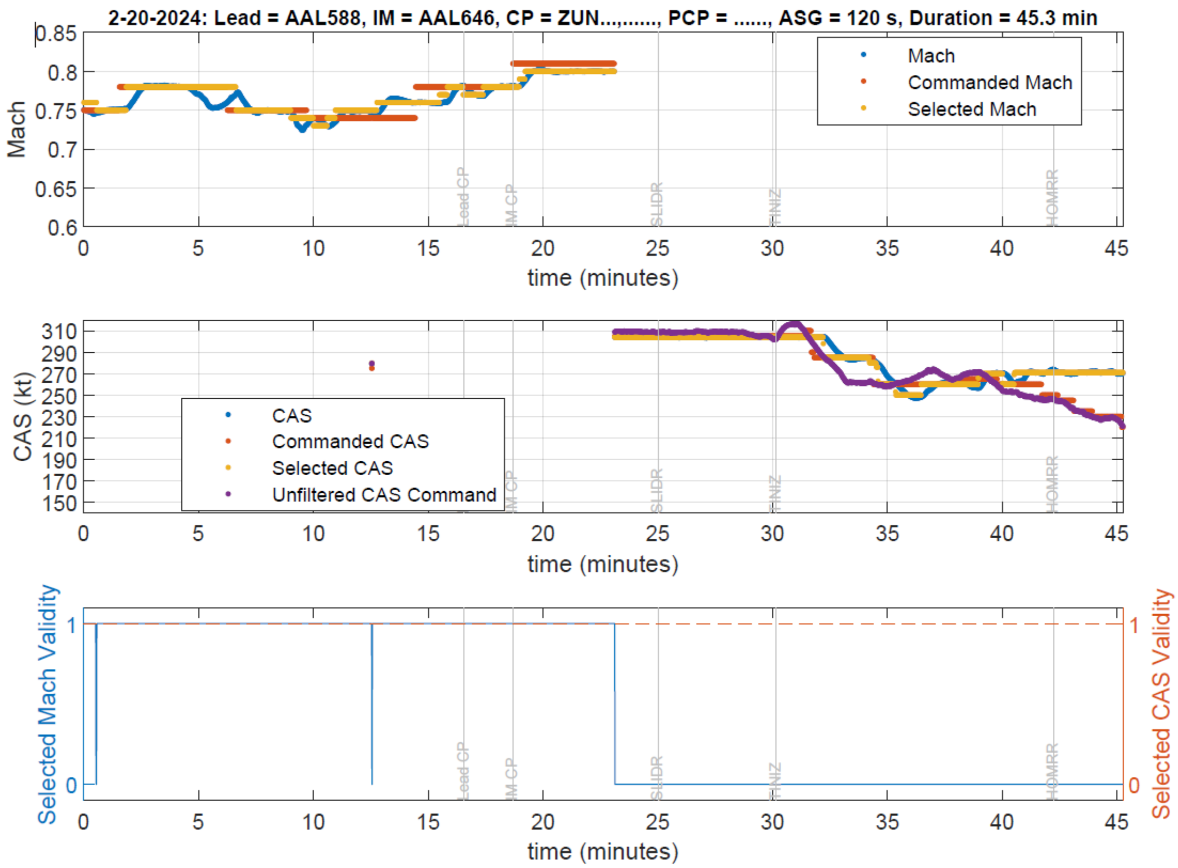


Figure 31 - IM Speed in Mach (top) and CAS (middle) and Selected Mach and CAS Validity (bottom)

The top plot in Figure 32 shows the spacing interval calculated by the SafeRoute+ Spacing application as a function of time (the pink line). The ASG is also shown by the thick black line, and the dashed black lines show the 10-second tolerance relative to the ASG. For a time-based IM operation, the spacing interval should be within 10 seconds of the ASG when the IM aircraft crosses the CP and should remain within 10 seconds of the ASG until the IM operation is cancelled. The bottom plot again shows the ground speed profiles for the Lead and IM aircraft to help evaluate the spacing interval behavior.

In this IM operation, the initial spacing was around 200 seconds and decreased to within the 10-second tolerance of the 120-second ASG by the time the IM aircraft crossed the CP. The spacing interval remained within the 10-second tolerance between the CP and HOMRR, at which time the flight crew likely stopped complying with the IM speeds before cancelling the IM operation in the SafeRoute+ Spacing application.

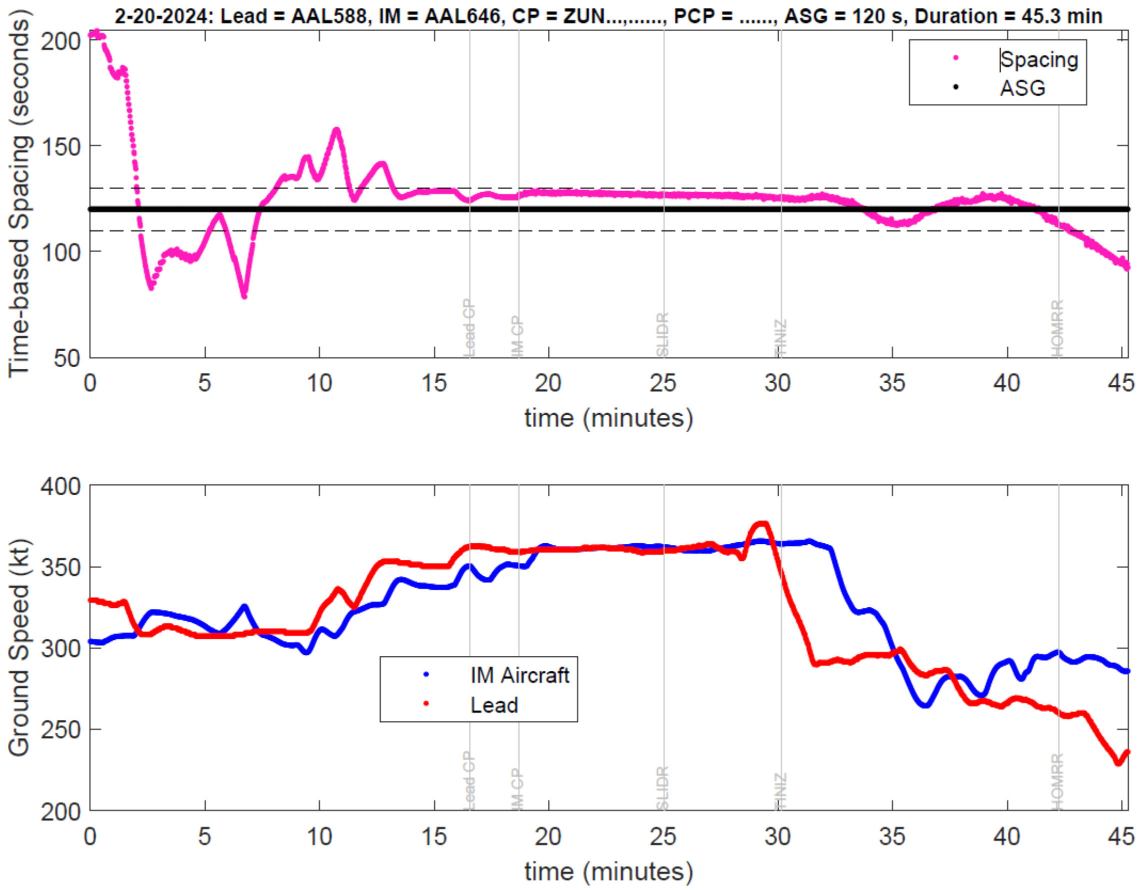


Figure 32 - Spacing Interval and ASG (top) and Ground Speed (bottom)

Figure 33 shows IM speed limits used by the SafeRoute+ Spacing application to limit the IM speeds displayed to the flight crew (see Appendix 9.1 for how these IM speed limits are calculated). The top plot shows the commanded Mach in orange, the IM aircraft's actual Mach in blue, and the Lead aircraft's estimated Mach in green. Note that the estimated Mach is calculated by using pressure altitude to convert the Estimated TAS of TTF (Lead aircraft) parameter from Table 5 to the estimated Mach. The middle plot shows the same information as the top plot but for IM speeds shown in CAS. The colored portions of the lines indicate when the IM speeds were displayed in Mach or CAS. The bottom plot again shows the ground speed profiles to support the evaluation of IM operations. As errors in the Lead aircraft's estimated CAS can result in IM speed limits that exceed airframe performance limits, the SafeRoute+ Spacing application's speed limiting logic uses additional limits to ensure no unsafe speeds are displayed to the flight crew.

In this IM operation, the commanded Mach and commanded CAS were within the IM speed limits throughout the IM operation, which indicates the speed limits did not bound the IM speeds. In cases where the IM speeds are limited, the spacing interval will often not be within the 10-second tolerance at the CP or during some portion of the maintain stage of the IM operation.

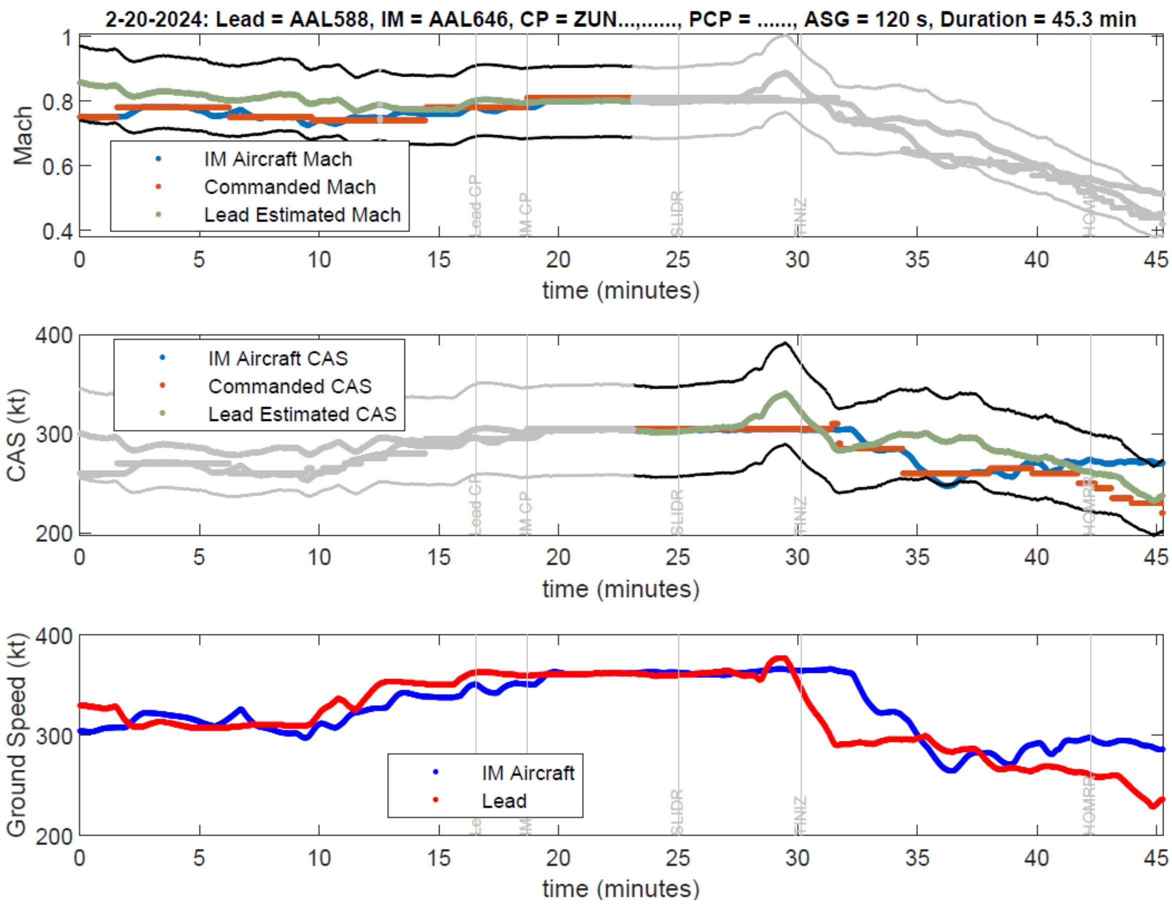


Figure 33 - IM Speed Limits for Mach (top) and CAS (middle) and Ground Speed Profiles

As previously noted, the AIRS team started generating these graphics from the SafeRoute+ data for selected IM operations part way through the first year of data collection. When ZAB personnel requested these graphics for every IM operation, a fully automated process for generating the figures was put in place. This involved identifying IM operations contained in the ACSS SafeRoute+ data[17], correlating IM operational data records with those from the controller feedback forms, and generating the graphics. ZAB personnel noted that having greater insight into the SafeRoute+ Spacing application's performance and flight crew behavior was critical to their agreement with continuing the AIRS evaluation for a second year. During year two of the AIRS evaluation, the graphics were generated as new data was received from ACSS – typically every few weeks.

[17] The ACSS SafeRoute+ data cards contained Spacing application use records in addition to those initiated by ZAB controllers. This data indicated flight crews were exploring the use of the Spacing application. In some cases, the Spacing application never went into mode 5 (Executing), though some showed flight crews entered IM information that was feasible, and the Spacing application did go into mode 5. Spot checks of those cases showed that flight crews were not complying with the IM speeds.

4 Analysis and Results

The goal of the operational evaluation was to determine and evaluate the benefits associated with IM operations. This section provides a summary of the results and analyses obtained during 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 safety monitoring plan). There were no IM operations that led to a loss of separation effect. 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.

At the end of the operational evaluation (November 7, 2024), the AIRS project safety team reviewed the data. The results were compared against the Predicted Hazards, Performance Targets, and Monitoring Parameters identified by the SRM panel and documented in the SRMD.

The safety team concluded the following:

- Throughout the operational evaluation, no loss of separation occurred. Additional workload was realized during various aspects of the operations. The situations causing additional workload had been predominantly anticipated, and thus, manageable with ZAB controller SMEs and additional flight crew training and memos.
- The AIRS team encountered new concerns and issues throughout the operational evaluation. These issues were often resolved operationally (e.g., phraseology modifications).
- Overall, the operational evaluation maintained a low risk profile. The aircraft involved in IM operations were normally spaced appropriately with adequate time for safe adjustments. As with any new operation, new issues were identified that could be addressed and improved upon in a future deployment. As pilots and controllers use the IM capability more regularly, IM operation would be expected and become a routine part of daily operations.

The remainder of this section describes an assessment of each of the identified hazards at the end of the operational evaluation.

I-IM-1 "Designate the wrong Lead aircraft" was when either the flight crew or the controller mistakenly identified or designated an incorrect Lead aircraft for the IM operation or there was a call sign mismatch where the Lead aircraft was 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. There was no data that indicated an incorrect Lead aircraft was designated.

I-IM-2 "Wrong ASG input into MCDU and used for IM Operation" was when either the flight crew or controller mistakenly entered/provided an incorrect time-based or distance-based ASG and this ASG was 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. There were no discussions or data indicating this hazard occurred.

I-IM-3 "Controller uncertain about speed adjustment during IM operation" acknowledged the learning curve at the beginning of the operational evaluation when controllers might not be familiar or comfortable with the IM speeds that the IM aircraft was flying to achieve/maintain the ASG. This was especially a concern when using a time-based ASG. This hazard also covered the cases when the flight crew of the IM aircraft may have intentionally or unintentionally entered 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. Controller workload was only an issue when initially communicating an IM clearance, not while monitoring IM operations. There were no feedback forms, observations, or complaints recorded from controllers that monitoring 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 a pilot to inform a controller of an IM operation 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 pilot self-reporting an IM operation 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 (see Section 4.5). Even though this happened regularly, it never led to increased controller workload. Throughout the operational evaluation, there were ZAB controller SMEs to aid controllers in issuing the IM clearances and monitoring IM operations. The ZAB controller SMEs were an additional control for this hazard but were not necessary for safety.

I-IM-5 "Additional coordination necessary for IM Operation across multiple sectors" was when there was one controller controlling a Lead aircraft and another controller controlling the IM aircraft. This hazard was due to workload issues that could result from coordination between different sector controllers during these IM operations and the lack of ATC automation 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. IM operations were rarely conducted with aircraft in different sectors. When this did occur, it required ZAB controller SMEs to coordinate with the controllers in different sectors and aid in monitoring such IM operations. 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 ATC 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 Controller Feedback

4.2.1 ZAB Controller SME Feedback

Controller feedback forms were used to collect information on IM operations conducted by ZAB controllers (see Section 3.3). These forms included a section where controllers could provide subjective feedback on their observations during the operation. This information was reviewed by ZAB controller SMEs and discussed by AIRS team members during weekly telecons and monthly meetings. Additionally, during monthly meetings, ZAB controller 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 and specific events are discussed below.

ZAB controller 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 be beneficial and they conducted IM operations when possible.
- **Neutral** – They were happy to do the operation if the ZAB controller SMEs pointed out feasible IM aircraft pairs and provided necessary coordination.
- **Negative** – They did not see the benefit of IM for their operation.

ZAB controller SMEs noted that many ZAB controllers had a neutral opinion of IM. ZAB controller 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 controllers 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 ERAM displays.

Some of the information controllers stated would be needed included:

- Indication of which aircraft can conduct IM
- Identification and display of Lead aircraft and the IM aircraft following
- Time-based ASGs derived from the planned times of arrival of the Lead and IM aircraft at a common fix
- Display of ASG at a controller position issuing an IM clearance
- Coordination across sectors

The ZAB controller SMEs provided a workaround for the lack of automation, but without the ZAB controller SMEs or automation upgrades, the ZAB controllers stated the operational benefit did not outweigh the effort to use IM.

During the second year of the operational evaluation, the color of aircraft capable of performing IM was changed on the ESIS board that projected the Traffic Situation Display (TSD) for PHX arrivals[18]. As shown in Figure 34, ZAB controllers could easily ascertain which aircraft were

[18] This was accomplished by coding all aircraft with “AAL” as their call sign prefix and an aircraft type designator of either “A321” or “A21N” in a different color on the TSD.

eligible for an IM operation by glancing at the ESIS board, which is done often during arrival pushes to PHX.

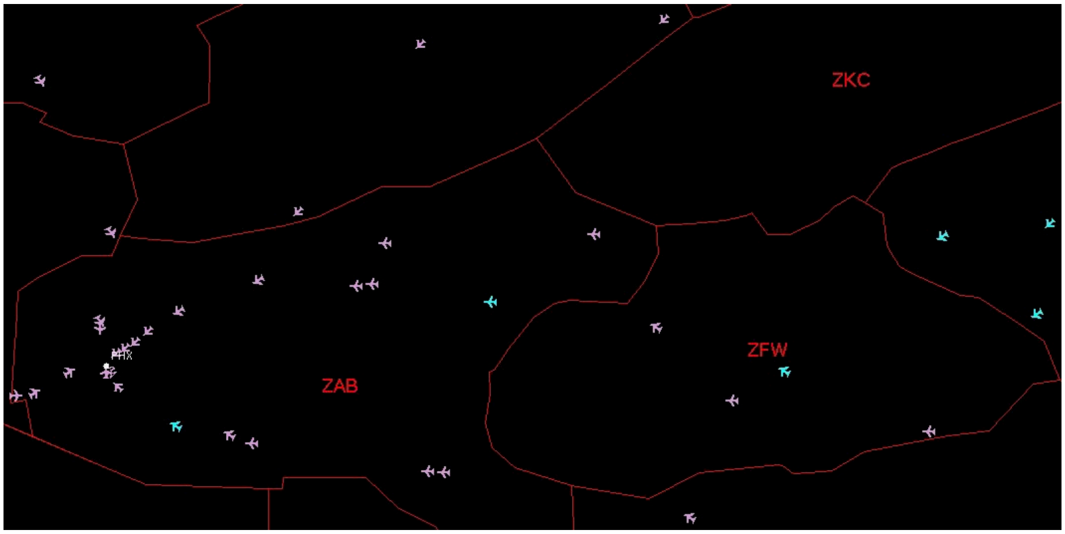


Figure 34 – TSD View Showing PHX Arrival Traffic with AAL A321 Aircraft Color-Coded

Another change that occurred late in the second year of the operational evaluation was the addition of an IM (ADS-B In) Capability Indicator on ERAM displays. Beginning in July 2024, for all equipped A321 aircraft, AAL inserted "B2" in Field 10 and "I0" in Field 18 of each flight plan (per FAA guidance) to indicate the aircraft were ADS-B In equipped and capable of conducting IM operations. ERAM would parse this flight plan information, and a green "M" was placed near the position symbol of the IM-eligible aircraft on the controller display, as shown in Figure 35.

Since this happened late in the operational evaluation, controllers did not have much experience using this capability indicator. One comment that was received was that it would have been more effective to have the "M" as part of the data block and not adjacent to the aircraft symbol, as most controllers focus on the data block information.

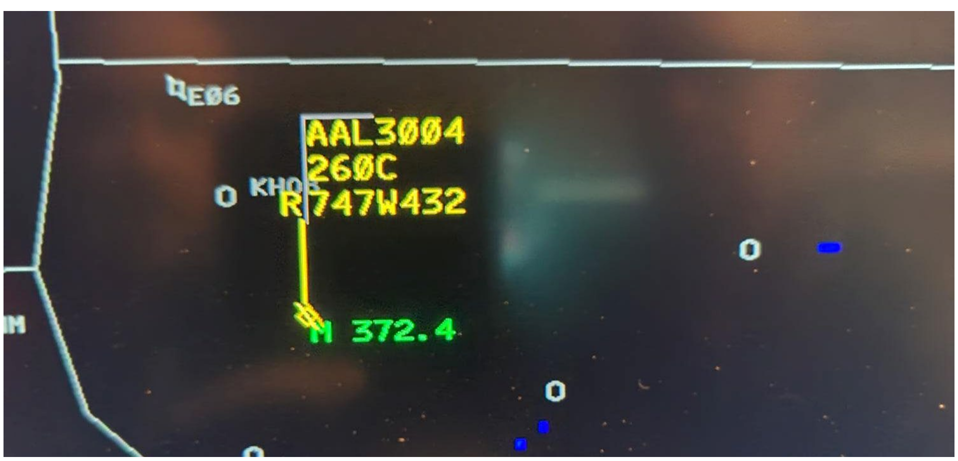


Figure 35 – IM (ADS-B In) Capability Indicator on ERAM display

ZAB controllers also pointed out that it was difficult to use IM when dealing with nearby convective weather. Convective weather can disrupt operations and prevent the use of PBN procedures. If ZAB 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 ZAB controller acceptance of IM. Early in the evaluation, some flight crews were hesitant to accept IM clearances. One reason for this reluctance included a lack of familiarity with the IM operation and the SafeRoute+ Spacing application. Flight crews were trained in July 2022, but the operational evaluation did not start until November of that year. Additionally, as mentioned in Section 2.11, while ZAB controllers might see a few IM opportunities per day, it might take months for a flight crew to see an IM operation. This resulted in a longer learning curve for the flights crews than for the ZAB controllers.

Flight crew reluctance to accept clearances meant controllers could not always count on a flight crew accepting an IM clearance. This meant that controllers had to be prepared to offer non-IM clearances. At other times, flight crew lack of familiarity with IM resulted in controllers spending extra time guiding a flight crew through the operation (including instructing flight crews on how to enter the IM clearance into the aircraft MCDU), which ZAB controllers were willing to do when they had time. However, this resulted in extra time for controllers to issue IM clearances. Both situations would sometimes lead to a reluctance by a controller to offer an IM clearance.

As discussed in Section 4.3, AAL provided additional briefings and information to flight crews that provided additional clarity regarding IM operations. Proficiency also improved as more pilots received IM clearances and gained experience. As a result, the need for ZAB controllers to guide flight crews decreased.

Another concern expressed was the lack of opportunities to use IM operations. Even though AAL had equipped approximately 300 aircraft with the SafeRoute+ system, most aircraft in the airspace were not equipped to perform IM operations. There were times when there was a grouping of aircraft that would benefit from IM, but an equipped aircraft was in front of an 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 operational evaluation. 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.

As discussed in Section 2.8, near the end of the first year of the operational evaluation, ZAB controller SMEs recommended modification to the initial phraseology. After discussions with the AIRS team, ZAB 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 123, designate Southwest 2345”
- Pilot: “American 123 has Southwest 2345 designated”
- Controller: “American 123, cross SLIDR at and maintain 8 miles behind designated traffic”

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

4.2.2 Example of Improperly Entered IM Clearance (Bad Geometry)

One of the issues faced by ZAB controllers was that AAL flight crews sometimes struggled to enter the IM clearance correctly into the SafeRoute+ Spacing application. This led to eventual changes in the flight crew interface, as described in Section 4.3.3.

One example of this was an IM operation conducted on November 8, 2022, shortly after the AIRS Evaluation started. According to the controller feedback form, the ZAB controller issued an IM Cross clearance to the flight crew, the flight crew entered the clearance information into the Spacing application, but it would not execute the clearance due to a "bad geometry" message. From the ZAB controller's perspective, no IM operation occurred. However, SafeRoute+ data showed a more nuanced story of what happened.

Figure 36 shows the avionics mode (top) and CP entry (bottom).

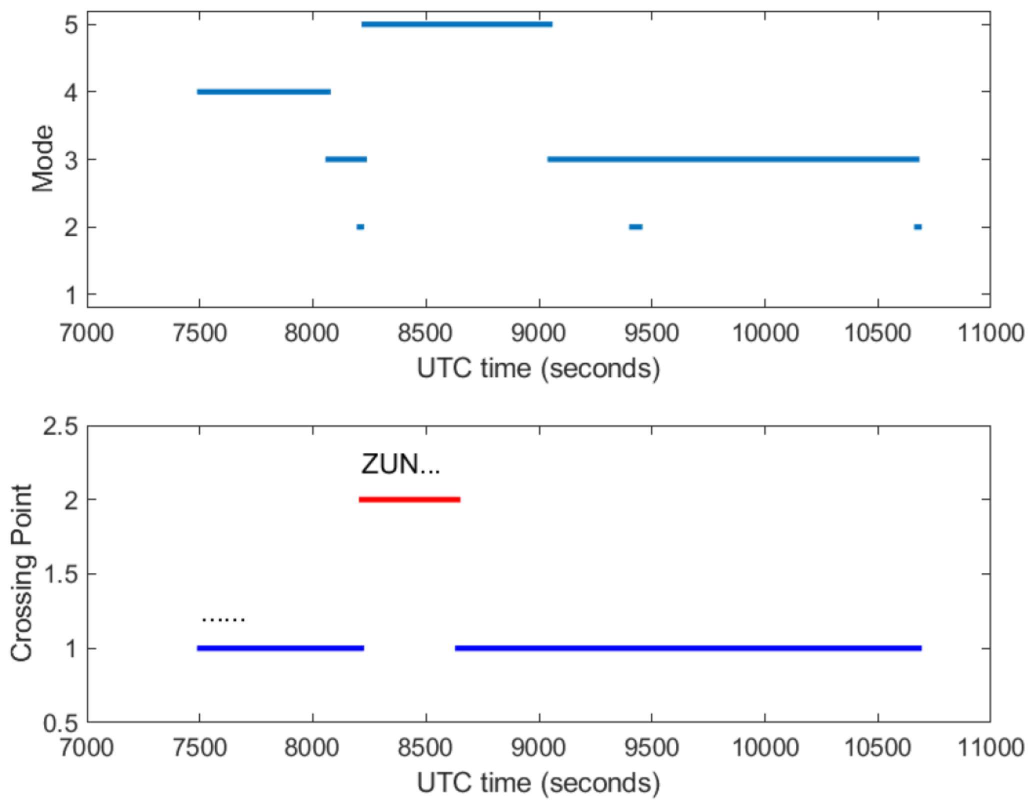


Figure 36 - Avionics mode (top) and CP (bottom) for IM operation from November 8, 2022

The blank CP entry shows that no CP was initially entered into the SafeRoute+ Spacing application, and the avionics mode was equal to 4 (Waiting for Environment), which indicated that the Lead and IM aircraft geometries were inconsistent with the Maintain stage of the Spacing application. The avionics mode later briefly changed to 3 (Ready to Execute), and shortly after that, the flight crew entered ZUN as the CP (about 400 seconds before the IM aircraft reached ZUN). The flight crew began executing the IM operation as indicated by the transition to mode 5 (Executing). The CP transitioned to "……" when the IM aircraft crossed ZUN, which indicated the Spacing application automatically transitioned to the Maintain stage. The avionics mode was still Executing for some time after the CP changed, but the avionics mode subsequent transition back to mode 3 indicated that the flight crew stopped the operation in the Spacing application.

Figure 37 shows the lateral path of the Lead and IM aircraft when the SafeRoute+ Spacing application was executing. While the Lead and IM aircraft were direct to ZUN, the merge angle was shallow. The avionics mode changing to 3 (Ready to Execute) before the flight crew entered ZUN as the CP occurred because the Lead aircraft had flown in the 6 NM wide swimlane around the IM aircraft projected track, as discussed in Section 2.4.

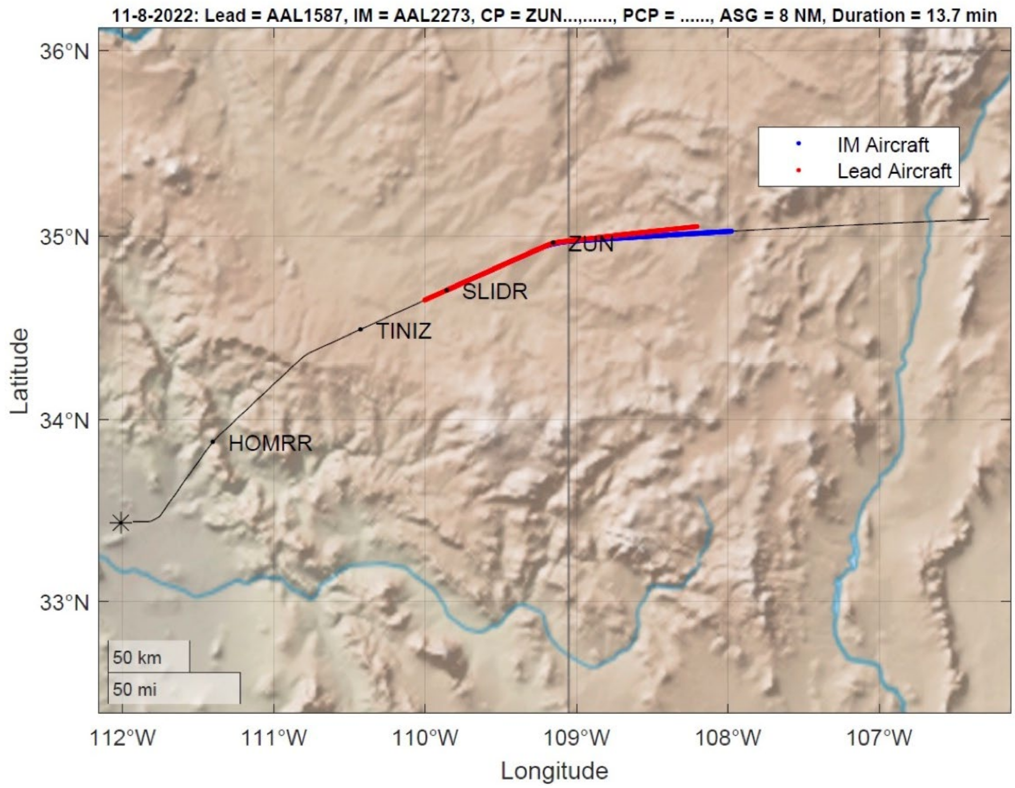


Figure 37 - Lead (red) and IM Aircraft (blue) Lateral Paths for IM operation from November 8, 2022

Figure 38 (top) shows that when the IM operation was initiated, the Lead aircraft was descending from 36,000 feet with the IM aircraft level at 30,000 feet. The IM speeds showed the flight crew complied with some speeds as shown in Figure 38 (middle), and the spacing interval increased from 5 NM at initiation to around 8.5 NM when the Lead aircraft passed over the CP given an ASG of 8 NM (bottom).

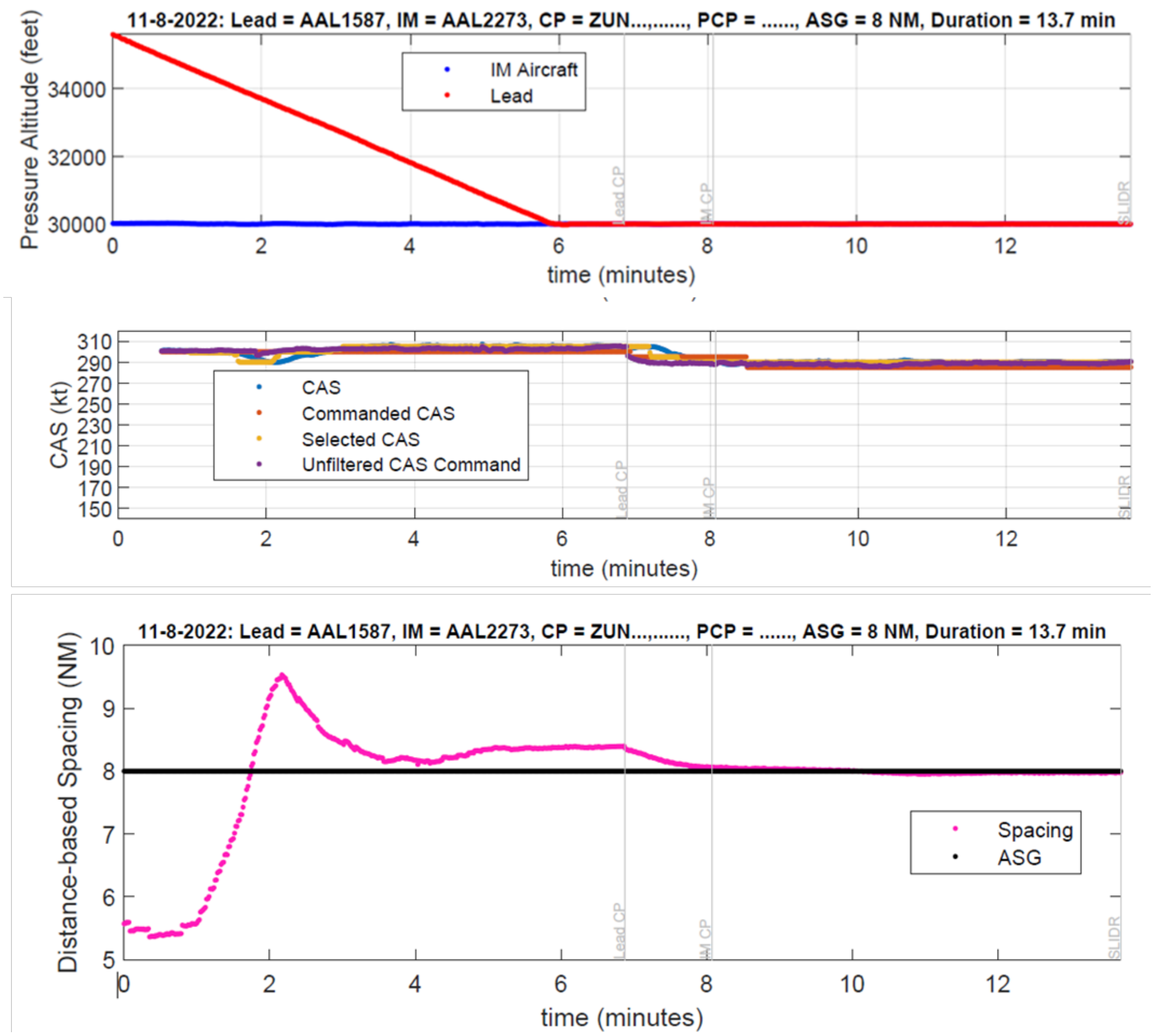


Figure 38 - Pressure altitude (top), IM speeds in CAS (middle), and Spacing Interval (bottom) for IM operation on November 8, 2022

4.2.3 First Example of IM Speed Limiting

During an IM operation in November 2022, a flight crew followed the IM speeds but was unable to achieve the assigned spacing goal. The controller eventually canceled the IM operation and used standard, non-IM operations. The controller also noted the event on the controller feedback form and recommended that the AIRS team perform a detailed investigation.

Discussions with the flight crew revealed that the IM speed was too low for the operation and the Lead aircraft was gradually pulling away from the IM aircraft. The AIRS team reviewed the SafeRoute+ data (as discussed in Section 3.1 and Section 3.10) and determined that IM speed was limited due to a Mach limit calculation within the SafeRoute+ Spacing application. This was a relatively infrequent event but needed to be understood.

The operation reviewed involved an IM Cross clearance with an ASG of 20 NM at the INW waypoint (see Figure 39). The IM aircraft (blue line) was at FL320, and the Lead aircraft (red line) was at FL400.

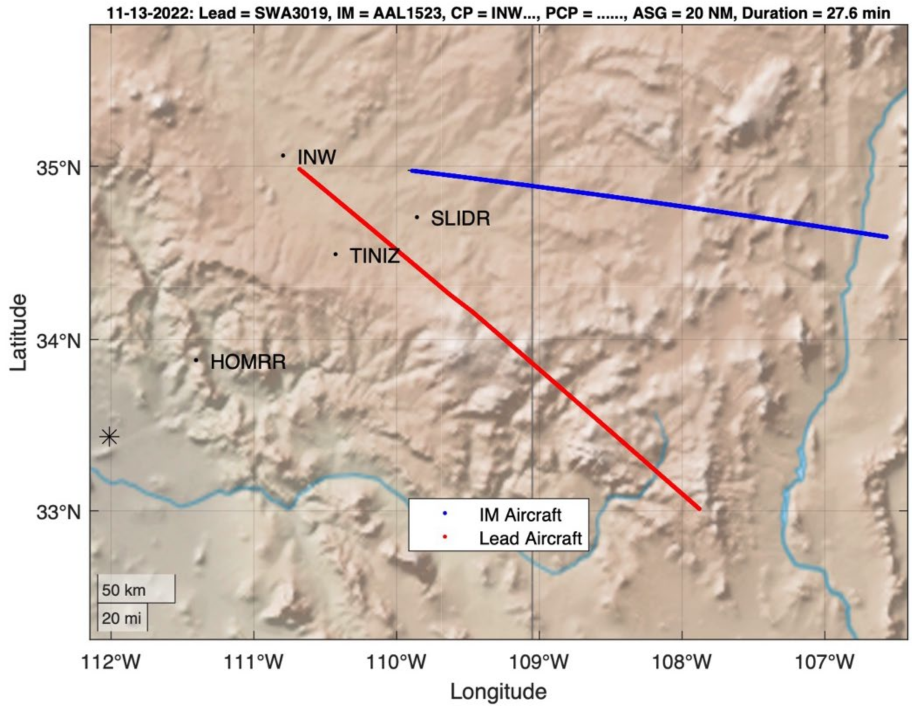


Figure 39 - Lead (red) and IM Aircraft (blue) Lateral Paths for IM operation from November 13, 2022

Figure 40 is a graph of the spacing error (top graph) and the different ground speeds of the two aircraft. The top graph shows the ASG of 20 NM (solid black line) and the actual spacing between the two aircraft (magenta line). As the operation progresses, the distance between the ASG and the spacing between the aircraft grows (increasing spacing error).

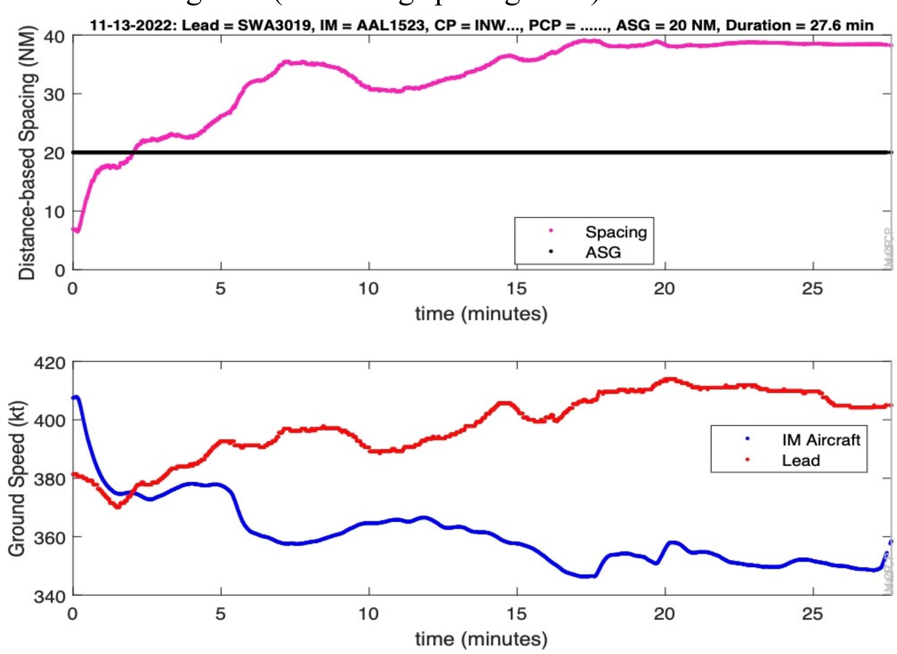


Figure 40 - Top: Spacing error; Bottom: Lead (red) and IM Aircraft (blue) Groundspeeds for IM operation from November 13, 2022

Figure 41 is a display of the IM aircraft's Mach number (blue line), IM speed in Mach (red line), and the Lead aircraft's Mach number as estimated by the SafeRoute+ Spacing application (green line). Also shown in the figure, as indicated by the dark black lines, is a calculated limit for the IM speed that was developed to approximate a FIM MOPS requirement to limit IM speeds to within 15% of the IM aircraft's airspeed profile. However, since the SafeRoute+ Spacing application had no knowledge of the IM aircraft's planned speed profile, this limit was instead based on the Lead aircraft's estimated CAS.

As seen in Figure 41, the IM speed was essentially constrained by the Mach upper speed limit (i.e., the IM speed was either higher or about the same as the upper limit Mach throughout this IM operation). This limiting resulted in the SafeRoute+ Spacing application providing an IM speed that was too low, which resulted in the IM aircraft not meeting the ASG.

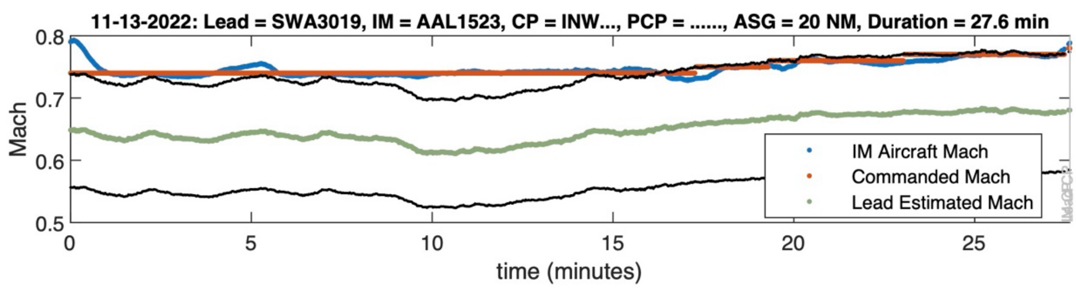


Figure 41 - Lead aircraft Estimated Mach (green) and IM aircraft Mach (blue), and IM Speed in Mach for IM operation on November 13, 2022

Since the SafeRoute+ system has no information about the Lead aircraft's wind field, the Lead aircraft's wind field was assumed to be the same as the IM aircraft's wind field. Additionally, the Lead aircraft's CAS was estimated based on the IM aircraft's static air temperature. Typically, these were reasonable assumptions. However, due to the significant altitude difference and different tracks of the two aircraft, the static air temperature and wind fields were very different in this case. This resulted in unreasonable limits on the IM speeds when using the assumptions built into the SafeRoute+ Spacing application.

The AIRS team tracked the impact of this IM speed limiting, and this situation occurred rarely during the operational evaluation.

4.2.4 Second Example of Speed Limiting

This IM operation was on February 23, 2024. The Lead and IM aircraft were direct to SLIDR, which was the CP. The flight crew entered the PCP as SLIDR resulting in the IM operation ending as the IM aircraft crossed SLIDR.

The pressure altitude plot in Figure 42 (top) shows that the Lead and IM aircraft initial altitudes were 26,000 and 34,000 feet, respectively. The IM speeds were presented in Mach, and the second-from-top plot shows that for most of the operation, only a single speed was displayed. As noted in the prior section, new IM speeds may have been suppressed while the spacing interval was within 5 seconds of the ASG (shown in the bottom plot). Additionally, the IM speed limits (second from bottom) show that the Lead aircraft's estimated Mach was around 1.0 and exceeded 1.0 for part of the IM operation. As a result, the IM speed was less than the lower speed limit (i.e., 15% less than the Lead aircraft's estimated CAS) despite the spacing interval being less than the ASG, which suggested the IM aircraft needed to decrease its speed further from the current IM speed. The second-from-top plot shows the flight crew did deviate from the IM speed and decreased the speed, which corresponded with the spacing interval increasing and overshooting the ASG in the bottom plot. The flight crew then increased their speed relative to the IM speed, and the spacing interval was within a 10-second tolerance of the ASG.

The poor estimate of the Lead aircraft's CAS and the resulting speed limits were a result of the altitude difference between the Lead and IM aircraft. As previously described, the Lead aircraft's CAS was estimated using the IM aircraft's sensed winds and temperatures. When the Lead and IM aircraft were further apart geographically and in altitude, applying the IM aircraft's sensed winds and temperatures was a poor assumption. At the start of the IM operation, the IM speed was not changing since the IM speed was less than the lower speed limit, despite the calculated spacing interval being about 20 seconds smaller than the ASG. This behavior could have been counter-intuitive to the flight crew, as they likely expected a slower IM speed to increase the spacing interval. The flight crew selected a slower speed, which increased the spacing interval and then became larger than the ASG. Around 4 minutes into this operation, the flight crew selected speeds closer to the IM speed but did not follow the IM speeds until around 7 minutes into this operation, when the spacing error was near zero. As a result of the IM speed limiting, only a single IM speed was displayed throughout much of the IM operation.

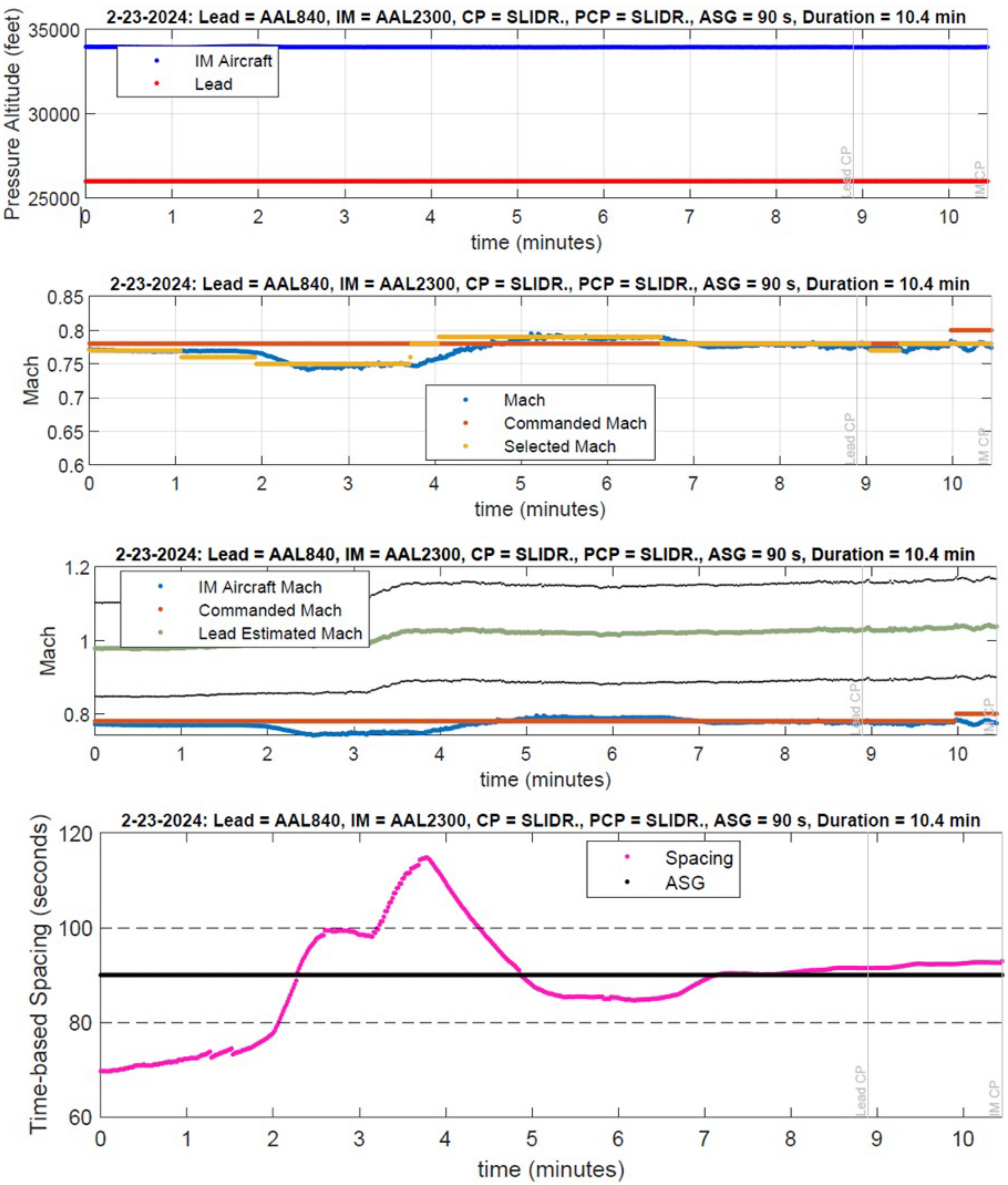


Figure 42 - Pressure altitude (top), IM speeds in Mach (second from top), IM speed limits in Mach (second from bottom), and Spacing Interval (bottom) for IM operation from February 23, 2024

4.2.5 Example of IM Operation during Descend Via procedure

The second year of the operational evaluation focused on IM operations along the EAGUL arrival. One characteristic that was noted numerous times by controllers and pilots was that the SafeRoute+ Spacing application seemed to provide IM speed changes later than expected during operations along the EAGUL arrival. The following IM operation and analysis illustrated this situation and discussed this behavior.

Figure 43 shows an IM aircraft (blue line) with an IM clearance to cross SLIDR at and maintain 100 seconds behind the Lead aircraft (red line). The IM aircraft was AAL1958 and the Lead aircraft was ENY3739, an Embraer regional jet. Though not shown here, the IM and Lead aircraft were co-altitude at FL300 until the Lead aircraft crossed TINIZ, where the Lead aircraft started their descent.

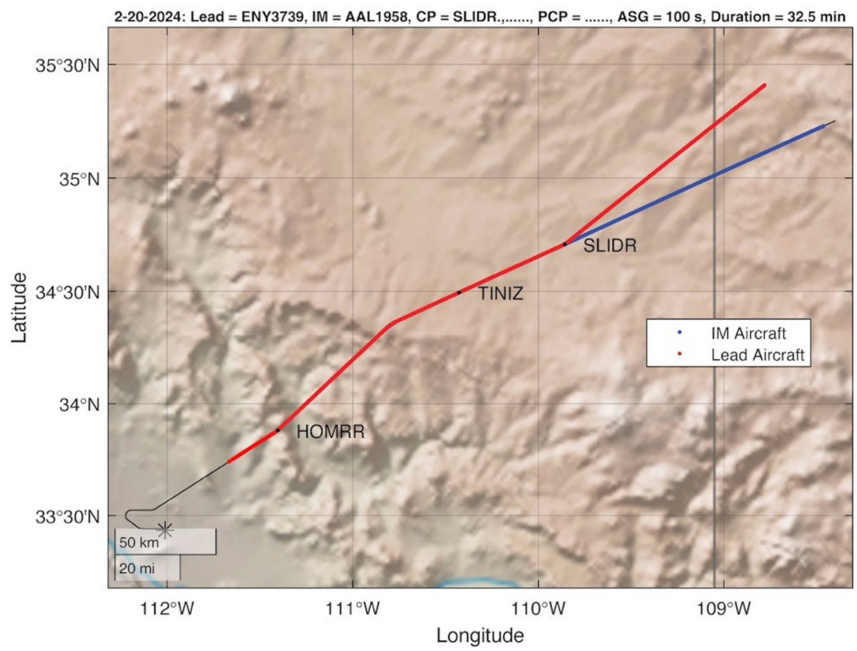


Figure 43 – Top-down view of a Cross-Maintain IM operation on the EAGUL6 arrival from February 20, 2024

Figure 44 is a screenshot from the Falcon replay for both aircraft as they approached TINIZ. The "leader lines" ahead of each aircraft represented a 1-minute extrapolation of the current tracker velocity for that aircraft. The range ring around AAL428 had a radius of 6 NM. Note that the waypoints were located under the vertical middle of the first letter in the waypoint name (shown in red text). From the separation detail table, ENY3739 had a groundspeed of 352 knots and AAL1958 had a groundspeed of 364 knots. The distance between the two aircraft was 9.72 NM with a closure groundspeed of 12 knots.

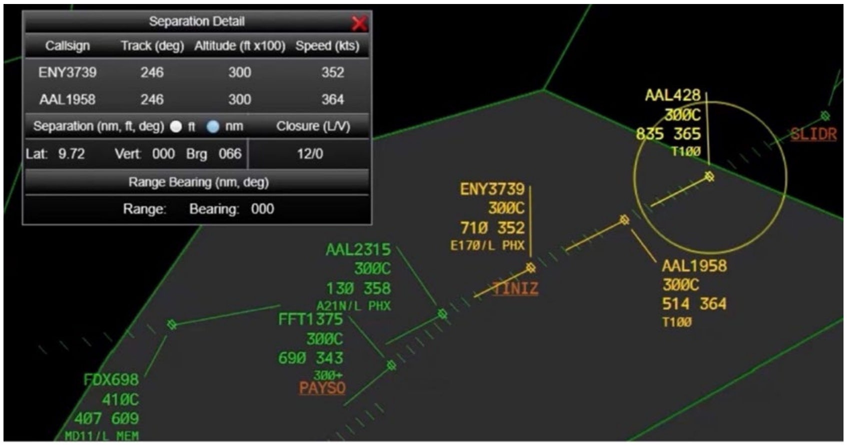


Figure 44 – Falcon Replay Screenshot of the Lead and IM aircraft prior to reaching TINIZ, February 20, 2024

Figure 45 is a screenshot from the Falcon replay when ENY3739 had passed TINIZ and had slowed down to a groundspeed of 309 knots. AAL1958 was approaching TINIZ and still had a groundspeed of 365 kts. The distance between the two aircraft had decreased and the closure speed was 56 kts.

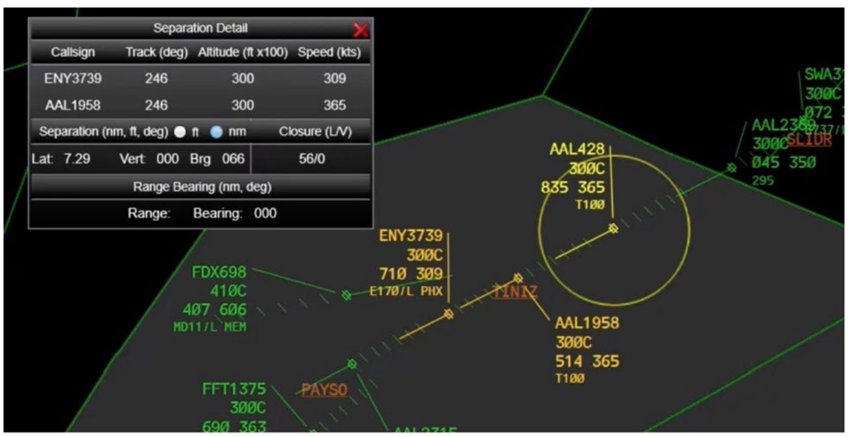


Figure 45 – Falcon Replay Screenshot when the Lead and IM aircraft are on different sides of TINIZ, February 20, 2024

Once both aircraft crossed TINIZ (Figure 46), both aircraft had similar groundspeeds, and the distance remained about 8 NM apart until they exited ZAB airspace.

Figure 46 – Falcon Replay Screenshot after both Lead and IM aircraft passed TINIZ, February 20, 2024

There were no flight crew errors observed with this operation and the spacing was maintained within an acceptable tolerance from a controller's perspective. However, both the flight crew and the controllers expected the IM aircraft to slow down at about the same location as where the Lead aircraft had slowed and asked for an explanation.

Figure 47 shows plots from the SafeRoute+ data obtained about a month after this IM operation occurred, as described in Section 3.1 and Section 3.9, per the discussion in Section 3.10. The upper plot in Figure 47 shows the aircraft's actual airspeed, the IM speed as displayed on the AGD, the pilot-selected speed, and the unfiltered IM speed (IM Computed IAS from Table 5). The middle plot in Figure 47 shows the spacing interval calculated by the SafeRoute+ Spacing application and the ASG (spacing goal), with the horizontal dotted lines indicating the 10-second tolerance around the ASG. The bottom plot in Figure 47 shows the groundspeeds of the Lead and IM aircraft.

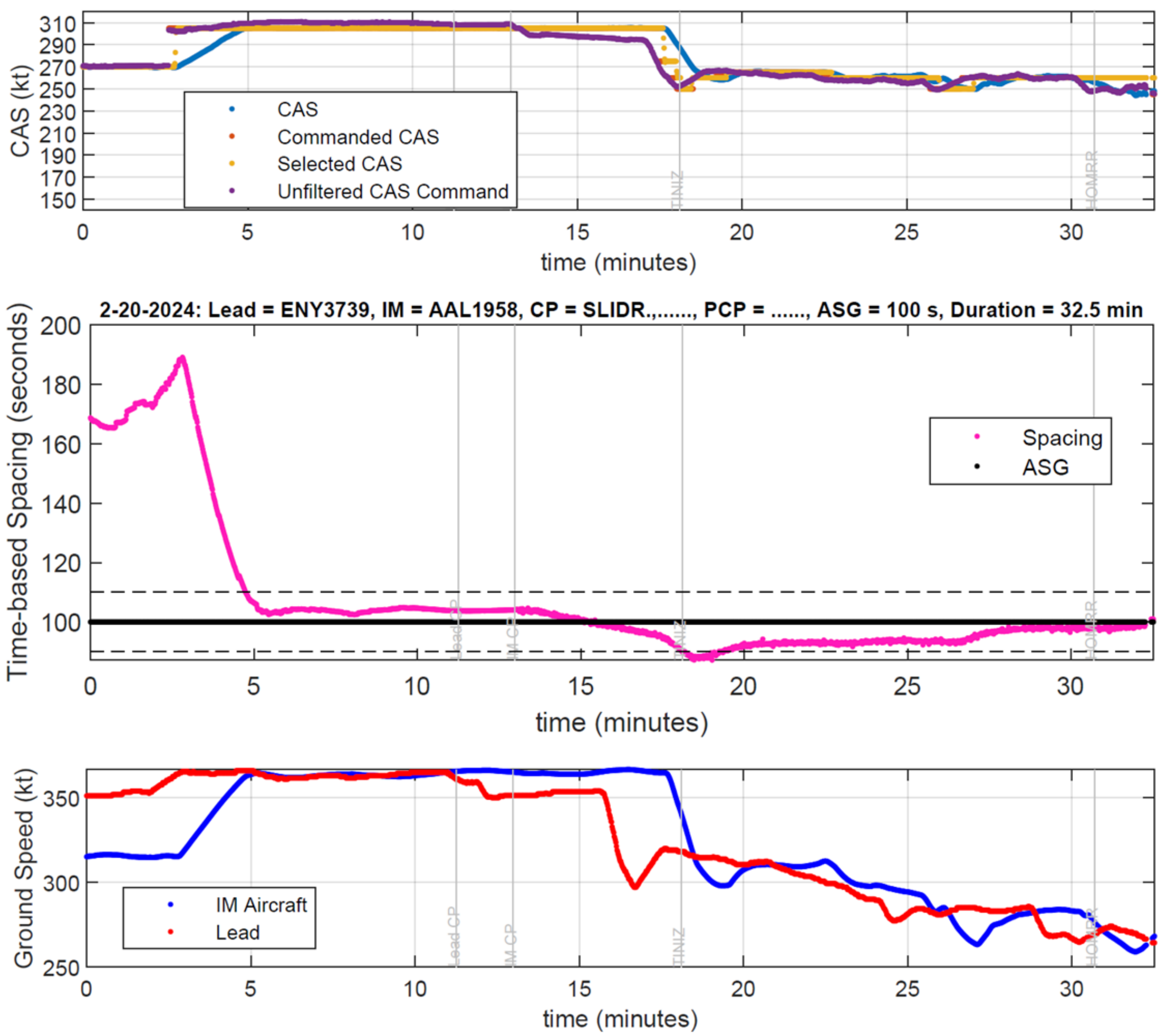


Figure 47 – IM speeds in CAS (top), Spacing Interval (middle), and Ground Speeds for IM operation from February 20, 2024

The flight crew followed the IM speeds and the operation progressed smoothly as both aircraft crossed SLIDR and continued on the arrival toward TINIZ. However, prior to TINIZ, ENY3739 slowed down to meet the speed constraint of 270 knots at TINIZ, as shown by the rapid decrease in groundspeed for the Lead aircraft in the bottom plot of Figure 47. There was a corresponding decrease in the time-based spacing between the two aircraft (middle plot of Figure 47) as the IM aircraft continued at around 305 knots until just prior to TINIZ (top plot of Figure 47), where the IM aircraft started its slowdown to around 260 knots. Other factors in this scenario were that the Lead aircraft slowed more quickly than the IM aircraft and that the Lead aircraft initially decelerated below the "at 270 knots" restriction at TINIZ and then accelerated back to 270 knots[19]. Beginning around TINIZ, the difference between the ASG and actual spacing exceeded 10 seconds for about one minute, though the spacing error never exceeded 15 seconds. Eventually the time-based spacing moved closer to the ASG and the operation progressed smoothly to completion.

To minimize changes in IM speeds, the SafeRoute+ Spacing application included a deadband[20] around the spacing error. In this example, and in similar situations, this deadband caused a delay in the issuance of an IM speed change; this can be seen in the top plot of Figure 47 by comparing the purple line (unfiltered CAS command) with the orange[21] line (Commanded CAS, or IM speed) just before TINIZ. The unfiltered CAS command started to decrease significantly about a minute before the IM aircraft reached TINIZ, but the IM speed on the AGD didn't change until about 30 seconds later when the spacing error exceeded the deadband and the IM speed reduced by 30 knots. The spacing error as shown in the middle plot of Figure 47 shows that the spacing error exceeded the 10 second goal for about one minute before the spacing error reduced and this IM operation completed at HOMRR with almost zero spacing error. This situation was exacerbated by the fact that the IM aircraft was an A321 and the Lead aircraft was an Embraer regional jet, since such a Lead aircraft can slow somewhat more quickly than an A321 is able to. Once ZAB controllers understood this behavior, they adjusted their expectations and anticipated the compression without reacting and canceling the IM operation.

4.2.6 Directed Discussions

ZAB controller feedback was obtained by ZAB controller SMEs through informal discussions ("directed discussions") with their colleagues during team briefings. These discussions were conducted approximately nine months after the start of operations. By that time, most controllers were familiar with IM operations 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. Details 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 were proficient with the SafeRoute+ system, the operation worked well.
    - Most controllers have had a positive experience with IM operations.
    - Several controllers stated they had experienced no issues with IM.

[19] This was inferred from the Lead aircraft being in level flight and was based on groundspeed only; there was no data on the Lead aircraft's actual airspeed.
[20] This means that within a specified range of spacing error values, the application treated those values as being = 0.
[21] In this plot, the orange line can usually not be seen underneath the yellow line since the flight crew did such a good job of complying with the IM speeds.

- IM operations have been primarily prompted by ZAB controller SMEs.
- 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 arrival sequencing to PHX.
- IM is out of sight, out of mind, until a ZAB controller SME asks for it (this was stated several times).

- Additional automation requests
  - Additional automation would encourage utilizing IM on a regular basis and reduce the need for ZAB controller SMEs.
  - Fourth line coordination is sometimes inadequate when dealing with multiple IM clearances or altitude stratums[22]. Coordination via the fourth line can be inadequate when multiple IM operations are underway simultaneously since all that is shown in the fourth line is Lead and/or Trail (IM) status, without any information on which Trail is following which Lead.
  - There needs to be a more efficient method of nonverbal coordination.
  - Some type of IM 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 IM clearances can be issued via a quick keyboard command, it would negate the negative cost-benefit.
- Controllers 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 IM speeds.
  - 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 Air Route Traffic Control Center (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 ZAB controller SMEs.
  - 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.

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

ZAB 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 ZAB controller SMEs provided a workaround for the lack of ERAM support, but without ZAB controller SME support or ERAM 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 Lead and IM aircraft
- When arrival metering is in use, time-based ASGs derived from the planned times of arrival of the Lead and IM aircraft at the first common arrival fix
- 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 was to create one, straightforward voice clearance that would support both Maintain and Cross clearances.

4.3 Flight Crew Feedback

4.3.1 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 experience with the IM operation, including phraseology, avionics interface, IM speeds, and the number of IM speed changes encountered.

The interviews were particularly focused on operations highlighted by ZAB controllers for additional study, as described in Section 3.1. 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. These interviews were also opportunities to answer any questions that flight crews might have and to clarify aspects of the operation that may be confusing to flight crews.

The results of these interviews were briefed to and discussed with the entire AIRS 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.

Throughout the operational evaluation, there were several consistent, repeated themes that came up in the interviews, which were noted and discussed by the AIRS team. A summary of these 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 reported that it took both pilots to monitor the AGD for IM speeds and spacing accuracy.
  - Attention spent on the AGD increased workload and distracted from other duties[23].
  - As the flight crews became more familiar with the display, reports of the stare factor decreased significantly.
- **Automation**
  - Pilots would prefer that the IM Speed be implemented via the autoflight system of the aircraft instead of manually adjusting the speed.
- **Bad Geometry Message**
  - Some pilots were confused about how to use the MCDU interface; particularly when inserting the CP into the system (previously noted in Section 4.2).
  - The "Bad Geometry" message led some pilots to believe there was a problem with the system.
- **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 precisely 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.

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

[23] APA interviewers pointed out this was a new piece of avionics and was not yet in every pilot's basic scan. APA interviewers told pilots there was no need to stare at the AGD and respond instantaneously to IM speed changes.

- **Characteristics of Unsuccessful Operations**
  - Had not recently reviewed the training material
  - Lack of training tools such as simulator training that provided "button pushing"
  - Attempted to manually meet the ASG (didn't follow the IM speeds)
  - Avionics interface confusion
  - Entered the CP incorrectly

As a result of these interviews and discussions with the AIRS team, AAL issued several communications to clarify that the only responsibility the pilot had was to comply with the IM Speed or advise a controller if the IM Speed could not be flown. Over the course of several months, understanding and compliance improved dramatically.

Many pilots commented they found the IM operation to be straightforward, easy, and intuitive. They found the pilot 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 initiated.

Many pilots initially commented about their concerns and perceptions with IM training. SafeRoute+ was not installed in the AAL Airbus flight simulators. Training was limited to bulletins, videos, and PowerPoint-like presentations, as well as briefing from instructors and check airmen. Several pilots voiced their concerns with this approach. Many noted that 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, known as ETHOS, was developed by ACSS for AAL pilots. The ACSS ETHOS Module was an interactive, procedural trainer that was hosted on a tablet or accessed via laptop/desktop computer. This training software included a SafeRoute+ Lesson that provided AAL pilots with an interactive tool simulating data entry and display depiction associated with the SafeRoute+ CAVS and Spacing applications. The lesson used a virtual interface to mimic the MCDU and AGD interfaces. The accompanying training tutorial walked a pilot through the required data entry and resulting responses for the SafeRoute+ CAVS and Spacing applications. The interactive tutorial demonstrated normal system behavior as well as responses to incorrect data entry and various SafeRoute+ CAVS and Spacing application failures. The ACSS ETHOS Module was released to AAL flight crews about halfway through the operational evaluation.

Another frequent observation was pilot confusion regarding the current spacing information on the AGD during a Cross operation (see Figure 11). Pilots reported concerns that the current spacing did not always match the ASG. Recall from Section 2.4 how current spacing was estimated during a Cross operation.

APA and AAL took steps to clarify how the assigned spacing was achieved by the SafeRoute+ Spacing application and the flight crew's responsibility was to set the aircraft's speed to match the current IM speed. Human factors likely played a role, as pilots are conditioned to expeditiously comply with ATC instructions, though as noted in Section 2.4, the SafeRoute+ Spacing application was not designed for expeditious action under all conditions. When assigned a spacing goal, some pilots expected the avionics to achieve the spacing sooner than what was being observed. This could result in the manipulation of aircraft speed to try and achieve the spacing goal in less time. Such action usually resulted in a higher workload than necessary due to multiple self-induced speed changes. This was confirmed by examining SafeRoute+ Spacing application data, as discussed in Section 3.10.

Some pilots reported that the AGD would display frequent and/or excessive numbers of IM speeds. At times, the IM speeds would change dramatically (e.g., jump from Mach 0.72 to Mach 0.76) or the AGD would display several IM 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 get the displayed current spacing to match the ASG rather than following the IM speeds. On a few occasions, the cause of rapid changes in IM speed was caused by assumptions within the SafeRoute+ Spacing application.

Many pilots reported several benefits with the CDTI as part of their flight deck technology. The primary advantage was increased situational awareness. Pilots noted they were more aware of what was going on with the traffic around them and felt they were more in sync with controllers in both terminal and en route airspace. By having the flight identification of other traffic, flight crews were more aware of what frequency changes were coming and the next instructions they could expect to receive from the controller. This helped to prevent read-back hear-back errors and missed or repeated frequency changes.

Pilots reported that they avoided areas of turbulence when they could pinpoint a specific flight or aircraft that reported a turbulence encounter and located them on the AGD. Flight crews could also contact aircraft directly on VHF to ask specific flight-related questions.

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

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

4.3.2 LOSA Observations

In addition to flight crew feedback collected through APA interviews, AAL's LOSA program conducted 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 2023. During the operational evaluation, at least 15 LOSA observations were successfully conducted for flights involving IM clearances. Even with the limited number of observations, the LOSA data proved valuable as it gave the AIRS team members the "pilot's perspective" of what is seen from the flight deck during IM operations. The LOSA data helped identify the need for improved crew training as well as flight crew interface improvements that were needed. It also drove improvements in phraseology, as described in Section 2.8.3.

Like feedback received during the APA interviews, LOSA observed flight crew discussions about why the SafeRoute+ Spacing application provided IM speeds that seemed counterintuitive. Flight crews did not understand why the system would still command a slower speed when the distance or time (displayed "current spacing") was larger than the ASG (displayed "assigned spacing"). Flight crews would also question the system when they observed the Lead aircraft slowing down for a published STAR speed restriction, while the SafeRoute+ Spacing application still provided a faster IM speed than the published speed when the distance or time requirement appeared to be met (comparing "current spacing" with "assigned spacing" on the AGD).

The observed data helped the FAA and ZAB controllers who participated in issuing clearances understand what did and did not work during IM operations. Overall, the lessons learned contributed to more efficient IM operations.

4.3.3 Flight Crew Interface Changes Resulting from the Operational Evaluation

As a result of pilot and controller feedback discussions, the AIRS team recommended the removal of current spacing information on the AGD (see Figure 11). Many pilots misunderstood the definition of this information, found this information compelling and rather than complying with the IM speed on the AGD, they tried to manage spacing by selecting their own aircraft speeds. Removal of the current spacing information was recommended to reduce the likelihood of flight crews selecting different speeds than the IM speeds. Working with AAL, ACSS developed the new MCDU interface shown in Figure 48.

Figure 48 - ADS-B In Guidance Display as modified for the SafeRoute+ Spacing application

Data collected during the operational evaluation indicated that many flight crews had difficulty correctly entering required information for Cross operations in the MCDU. This situation often occurred for two reasons: pilot unfamiliarity with the default MCDU page for entering data and pilot confusion over how to enter the CP.

The default MCDU page for entering data supported a Maintain clearance as shown on the left side of Figure 49. To get to the page for entering a Cross clearance, flight crews had to select the button adjacent to the arrow by the word CROSS (left side, second line select key from the top).

Without selecting the CROSS key, the SafeRoute+ Spacing application remained in the default state of a Maintain operation. As a result, instead of entering Cross clearance information (e.g., CP, ASG, etc.) on the CROSS page, flight crews were entering information on the MAINTAIN page. 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. The SafeRoute+ Spacing application would then display a BAD GEOMETRY message, as shown on the right side of Figure 49.

Figure 49 – Left: MCDU Spacing page for Maintain Operation; Right: MCDU Bad Geometry Message on Maintain page

Additionally, flight crews noticed that there was a place to enter a value under CROSS using the third line select key from the top on the left side of the MCDU. As evidenced by data entry as recorded on the CF cards (see Section 3.9), many flight crews interpreted this to mean they should enter the CP in this location. Unfortunately, this line select key is for entering the Planned Cancellation Point (PCP) (called termination point in this version of the software). Flight crews thought they were entering the CP for the operation, when instead they were entering the PCP.

When a bad geometry condition existed, the EXECUTE prompt was not displayed and therefore the flight crew could not conduct an IM operation even though the flight crew thought they had entered the information correctly. This proved to be frustrating to pilots and controllers.

The AIRS team recommended that the MCDU interface be redesigned to avoid these confusions. Working with AAL, ACSS developed the new MCDU interface shown in Figure 50.

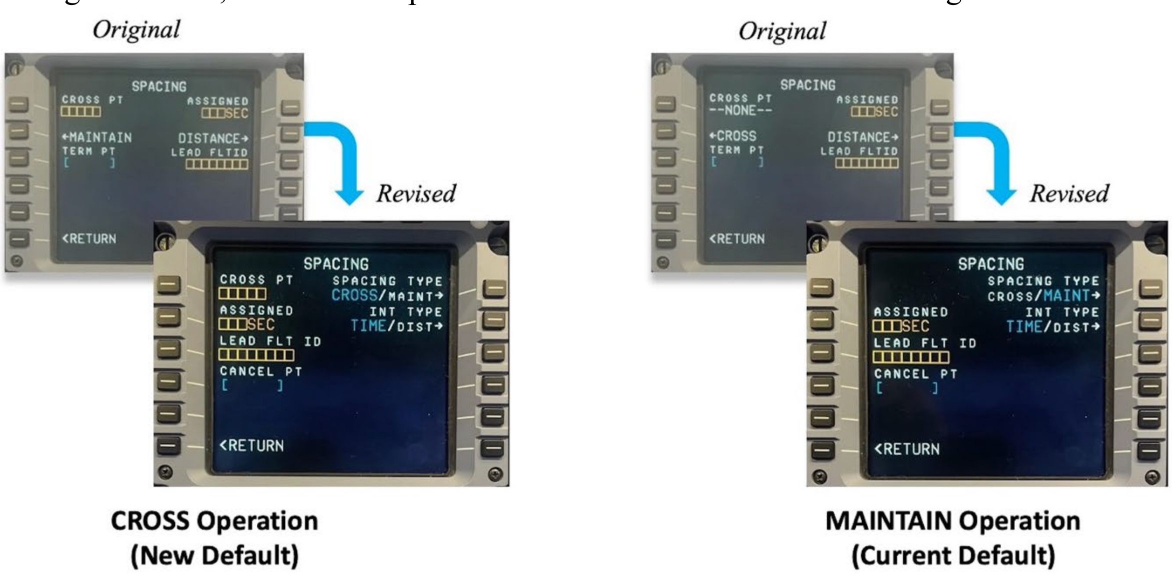


Figure 50 – Revised MCDU interface for Spacing Application

For this design, the Cross operation is the default, so the interface shows the appropriate page for entering that information. Next to the top right line select key, 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 the top right line select key, which then highlights the word "MAINT" 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".

ACSS designed, tested, and certified this updated interface late in the second year of the operational evaluation. The updated interface received STC approval on the A321ceo in August 2024 and software updates began in October 2024, just before the operational evaluation concluded in early November 2024. The updated interface received STC approval on the A321neo in April 2025 and software updates began in May 2025.

4.4 Number of Attempted IM Operations from Controller Feedback Forms

Figure 51 shows the progression of attempted IM operations through the operational evaluation, as measured by controller feedback forms (see Section 3.1 and Section 3.3). Since a controller feedback form was typically completed whenever an IM clearance was issued by a ZAB controller, any flight crew response of "unable" or other inability of the flight crew to execute the IM clearance would be recorded by a controller feedback form, even if no IM operation resulted. This is why the term "attempted IM operation" is used. After the first few weeks, ZAB controller SME support was discontinued and the number of attempted IM operations sharply decreased. The belief at the beginning of the operational evaluation was that ZAB controllers with an understanding of IM could initiate and monitor IM operations. One of the lessons learned during this early period was that most ZAB controllers needed additional support to initiate IM operations. To initiate IM operations on a routine basis, controllers needed to feel confident that when an IM clearance was issued, that would lead to an IM operation. Given that the ZAB sectors with the most IM opportunities (arrivals to PHX from the east) were encouraged to use a time-based ASG, many controllers were not comfortable initiating an IM clearance and continued performing standard operations.

Starting in May 2023, ZAB controller SMEs resumed providing IM clearance information to controllers in different sectors of ZAB. The number of attempted IM operations generally improved until November 2023. Starting in November 2023, the operational evaluation was focused on two sectors of ZAB, with a cadre of experienced controllers that handle most of the westbound arrival traffic into PHX on the EAGUL arrival. The operational evaluation remained in this configuration until completion. With this focus, the ZAB controller SMEs were generally able to identify more IM clearances for controllers. See Section 4.2 for further discussion of factors which affected opportunities for IM operations in ZAB.

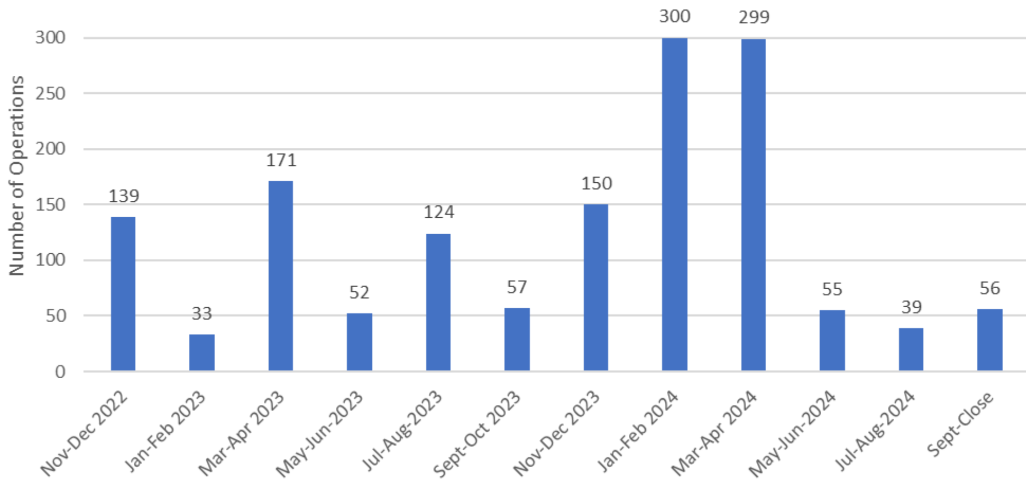


Figure 51 - Number of Attempted IM Operations recorded from Controller Feedback Forms

4.5 Tracking Concerns and Issues

Over the operational evaluation, several issues and concerns were categorized and tracked, based on the controller feedback forms and ZAB controller SME discussions. Concerns were defined as items that affected operations but did not cause an IM operation to be cancelled. Issues were defined as problems that caused an IM operation to end early or prevented the IM operation from beginning.

4.5.1 Concerns and Issues

Figure 52 shows the total number of reported concerns/issues by category, as captured in controller feedback forms or APA pilot discussion documentation for attempted IM operations. Note that a single attempted IM operation could have multiple concerns and/or issues associated with it (including multiple concerns/issues in each category). The numbers shown in the figure cannot be added together to conclude how many attempted IM operations had a concern or an issue.

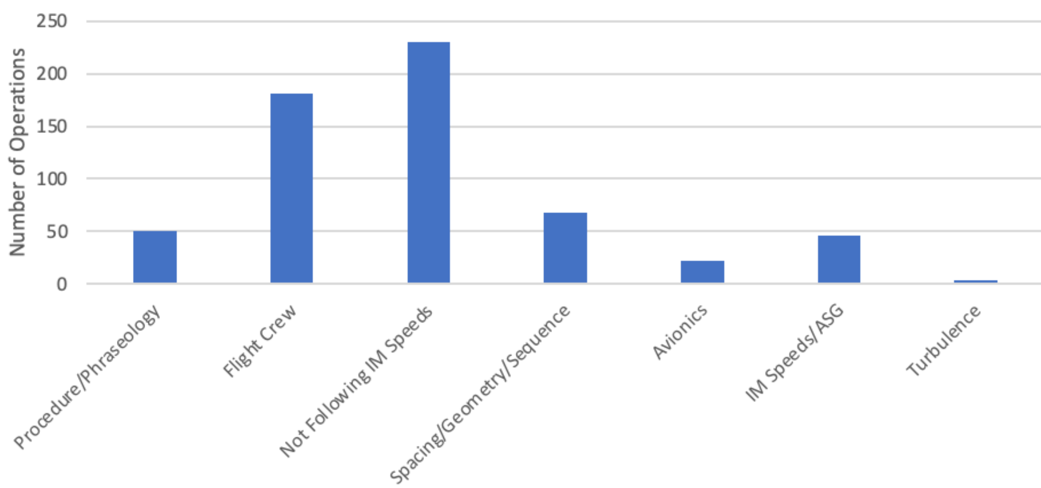


Figure 52 - Total number of Concerns and Issues

Each category was defined as follows:

Procedure/Phraseology

- Procedural Misunderstanding – A misunderstanding during an attempted IM operation occurred between the flight crew and controller. This was typically caused by flight crew misunderstanding of the IM operation. As an example, during one IM operation, a flight crew thought they had to call the Lead aircraft on their VHF radio.
- Phraseology – Flight crew was confused or did not understand phraseology for the IM operation.

Flight Crew

- Unable – Flight crew was unable to conduct the IM operation.
- Training – Flight crew reported not having been trained.
- Pilot Did Not Self-Report – Flight crew did not provide IM operation information when checking in with the next ZAB sector.
- Entry Error – Flight crew entered the IM clearance incorrectly into the SafeRoute+ Spacing application and received feedback that there was an error, or a flight crew erroneously entered the CP into the PCP field of the MCDU, which would cause IM speeds to end at the CP when the controller intended for the IM operation to continue.
- Could Not Locate Traffic– Flight crew could not find and designate the Lead aircraft for the IM operation.
- Unequipped – Flight crew reported they were not equipped with SafeRoute+.
- Distraction – Flight crew reported that IM Speeds were distracting and a nuisance.
- High Workload – Flight crew reported the IM operation was too work-intensive. This may have been due to the initial communication and length of the IM clearance, or to the flight crew trying to match the "Current Spacing" with the "Assigned Spacing" on the AGD.
- Confidence in Outcome – Flight crew reported that they were not confident of the outcome of the operation or avionics.

Not Complying With IM Speeds

- Flight crew not complying with IM speeds displayed on the AGD. This was evaluated by a ZAB controller SME using the data provided, as described in Section 3.10, but was generally considered to be an IM speed compliance (see Section 4.7) of less than 50%.

Spacing/Geometry/Sequence

- Traffic Sequence – Controller had concerns over traffic sequencing when using the IM operation, or if a controller did not realize the IM aircraft or Lead aircraft had been given a "direct-to" clearance that took them off their original routing.
- Spacing Unavailable Message – Flight crew received an "Unable Spacing" error from the SafeRoute+ Spacing application. This could be due to a drop in ADS-B quality parameters of either the IM or Lead aircraft, or due to unacceptable flight path geometry.
- Unable Cross but able Maintain – Flight crew reported that they are unable to do the Cross clearance but could do a Maintain clearance.
- Bad Geometry – Flight crew received a "Bad Geometry" message from the SafeRoute+ Spacing application. This message could appear when the Lead or IM aircraft were not flying direct to the CP, when the IM aircraft had deviated from the Lead aircraft's flight

path during a Maintain IM operation, or when the IM aircraft was closer in distance to the CP than the Lead aircraft[24].
- Metering Schedule – The Metering schedule caused a change in the arrival sequence.

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

IM Speeds/ASG
- Number of IM Speeds – Flight crew reported there were too many IM Speeds.
- IM or Descend Via Speeds – Flight crew reported they could not apply the IM Speed with the "Descend Via" procedure. This could have been flight crew confusion over the precedence of IM Speeds or that the IM Speed did not provide a suitable descent rate to meet the STAR's altitude constraints.
- IM Speed Too Low or Too High – Flight crew reported the SafeRoute+ IM Speed was either too low or too high for operational acceptability. This could have been due to flight crew comfort level or other operational constraints.
- ASG Too Small – Flight crew received an "Interval Too Small" error from the SafeRoute+ Spacing application feasibility check (the feasibility check was done for Cross clearances with time-based ASGs only).

Turbulence
- Wake Turbulence – Flight crew reported they had to adjust speed or spacing due to wake.
- Atmospheric Turbulence – Flight crew was unable to comply with IM Speeds due to atmospheric turbulence.
- Aircraft Weight – Flight crew reported they could not comply with the IM Speed due to the aircraft gross weight or aircraft center-of-gravity.
- Convective Weather – Flight crew or controller reported issues with the operation due to convective weather.

4.5.2 Concern and Issue Trends

Concerns and issues noted in the controller feedback forms or in follow up data correlation were tracked throughout the operational evaluation to determine trends. After noting a trend during operations per the processes described in Section 3.1, the AIRS team would determine appropriate response action(s). Figure 53 shows the trends of concerns and issues over the course of the operational evaluation.

[24] This could occur only in an IM Cross operation when based on groundspeed differences, the controller could discern that the IM aircraft would arrive at the CP after the Lead aircraft.

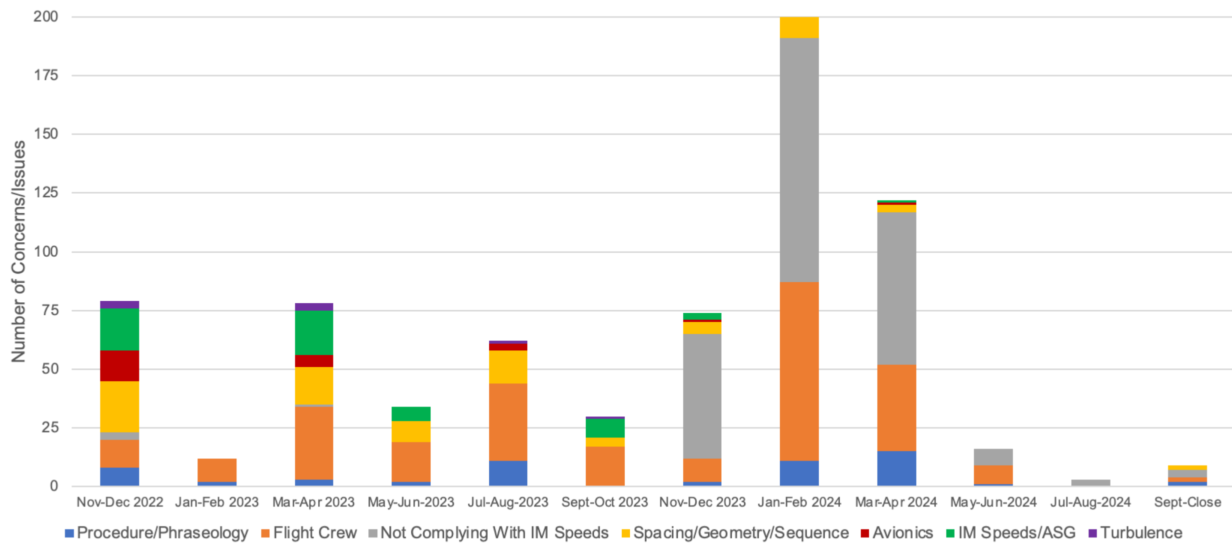


Figure 53 - Trends of Key Concerns and Issues

During the operational evaluation, several concerns/issues were resolved through improved proficiency with the operation or changes of phraseology. Figure 54 shows the percentage of attempted IM operations with a concern or issue by category during the operational evaluation. At the beginning of the operational evaluation, there were concerns and issues in each defined category. The persistent concern and issue category during the entire evaluation was the Flight Crew. This was primarily due to two factors: flight crew Unable responses and flight crews not self-reporting when checking in with a downstream controller. The prevalence of the Flight Crew category of concerns/issues generally reduced during the operational evaluation. In the second year of the operational evaluation, with more IM operations along the EAGUL arrival into PHX, and with more AIRS team focus on flight crews not complying with IM speeds, the "Not Complying with IM Speeds" category was initially the largest category of concerns/issues. However, this category became a smaller percentage during the second year.

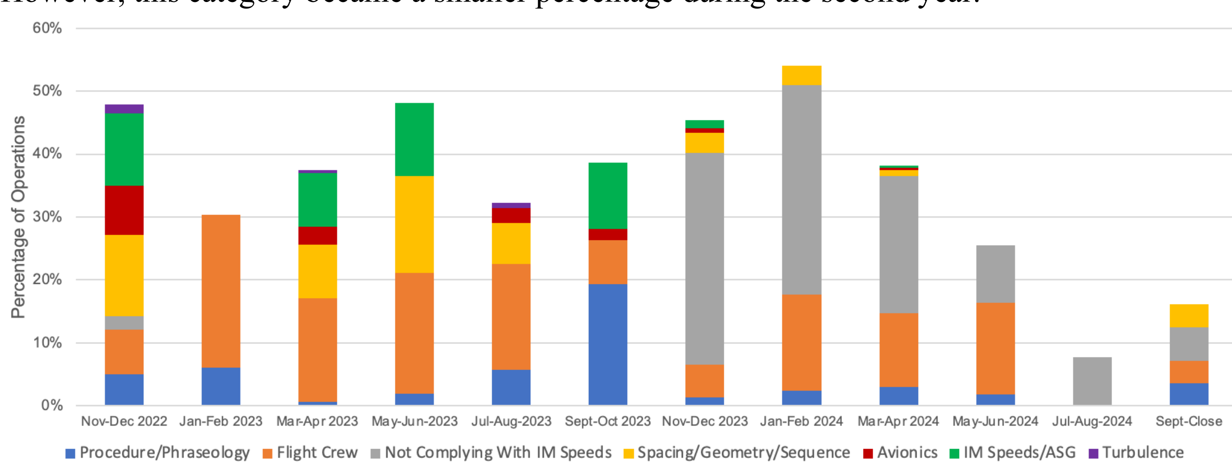


Figure 54 - Trend in Key Concerns and Issues as a Percentage of Attempted IM Operations

4.6 Number of IM Events from SafeRoute+ Data

SafeRoute+ data was recorded every second the Spacing application was in use (see Section 3.9). This data was provided to the AIRS data collection team semi-monthly. The data was processed and aggregated into “events” and to determine the relevant operations and performance metrics. In general, an ACSS event was defined as a continuous period greater than or equal to five minutes where the Spacing application was executing.

Data captured from the SafeRoute+ system included ACSS events when the flight crews may have been familiarizing themselves with the equipment (versus performing an IM operation in ZAB airspace per a controller clearance). This data had to be filtered to identify ACSS events that were relevant to the scope of this operational evaluation. The SafeRoute+ data was correlated with controller feedback forms and other data sources to obtain a more complete picture of each IM operation.

There were at least 1398 operationally relevant ACSS events captured for analysis during the evaluation. Because of SafeRoute+ data loss (see Section 3.9) and incompleteness of controller feedback forms and voice transcript data, there were likely several IM operations not captured during the analysis.

4.6.1 Approach to Determine Relevant IM Events

The following steps were used in the process shown in Figure 55:

- An ACSS event was defined for each time range where the avionics mode was listed as “executing” and duration was greater than or equal to five minutes.
- If a pilot entered a new Lead aircraft, ASG, or CP, the SafeRoute+ Spacing application was no longer in an “executing” state, so one event stopped and a new one began. Therefore, a given IM clearance could generate multiple ACSS events.
- ACSS events were correlated with the voice transcript data and the controller feedback form data to verify a controller’s interaction with the flight crew of an IM aircraft (the IM operation required actions by both the pilot and controller). To qualify as a Relevant IM event, an ACSS event needed to correlate with at least one of the other data sources available to confirm controller interaction.

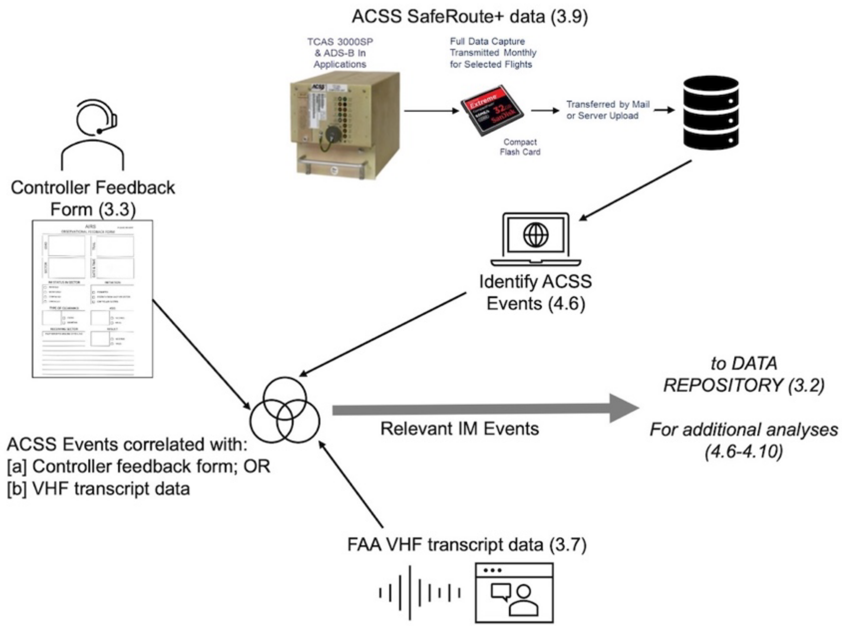


Figure 55 – Data Correlation Process to determine Relevant IM Events

After processing, the number of Relevant 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)

Note that an ACSS event was defined as concluded once the aircraft crossed into Phoenix Terminal Radar Approach Control (TRACON), known within the FAA as P50, and approximated by a 50 NM radius around PHX, because the operational evaluation was limited to ZAB airspace. This determination was made by correlating Relevant IM Events with IOAA trajectory data in a separate process not shown in Figure 55.

4.6.2 Number of Relevant IM Events

Table 6 shows counts of ACSS events and how many of these ACSS events correlated with either a controller feedback form or voice transcript data to yield Relevant IM events. Each row contains results for each month of the operational evaluation. The second column lists the number of ACSS events per month. Note that it was possible to have multiple ACSS events for a given IM operation. This occurred in cases where the flight crew used the Spacing application for at least five minutes, then stopped the Spacing application, and executed it again for at least five minutes[25]. The third column ("Feedback Form Match") lists the number of controller feedback forms per month which matched one or more ACSS events. Since multiple ZAB controllers may have interacted with a given aircraft over an IM operation spanning multiple ZAB sectors, there

[25] An example of this would be where the flight crew inadvertently entered the CP as the PCP and the Spacing application automatically stopped at the CP, and then a ZAB controller would ask the flight crew if they were still conducting IM and the flight crew, realizing their error, would restart the Spacing application.

may be multiple controller feedback forms for the same IM operation. After querying transcript data (as described in Section 3.7), the resulting transcript information was filtered to match ACSS events using the date, time, and relevant information from the IM operation (as described in Section 4.6.1) and the monthly number of ACSS events that correlated with the transcript data was placed in the fourth column ("Transcript Match"). The fifth column ("Relevant IM events") reports the superset of the "match" columns – these are the number of ACSS events where there was at least one indication of controller interaction (either feedback form or transcript); these are the Relevant IM events used in the remainder of the analysis in this report.

Table 6. Counts of ACSS Events, Feedback Form & Transcript Matches, and Relevant IM events by Month

By Month	ACSS events	Feedback Form Match	Transcript Match	Relevant IM events
11/2022	253	112	146	152
12/2022	86	4	6	9
01/2023	45	4	6	7
02/2023	74	19	22	23
03/2023	139	60	63	69
04/2023	132	70	71	74
05/2023	61	8	10	10
06/2023	80	19	19	20
07/2023	103	60	62	68
08/2023	84	43	40	48
09/2023	100	48	29	51
10/2023	58	7	9	9
11/2023	112	59	58	65
12/2023	134	73	73	81
1/2024	216	155	125	173
2/2024	180	128	110	143
3/2024	241	176	28	179
4/2024	181	101	37	104
5/2024	79	41	0[26]	41
6/2024	43	7	0	7
7/2024	65	13	0	13
8/2024	46	13	0	13
9/2024	43	17	0	17
10/2024	56	16	0	16
11/2024	25	6	0	6
Total	**2638**	**1259**	**914**	**1398**

Another outcome from matching controller feedback forms and voice transcript data with ACSS events was an ability to quantify cases where ACSS data card information was missing. It is

[26] As stated in Section 3.7, no transcript data was available after April 20, 2024; this row and subsequent rows are therefore zero due to no data being available.

estimated that at least 44 ACSS events were missing due to issues obtaining the SafeRoute+ data, as described in Section 3.9.

Table 7 shows the Total row from Table 6, categorized by IM Clearance type.

Table 7. Total ACSS Events, Feedback Form & Transcript Matches, and Relevant IM Events by IM Clearance Type

Clearance Type	ACSS events	Feedback Form Match	Transcript Match	Relevant IM events
Cross	285	192	157	224
Cross-Maintain	709	594	425	643
Maintain	1644	473	332	531
Total	**2638**	**1259**	**914**	**1398**

Results based on these 1398 Relevant IM events are presented in Section 4.7, Section 4.8, and Section 4.9.

4.7 IM Speeds, Pilot-Selected Speeds, and Speed Compliance

This section describes the approach and results for measuring IM speeds displayed to the pilot on the AGD, pilot-selected speeds, and flight crew compliance with IM speeds. These metrics were analyzed for every Relevant IM event and the results led to some recommendations for future IM operations, which are described in Section 5.

4.7.1 Approach to Count Speeds and Determine Speed Compliance

Per the AAL training, the pilot should implement the IM speeds 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 speeds, pilot-selected speeds, and the compliance of pilot-selected speeds with the IM speeds. The IM 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 (Mach or CAS) during the operation and the IM speed output mirrors the pilot's selection. Both the number of IM speeds and the number of pilot-selected speeds were computed.

In performing this analysis, it was recognized that pilot reactions are not instantaneous and may take a few seconds. An analysis was conducted of pilot reaction times for selecting a new speed when an IM speed was issued. This analysis was done with the entire data set where speed compliance was greater than 70% and for a subset of the data requested by the project team for arrival segments corresponding with "Descend Via" instructions. Figure 56 shows the distribution of pilot reaction times in seconds. The results show a distribution with a mode[27] of 9 seconds. Pilot reaction times greater than a minute were treated as outliers and grouped at 60 seconds, as shown by the jump in the data on the right-hand side of Figure 56.

[27] Mode is the value that appears most often in a set of data values.

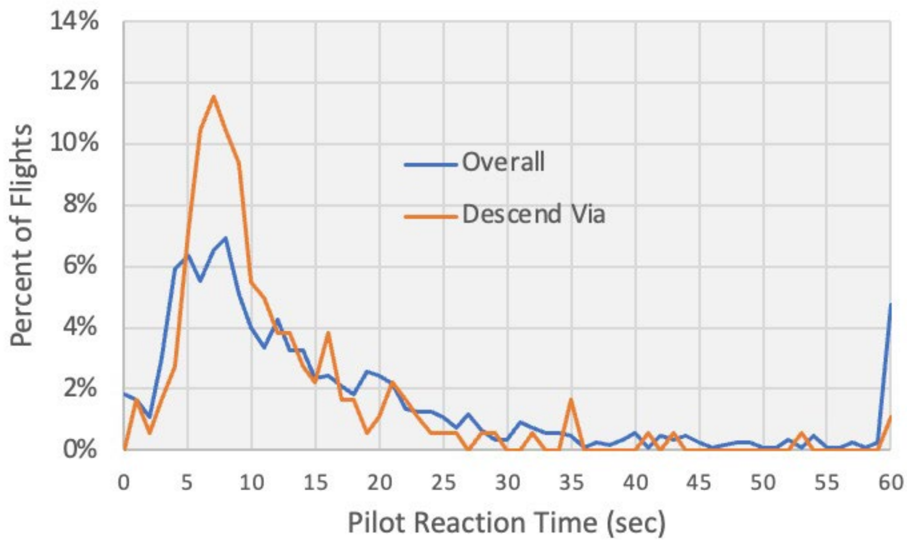


Figure 56 - Distribution of Pilot Reaction Times

Using the results of Figure 56, the analysis team decided to exclude pilot-selected speeds with durations of less than 10 seconds to account for the time pilots need to dial in new speeds. When a pilot switched from Mach to Calibrated Airspeed units, this was counted as a new speed for both the IM speed and pilot-selected speed totals.

Speed compliance was calculated as the percentage of time the pilot-selected speed was within a certain tolerance of the IM speed. For this analysis, the following speed compliance criteria was chosen:

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

4.7.2 Results on Speeds and Speed Compliance

Table 8 compares the mean and median number of IM speeds versus the mean and median number of pilot-selected speeds for all Relevant IM events. In the table, the mean value is listed first, with the median value in parentheses immediately adjacent. Figure 57 shows the number of IM speeds (blue bars) and pilot-selected speeds (orange bars) for all Relevant IM events. Both Table 8 and Figure 57 indicate that pilots were selecting more speeds than the number of IM speeds. Section 4.3 addresses this topic in more detail.

Table 8. Mean (Median) of IM speeds versus Mean (Median) of pilot-selected speeds

Type of IM Operation	Number of Relevant IM Events Analyzed	Mean (Median) of IM Speeds	Mean (Median) of Pilot-Selected Speeds
Maintain	531	5.1 (5.0)	6.7 (6.0)
Cross	224	2.4 (2.0)	4.2 (3.0)
Cross-Maintain	643	5.6 (5.0)	7.7 (7.0)
Combined	1398	4.9 (4.0)	6.8 (6.0)

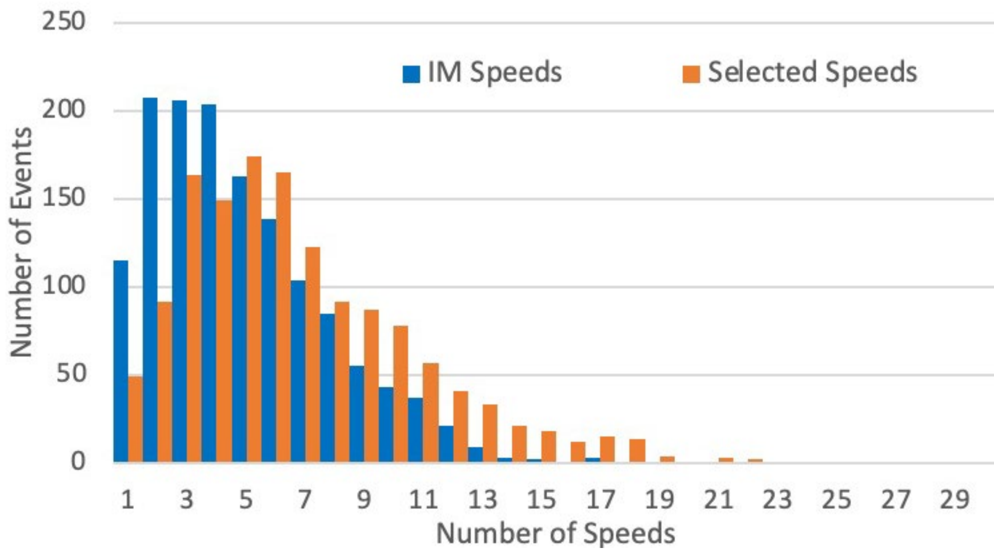


Figure 57 - Number of IM speeds and pilot-selected speeds

Figure 58 shows the number of IM speeds and pilot-selected speeds versus the duration of the IM operation. The dotted lines in Figure 58 represent a linear fit to the data and demonstrate that, on average, the number of both commanded and selected speeds increases with duration. Similar to Table 8 and Figure 57, Figure 58 demonstrates that pilots were selecting more speeds than those provided by the IM avionics.

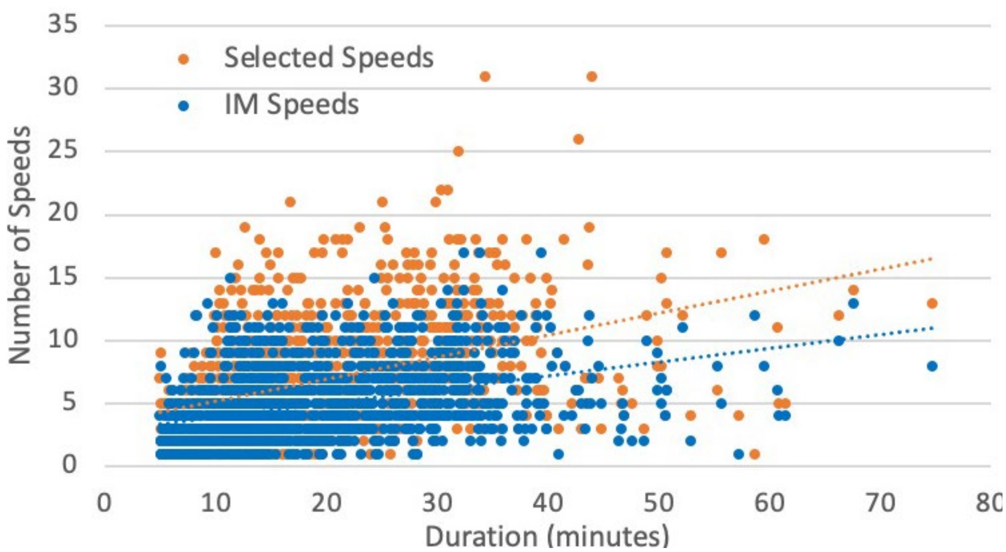


Figure 58 - Number of speeds (pilot-selected or IM) versus Duration

Table 9 and Table 10 show the number of Relevant IM events when pilot-selected speed complied with the IM speed, sorted by compliance percentage in 10-percent increments. Table 9 summarizes results for all Relevant IM events during the evaluation while Table 10 summarizes results for segments when an IM operation was occurring between TINIZ and EAGUL. Typically, ZAB controllers issued a "Descend Via" clearance to flight crews during this portion of their flights into PHX. These Relevant IM events were analyzed separately to assess the compatibility of IM operations with Descend Via operations.

Table 9. Pilot-Selected Speed Compliance during the Operational Evaluation

Pilot-selected speed compliance (%)	Number of flights	Percentage of flights[28]
0-10	71	5
10-20	26	2
20-30	41	3
30-40	55	4
40-50	65	5
50-60	100	7
60-70	99	7
70-80	179	13
80-90	250	18
90-100	512	37

Table 10. Pilot-Selected Speed Compliance during the Operational Evaluation for Descend Via only

Pilot-selected speed compliance (%)	Number of flights	Percentage of flights
0-10	48	7
10-20	22	3
20-30	28	4
30-40	29	4
40-50	31	5
50-60	51	8
60-70	57	8
70-80	74	11
80-90	124	18
90-100	211	31

A comparison of Table 9 and Table 10 reveals that pilot-selected speed compliance for the Descend Via operations appeared to be lower than compliance for all operations. For example, 60% of Descend Via flights exhibited high pilot-selected speed compliance (greater than 70%) while 68% of all flights exhibited high compliance.

The information from Figure 57 and Table 9 was combined to present the difference in the number of pilot-selected speeds and IM speeds versus speed compliance percentage (see Figure 59). As in Table 9, the compliance is presented in 10 percent bins. In Figure 59, the numbers are the mean value within the bin and the error bars represent the standard deviation of the data in each bin. For the lowest bin (0-10%), the negative value suggests the flight crew was not changing speeds as often as the IM speed changed. The positive values for the remainder of the bins mean the flight

[28] The numbers in this column and the same column in Table 10 may not add up to 100 due to rounding.

crew was selecting speeds more often than the IM speed changed. For six of the bins, the mean difference per bin was greater than three. As speed compliance increased, the difference between the number of pilot-selected speeds and IM speeds per event decreased to near one. In addition, the standard deviation decreased as speed compliance increased, suggesting less variation.

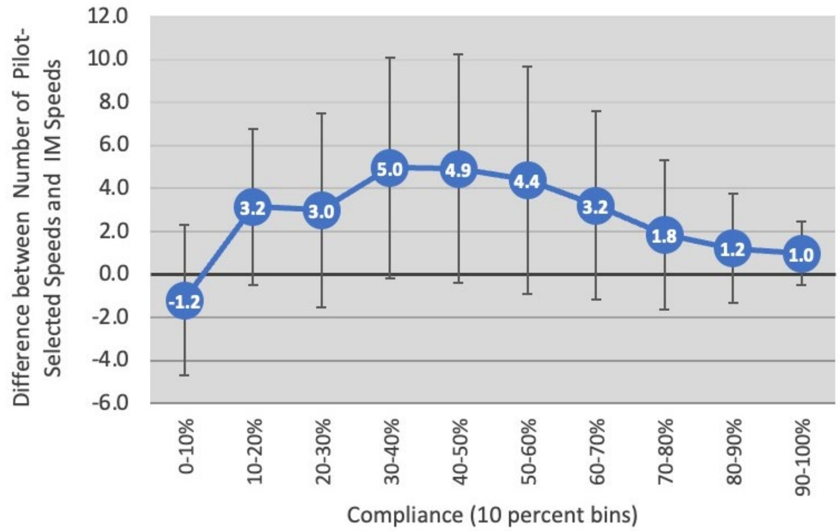


Figure 59 - Difference between number of Pilot-Selected Speeds and IM Speeds vs Speed Compliance Percentage

4.7.3 Example of Good Speed Compliance

This IM operation was conducted on February 20, 2024. Figure 60 shows the lateral paths of the Lead and IM aircraft, which were direct to ZUN and then on the EAGUL6 arrival. The CP was ZUN, and the IM operation transitioned to the Maintain stage after the IM aircraft crossed ZUN. The ASG was 80 seconds, and the IM operation lasted over 30 minutes.

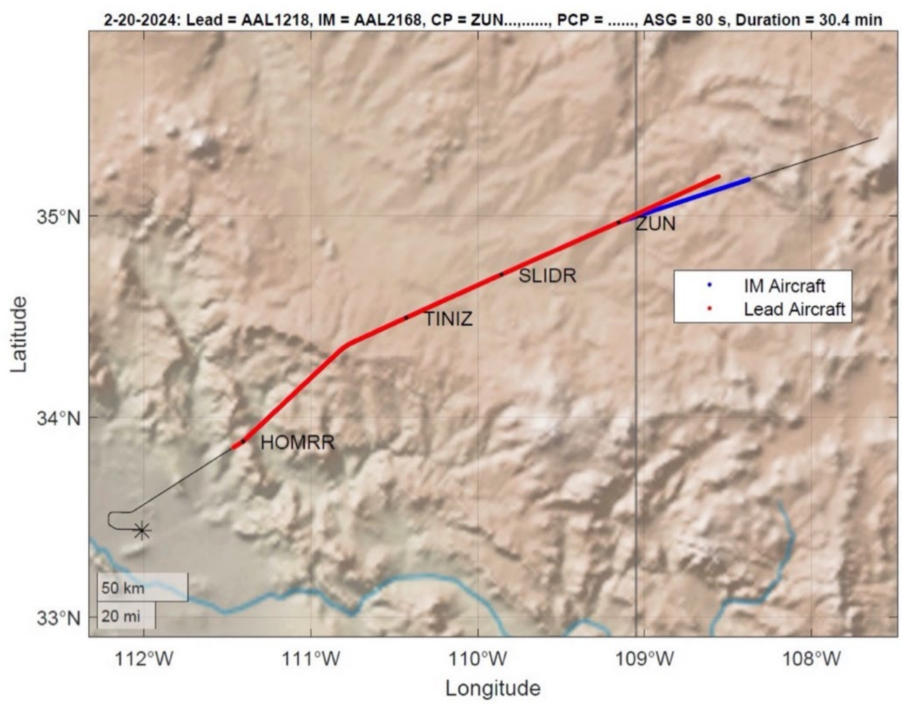


Figure 60 - Lead (red) and IM Aircraft (blue) Lateral Paths for IM operation from February 20, 2024

Figure 61 (top) shows the Lead and IM aircraft were co-altitude at 30,000 feet at the start of the IM operation. The middle plot shows the selected CAS matching the IM speed for the entire IM operation. The orange line is observed only at the start of a new IM speed before the flight crew had selected a new speed in the aircraft autoflight system. The resulting spacing interval is shown in the bottom plot. The spacing interval is within the 10-second tolerance of the ASG when the IM aircraft crossed ZUN and during the Maintain stage.

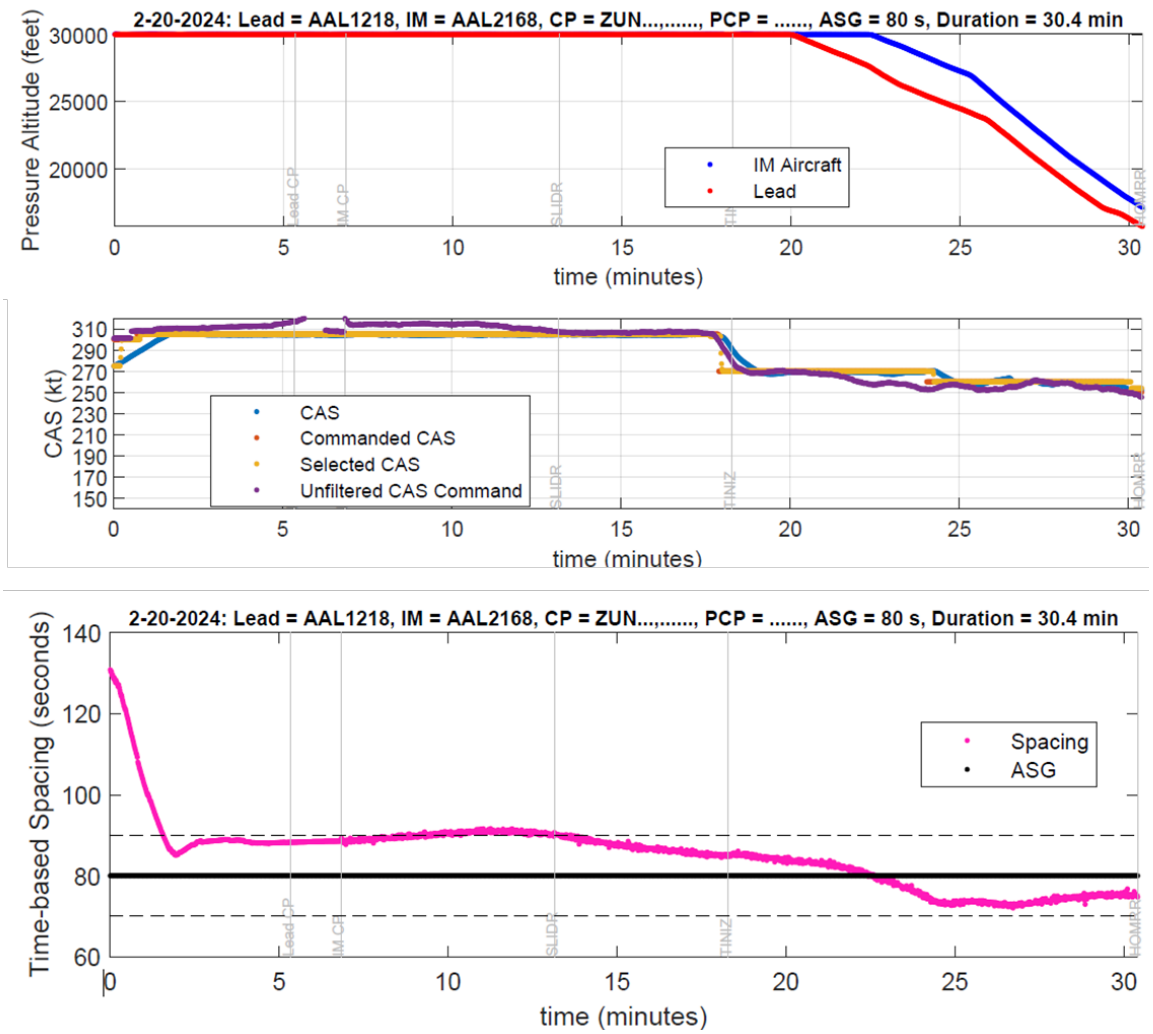


Figure 61 - Pressure altitude (top), IM speeds in CAS (middle), and Spacing Interval (bottom) for IM operation from February 20, 2024

4.7.4 Example of Poor Speed Compliance

This example IM operation was from November 29, 2023. The Lead and IM aircraft were direct to SLIDR and that was the CP, with a 90-second ASG. The IM aircraft was assigned to maintain the 90-second spacing to around HOMRR. The IM operation lasted 25 minutes.

Figure 62 (top) shows the pressure altitudes for the Lead and IM aircraft. The Lead aircraft had an initial altitude of 28,000 feet, and the IM aircraft was at 34,000 feet. The descent profiles of both aircraft were similar. The IM speeds in Mach are shown in the second-from-top plot. The commanded Mach remained constant for more than 10 minutes. However, the flight crew selected several additional speeds, as indicated by the yellow line. The commanded Mach remained constant due to the design of the SafeRoute+ Spacing application, which was designed to suppress new IM speeds if the spacing remained within 5 seconds of the ASG. During this time in the IM operation, as shown in the bottom plot, the spacing interval was within 5 seconds of the ASG. As such, no new IM speeds would have been displayed. The flight crew continued to select CAS values that deviated from the IM speed when the IM speed was displayed in CAS (the second-from-bottom plot). When compared to the good speed compliance example, the flight crew selected far more speeds, and the oscillatory nature of the spacing interval was also evident.

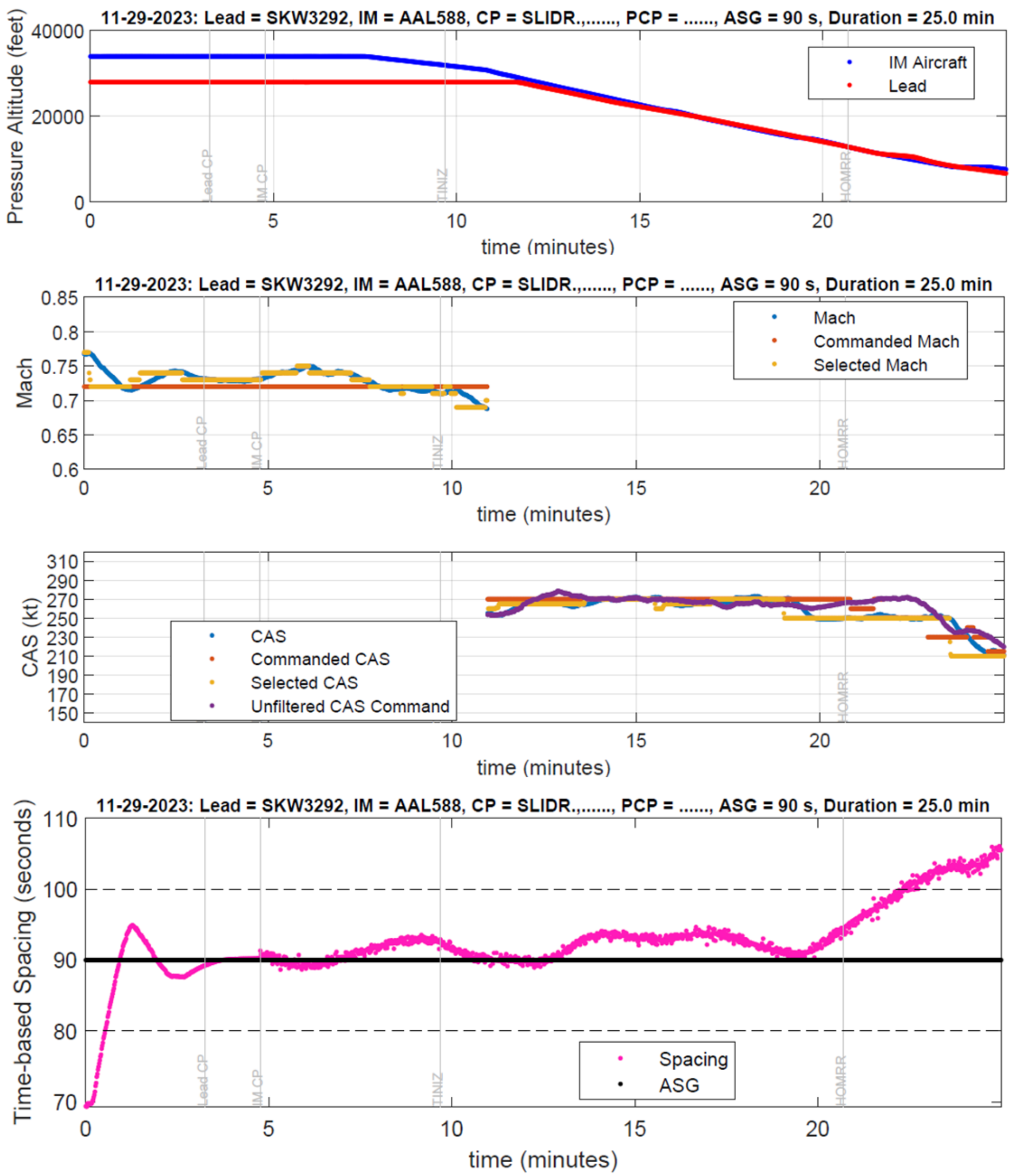


Figure 62 - Pressure altitude (top), IM speeds in Mach (second from top), IM speeds in CAS (second from bottom), and Spacing Interval (bottom) for IM operation from November 29, 2023

4.7.5 Speed Compliance Issues Associated with Display of Current Spacing

The results described in this section indicated that flight crews did not always follow the IM speeds. Through further investigation, it was determined that flight crews may have been using the current spacing information on the AGD and their own speed discretion to try to align the current spacing and assigned spacing values displayed, instead of complying with the IM speeds. The speed compliance issue is discussed further in Section 4.3.

Some pilots provided feedback that the IM operations were too workload intensive (see Section 4.3). Some of these workload issues likely resulted from pilots frequently changing speeds to manually align the current spacing to the ASG instead of complying with the IM speeds. In the following sections, lower flight crew speed compliance is also shown to be one of the factors related to decreased delivery accuracy.

4.8 Delivery Accuracy and Error for Relevant IM Events

An analysis was conducted of delivery accuracy and error for Relevant IM events. The IM delivery accuracy and error were also compared to delivery accuracy and error associated with current TBFM controller tools.

4.8.1 Analysis Methodology for Delivery Accuracy and Error

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

Delivery error 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.

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

The mean of the delivery errors indicated how far, on average, the actual spacing for a set of IM operations was from the ASG, while the standard deviation of the delivery errors was an indication of the spacing precision.

Delivery accuracy is a presentation of how far a set of data is from a goal, which for IM is the ASG. In this report, delivery accuracy results are presented as tables showing the number and percentage of Relevant IM events where the absolute value of the delivery error (|*Delivery Error*|) is within specified time or distance thresholds around the ASG.

Delivery error and delivery accuracy for IM were calculated at two locations:

1. At the CP for Cross operations
2. At the End of IM operation for all operations.[29]

[29] End of the operation is defined as the time when SafeRoute+ stops executing the IM Application or when Aircraft crosses a 50 NM circle around PHX.

For distance-based ASGs, the actual spacing was measured as the along-path distance between the Lead aircraft and IM aircraft when the Lead aircraft crossed the referenced location. For time-based ASGs, the actual spacing was measured as the difference between the times when the Lead aircraft and IM aircraft crossed the same location (calculated when the IM aircraft has crossed the location). These metrics were used to calculate distributions and associated statistics of the delivery errors (i.e., mean and standard deviation) as well as a presentation of the delivery accuracy in terms of time and distance away from the ASG.

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

1. <u>Relevant IM events</u>: All Relevant IM events were truncated at a 50 NM circle around PHX
2. <u>Cross Point (CP) filter</u>: For Cross operations, flights were removed if they terminated more than 2 NM before reaching the CP
3. <u>Speed compliance filter</u>: Relevant IM events were removed when speed compliance was less than 70%
4. <u>Year filter</u>: The second year of the operational evaluation focused on IM operations using time-based ASGs and operating on a single arrival procedure (EAGUL). The analysis team decided that a filter to select second-year data would be useful when segregating the data.
5. <u>Feasibility filter for time-based operations</u>: Flights were removed if they did not meet a threshold related to the difference between the time that needs to be gained or lost to meet the ASG and the distance left for the aircraft to make the necessary speed changes (see explanation in following paragraph). Two separate feasibility metric calculations were made: one for the distance to the CP and the other for the distance to the end of the IM operation.

The data team defined the feasibility metrics as follows:

CP Feasibility metric = (Initial Predicted Time Spacing at CP – ASG)/Initial Distance to CP

End of IM Operation Feasibility metric = (Initial Time Spacing – ASG)/Initial Distance to End of IM Operation

For a Cross-Maintain IM operation:

Initial Time Spacing = Initial Predicted Time Spacing at CP

For a Maintain IM operation:

Initial Time Spacing = Initial Spacing when Maintain stage is first activated

Figure 63 presents the delivery errors relative to both feasibility metrics for the Relevant IM events. The blue-shaded area in Figure 63 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 errors than desirable (data points outside the desired delivery accuracy range). When the feasibility metric is less than zero, the aircraft's predicted spacing is less than the ASG 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 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, this will produce a value farther from zero on the horizontal axis. For a commercial airliner in cruise flight, it is typically easier to slow down quickly to meet the ASG (left side of the plots in Figure 63) than it is to speed up. This resulted in several IM aircraft not meeting the delivery accuracy goal (right side of the plots in Figure 63, areas shaded red). A value of 0.5 was determined by visual inspection of the data in Figure 63 and applied when using both feasibility metrics for the time-based IM operations feasibility filter.

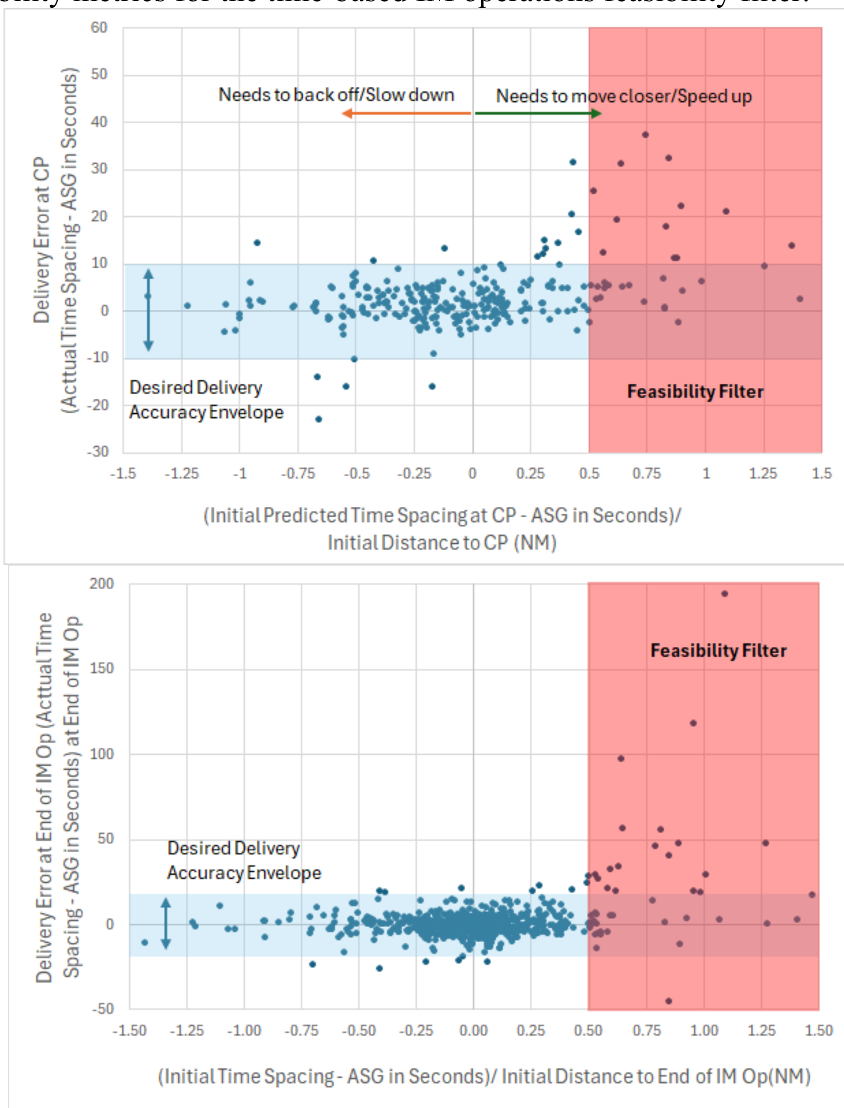


Figure 63 - Delivery Error vs. Feasibility Metrics at the CP (top) and at the end of IM operation (bottom)

4.8.2 Delivery Accuracy and Error Analysis Results for IM Aircraft with Distance-Based ASGs

This section applies to Relevant IM events where a distance-based ASG was used. During the operational evaluation, 300 distance-based Relevant IM events were recorded. Table 11 presents an analysis of distance-based delivery accuracy at the end of IM operation in 0.5 NM increments. The first two columns present the results for all the data; the middle two columns present results for the data removed by the speed compliance filter; and the last two columns present results for the data applying the speed compliance filter. For distance-based Relevant IM events, the year filter was not used because all distance-based Relevant IM events occurred in the first year of the operational evaluation. Also, the feasibility filter discussed in the prior subsection (Section 4.8.1) does not apply to distance-based Relevant IM events.

Table 11. Distance-based IM Delivery Accuracy at the End of IM Operation

Distance from ASG	All Data		Data Removed by Filters		Filtered Data (Speed Compliance ≥ 70%)	
	Number	Percent	Number	Percent	Number	Percent
Within 0.5 NM	159	53%	35	40%	124	58%
Within 1.0 NM	221	74%	51	59%	170	80%
Within 1.5 NM	243	81%	58	67%	185	87%
Within 2.0 NM	257	86%	65	75%	192	90%

During the operational evaluation, 219 distance-based Relevant IM events with a CP were recorded (the other Relevant IM events were maintain-only). The CP filter also removed IM events that terminated more than 2 NM from the CP, leaving 155 remaining Relevant IM events. Table 12 presents an analysis of distance-based delivery accuracy at the CP using the remaining events in 0.5NM increments. The first two columns present the results for the 155 events; the middle two columns present results for the data that was removed by the speed compliance filter; and the last two columns present results after applying the speed compliance filter.

Table 12. Distance-based IM Delivery Accuracy at the CP

Distance from ASG	Data Meeting CP Filter		Data Removed by Speed Compliance Filter		Filtered Data (Speed Compliance ≥ 70%)	
	Number	Percent	Number	Percent	Number	Percent
Within 0.5 NM	96	62%	19	50%	77	66%
Within 1.0 NM	145	94%	34	89%	111	95%
Within 1.5 NM	148	95%	36	95%	112	96%
Within 2.0 NM	155	100%	38	100%	117	100%

Figure 64 shows the distance-based IM delivery error distributions when filtered for speed compliance. The blue line shows the delivery error distribution at the CP, and the orange line shows the delivery error distribution at the end of IM operation. Both lines suggest a normal distribution, which means the delivery accuracies may be sufficiently described using the mean values and standard deviations of the IM delivery errors as seen below.

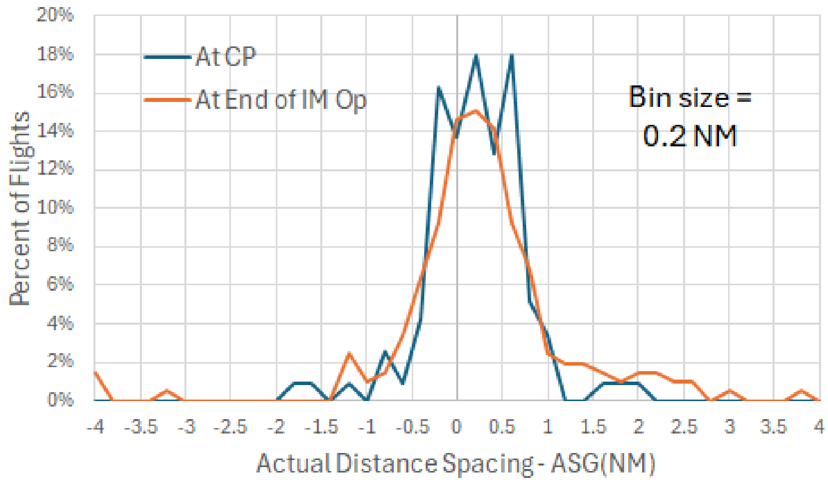


Figure 64 - Distance-based IM delivery errors

Table 13 and Table 14 present distribution statistics for the distance-based IM delivery errors segregated by operation type (Cross, Cross-Maintain, Maintain), including the count, the mean value, and the standard deviation (StdDev) around the mean. Table 13 shows these statistics at the end of IM operation while Table 14 shows these statistics at the CP. The Cross operations shown in Table 13 which do not appear in Table 14 are an indication that these IM operations terminated before the Lead aircraft reached a point within 2 NM of the CP. Additionally, Table 14 shows that 20 Cross-Maintain operations included in Table 13 were excluded from the CP analysis. The reasons for this were varied, but can be summarized as occurring due to large gaps in the data (for the Lead or IM aircraft) around the CP. In some cases, this occurred because the aircraft overflew a portion of the 50 NM radius circle around PHX (on their way to LAS or LAX) and such trajectory data was filtered out.

Table 13. Distribution Statistics for Distance-based IM Delivery Errors at the End of IM Operation

Mean & StdDev units in NM	**All Data**			**Data Removed by Filter**			**Filtered Data (Speed Compliance ≥ 70%)**		
Operation	Observations	Mean	StdDev	Observations	Mean	StdDev	Observations	Mean	StdDev
Cross	44	0.6	3.9	12	0.1	3.7	32	0.8	4.0
Cross-Maintain	175	0.4	1.4	48	0.4	1.9	127	0.4	1.1
Maintain	81	0.3	2.4	27	0.4	3.8	54	0.2	1.1
Total	**300**	**0.4**	**2.2**	**87**	**0.4**	**2.8**	**213**	**0.4**	**1.9**

Table 14. Distribution Statistics for Distance-based IM Delivery Errors at the CP

Mean & StdDev units in NM	**All Data**			**Data Removed by Filter**			**Filtered Data (Speed Compliance ≥ 70%)**		
Operation	Observations	Mean	StdDev	Observations	Mean	StdDev	Observations	Mean	StdDev
Cross									
Cross-Maintain	155	0.2	0.6	38	0.4	0.6	117	0.2	0.6
Maintain									
Total	**155**	**0.2**	**0.6**	**38**	**0.4**	**0.6**	**117**	**0.2**	**0.6**

4.8.3 Delivery Accuracy and Error Analysis Results for IM Aircraft with Time-Based ASGs

This section analyzes Relevant IM events where a time-based ASG was used. During the operational evaluation, 1098 time-based Relevant IM events were recorded. Table 15 presents an analysis of time-based delivery accuracy at the end of IM operation in increments of five and ten seconds. The first two columns present the results for all the data; the middle two columns present results for the data removed by filtering; and the last two columns present the results for the data after applying the speed compliance filter, the year filter, and the feasibility filter at the end of the IM operation (as described in Section 4.8.1).

Table 15. Time-based IM Delivery Accuracy at the End of IM Operation

Distance from ASG	All Data		Data Removed by Filters		Filtered Data (Speed Compliance ≥ 70%)	
	Number	Percent	Number	Percent	Number	Percent
Within 5 seconds	700	64%	322	60%	378	67%
Within 10 seconds	952	87%	422	79%	530	94%
Within 20 seconds	1029	94%	476	89%	553	98%
Within 30 seconds	1052	96%	493	92%	559	99%

During the operational evaluation, 648 time-based Relevant IM events with a CP were recorded (the other Relevant IM events were maintain-only). The CP filter also removed IM events that terminated more than 2 NM from the CP, leaving 552 remaining Relevant IM events. Table 16 presents an analysis of time-based delivery accuracy at the CP using the remaining events in 0.5NM increments. The first two columns present the results for the 552 events; the middle two columns present results for data removed by filtering; and the last two columns present the results for the data after applying the speed compliance filter, the year filter, and the feasibility filter at the CP.

Table 16. Time-based IM Delivery Accuracy at the CP

Distance from ASG	All Data		Data Removed by Filters		Filtered Data (Speed Compliance ≥ 70%)	
	Number	Percent	Number	Percent	Number	Percent
Within 5 seconds	414	75%	171	67%	243	82%
Within 10 seconds	484	88%	206	81%	278	93%
Within 20 seconds	523	95%	230	91%	293	98%
Within 30 seconds	552	100%	254	100%	298	100%

Figure 65 shows the time-based IM delivery error distributions when filtered for speed compliance, year, and feasibility. The blue line shows the delivery error distribution at the CP, and the orange line shows the delivery error distribution at the end of IM operation. 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 (see Table 17 and Table 18). It is interesting that the peak of the time-based IM delivery errors at the end of IM operation appears shifted versus the peak of the time-based IM delivery errors at the CP. Also, the time-based IM delivery error distribution at the end of IM operation is wider than the time-based IM delivery error distribution at the CP, which suggests more variation in performance. This could be due to the IM speed behavior that was observed and described in Section 4.2.5. Note that both delivery error distributions generally fall within ± 10 seconds.

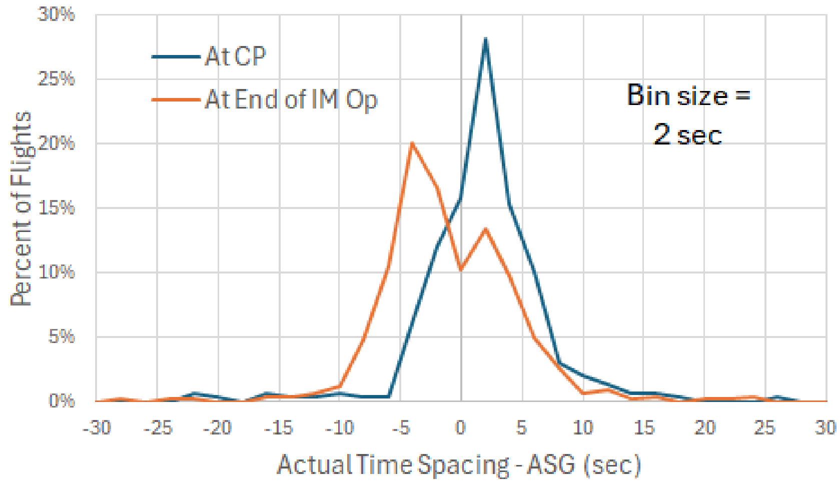


Figure 65 - Time-based IM Delivery Errors

Table 17 and Table 18 present distribution statistics for the time-based IM delivery errors segregated by operation type (Cross, Cross-Maintain, Maintain), including the count, the mean value, and the standard deviation (StdDev) around the mean. Table 17 shows these statistics at the end of IM operation while Table 18 shows these statistics at the CP. Note that since 96 IM Cross operations ended more than 2 NM before the IM aircraft reached the CP, they do not appear in Table 18.

Table 17. Distribution Statistics for Time-based IM Delivery Errors at the End of IM Operation

Mean & StdDev units in sec	**All Data**			**Data Removed by Filter**			**Filtered Data (Speed Compliance ≥ 70%)**		
Operation	Observations	Mean	StdDev	Observations	Mean	StdDev	Observations	Mean	StdDev
Cross	180	5	46	114	6	57	66	1	11
Cross-Maintain	468	0	11	187	3	15	281	-1	6
Maintain	450	0	18	233	1	24	216	-2	4
Total	1098	1	23	534	3	32	563	-1	6

Table 18. Distribution Statistics for Time-based IM Delivery Errors at the CP

Mean & StdDev units in sec	**All Data**			**Data Removed by Filter**			**Filtered Data (Speed Compliance ≥ 70%)**		
Operation	Observations	Mean	StdDev	Observations	Mean	StdDev	Observations	Mean	StdDev
Cross	84	1	8	39	2	10	45	1	4
Cross-Maintain	468	3	11	215	6	14	253	1	6
Maintain									
Total	552	3	10	254	5	14	298	1	5

The time-based IM results were also compared to other FAA capabilities that assist controllers when time-based metering operations are used. For each metered flight, TBFM produces a scheduled time of arrival (STA) at a specific meter point (MP) and provides controllers with the time delay needed for the flight to meet the STA. In most TBFM operations, it is up to the controller to decide on a methodology (speed control, vectoring, etc.) to delay the flight. A few ARTCCs (including ZAB) use a TBFM feature that can automatically produce a speed advisory for an aircraft to meet the STA. Once a speed advisory is produced, the controller may communicate the speed instruction to the pilot who may either accept or reject the controller's speed instruction based on operational viability.

In either TBFM case, the delivery error at a meter point can be defined as:

TBFM Delivery Error = Actual Cross Time at the MP – STA

For the comparison to IM, delivery accuracy and error was calculated for two sets of TBFM-metered flights:

1. TBFM-metered flights with accepted speed advisories bound for PHX (multiple MPs). There were 17,526 such flights during the operational evaluation.
2. TBFM-metered flights without speed advisories inside ZAB but bound for either PHX or LAX (multiple MPs). There were 270,462 such flights during the operational evaluation.

A more direct comparison of IM and TBFM-metered flights to the same MPs was not possible because such data did not exist during the operational evaluation. However, the data analysis team and operational SMEs suggested that comparison of IM delivery accuracy and error to TBFM delivery accuracy and error would still be comparable within the same ARTCC.

Table 19 presents the time-based IM delivery accuracy at the CP (subset of the data from Table 16) and the TBFM delivery accuracy at the MP for flights with and without speed advisories. A difference between IM and TBFM delivery accuracy is that IM spacing is relative to the other aircraft at the CP while TBFM spacing is absolute based on a scheduled time at the MP. The comparison of data in Table 19 shows IM had higher delivery accuracy as compared to TBFM capabilities that existed during the operational evaluation period.

Table 19. Time-based IM Delivery Accuracy at the CP compared to TBFM Delivery Accuracy at the MP in seconds

Variation fromASG or Scheduled Time	IM (All Data)	IM (Filtered Data)	TBFM with Speed Advisories	TBFM without Speed Advisories
Within 5 seconds	75%	82%	19%	17%
Within 10 seconds	88%	93%	34%	31%
Within 20 seconds	95%	98%	58%	52%
Within 30 seconds	100%	100%	74%	66%
Within 60 seconds			93%	86%
Within 90 seconds			97%	95%

Figure 66 presents a distribution of delivery errors at the MP for TBFM metered flights with and without speed advisories. The distribution with speed advisories is slightly more peaked than the distribution without speed advisories, indicating a modest increase in precision when using speed advisories.

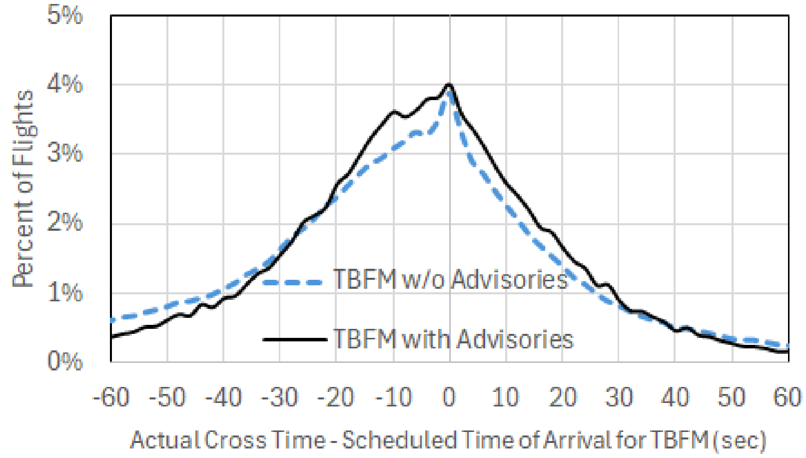


Figure 66 – Delivery Error Distributions for TBFM-Metered Flights with and without Speed Advisories

Figure 67 compares the TBFM-metered delivery error distributions at the MP seen in Figure 66 to those for time-based Relevant IM events at the CP (as seen previously in Figure 65). The IM distribution is dramatically more peaked than either of the TBFM distributions, suggesting a dramatic increase in precision.

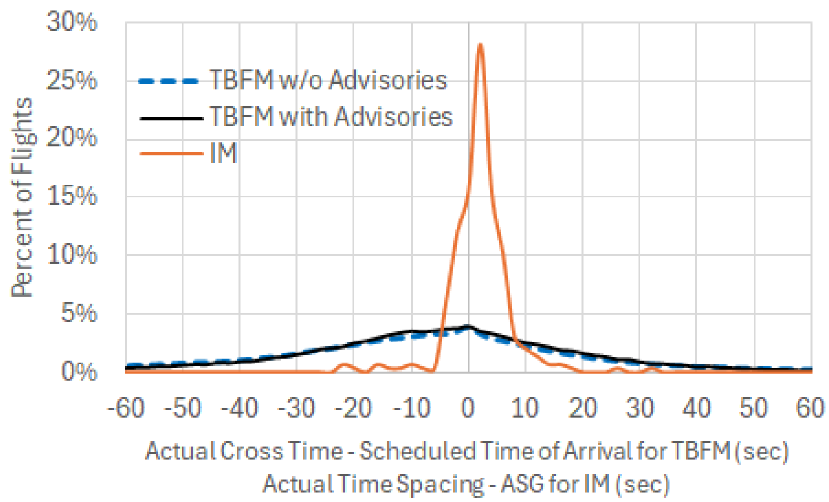


Figure 67 – Delivery Error Distributions for Time-based IM and TBFM with and without Speed Advisories

Table 20 presents the normal distribution statistics related to the distributions seen in Figure 67.

Table 20. Normal distribution statistics for Time-based Relevant IM events at the CP and TBFM-metered flights at the MP

		Actual Time Spacing – ASG (sec)		**Actual Cross Time – Scheduled Time of Arrival (sec)**	
Operation	Observations	Mean	StdDev	Mean	StdDev
IM (Time-based)	298	1	5		
TBFM w/ Speed Advisories	67,540			-9	27
TBFM w/o Speed Advisories	270,462			-6	31

A difference in both delivery accuracy and delivery error distributions between IM and TBFM was expected. While the TBFM system produces estimated times of arrival (ETAs) and STAs down to the second, most FAA ATC facilities (including ZAB) present controllers with metering delay values in rounded minute increments. As a result, FAA controllers do not typically issue instructions to a flight crew to close a gap between ETA and STA until errors of 31 seconds or greater are predicted to occur. Furthermore, controllers were not (and should not be) expected to issue speed instructions to address this difference as frequently as IM speeds were provided to AAL flight crews.

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

The following analysis compared the inter-arrival spacing accuracy at meter points for IM operations and aircraft not conducting IM operations. Unlike the analyses in Section 4.8, this analysis used trajectory data for all flights bound for PHX along the selected arrival, as opposed to just the IM flights.

4.9.1 Analysis Methodology for Inter-arrival Time and Inter-arrival Distance

Based on prior analysis and the results in Section 4.8, aircraft conducting an IM operation were expected 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 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 and Lead aircraft when the Lead aircraft crosses the fix.

The intended spacing interval for IM operations is the ASG, which was recorded and known for this analysis. However, the intended spacing for non-IM flights can differ based on demand or other factors and was not known. For this reason, the analysis was limited to the SLIDR and EAGUL fixes on the EAGUL arrival where it is commonplace for ZAB controllers to use 8 miles-in-trail (8 NM) to manage this arrival flow into P50.

The steps used to perform these analyses were as follows:

1. Calculate the IAT and IAD at SLIDR and EAGUL for all arrivals overflying 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. Filter data to flights where inter-arrival spacing > 7 NM or > 60 seconds to remove outliers and flights separated by altitude when overflying the fix.
4. Identify two relevant sets of IM flights for comparison to non-IM flights:
    a. All flights where IM was active when the flight overflew the fix
    b. Subset of flights where IM was active when the flight overflew the fix AND where the fix (SLIDR or EAGUL) was entered in the avionics as either the CP or PCP

5. Apply operating time qualification checks for IM flights:
    a. IM operation started prior to the IM aircraft overflying a given fix (ACSS Start time earlier than actual fix overflight time)
    b. IM operation with a time-based ASG ended no sooner than one minute prior to overflying a given fix (ACSS End time no earlier than one minute before the actual fix overflight time)
    c. IM operation with a distance-based ASG ended no sooner than three minutes prior to overflying a given fix (ACSS End time no earlier than 3 minutes before the actual fix overflight time). For distance-based events when the flight crew entered the PCP as SLIDR or EAGUL, the operation ended when the Lead aircraft crossed the PCP. Therefore, IM operations that ended further from the fix were allowed.

The resulting metrics were used to calculate distributions and associated statistics.

An example of the types of operations used for this analysis is shown in Figure 68. This figure shows a busy push over SLIDR for arrivals to PHX on September 7, 2023. The top image shows a string of non-IM aircraft where the numbers are the initial inter-aircraft spacing values in NM between each pair. The middle image shows the initial string of non-IM aircraft immediately after their entry into P50, with the normal distance compression that occurs during such arrival operations. This middle image also shows a string of IM aircraft and their initial inter-aircraft spacing values in NM. The bottom image shows the string of IM aircraft immediately after their entry into P50, with the normal distance compression that occurs during arrival operations, though in this case, the IM aircraft were managing a time-based ASG until they reached HOMRR. In this example, the IM aircraft inter-aircraft spacings were more consistent (and slightly smaller) than the non-IM aircraft inter-aircraft spacings as they passed over HOMRR.

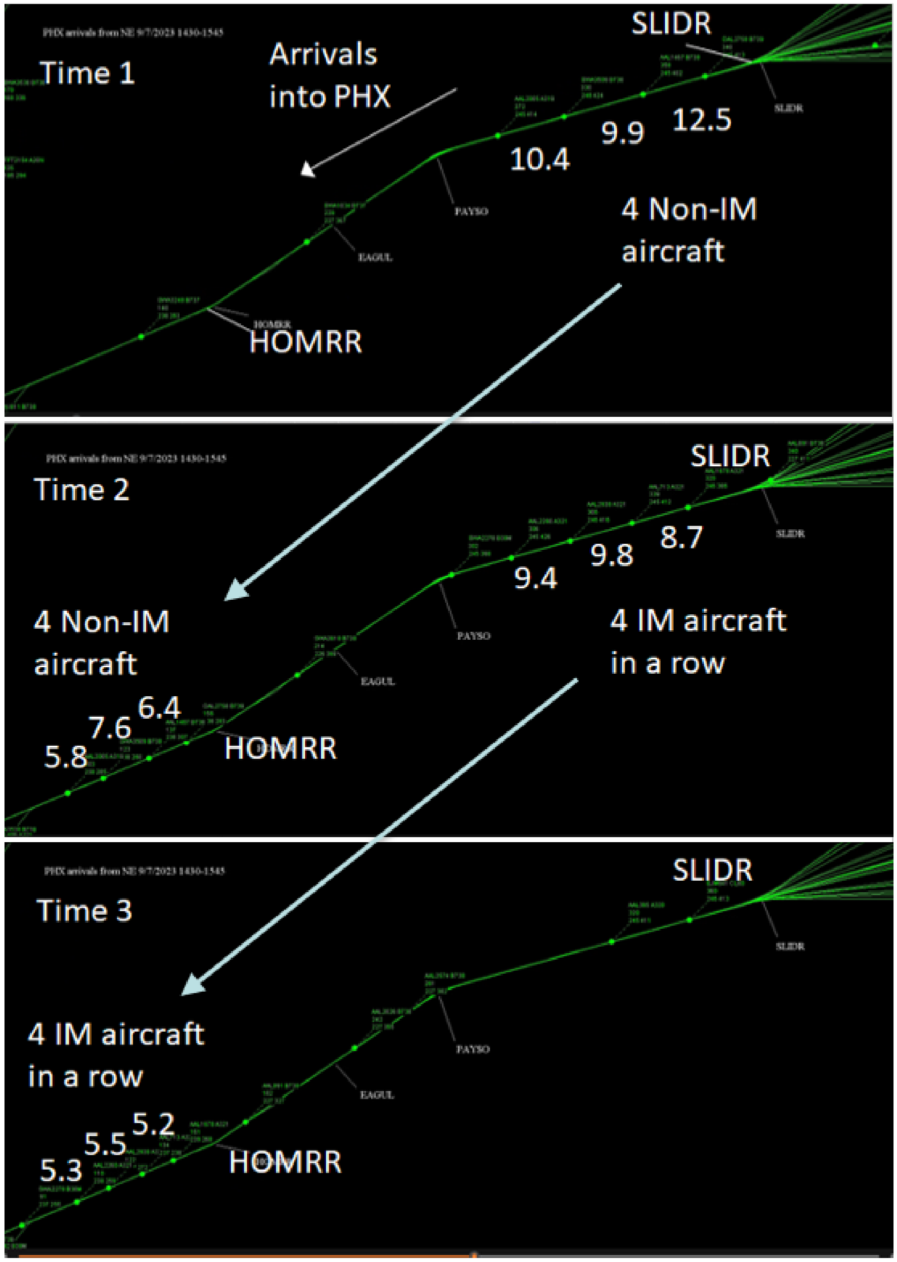


Figure 68 - Example of operations used for Inter-arrival Time and Inter-arrival Spacing analyses at SLIDR for Aircraft Conducting IM and Aircraft Not Conducting IM (Non-IM)

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

4.9.2 Results of Inter-arrival Time and Inter-arrival Distance Analyses for IM and Non-IM flights

Figure 69 shows the IAT results for time-based IM and non-IM aircraft that overflew SLIDR. The data has been filtered as described in Section 4.9.1. Table 21 contains a summary of the mean and standard deviation for the IATs. The first row – labeled as IM (time-based) – includes all aircraft that were executing an IM operation when they overflew SLIDR. The second row – labeled as IM (time-based) with CP or PCP at SLIDR – contains aircraft that were executing an IM operation that both overflew SLIDR and entered SLIDR as the CP or PCP. The right two columns of the table show the mean and standard deviation of the difference between the actual time spacing at SLIDR and the ASG.

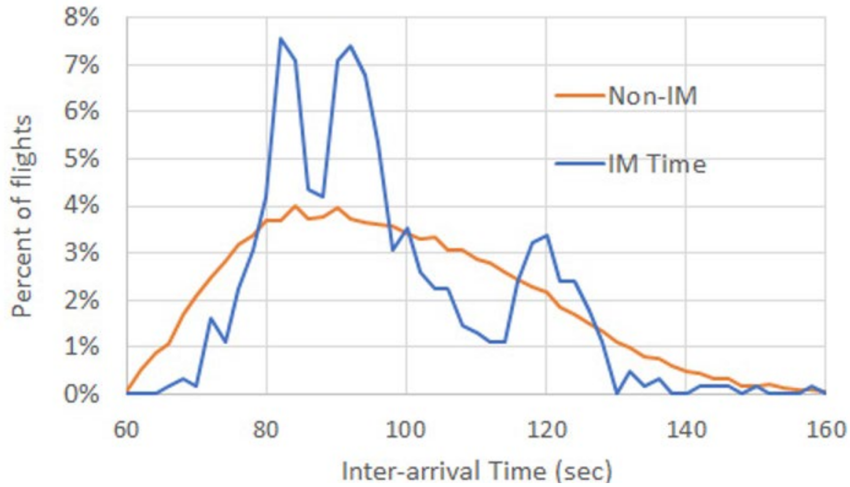


Figure 69 - IAT distributions for Time-Based IM Operations and non-IM Operations crossing SLIDR

Table 21. IAT Statistics for Time-based IM aircraft and non-IM aircraft overflying SLIDR in seconds

		Time Spacing (sec)		Actual Time Spacing – ASG (sec)	
Operation	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
IM (Time-based)	619	96	16	2	7
IM (Time-based) with CP or PCP at SLIDR	379	95	15	2	6
Non-IM	51,934	98	20		

The time-based IM flights, in general, exhibited 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 the actual spacing and the ASG was very small. The multi-peak shape of the IAT distribution for IM flights reflects the fact that controllers used different ASGs (e.g., 80 seconds, 95 seconds, or 120 seconds) when using IM in this operational evaluation. The intended time spacing for the Non-IM aircraft is unknown, so an Actual Time Spacing – ASG could not be calculated.

Figure 70 shows inter arrival distance (IAD) results from the distance-based IM and non-IM operations overflying SLIDR that were filtered as described in Section 4.9.1. Table 22 shows the means and standard deviations of the inter-arrival spacing values for these operations.

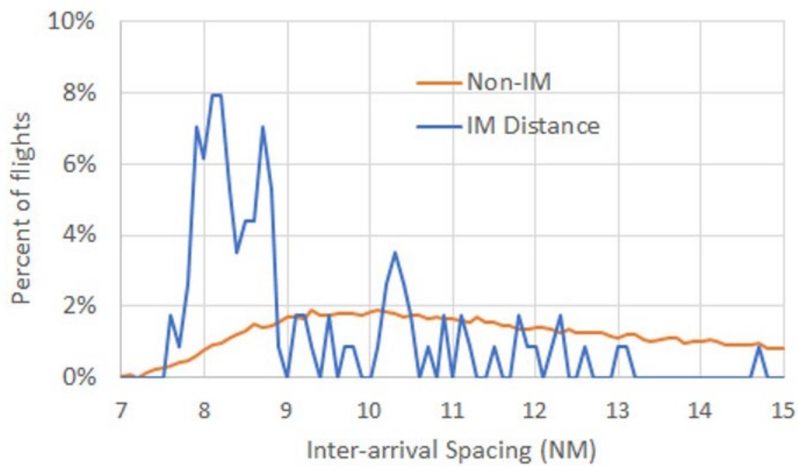


Figure 70 - IAD results for Distance-Based IM Operations and non-IM Operations overflying SLIDR

Table 22. IAD statistics on Distance-Based IM and non-IM for flights overflying SLIDR

		Distance Spacing (NM)		Actual Distance Spacing – ASG (NM)	
Operation	**Observations**	**Mean**	**StdDev**	**Mean**	**StdDev**
IM (Distance-based)	114	9.1	1.5	0.5	1.3
IM (Distance-based) with CP or PCP at SLIDR	92	9.1	1.4	0.5	1.4
Non-IM	51,934	11.0	2.0		

Like the IAT results for time-based IM operations, the IAD results for distance-based IM operations showed smaller means and standard deviations for IM aircraft, as compared to Non-IM aircraft. Like the time-based calculations, the intended distance spacing for the Non-IM aircraft is unknown, so an Actual Distance Spacing – ASG could not be calculated. However, SME input suggested that in normal busy operations the intended spacing is 8 NM.

The prior analysis for flights overflying SLIDR was repeated for flights overflying EAGUL. One difference between SLIDR and EAGUL was that flight crews rarely entered EAGUL as a CP or PCP. EAGUL was only entered twice as the CP during the operational evaluation. Therefore, the IM operations are not segregated in the remaining tables of this subsection as they were in the immediately preceding tables. Figure 71 and Table 23 present IAT results for time-based IM operations overflying EAGUL. Like Figure 69, the IM distribution is multi-peaked, reflecting the use of multiple ASGs during this operational evaluation.

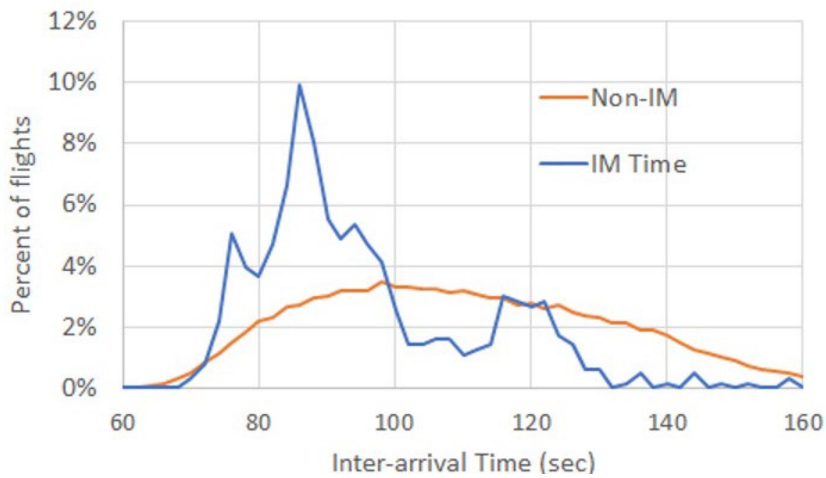


Figure 71 - IAT distributions for Time-Based IM Operations and non-IM Operations crossing EAGUL

Table 23. 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)	633	95	16	-0.3	6
	Non-IM	58,492	110	23		

Figure 72 and Table 24 present inter-arrival spacing results for distance-based IM operations overflying EAGUL. Distance-based ASGs were primarily used in the first year of the study and only 26 IM flights with distance-based ASGs overflew EAGUL while IM was being conducted.

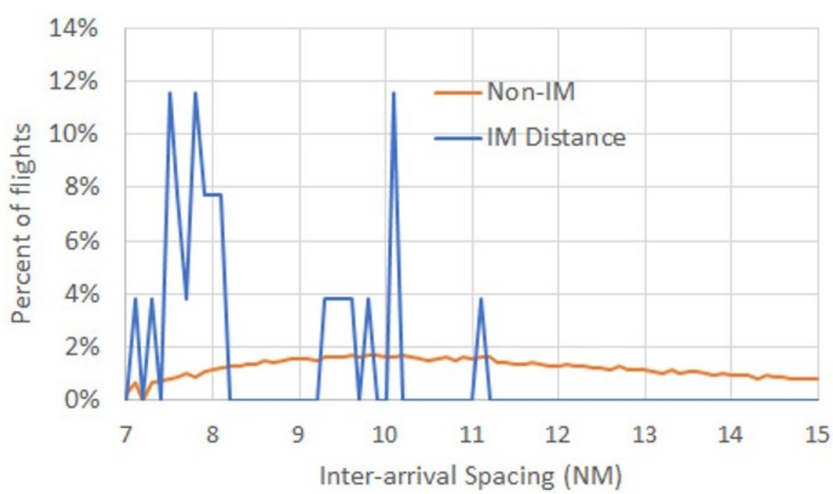


Figure 72 - IAD distributions for Distance-Based IM Operations and non-IM Operations crossing EAGUL

Table 24. IAD statistics on Distance-Based IM and non-IM for flights overflying 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	58,492	10.8	2.1		

The results at EAGUL showed similar trends to those at SLIDR. In each case, the mean and standard deviation of the IAT and inter-arrival spacing were smaller for IM aircraft compared to non-IM aircraft.

4.10 CP and PCP Issues

The data entry page on the MCDU for a spacing operation included a field where the flight crew could enter a PCP if included in the spacing clearance. Controllers did not routinely issue PCPs during the operational evaluation and there were times when IM operations ended earlier than expected. The AIRS team investigated if flight crews erroneously entering a PCP impacted operations. When analyzing the SafeRoute+ Spacing application data to determine the number of relevant operations for analysis (as described in Section 4.6.1), the number of Relevant IM events when a flight crew entered a PCP was also determined. Additionally, a determination was made of the number of Relevant IM events when a flight crew entered the controller-issued CP as both the CP and PCP in the SafeRoute+ Spacing application.

Table 25 shows the number of Relevant IM events with PCPs entered in the SafeRoute+ Spacing application and the number of Relevant IM events with PCPs that were the same as CPs, arranged by IM clearance type. Table 26 shows the data from Table 25 by month.

Table 25. Number of Relevant IM events with a PCP entered or with CP same as PCP

IM Clearance Type	Relevant IM Events	PCP count	PCP same as CP
Cross	224	112	112
Cross-Maintain	643	33	29
Maintain	531	97	N/A
Total	**1398**	**242**	**141**

Table 26. A month-by-month comparison of the number of Relevant IM events with a PCP entered or with CP same as PCP

By Month	Relevant IM Events	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	69	16	9
04/2023	74	25	16
05/2023	10	2	2
06/2023	20	2	0
07/2023	68	18	8
08/2023	48	6	4
09/2023	51	10	8
10/2023	9	4	0
11/2023	65	8	5
12/2023	81	11	5
1/2024	173	33	21
2/2024	143	27	17
3/2024	179	29	14
4/2024	104	20	13
5/2024	41	3	1
6/2024	7	1	1
7/2024	13	0	0
8/2024	13	1	1
9/2024	17	1	1
10/2024	16	1	1
11/2024	6	0	0
Total	1398	242	141

The above results reinforced pilot and controller feedback regarding the flight crew's proper entry of CP information and led to a review of the SafeRoute+ MDCU page design and whether flight crews were confused about where to enter the CP. See Section 4.3 for further discussion.

5 Lessons Learned

Although Interval Management has been studied for many years, there were still several key lessons that were learned from conducting this operational evaluation. Some of the more significant lessons learned are outlined below.

5.1 Operational Evaluation Approach and Focus

AIRS team members often reflected on the value of conducting an operational evaluation versus a flight test or a flight demonstration. This approach allowed both the FAA and industry to manage the risks associated with introducing new technologies and operations into the NAS. The approach used for this operational evaluation allowed the FAA and industry to make modifications based on the data obtained and then evaluate those modifications. The collaborative reviews and problem-solving based on data were key to making this operational evaluation successful.

The AIRS team also learned that to evaluate the avionics and gauge controller and pilot acceptance, it was more effective to focus on areas of operations where IM could be used instead of legacy spacing tools. This improved acceptability of the IM procedure and provided the benefit of comparing IM results to legacy tools. At the beginning of the operational evaluation, IM was used throughout ZAB's airspace. The focus on the EAGUL arrival during the second year of the operational evaluation provided additional insights about how the avionics performed and helped controllers know what to expect during an IM operation.

5.2 Phraseology

Phraseology needs to be as short as possible, but not so short that it does not give pilots enough information. It was determined that providing multiple short instructions/clearances versus one long clearance was beneficial. The AIRS team used several different approaches and determined the best approach was to instruct the flight crew to designate the Lead aircraft before providing the IM clearance. This had flight crews perform a more familiar task first (traffic designation), which reduced their "startle factor" and reduced the number of elements in the subsequent IM clearance, making it easier for flight crews to receive and readback.

The AIRS team also learned that while phraseology may be very explicit to controllers, it can be less clear to flight crews. For example, during a Cross clearance, once the IM aircraft reached the CP, the SafeRoute+ Spacing application changed to the Maintain stage and the IM speeds were calculated to maintain the ASG. Controllers intuitively understood this, but it was not always clear to flight crews. As discussed in Section 2.8, phraseology was changed to make the instruction more explicit to remove any confusion that might arise.

5.3 Lack of IM-Specific ATC Automation Tools

The AIRS project intentionally did not include any costly, time-consuming modifications to ERAM. The objective was to evaluate the benefits and operational feasibility of IM before investing significant resources in the development of ATC automation upgrades.

However, the lack of IM-specific automation capability did impact the use of IM operations. Some key impacts included:

- Lack of an IM capability indicator in ERAM (until very late in the operational evaluation) made it difficult for controllers to easily identify IM-capable aircraft. This lack of an IM capability indicator also made it less likely that controllers would remember to issue an IM clearance without a prompt.
- Coordinating IM operations between sectors/areas was done using the fourth line in the ERAM data block, but this approach had limitations and could be confusing when used.
- There was no easy way to present the required ASG to a controller for time-based IM operations. ZAB controllers often had to determine the ASG or used an ASG that "worked before."

Most of these concerns were alleviated by having ZAB controller SMEs physically in the area to act as a mitigation for the lack of automation and address these issues.

The only current automation used that made a difference was changing the color of IM-equipped aircraft on the ESIS board that projected the TSD for PHX arrival flow. Controllers could easily ascertain which aircraft were IM-equipped by glancing at the ESIS board, which is done often during arrival pushes to PHX.

5.4 Pilot Training

Pilots strongly requested hands-on, interactive training for IM, which involved new equipment, new procedures, and new phraseology (see Section 4.3.1). This was particularly important due to the infrequency of IM clearances given to pilots. Pilots felt training by bulletin was insufficient.

6 Conclusion

The Automatic Dependent Surveillance-Broadcast (ADS-B) In Retrofit Spacing (AIRS) Initial–Interval Management (I-IM) operational 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). I-IM operations, leveraging AAL's Airbus A321 fleet equipped with ACSS's SafeRoute+ Spacing application, were conducted from November 2022 through November 2024. During the operational evaluation, at least 1398 IM operations were conducted.

Data was collected and analyzed from several sources as a part of the operational evaluation. FAA data sources included Falcon replays, trajectory data from Instrument Flight Procedures (IFP), Operations, and Airspace Analytics (IOAA), Aviation System Performance Metrics (ASPM), Voice Transcript Data, and Time-Based Flow Management (TBFM) data. Other data sources included SafeRoute+ data, ZAB controller feedback forms and observations, and AAL/APA flight crew feedback and observations.

During the operational evaluation, over 1475 IM clearances were issued, with most resulting in completed I-IM operations. Concerns or issues were identified via controller and flight crew feedback and were tracked by the AIRS team. Examples of concerns and issues noted included phraseology interpretation and understanding, flight crews deviating from IM speeds, and use of the flight crew interface to the aircraft Multi-purpose Control and Display Unit (MCDU). These concerns and issues were tracked and studied throughout the operational evaluation. Some of these issues and concerns resulted in procedural changes (e.g., phraseology modifications) and others led to changes in the SafeRoute+ system. There were also lessons learned for future activities.

Analyses of IM distance-based operations data indicated that at the Cross Point (CP), the average difference between the observed inter-aircraft distance and the spacing goal was 0.2 nautical miles (NM), with 95% of the flights being within ± 1 NM of this average. Similarly, analyses of IM time-based operations data indicated that at the CP, the average difference between the observed time and the time-based spacing goal was -1 second (early), with 93% of the flights being within ± 10 seconds of this average.

Analyses were conducted to compare the delivery accuracy of the aircraft conducting IM operations over meter points versus the delivery accuracy of those aircraft that were not conducting IM operations. Aircraft conducting IM operations demonstrated smaller mean values and standard deviations in both inter-arrival time (IAT) (for time-based IM operations) and inter-arrival distance (IAD) (for distance-based IM operations), as compared to non-IM operations. The improved delivery accuracy demonstrated with IM operations in this operational evaluation supports future Trajectory-Based Operations that minimize vectoring from Performance-Based Navigation (PBN) arrival routes.

Discussions with ZAB controllers indicated that most of them found that when none of the previously mentioned issues occurred, 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 operations was displayed by the En Route Automation Modernization (ERAM) system.

AAL pilots did not have an opportunity 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+ Spacing application and IM operations. AAL developed a Quick Reference Guide (QRG) that was reported to be effective and helpful for pilots prior to and during IM operations. As flight crews became more familiar with the operation, most found IM to be straightforward and intuitive. ACSS developed interactive procedural training software that was hosted on a tablet or accessed via laptop/desktop computer to allow pilots to practice using the SafeRoute+ Spacing application. ACSS also modified the SafeRoute+ Spacing application's MCDU interface to enable more intuitive use by flight crews; however, the operational evaluation ended before this could be evaluated.

The results showed the spacing precision claimed in prior work was achieved in a real-world environment including operational uncertainties, such as winds and unexpected speed changes from the Lead aircraft. IM spacing performance was significantly better than time-based metering decision support tools and controller-issued speed instructions alone. This should enable safety and efficiency benefits because flights are better able to remain on their planned arrival routes. The objective findings, along with controller and flight crew feedback, support continued development and integration of IM operations into the NAS.

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 Air Traffic Organization Performance Analysis Group
ARTCC	Air Route Traffic Control Center
ASDE-X	Airport Surface Detection Equipment Model 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
FAA	Federal Aviation Administration
FAF	Final Approach Fix
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
DFW	Dallas-Fort Worth International Airport
LAS	Harry Reid International Airport (Las Vegas)
LAX	Los Angeles International Airport
PHX	Phoenix Sky Harbor International Airport
SAN	San Diego International Airport
MCDU	Multi-Function Control and Display Unit
MF	Meter Fix
MOPS	Minimum Operational Performance Standards
MRP	Meter Reference Point

ND	Navigation Display
NEO	New Engine Option
NOP	National Offload Program
P50	Phoenix TRACON
PF	Pilot Flying
PCP	Planned Cancellation Point
PM	Pilot Monitoring
RNAV	Area Navigation
SBS	Surveillance and 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
TCAS	Traffic Alert and Collision Avoidance System
TDP	Transportation Data Platform
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
TSD	Traffic Situation Display
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 References

[1] International Air Transport Association, "Global Outlook for Air Transport: Deep Change," IATA, 2024. Retrieved in 2025 from https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport-june-2024-report

[2] Hicok D., Barmore B. *Concept of Operations for Interval Management Arrivals and Approach*. 2016. Retrieved in 2025 from https://ntrs.nasa.gov/api/citations/20160007720/downloads/20160007720.pdf

[3] *A Report from the ADS–B In Aviation Rulemaking Committee to the Federal Aviation Administration: Recommendations in Response to the Federal Aviation Administration May 30, 2012, Tasking*. Washington, DC, October 31, 2012. Retrieved in 2025 from https://www.faa.gov/sites/faa.gov/files/air_traffic/technology/adsb/quicklinks/ADS-BInARCReportOct2012.pdf located at https://www.faa.gov/air_traffic/technology/adsb/documents

[4] RTCA. *Safety, performance, and interoperability requirements document for Airborne Spacing – Flight Deck Interval Management (ASPA-FIM) (DO-328B).* Washington, DC: RTCA, 2020. Available from https://products.rtca.org (charge for non-members).

[5] EUROCAE. *Safety, performance, and interoperability requirements document for Airborne Spacing – Flight Deck Interval Management (ASPA-FIM) (ED-195B).* St Denis, France: EUROCAE, 2020. Available from https://eshop.eurocae.net/eurocae-documents-and-reports (charge for non-members).

[6] RTCA. *Minimum Operational Performance Standards (MOPS) for Flight-Deck Interval Management (FIM) as modified by Change 1(DO-361A as modified by Change 1).* Washington, DC: RTCA, 2020. Available from https://products.rtca.org (charge for non-members).

[7] EUROCAE. *Minimum Operational Performance Standards (MOPS) for Flight-Deck Interval Management (FIM) as modified by Change 1(ED-236A as modified by Change 1).* St Denis, France: EUROCAE. 2020. Available from https://eshop.eurocae.net/eurocae-documents-and-reports (charge for non-members).

[8] L. A. Weitz and H. Stassen, "A New Spacing Algorithm to Support Near-term Interval Management Operations," presented at the AIAA AVIATION Forum, June 2014. Retrieved in 2025 from https://doi.org/10.2514/6.2014-3149

[9] 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. Retrieved in 2025 from: https://drive.google.com/file/d/1S0rc9_EO4atOUx4elPBbE2eKm-_tyyqW/view?usp=sharing located at https://www.atmseminar.org/past-seminars/13th-seminar/papers-and-presentations

[10] ADS-B Equip2020, Working Group 4, "ADS-B In Strategy Document: Closing the Loop on the Flight Deck," Washington, DC, 2019. Retrieved in 2025 from https://www.faa.gov/sites/faa.gov/files/air_traffic/technology/adsb/quicklinks/ADS-B_In_Strategy.pdf located at https://www.faa.gov/air_traffic/technology/adsb/documents

[11] *ADS-B In Retrofit Spacing (AIRS), Initial–Interval Management (I-IM) Operational Description, Version 2*, June 1, 2022. Retrieved in 2025 from https://www.faa.gov/air_traffic/technology/adsb/quicklinks/AIRS IM Operational Description v2.0_final for website.pdf located at https://www.faa.gov/air_traffic/technology/adsb/documents

[12] S. Priess and L. A. Weitz, "Benefits of Required Time of Arrival (RTA) and Interval Management (IM) Operations," The MITRE Corporation, McLean, VA, 2022. Retrieved in 2025 from https://www.researchgate.net/publication/390755985_Benefits_of_Required_Time_of_Arrival_RTA_and_Interval_Management_IM_Operations

[13] B. Lascara, Lesley A. Weitz, Thomas Monson, Robert Mount, "Measuring Performance of Initial Ground-based Interval Management – Spacing (GIM-S) Operations", in twelfth *USA/Europe Air Traffic Management Research and Development Seminar (ATM2017)*, 2017. Retrieved in 2025 from https://innaxis-comm.s3.eu-central-1.amazonaws.com/ENGAGE/WIKI/PAPERS/ATMSEMINAR/2017/12th_ATM_RD_Seminar_paper_43.pdf

[14] R. S. Bone, W. J. Penhallegon, L. M. Benson, and G. L. Orrell, "Evaluation of Pilot and Air Traffic Controller Use of Third-Party Call Sign in Voice Communications with Pilot Utilization of Cockpit Display of Traffic Information" (MTR130347R1), The MITRE Corporation, McLean, VA, 2013. Retrieved in 2025 from https://apps.dtic.mil/sti/pdfs/AD1107243.pdf

[15] *ADS-B In Retrofit Spacing (AIRS) Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS) Operations and CDTI Assisted Separation on Approach (CAS-A) Operational Evaluation: Final Project Review Report (2023-2024)*, 2025.
Located at https://www.faa.gov/air_traffic/technology/adsb/documents

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)

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 as modified by Change 1. 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 Cross Point (CP)[30]. 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) [31]. Example IM clearances are depicted in Figure 1.

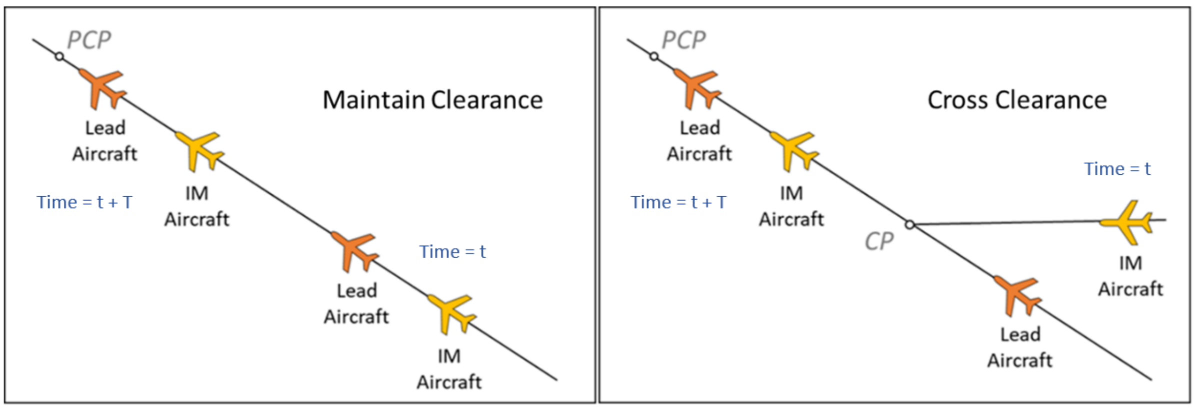


Figure 1: Example IM clearances, from AIRS IM Operational Description

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 (hereafter referred to as the FIM MOPS). In 2023, the FAA defined new equipment classes in TSO-C195c[32] which invoked 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+ met requirements for other ADS-B In applications, it was developed many years prior to the publication of the FIM MOPS. As a result, SafeRoute+ did not meet the full set of requirements within the FIM MOPS and, as such, the ACSS SafeRoute+ Spacing application is not 'MOPS-compliant.'

The ADS-B In Retrofit Spacing (AIRS) Evaluation project was 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 conducted operational evaluations of Cockpit Display of Traffic Information (CDTI)-Assisted Separation

[30] The CP is called the Achieve-by Point (ABP) in the FIM MOPS.
[31] The PCP is called the Planned Termination Point (PTP) in the FIM MOPS.
[32] See https://drs.faa.gov/browse/excelExternalWindow/DRSDOCID176689801820230623115932.0001.

(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 were conducted at the Dallas Terminal Radar Approach Control Facility (TRACON) (D10). The AIRS IM operations were conducted at the Albuquerque Air Route Traffic Control Center (ARTCC) (ZAB).

Simultaneously, the FAA ADS-B In Systems Engineering Working Group (SEWG) developed operational descriptions of IM operations that could be deployed with fewer changes to Air Traffic Control (ATC) automation. The SEWG considered these IM operations for use in both ARTCCs and TRACONs. In this effort, a range of operations were defined, supported by SafeRoute+ equipment, and were 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 were observed. While the generalized IM benefit of more precise spacing in the aforementioned operations could be achieved with both SafeRoute+ and MOPS-compliant FIM Equipment, the operational applicability of IM is reduced when assuming the more limited SafeRoute+ Spacing application. The intent of this paper is to enumerate the functional differences between MOPS-compliant FIM Equipment and the SafeRoute+ Spacing application, 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 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 current position or the Lead aircraft'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.

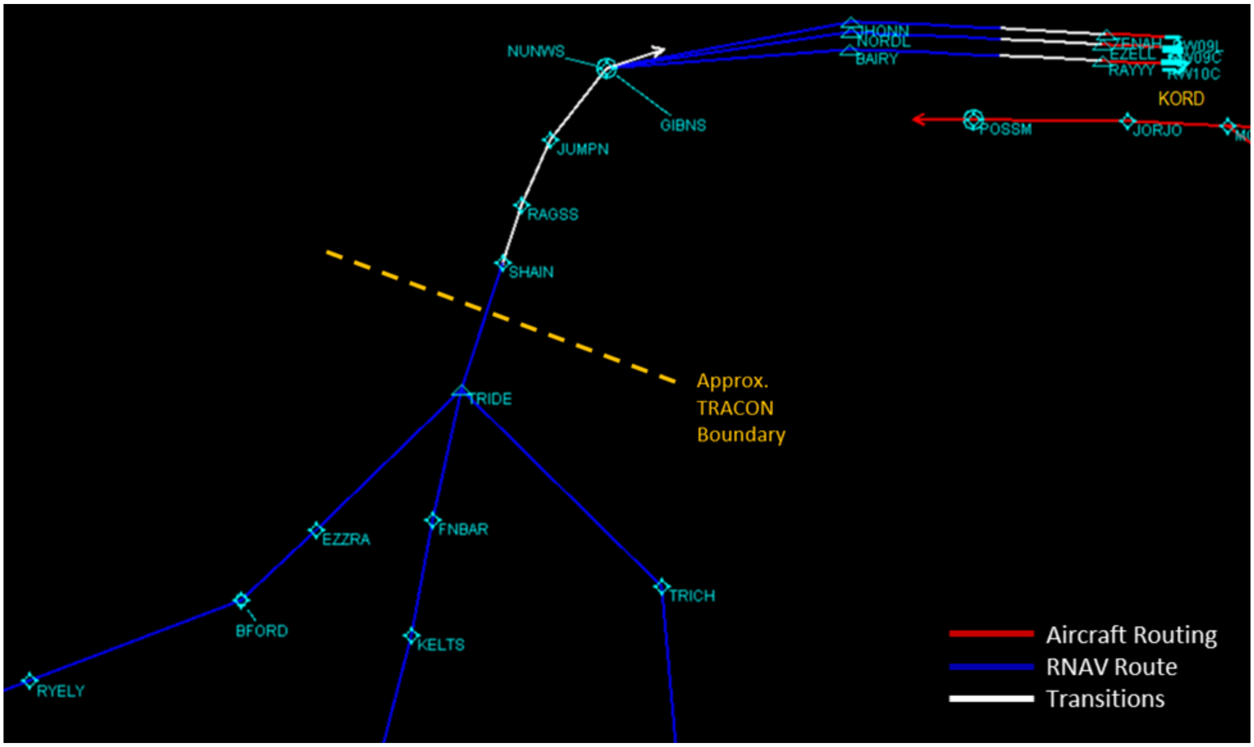


Figure 2: SHAIN2 RNAV Transitions and Arrival

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.

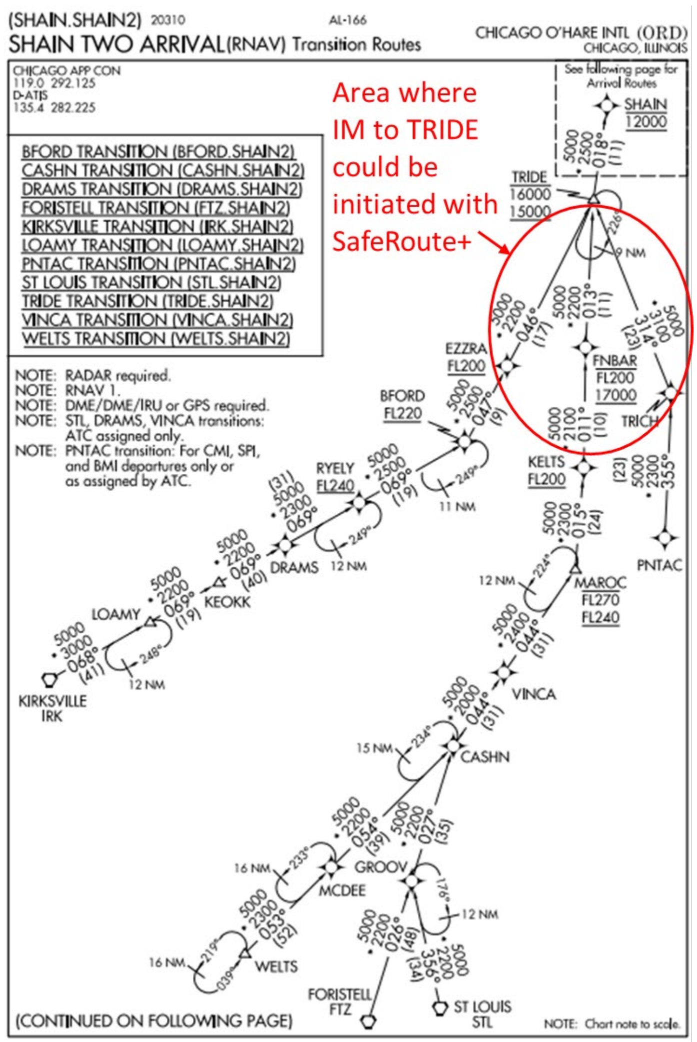


Figure 3: Full SHAIN2 RNAV Transitions and Arrival prior to SHAIN

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 DFW (in 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.

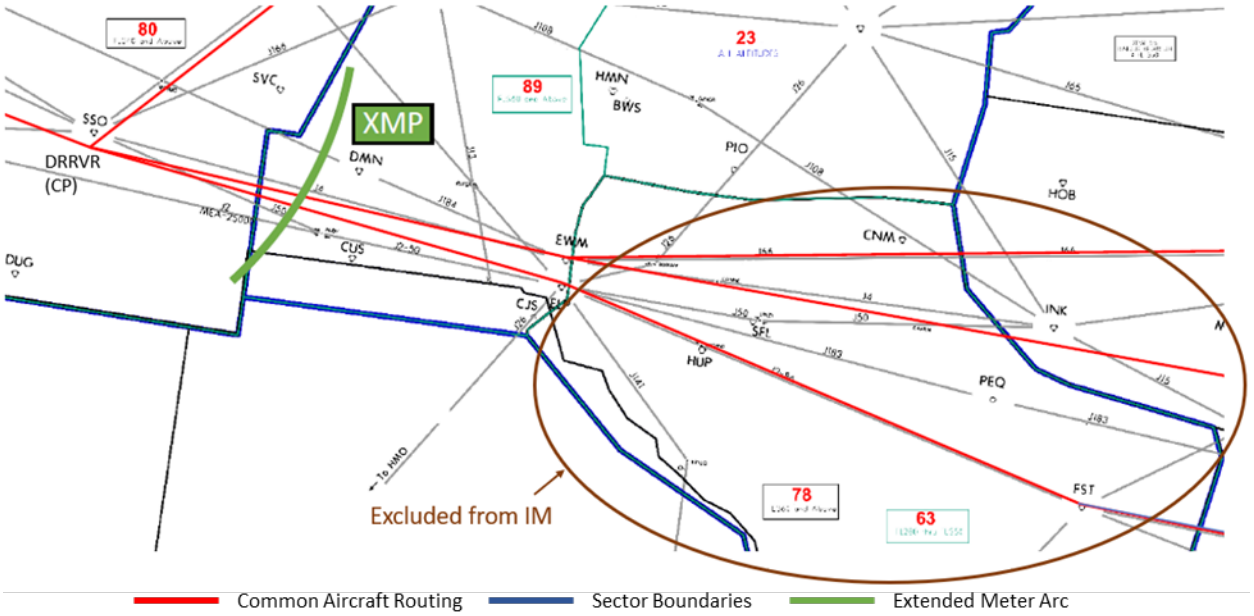


Figure 5: ZAB sectors prior to PINNG arrival, aircraft flows right to left

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.

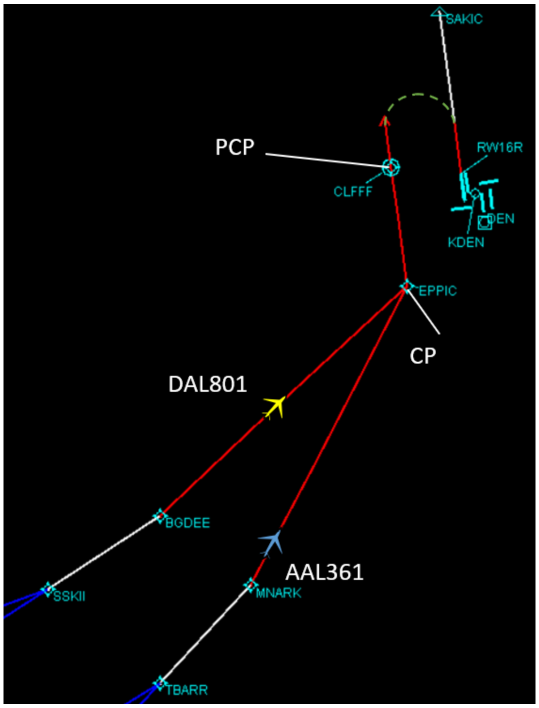


Figure 6: Dual Arrival Merge at DEN

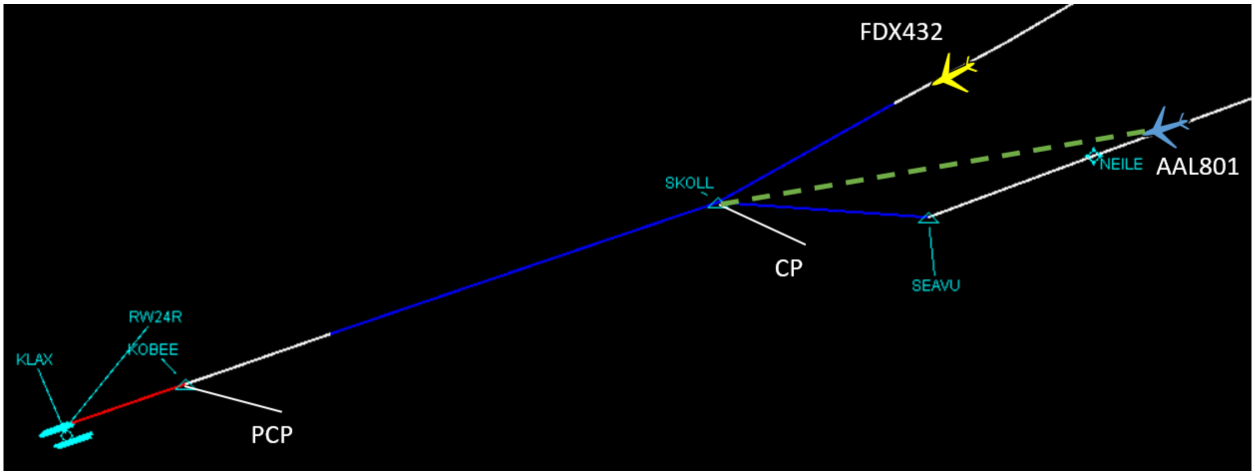


Figure 7: Dual Arrival to FAF Merge at LAX, with Trail Aircraft shortcut to SKOLL

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.

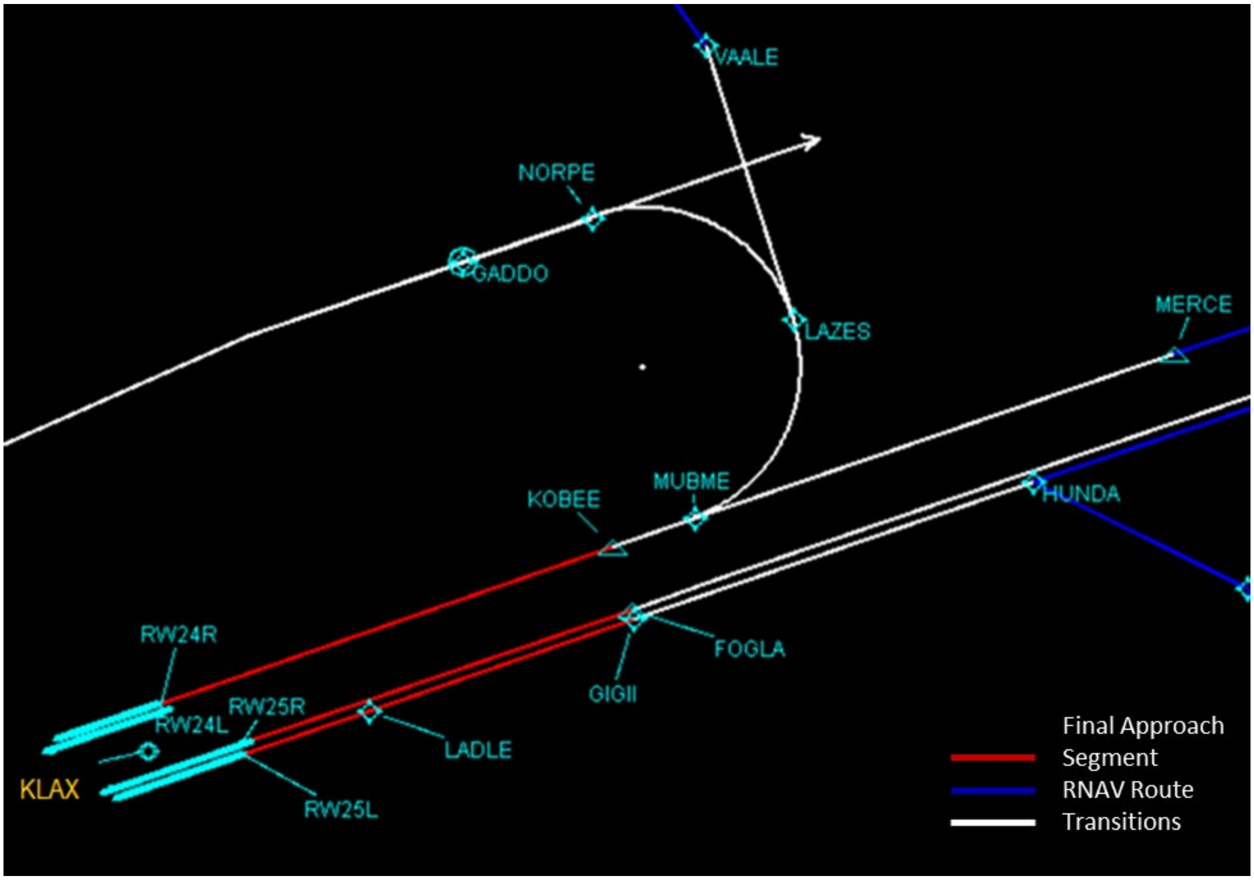


Figure 8: LAX RF turn to final approach

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 in Charlotte TRACON (CLT) from Atlanta ARTCC (ZTL), depicted in Figure 9.

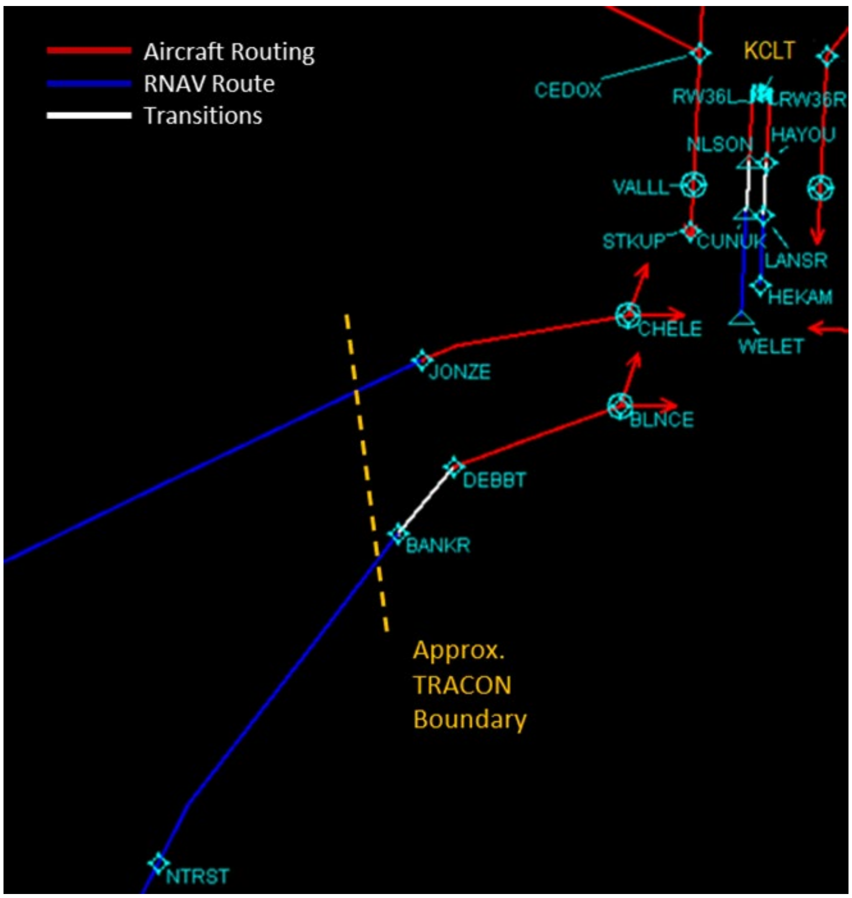


Figure 9: Southwest arrivals from ZTL into CLT

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.

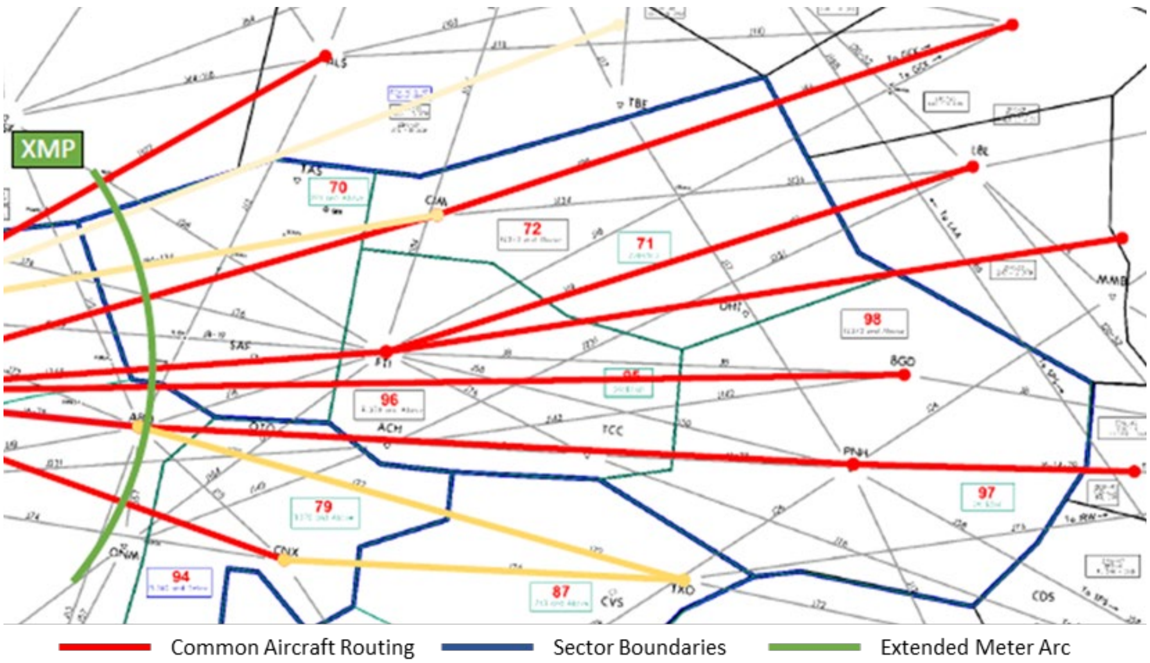


Figure 10: Combined east area sector at ZAB, aircraft flows right to left

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[33] 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.

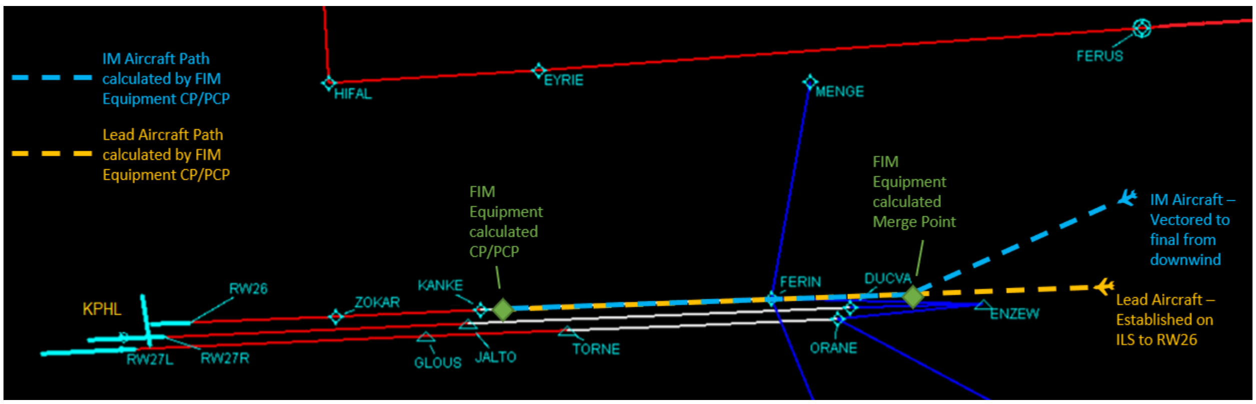


Figure 11: Example Final Approach Spacing clearance at PHL

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[34]. 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 consequences for controllers. In an operational environment with both SafeRoute+ and MOPS-

[33] 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.

[34] 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.

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 affect 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%.[35] 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.

Beyond the IM Speed limiting that SafeRoute+ performs, MOPS-compliant FIM Equipment implementations have additional requirements for speed limiting during RF turns. However, this

[35] In DO-361/ED-236, 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/ED-236A. The bound itself is required to be configurable at installation for a MOPS-compliant system.

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.

9.1.1 Other Avionics Differences

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).

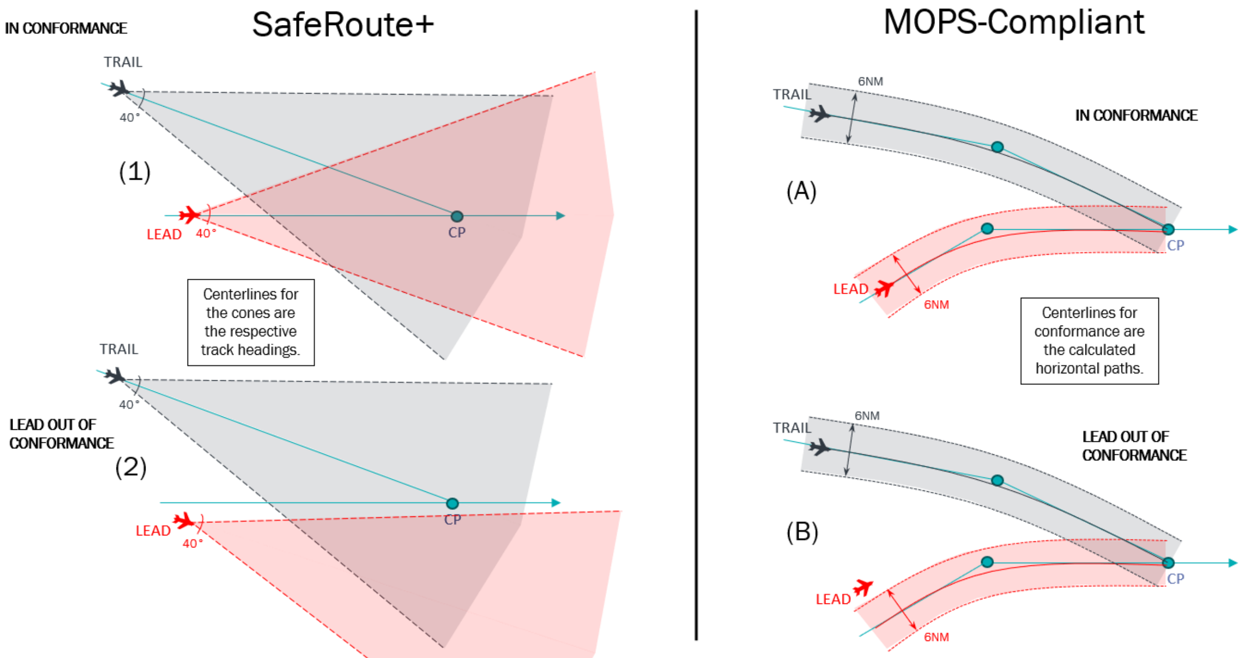


Figure 12: Horizontal Path Conformance checking prior to CP

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).

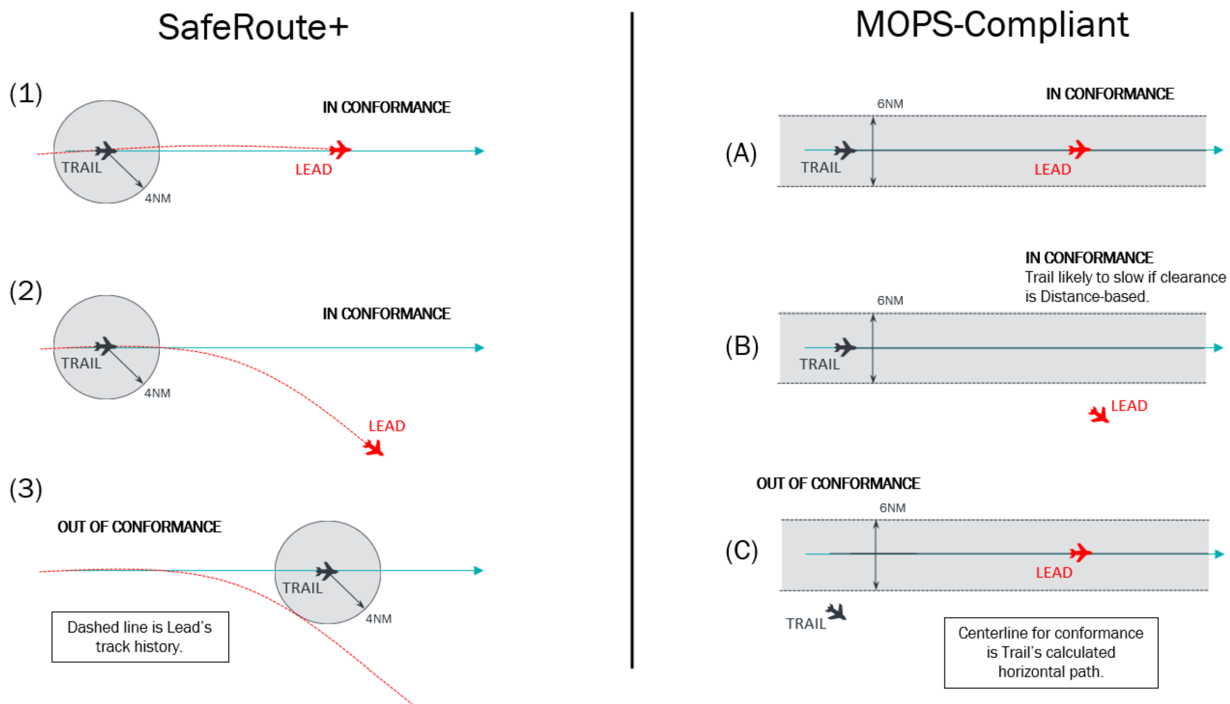


Figure 13: Horizontal Path Conformance checking during Maintain

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.

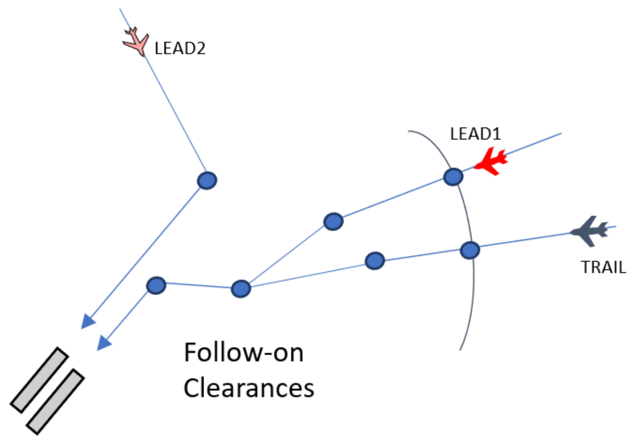


Figure 14: Follow-on IM Clearance Example

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[36],
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.

[36] 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.

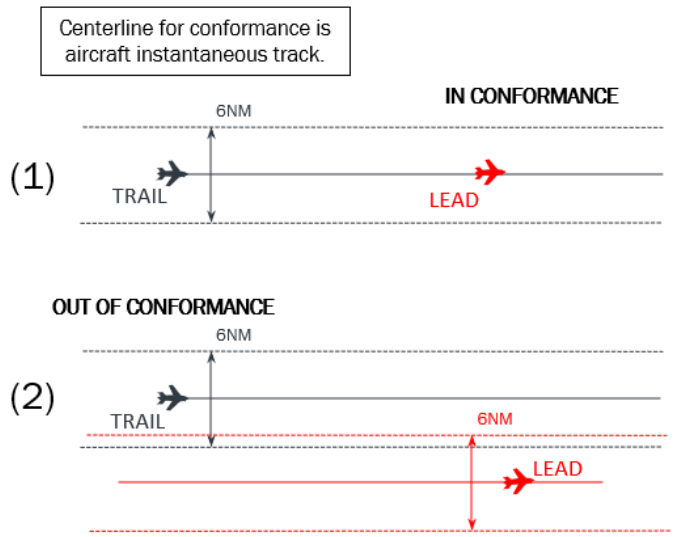


Figure 15a: SafeRoute+ Maintain clearance initiation criteria - swimlane

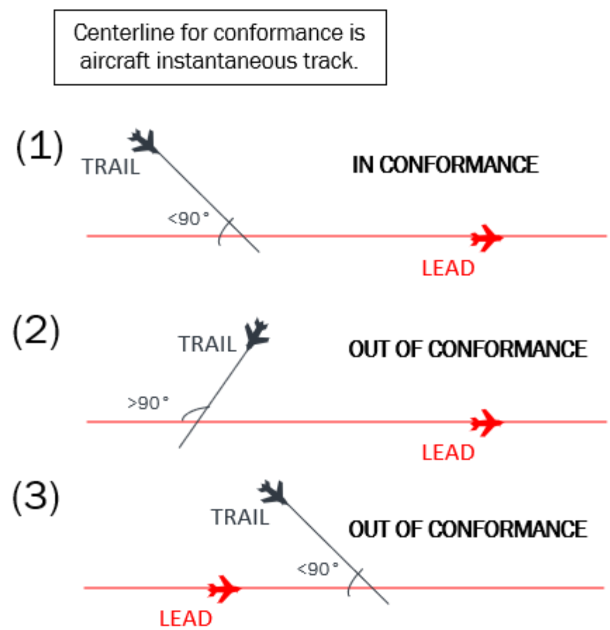


Figure 15b: SafeRoute+ Maintain clearance initiation criteria – intercept angle

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 the FIM MOPS 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

North Area

- Most controllers agree that it "works fine," but 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 IM 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 IM 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 so they know what to do on their side when an IM clearance 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 about IM 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 IM clearance.
- Most of the controllers are willing to do IM when there is a ZAB controller SME present 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 IM 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.

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 EAGUL. 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 ZAB controller SMEs 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 ZAB controller SMEs.

East Area

- All IM operations were prompted by ZAB controller SMEs and not aware of any controllers using it on their own.
- In an IM operation conducted last week, the ZAB controller SME had to walk a pilot through an issue. Even after all this was sorted out, when shipped to the next sector, one pilot checked on correctly and the following aircraft did not.
- When the pilots are up to speed, we have seen the system work well in the past.
- Everyone's experience with IM has been positive in general and all had experienced the "bad geometry" issues in the beginning.
- One controller experienced a time when the pilot responded that they could not comply with the clearance due to an IM speed increase to M.82.
- Reasons they had for not utilizing IM clearances were perceived conflicts with extended metering to KPHX and wondering if it would be beneficial for Sector 93 when blending in Denver Center stream.
- The group agreed that additional automation would encourage utilizing IM on a regular basis and make it more tangible.
- They mentioned a couple times when a ZAB controller SME wanted to do an IM operation, they requested the ZAB controller SME leave the area as the floor was too busy.
- They are aware they can do IM operations if they find a good opportunity.
- Two instances appeared to work very well.
- Controllers feel they would have a lot more opportunity to conduct IM operations if it was available going into Ft. Worth Center airspace. Being forced to terminate at the ZAB boundary makes it not worth it.
- Controllers also brought up that with constant deviations the last few months it makes it very hard to conduct IM operations.
- 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 declined by the pilot due to "workload".

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.
- IM is out of sight, out of mind, until a ZAB controller SME 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.
- "it's in my toolbox, but still hidden away in the corner."
- both controllers present today participated only when it was ZAB controller SME 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).
- one controller has tried to perform an IM operation six times with "we can't do that" from the pilots all six times
- unlikely to participate without ZAB controller SME s, especially with weather, volume, bad rides, etc... impacting the sector
- 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.

Ideas:

- Focus on terminal phase of flight
- Some type of IM reminder directly on data block
- Specific operations pre-coordinated for IM clearances, where pilots and controllers are expecting it
- a fourth-line indicator denoting an IM-eligible aircraft might encourage more participation from the controllers
- an indicator in the data block showing eligible aircraft may help to encourage participation
- 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.

Southwest Area

Questions asked by ZAB controller SME and responses:

- "Have you been utilizing AIRS?" Answer: "Only when prompted by the ZAB controller SMEs."
- "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 IM but now they are more receptive and knowledgeable."
- "Who has done an IM operation?" Answers: "Everyone said yes but only when prompted to by a ZAB controller SME."
- "Were there any issues giving the clearances?" Answers: "Not on our end. Some pilots don't like to do it."

Feedback from the controllers 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 P50 involved to see the full potential of the clearances.
- No issues with the pilots accepting the clearances.
- They appreciate the ZAB controller SME 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 and IM at the same time.
- Complained about the pilots speeding up and slowing down several times.
- Why focus on IM when we have CPDLC coming soon?

9.3 AIRS A321 Workaround SRM Document

See

https://www.faa.gov/sites/faa.gov/files/A321%20Workaround%20SRM%20Document.pdf

9.4 AIRS I-IM ZAB Operational Evaluation SRM Document

Surveillance and Broadcast Services (SBS) Group

Safety Risk Management (SRM) Document for Automatic Dependent Surveillance-Broadcast (ADS-B) In Retrofit Spacing (AIRS) Initial-Interval Management (I-IM) Operational Evaluation at Albuquerque Air Route Traffic Control Center (ZAB)

SBS-203, Rev. 01
SMTS2022081800345

MAY 31, 2022

Approved by:

PAUL DOUGLAS ARBUCKLE Digitally signed by PAUL DOUGLAS ARBUCKLE Date: 2022.08.19 13:24:26 -04'00'

Doug Arbuckle, Chief Scientist & International Lead
Surveillance Services Directorate, AJM-4

19-Aug-2022
Date

Federal Aviation Administration
600 Independence Avenue, SW
Washington, DC 20591

Revision History for
Safety Risk Management (SRM) Document
For AIRS I-IM Operational Evaluation at Albuquerque Air Route Traffic Control Center (ZAB)
SBS-203, Revision 01

Revision Number	Description	Document Date
01	Initial Baseline	May 31, 2022

Title: Safety Risk Management (SRM) Document for AIRS I-IM Operational Evaluation at Albuquerque ARTCC (ZAB)

Initiator: Doug Arbuckle, Chief Scientist & International Lead
Initiator's Organization: Surveillance Services Directorate, AJM-4
Initiator's Phone Number: (757) 846-4225

Submission Date: May 31, 2022
SRMD Revision Number: SBS-203, Revision 01
SRMD Revision Date: May 31, 2022

SRMD Signatures:

Approved by: Digitally signed by MARK W STEINBICKER Date: 2022.09.07 15:56:38 -04'00' Date: 9/7/22

Robert M. Ruiz
Director, Office of Safety Standards, AFS-1

Title: Safety Risk Management (SRM) Document for AIRS I-IM Operational Evaluation at Albuquerque ARTCC (ZAB)

Initiator: Doug Arbuckle, Chief Scientist & International Lead
Initiator's Organization: Surveillance Services Directorate, AJM-4
Initiator's Phone Number: (757) 846-4225

Submission Date: May 31, 2022
SRMD Revision Number: SBS-203, Revision 01
SRMD Revision Date: May 31, 2022

SRMD Signatures:

Digitally signed by EVAN W SETZER
Date: 2022.08.23 11:47:18 -04'00'
Adobe Acrobat version: 2022.001.20169

Reviewed by: ______________________ Date: 08/23/2022

Evan W. Setzer
Group Manager, Surveillance & Broadcast Services, AJM-42

Title: Safety Risk Management (SRM) Document for AIRS I-IM Operational Evaluation at Albuquerque ARTCC (ZAB)

Initiator: Doug Arbuckle, Chief Scientist & International Lead
Initiator's Organization: Surveillance Services Directorate, AJM-4
Initiator's Phone Number: (757) 846-4225

Submission Date: May 31, 2022
SRMD Revision Number: SBS-203, Revision 01
SRMD Revision Date: May 31, 2022

SRMD Signatures:

Risk Acceptance by: PHILLIP C SPIKES Digitally signed by PHILLIP C SPIKES Date: 2022.09.14 11:46:54 -06'00' Date: 09/14/2022

Phil Spikes
Albuquerque ARTCC ATM

Title: Safety Risk Management (SRM) Document for AIRS I-IM Operational Evaluation at Albuquerque ARTCC (ZAB)

Initiator: Doug Arbuckle, Chief Scientist & International Lead
Initiator's Organization: Surveillance Services Directorate, AJM-4
Initiator's Phone Number: (757) 846-4225

Submission Date: May 31, 2022
SRMD Revision Number: SBS-203, Revision 01
SRMD Revision Date: May 31, 2022

SRMD Signatures:

Approved by: ______________________ Date: 10/18/22
Danny Watson
Albuquerque ARTCC NATCA Facility Rep

Executive Summary

The Federal Aviation Administration (FAA) Surveillance and Broadcast Services (SBS) Group is interested in promoting the adoption of Automatic Dependent Surveillance-Broadcast (ADS-B) In applications that can increase the safety and efficiency of the National Airspace System (NAS). The FAA, American Airlines, Inc. (AAL), and Aviation Communication & Surveillance Systems, LLC (ACSS) entered into an agreement in September 2017 to support the evaluation of ADS-B In operations by equipping the entire AAL Airbus A321 (A321) fleet with certified ACSS SafeRoute+™ avionics. The ADS-B In operations being evaluated are Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS), CDTI Assisted Separation on Approach (CAS-A), and Initial-Interval Management (I-IM). The primary objective of this project is to promote the early adoption of ADS-B In applications by fielding a cost-effective retrofit solution.

ACSS developed a retrofit architecture using existing flight deck displays supplemented with a graphical ADS-B Guidance Display (AGD). The architecture includes the display of ADS-B equipped traffic along with Traffic Collision Avoidance System (TCAS) equipped 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. For the ACSS SafeRoute+™ implementation, the combination of AGD, TCAS display, and MCDU are collectively referred to as the CDTI. This architecture is more economically viable than previous retrofit architectures and has the potential to enable early adoption of ADS-B In applications without waiting for forward fit implementations.

This Safety Risk Management (SRM) document addresses the operational evaluation (OpEval) of I-IM in Albuquerque Air Route Traffic Control Center's (ZAB ARTCC denoted throughout as ZAB in this document) airspace for overflight aircraft and arrival aircraft to Phoenix. The scope includes the coordinated use of I-IM by the En Route controllers in ZAB airspace and the American Airlines pilots operating ACSS-equipped A321 aircraft in-trail of an ADS-B Out aircraft. A Safety Risk Management Panel reviewed the Operational Description as part of the hazard assessment and provided input to assist the trial site in finalizing their Standard Operating Procedures (SOPs) and phraseology.

Summary of Findings

An SRM Panel convened in-person and virtually on May 24 and 25, 2022 to identify and assess the hazards associated with the proposed I-IM OpEval in the ZAB airspace. The panel was comprised of stakeholders representing the Surveillance and Broadcast Services (SBS) Group, FAA Flight Standards Service (AFS), FAA Air Traffic Services (AJT), FAA Mission Support Service (AJV), Albuquerque 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, Interval Management, 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 having 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 (see Section 4.5).

Table ES-1 below summarizes the identified hazards.

Table ES-1: I-IM OpEval Hazard Summary

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)

Figure ES-1 is an illustration of the hazards' Initial and Predicted Residual Risk based on the SRM Panel results.

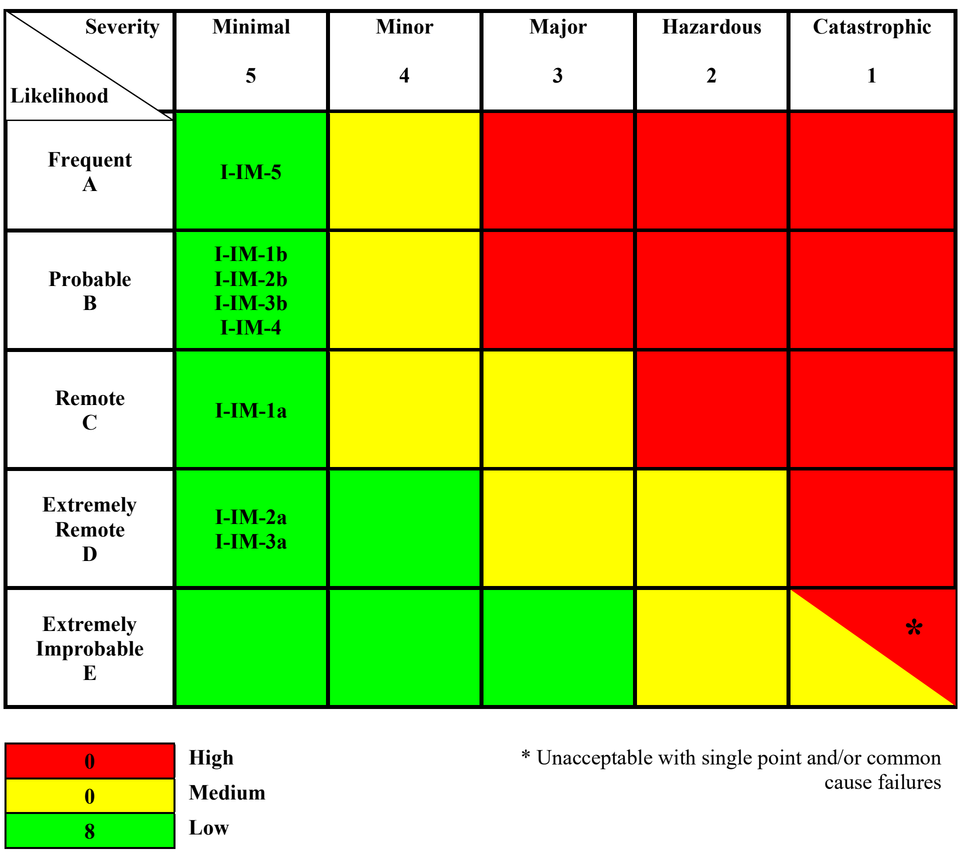


Figure ES-1: I-IM Initial and Predicted Residual Risk Matrix

The OpEval will be conducted over a period of one year for ACSS-equipped American Airlines A321 aircraft transiting ZAB airspace. The ADS-B In Retrofit Spacing (AIRS) I-IM team will use data sources and parameters identified in the monitoring plan of this SRM document to evaluate the performance and operational efficiencies of I-IM in ZAB airspace (Section 4.9). The resultant data should provide both quantitative and qualitative feedback which is expected to support the potential future NAS-wide expansion of I-IM.

Table of Contents

1 Introduction ... 1
2 Current System ... 1
3 Description of Change ... 2
4 Hazard Identification and Risk Determination ... 10
4.1 Preliminary Safety Analysis Meeting ... 10
4.2 Operational Evaluation Scope ... 11
4.3 Assumptions ... 11
4.3.1 ZAB Assumptions ... 11
4.3.2 Flight Crew Assumptions ... 12
4.3.3 System Assumptions ... 12
4.4 Hazard Model Definitions ... 12
4.5 Identified Hazards ... 12
4.6 Hazard Risk Matrix ... 16
4.7 Additional Hazards Considered ... 17
4.8 Safety Recommendations ... 19
4.9 Monitoring Plan ... 19
4.10 SRM Panel Participants ... 20
5 Conclusion ... 23

List of Tables

Table ES-1: I-IM OpEval Hazard Summary viii
Table 3-1: I-IM Table of Differences 5
Table 4-1: I-IM 5M Elements 11
Table 4-2: I-IM OpEval Hazard Summary 16
Table 4-3: I-IM Hazard Monitoring Parameter 19
Table 4-4: AIRS I-IM ZAB OpEval SRM Panel 21

List of Figures

Figure ES-1: I-IM Initial and Predicted Residual Risk Matrix viii
Figure 3-1. ZAB Airspace 3
Figure 3-2. Flight Deck Avionics (clockwise from left: AGD, traffic display, and MCDU) 4
Figure 4-1: I-IM Risk Assessment Matrix 17

List of Appendices

ACRONYMS .... APPENDIX A
REFERENCE DOCUMENTS .... APPENDIX B
I-IM HAZARD ANALYSIS WORKSHEET .... APPENDIX C
TBFM SWIM-BASED ASG TOOL TESTING .... APPENDIX D
AIRS I-IM OPERATIONAL DESCRIPTION .... APPENDIX E

1 Introduction

The Federal Aviation Administration (FAA) Surveillance and Broadcast Services (SBS) Group is interested in promoting the adoption of Automatic Dependent Surveillance-Broadcast (ADS-B) In applications that can increase the safety and efficiency of the National Airspace System (NAS). The FAA, American Airlines, Inc. (AAL), and Aviation Communication & Surveillance Systems, LLC (ACSS) entered into an agreement in September 2017 to support the evaluation of ADS-B In operations by equipping the entire AAL Airbus A321 (A321) fleet with certified ACSS SafeRoute+™ avionics. The ADS-B In operations being evaluated are Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS), CDTI Assisted Separation on Approach (CAS-A), and Initial-Interval Management (I-IM). The primary objective of this project is to promote the early adoption of ADS-B In applications by fielding a cost-effective retrofit solution.

ACSS developed a retrofit architecture using existing flight deck displays supplemented with a graphical ADS-B Guidance Display (AGD). The architecture includes the display of ADS-B equipped traffic along with Traffic Collision Avoidance System (TCAS) equipped 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. For the ACSS SafeRoute+™ implementation, the combination of AGD, TCAS display, and MCDU are collectively referred to as the CDTI. This architecture is more economically viable than previous retrofit architectures and has the potential to enable early adoption of ADS-B In applications without waiting for forward fit implementations.

This Safety Risk Management (SRM) document addresses the operational evaluation (OpEval) of I-IM in Albuquerque Air Route Traffic Control Center's (ZAB ARTCC denoted throughout as ZAB in this document) airspace for overflight aircraft and arrival aircraft to Phoenix. The scope includes the coordinated use of I-IM by the En Route controllers in ZAB airspace and the American Airlines pilots operating ACSS-equipped A321 aircraft in-trail of an ADS-B Out aircraft. A Safety Risk Management Panel reviewed the Operational Description as part of the hazard assessment and provided input to assist the trial site in finalizing their Standard Operating Procedures (SOPs) and phraseology.

2 Current System

Current ATC operations are provided to ensure spacing between aircraft and to issue control instructions. Control instructions are furnished to allow for an orderly flow of aircraft following a pre-determined spacing, such as Miles-In-Trail (MIT), which allows for safe and efficient operations. Spacing achieved and maintained by ATC allows for flights to proceed to their destination in an orderly manner across sectors. The controller monitors the distance between aircraft and assigns speed and/or vector changes to maintain desired spacing.

Aircraft positions are monitored using ADS-B, with radar data also available. Aircraft equipped with ADS-B Out provide their position information to other aircraft that are equipped with an ADS-B In receiver. Although the ADS-B In equipped aircraft can see the location (and other surveillance information) of the other ADS-B Out equipped aircraft, the flight crew are not able to appropriately space themselves relative to that aircraft based only on the surveillance information provided.

3 Description of Change

As stated in the Operational Description (ADS-B In Retrofit Spacing (AIRS) Initial-Interval Management (I-IM), Version 1.9.5, May 16, 2022) in Appendix E of this document, the objective of I-IM is to achieve consistent, low-variance spacing between paired aircraft during the level cruise or arrival phase of the aircraft's flight. Enabled by ADS-B reports from the Lead Aircraft, the IM (Trail) Aircraft calculates the necessary speed changes and presents those speeds to the flight crew for execution.

The I-IM operations will be performed in ZAB airspace (Figure 3-1) with AAL A321 aircraft on Area Navigation (RNAV) Standard Terminal Arrival Routes (STARs) into Phoenix Sky Harbor International Airport (KPHX), and overflight traffic transitioning ZAB airspace subject to Miles-In-Trail (MIT) spacing. IM is an additional technique available to ZAB controllers to achieve the desired spacing.

I-IM operations will be conducted during either Visual Meteorological Conditions (VMC) or Instrument Meteorological Conditions (IMC) under Instrument Flight Rules (IFR) in airspace with ATC surveillance. For the trial, air traffic controllers will use existing ATC automation with the A321 Workaround to identify those aircraft that are equipped with ACSS SafeRoute+™.

The IM operation will consist of a Lead Aircraft and an IM Aircraft. There are no IM-specific requirements for the Lead Aircraft. The IM Aircraft must be equipped with the ACSS SafeRoute+™ equipment (Figure 3-2) and have 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).

The routing for an aircraft pair will consist of either a common route or two separate routes merging at a common point, known as the Crossing Point (CP), followed by a common route. The routes prior to the CP, whether a published airway or direct to a fix, must be on a straight path directly toward the CP. Both routing types may include a Planned Cancellation Point (PCP) where the IM operation will end.

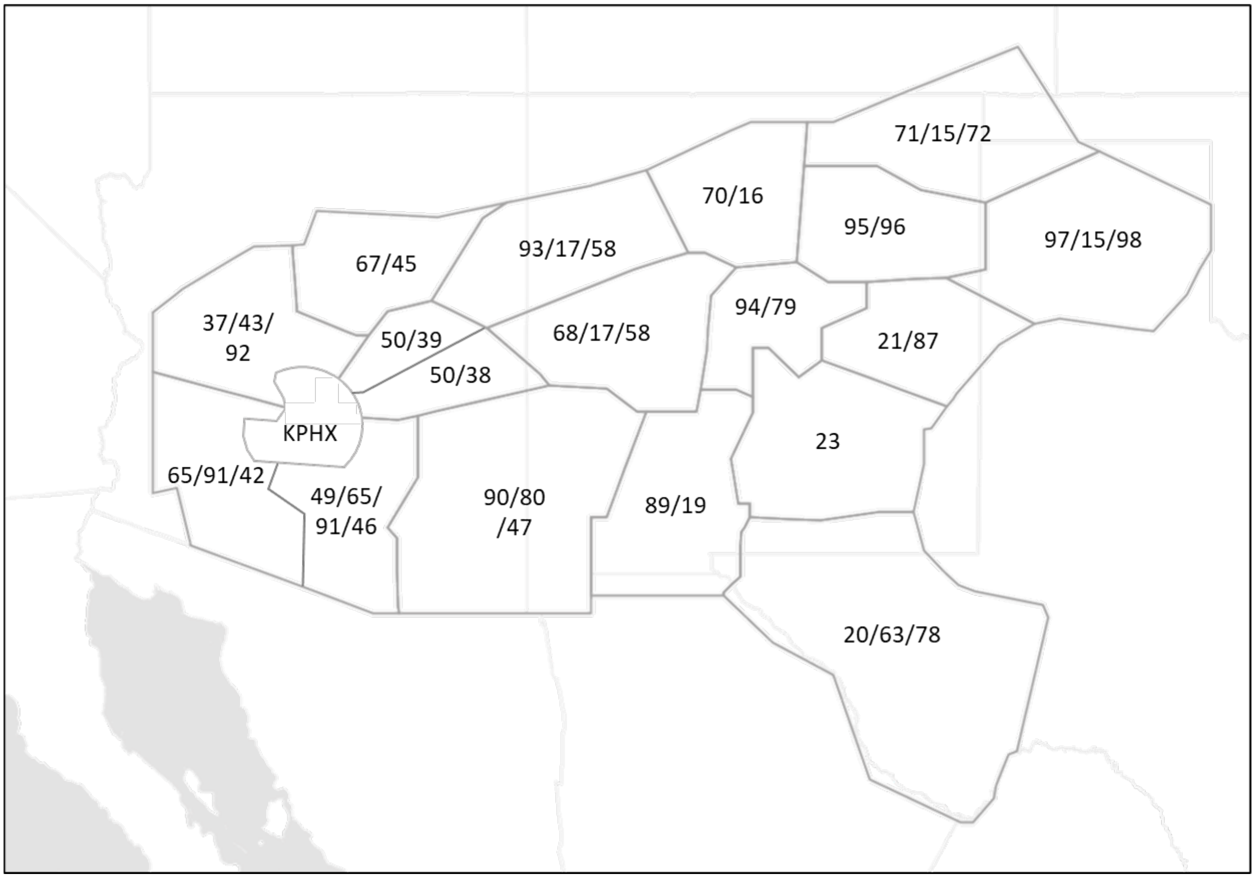


Figure 3-1. ZAB Airspace

The operational environment will include aircraft from several operators that are not equipped with the SafeRoute+™ equipment. These aircraft will operate in the same airspace and arrive at the same airports while equipped AAL aircraft are conducting IM. Only AAL's aircraft equipped with the SafeRoute+™ equipment will perform the role of the IM Aircraft in an aircraft pair. All aircraft operating in ZAB airspace may be designated as the Lead Aircraft in an aircraft pair.

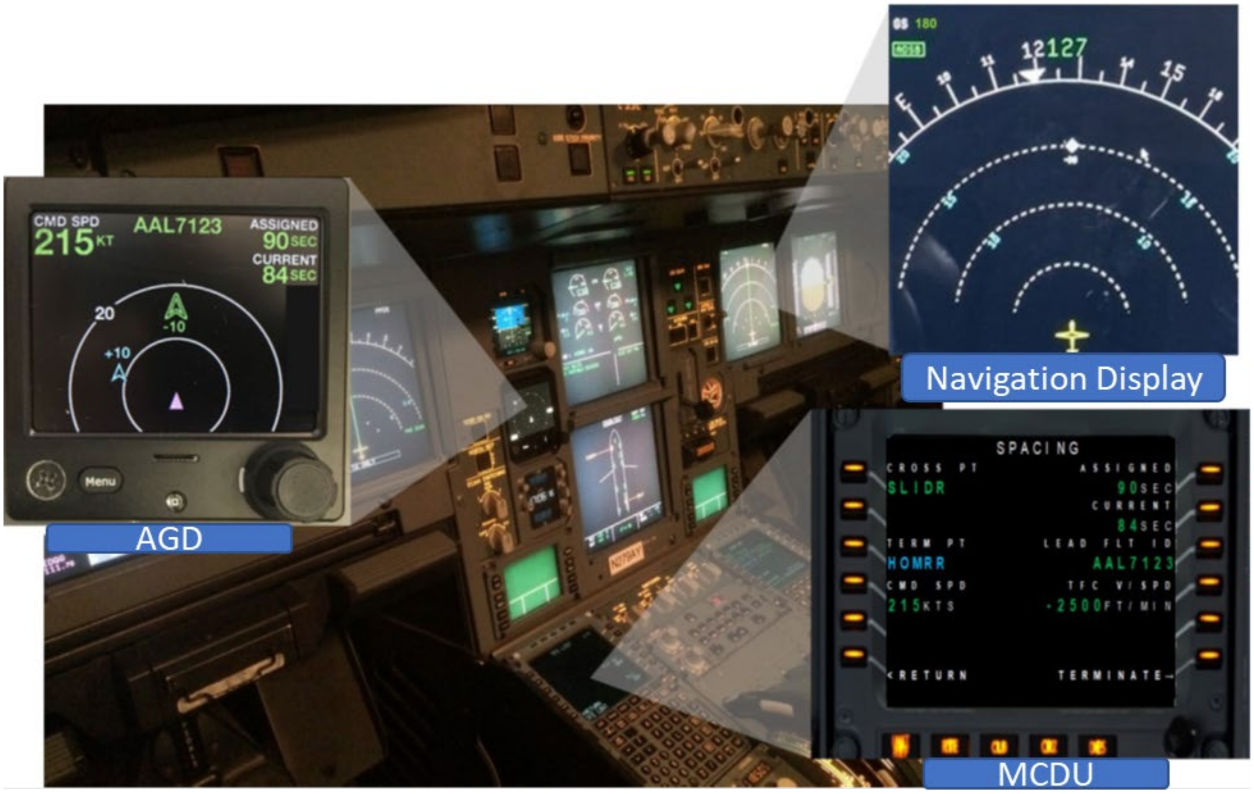


Figure 3-2. Flight Deck Avionics (clockwise from left: AGD, traffic display, and MCDU)

Operational differences comparing current tasks versus the proposed OpEval tasks are identified in the following tables. These were presented to the SRM Panel.

Table 3-1: I-IM Table of Differences

Operational Tasks	Current operations without IM capability	Future operations with IM capability
ASG		
Miles in Trail spacing goal	If spacing can be accomplished with speeds: • Use controller assigned speeds If speed only is not an option: • Controller will issue turns	If spacing can be accomplished with speeds: • Use controller assigned speeds • **Issue IM clearance** If speed only is not an option: • Controller will issue turns prior to IM
Identify ADS-B In capable aircraft	(N/A)	American Airlines A321 aircraft are IM capable
Identify TMI MIT (E.g., 15 MIT over INK DFW arrivals)	MIT and time frame for TMI available on ESIS board	(No change.)
Time-based clearances	Time based clearances not currently used	IM capabilities include spacing in seconds
Identify time-based ASG (E.g., 82 seconds at DRRVR for PHX arrivals)	(N/A)	Time-based Assigned Spacing Goal (ASG), Lead and Trail aircraft available on: • TBFM SWIM-based ASG Tool either on a monitor for the controller to look at or used by the TMU or the Supervisor then communicated to the controllers • ASG from "lookup table" used by either the TMU or Supervisor then communicated by the controllers

Operational Tasks	Current operations without IM capability	Future operations with IM capability
Metering		
Deliver +/-1 min to Schedule (schedule times give spacing goal)	If spacing can be accomplished with speeds: • Use GIM-S speeds • Use controller assigned speeds If speed only is not an option: • Controller will issue turns	If spacing can be accomplished with speeds: • Use GIM-S speeds • Use controller assigned speeds • **Issue IM clearance** If speed only is not an option: • Controller will issue turns prior to IM
Identify ADS-B In capable aircraft	(N/A)	American Airlines A321 aircraft are IM capable
Time-based clearances	Time based clearances not currently used	IM capabilities include spacing in seconds
Identify time-based ASG (E.g., 82 seconds at DRRVR for PHX arrivals)	(N/A)	Time-based ASG, Lead and Trail aircraft available on the TBFM Swim-based ASG Tool via Monitor
Identify time-based ASG (E.g., 82 seconds at DRRVR for PHX arrivals)	(N/A)	Time-based ASG, Lead and Trail aircraft available from supervisor or TMU using the TBFM Swim-based ASG Tool
Identify time-based ASG (E.g., 78 seconds at SLIDR for PHX arrivals)	(N/A)	Time-based ASG available from “lookup table” from TMU or Supervisor

Operational Tasks	Current operations without IM capability	Future operations with IM capability
Flight Crew		
Enter IM clearance	(N/A)	Designate Lead aircraft, Enter crossing point, and enter ASG in time or distance
Cross check clearance	(N/A)	Cross check IM clearance with both members of flight crew
Fly commanded speeds	Controller Provided speed commands	ACSS Saferoute+™ provides speed commands
Monitor avionics	(N/A)	Monitor ACSS Saferoute+™ for speed commands and failures (e.g., feasibility, new speed commands etc.)
Communications		
Clearance Verbiage (Special language)	(N/A)	Lead aircraft call sign **(Use of third-party call sign)** Trail aircraft call sign Crossing point ASG in time (seconds) or miles
Cross Clearance Example	(N/A)	"AAL753 cross EWM 15 miles behind DAL745" "AAL753 cross DRRVR 82 seconds behind DAL745" **Controller uses third-party call sign**

Operational Tasks	Current operations without IM capability	Future operations with IM capability
Maintain Clearance Example	(N/A)	"AAL753 maintain 15 miles behind DAL745" "AAL753 maintain 82 seconds behind DAL745 **Controller used third-party call sign**
Pilot self-reporting	Normal check on with altitude	Pilots will check on frequency and report they are spacing behind lead aircraft callsign. **Pilot will use third-party call sign upon check in**
Controller must cancel IM clearance before leaving ZAB airspace	(N/A)	Cancel Spacing and assign new speed to aircraft prior to leaving ZAB
Monitoring		
Track Lead and Trail aircraft	(N/A)	Controller will put "L" or "T" in forth line of data block
Monitor spacing	Controller is aware of speed and/or heading assigned	Avionics will present speed commands to flight crew, controller is not aware when speed commands are presented and will not know the extent of the speed change
Training		
Pilot Training	Basic pilot Training	IM Specific Training
Controller Training	Basic ATC Training	IM Specific Training

Operational Tasks	Current operations without IM capability	Future operations with IM capability
Equipment		
Aircraft Equipment Requirement	(N/A)	ACSS SafeRoute+™ Avionics
ATC equipment requirements	(N/A)	TBFM Swim-based ASG Tool, (displayed on a dedicated monitor, on the sup desk or TMU)
ATC references required	(N/A)	ASG look up table

4 Hazard Identification and Risk Determination

4.1 Preliminary Safety Analysis Meeting

A working group meeting was held April 27, 2022 to identify and discuss areas of concern for the proposed OpEval. The working group took the opportunity to begin a preliminary hazard list (PHL) and identified potential concerns that were not necessarily hazards but were points of discussion to be presented during the SRM panel on May 24 and 25, 2022. The session allowed stakeholders to express their concerns and identify areas requiring more supporting and/or historical background so the panel could adequately assess the issues for the meeting in May. The following is the list created at the April 27 meeting and the subsequent conclusions from the SRM panel in May are in bold text regarding these potential concerns. A description of the hazards is presented in section 4.5.

(1) *Callsign issues – third party flight ID using other airlines' callsigns* – **Not a hazard**

(2) *Designate the wrong traffic to follow (TTF)* – **Hazard I-IM-1**

(3) *Incorrect ASG* – **Hazard I-IM-2**
- *Issues with determining the appropriate static ASG to use* – **Cause of I-IM-2**
- *ASG Tool not updating TBFM data after traffic resequencing* – **Cause of I-IM-2**
- *Potential for a controller to be given an ASG of less than 5 nm to be assigned* – **Effect of I-IM-2**

(4) *ATC has not worked time-based spacing* – **Not a hazard**

(5) *Controllers monitoring a mix of time-based vs. distance-based aircraft* – **Not a hazard**
- Discrepancy between time-based ASG and what the requirement is at SLIDR. Mixing distance and time for these may not work well.

(6) *Lack of widespread aircraft equipage could lead to increased workload due to lack of proficiency* – **Cause of I-IM-1, I-IM-2, and I-IM-3**

(7) *Conflict alert/conflict probe* – **Not a new hazard**
- Conflict alerts/conflict probes may be triggered during normal operations and become a nuisance

(8) *Controllers unsure on what the trail aircraft's speed behavior will be* – **Hazard I-IM-3**
- Training/experience with "spacing clearances" dissimilar to any other instruction today

(9) *Flight crew workload may increase because of new entry of IM Clearances and more frequent speed changes they receive from the avionics* – **Not a new hazard**

(10) *Fail to cancel IM before leaving ZAB* – **Hazard I-IM-4**

(11) *Flight crew response time to indications and alerts – adjust speed prompt, feasibility check, conformance check, etc.* – **Cause of I-IM-3**

4.2 Operational Evaluation Scope

The SRM Panel was presented with an extensive description of the proposed operation, which is included in Appendix E. ACSS representatives described the avionics, ZAB representatives provided details about the approach controller operations, and AAL representatives provided information on flight deck procedures and a video of the cockpit system. From those descriptions, the panel reviewed and identified the following elements to assist in focusing the scope of the OpEval. Table 4-1 outlines the 5M elements involved in describing the proposed change.

Table 4-1: I-IM 5M Elements

Mission To demonstrate the consistent ability to achieve and maintain a desired spacing goal between paired aircraft during the level cruise and/or arrival phase of an aircraft's flight	
(hu)Man AAL Airbus Pilots trained for IM All Pilots made aware of new operations ZAB ATC Controllers ZAB Traffic Management Unit (TMU) ZAB Supervisor P50 Personnel	**Machine** ZAB Surveillance and Automation Platforms ADS-B Out ACSS Avionics Communications medium between ATC and flight-deck TBFM SWIM-based ASG Tool
Management FAA Order 7110.65 -Paragraphs 5.5.2, Target Separation -Paragraphs 5.5.4, Minima -Paragraphs 5-4-10, En Route Fourth Line Data Block Usage FAR Part 121.544, Pilot Monitoring Local ZAB Order Airline Ops Specs I-IM Ops Description Operational Agreements (LOA's, Operational Procedures with unions) American Airlines Training Procedures ZAB Training Procedures NOTAM/LTA – to alert other carriers of the operation	**Media (environment)** Airline Training Facility Flight-deck ZAB ARTCC Facility ZAB Test & Training Lab ZAB Airspace

4.3 Assumptions

The assumptions were obtained from the Operational Description and further developed by the SRM Panel.

4.3.1 ZAB Assumptions

- ATC responsibilities do not change when IM is being conducted

- ZAB Controllers will be trained for the operation prior to the start of IM operations
- Controllers aren't operationally required to use IM
- The identified candidate IM Aircraft is an equipped AAL A321
- IM will only be used in the ZAB airspace
- The aircraft are currently spaced such that achievement of the desired spacing is probable with speed only and additional vectoring of either aircraft is unlikely
- The aircraft are within ADS-B range of each other (90 NM)
- NOTAM/LTA will be issued for awareness to all aircraft

4.3.2 Flight Crew Assumptions

- Only American Airlines A321 aircraft equipped with ACSS SafeRoute+™ will participate as the trail aircraft in the I-IM Operations
- All American Airlines Airbus flight crews will be trained prior to the start of I-IM Operations.
- The entry of the IM clearance is verified by the other member of the flight crew.

4.3.3 System Assumptions

- AIRS Team and ZAB are satisfied with results of testing of TBFM Swim-based ASG Tool (refer to Appendix D).

4.4 Hazard Model Definitions

After identifying the list of potential issues, the panel reviewed the PHL to determine if each of the identified concerns was a hazard associated with the change, a cause or effect of the hazard, or if the hazard already exists in the NAS. This SRM document has been prepared in accordance with FAA Air Traffic Organization (ATO) Safety Management System (SMS) manual, April 2019. The severity and likelihood tables referenced by the panel are in Appendix B.

As the panel discussed the identified hazard, the severity of each effect was determined using the severity tables as guidance. The likelihoods for the hazard and its effects were determined based on qualitative estimates by the experienced stakeholders and SMEs on the SRM Panel. The risk associated with each effect was based on integrating the two factors: severity of consequence and likelihood of occurrence.

4.5 Identified Hazards

The I-IM OpEval SRM Panel identified five new hazards associated with aircraft performing IM operations in ZAB airspace as well as the surrounding airspace.

Hazard I-IM-1 – Designate the Wrong Lead Aircraft

The panel reviewed the one hazard that was identified during the SRM Panel for the AIRS CAS-A OpEval in D10's airspace, which was the potential to designate the incorrect TTF (refer to AIRS CAS-A D10 OpEval SRM document). The I-IM SRM Panel concurred that this hazard also pertains to the I-IM OpEval. The panel members identified the cause of this hazard to be that either the controller may provide the wrong traffic, or the flight crew hears the wrong aircraft ID or hears it correctly but enters it incorrectly. Another potential cause identified is the irregular use of the IM Operation, which may lead to lack of proficiency for both the pilots and ATC. Because of the limited scope of the OpEval and limited number of equipped aircraft, there may not be extensive opportunities to execute IM. A fourth potential cause is Call Sign Mismatch (CSMM), which could lead to the controller providing an aircraft flight ID for traffic that the flight crew cannot find on the CDTI because that aircraft is broadcasting the incorrect aircraft flight ID.

Through several discussions, the worst credible effect was determined to be the IM aircraft getting too close to another aircraft, either in front or behind them due to speed changes. The example scenario was getting too close to an aircraft behind them, which may close the distance rapidly if the IM aircraft suddenly slowed due to its proximity to the lead aircraft. The SRM Panel recognized the hazard may result in two separate effects. Given all potential causes of this hazard, existing controls were identified resulting in a severity rating of 5 (Minimal) for both effects. To reduce the likelihood of the hazard occurring, procedures require the flight crew to cross-verify the aircraft ID with each other as it is entered into the MCDU, as well as reading back the flight ID to ATC after designating traffic.

The panel determined the likelihoods based on the SMS Qualitative Table (see Appendix B). With the panel members' extensive experience within ZAB and on the flight deck, the panel concurred that the likelihoods would be C (Remote) and B (Probable).

The two separate effects of the hazard are as follows:

- *I-IM-1a – Loss of Separation*
  Once an incorrect aircraft is Designated and the operation continues with this error, the IM Aircraft may slow due to spacing off of an incorrect lead aircraft. This could lead to this effect for an aircraft that is behind the IM Aircraft. The result of this effect would be a non-participating aircraft maintaining its speed causing it to close in on the IM aircraft sooner than anticipated by ATC. The SMEs recognized the closure rate would be low and take multiple miles for it to occur. In addition, the Conflict Alert would notify ATC if it were to occur. The panel considered this to be 5 (Minimal) with a C (Remote) likelihood due to the experience of the controllers to set up the appropriate spacing between arrivals. Thus, it results in a 5C (Low) risk.

- *I-IM-1b – Additional workload*
  If the hazard is realized due to CSMM or the incorrect flight ID provided, the panel felt there would be a back-and-forth on the radio to resolve the issue and correct the situation. Therefore, the increase in communication and workload were effects that may occur and is part of normal operations. The ATC SMEs expect this to happen and considered this to be 5 (Minimal) with a B (Probable) likelihood, resulting in a 5B (Low) risk.

Hazard I-IM-2 – Wrong ASG input into MCDU and used for IM Operation

Time-based ASGs may be provided either by the TBFM SWIM-based ASG Tool or an ASG Look up Table. The SRM panel was made aware that the TBFM SWIM-based ASG Tool would be tested at the William J. Hughes Technical Center (refer to Appendix D) and that was added as an assumption. The ASG provided by the TBFM SWIM-based ASG Tool or an ASG Look up Table would either be provided to the controller via a monitor or via the supervisor or TMU. In the case of the ASG being provided by the supervisor or the TMU, the SRM Panel believed numbers could be transposed with the result being an erroneous entry into the MCDU on the IM aircraft. Another cause was cited due to infrequent use of the operation due to limited opportunities.

Distance-based ASGs are typically MITs but may also be set at the discretion of the controller. The MIT is provided via a monitor.

Several controls were identified which led the panel members to concur on the same effects as I-IM-1 with the same severities. They felt the likelihoods were somewhat different.

- *I-IM-2a – Loss of Separation*
  An incorrect ASG could allow the IM aircraft to become closer than anticipated to either a lead or trail aircraft. Here again, the SMEs recognized the closure rate would be low and take multiple miles for it to occur. The Conflict Alert would notify ATC if it would occur. The panel considered this to be 5 (Minimal) with a D (Extremely Remote) due to the experience of the controllers and their awareness of the new operation. Thus, it results in a 5D (Low) risk.

- *I-IM-2b – Additional workload (Loss of Assigned Spacing Goal or failure to meet ASG)*
  With the new operation, the ATC SMEs believed an incorrect ASG would result in additional work to stabilize the traffic flow. The ATC SMEs expect this to happen and considered this to be 5 (Minimal) with a B (Probable) likelihood, resulting in a 5B (Low) risk.

Hazard I-IM-3 – Controller uncertain about speed adjustment during IM operation

Due to the novelty of the IM Operations and that the IM aircraft would adjust speed without Controller input, the ATC SMEs in the SRM Panel raised concerns about how the IM Operations may abruptly change the initial speed command of the IM aircraft to meet the ASG. Controllers did acknowledge they could ask the flight crew their current speed to anticipate the impact with the new value given.

Discussions among the panel participants pointed out that during the maintain stage, the controller may know what the speed is based on the lead aircraft and the controllers could see the ground speed in the datablock. However, it was mentioned that controllers will need time to become comfortable with the IM Operations until they get use to the behavior of the IM aircraft adjusting their speeds. If there is a lot of cross traffic, then the various ATC SMEs said that they would not use IM.

The root of the problem is not knowing what speed the aircraft is doing to achieve or maintain the ASG. ZAB controllers have experienced aircraft speed changes, or the lack thereof, when the flight crews did not hear the new speed assignment, or they did not promptly respond to speed instructions. Additionally, the flight crew may enter the wrong IM speed, which could be done unintentionally, or intentionally by the flight crew (e.g., flight crew deciding to select their own speed and try to game the system). This OpEval would not be the first use of time-based spacing (currently use DCTs), but it is different from how it is used now (difference in STAs from the TBFM SWIM-based ASG Tool or an ASG from the ASG Look up Table). Time-based spacing does not mean time-based separation. Distance-based separation still applies and will still be used. The time-based ASGs provided via the TBFM SWIM-based ASG Tool or the ASG Look up Table do not violate the required distance-based separation. Also, the avionics will provide an indication (after 15 seconds) if the flight crew doesn't respond to the IM speed.

Controls listed for this hazard include aircraft performance limits and avionics speed limits. Because of these, there should not be excessive changes in the aircraft operation at cruise speeds. The Panel Members concurred on similar effects to the previous two hazards.

- *I-IM-3a – Loss of Separation*
  The result of this effect would be a non-participating crossing traffic which the ZAB controller was planning to pass either in front or behind of the IM aircraft ends up closer than anticipated because of a large speed adjustment by the IM aircraft. ATC SMEs recognized they would be providing more monitoring of the IM aircraft because of the OpEval. In addition, the Conflict Alert/Conflict Probe would notify ATC if separation was in doubt. The panel considered this to be 5 (Minimal) with a D (Extremely Remote) likelihood. Thus, it results in a 5D (Low) risk.

- *I-IM-3b – Additional workload*
  Here again, due to the increased monitoring of the aircraft involved in the OpEval, the panel members believed there would be a learning curve that would take more attention and effort when initiating the I-IM operation. The panel considered this to be 5 (Minimal) with a B (Probable) likelihood, resulting in a 5B (Low) risk.

Hazard I-IM-4 – Mismatch between IM state and controller awareness (whether internal to ZAB or external facilities) regarding IM Operation in effect

While the IM Operations are occurring, ATC SMEs raised concerns that the information about the pairing may not be recognized or communicated to adjacent sectors. The IM operation indicators provided on the 4th line of the data tag may be deleted, whether intentionally or not, which may impact the controller awareness of the pairing. Causes include failing to cancel IM or removing the data block indication before leaving ZAB airspace. Another cause is failing to coordinate between sectors in ZAB because the fourth line could give an indication that an IM Operation is ongoing, but it may be unknown with which controller to coordinate.

4th line data control is only for En Route operations and won't pass to the Terminal operations, so the TRACON controllers in Phoenix will not see it.

For a situation where the flight continues outside ZAB, if the pilot contacts ATC to check-in and informs the controller that they are doing an IM Operation, that controller may not know what is an IM Operation. The panel also discussed at the initiation of an IM Operation, the controller may insert the L or T into a data tag and forget to relay the IM clearance information to the IM aircraft.

Another potential issue raised is if an aircraft has lost its radio communications ability, whether due to failure or due to transiting beyond the radio sector region of the assigned frequency, which is known as a NORDO.

- *I-IM-4 – Additional workload*
  The effect would be an aircraft potentially operating in a manner for which the ZAB controller has not planned because the controller's belief about the aircraft's clearance is not correct or clarifying the clearance with an adjacent sector for an aircraft that is no longer in ZAB airspace. This may lead to an increase in communication and workload to rectify the confusion. The panel considered this to be 5 (Minimal) with a B (Probable) likelihood, resulting in a 5B (Low) risk.

Hazard I-IM-5 – Additional coordination necessary for IM Operation across multiple sectors

The En Route controllers working in ZAB recognized the IM aircraft could be at a different altitude than the Lead aircraft. Sectors within ZAB may be broken into various stratum for the same area. For example, the Lead aircraft may be at FL360 talking to a different controller than the IM aircraft 10 miles in trail at FL340.

This results in additional workload for the controller and could cause confusion, since they may be controlling the lead aircraft and won't know who to contact regarding control and clearance of the IM aircraft

ZAB SMEs indicated the 4th line will not be effective enough to coordinate these because of lack of knowledge of which ones are a pair when the pair is split between sectors. Because of the awareness regarding the OpEval, the controller should be aware of this potential scenario, but it could be a larger issue in the long term.

Controller training will include the back coordination when doing something with the lead aircraft and when the trail aircraft is in another sector. Front coordination will need to occur if a controller cancels IM and needs to let the controller that controls the lead aircraft to delete the "L" from the 4th line.

There is a desire for something like the TBFM SWIM-based ASG Tool on the glass, but it was decided that it would not be available for this trial. A request for this capability for the long-term implementation of IM has been made.

- *I-IM-5 – Additional workload/Distractions*
  The back and forward coordination when there are different controllers controlling the lead and IM aircraft will cause an increase in communication and workload. The panel considered this to be 5 (Minimal) with an A (Frequent) likelihood, because this coordination is going to happen at least once a day and will need to be resolved thru procedures. The resultant risk is 5A (Low).

Additional information regarding the panel's findings can be found in the Hazard Analysis Worksheet (HAW), included as Appendix C. Table 4-2 summarizes the identified hazards.

Table 4-2: I-IM OpEval Hazard Summary

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)

4.6 Hazard Risk Matrix

The hazard risk is determined from the Risk Assessment Matrix shown in Figure 4-1. Severity is shown in the top row and likelihood is in the left column. Severities range from minimal to catastrophic, while likelihoods range from frequent to extremely improbable. The five hazard's effects are identified within the table.

Severity / Likelihood	Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
Frequent A	I-IM-5				
Probable B	I-IM-1b I-IM-2b I-IM-3b I-IM-4				
Remote C	I-IM-1a				
Extremely Remote D	I-IM-2a I-IM-3a				
Extremely Improbable E					*

High
Medium
8 Effects Low

* Unacceptable with single point and/or common cause failures

Figure 4-1: I-IM Risk Assessment Matrix

4.7 Additional Hazards Considered

The following issues identified in the PHL and deliberated by the panel were considered not to be unique to the proposed change nor to introduce any new hazard to the NAS. Below is a summary of the points discussed related to each potential issue *(the number in parenthesis and the title refers to the identified issue in the PHL list, Section 4.1).*

- *(1) Callsign issues – third party flight ID using other airlines' callsigns*

  It was determined that this topic was not a safety issue for the CAS-A OpEval but more of a workload issue due to the extra communications. The panel members agreed that this is also the case for the I-IM OpEval, and that it is more of an effect rather than a hazard. Since altitude and vector instructions would not be used during this operation, this could not result in a third-party aircraft executing a command that was not intended for them.

  There was discussion of the option to use the phonetic alphabet when stating the callsign rather than using the airline name followed by the flight number, however it was concluded that it is best to use the airline name. If the controllers find this to be an issue, they may consider using the phonetic letters. The trial will allow for controllers to decide upon what is the best option. As with any new procedure, a learning curve is to be expected.

- *(4) ATC has not worked time-based spacing*

  It was reiterated that IM is not to be used for separation but is to be used for spacing. The intent of the trial is for the controllers to become comfortable with the differences and adapt accordingly. IM is intended as an additional tool for the controllers and is not to be used during less-than-ideal times such as when there is a larger amount of cross traffic present.

From the controllers' perspective, the root of the problem is not knowing what speed the aircraft is doing. However, it was discussed that ZAB would know the aircraft's ground speed and would then have an idea of their actual airspeed. Avionics will provide an indication (after 15 seconds) if the flight crew doesn't respond to the IM speed.

Controller training will need to focus on how fast the aircraft may close (or expand) during a maintain clearance where it is capturing the ASG versus the cross clearance where the avionics is achieving the ASG at a CP. Training will need to include best practices and what to expect with initiation.

The panel members concluded that this should be captured as a potential workload issue that will eventually subside as the controllers gain experience with the operation.

- *(5)* C*ontrollers monitoring a mix of time-based vs. distance-based aircraft*

  It was again emphasized that IM is not being used for separation, only spacing. Controllers will take time during training and during the trial to become more comfortable with the differences. It was discussed that metering is also time-based and is currently used in the NAS.

- *(7) Conflict alert/conflict probe*

  One of the ZAB controllers conducted a simulation in the lab to try to create a scenario where this would trigger unnecessarily for an IM pair and was unable to get the alert to trigger. It was concluded that this would not be a nuisance for other aircraft near the IM pair, and that this is not a hazard.

- *(9) Flight crew workload may increase because of new entry of IM Clearances and more frequent speed changes they receive from the avionics*

  The flight crew members on the panel discussed this potential issue and felt that it was not in fact a large workload increase. There is only a slight increase in workload due to the fact that the crew will have to manually enter the IM Clearance. The flight crew receiving a speed assignment from the avionics rather than a controller does not create a difference in workload.

  This potential concern was determined to be a cause of an identified hazard (I-IM-3) regarding the flight crew entering the wrong IM speed, whether unintentionally or intentionally. Flight crew training will place emphasis on preventing this from happening.

  In the case that the flight crew neglects to enter a new speed after given instruction to do so, there will be an indication on the AGD informing them of this. Although there is no aural indication given, it was felt that the visual provided on the AGD will catch the attention of the flight crew.

4.8 Safety Recommendations

Although the hazards were all identified as low risk, the panel made recommendations on how to reduce confusion and improve the OpEval's performance:

- Brief surrounding facilities about the OpEval, to include verbal coordination and procedures for adjacent facilities to instruct the Trail aircraft to resume normal speeds in order to cancel IM when IM Operations leak into non-participating facility's airspace.
- Controller training will include back and forward coordination for when the lead and IM aircraft are in two different sectors.
- NOTAM/LTA to create awareness of the trial
- Flight crew training will emphasize to follow the IM Speeds from the avionics and to not to try to determine their own speed to achieve/maintain the ASG according to their current spacing on the AGD.

4.9 Monitoring Plan

The Program Office is responsible for ensuring that the assumptions listed in Section 4.3 are implemented for the initialization of the proposed operational evaluation. Using input from the SRM Panel, the monitoring parameters in Table 4-3 provide data points to assist in assessing the effectiveness of the OpEval and ensuring the accuracy of the hazard analysis.

Table 4-3: I-IM Hazard Monitoring Parameter

Hazard ID	Hazard Description	Initial Risk	Safety Req	Res. Risk	Monitoring Task	Resource	Responsible Org	Due Date/ Freq.
I-IM-1	**Designate the wrong lead aircraft**	5C (Low) 5B (Low)	None	5C (Low) 5B (Low)	Review Performance Data points to confirm no abnormal effects from OpEval Review ATSAP reports to confirm no abnormal effects from OpEval	MORs	AJT/AJM AJM	Quarterly check in with ZAB/IM Team
I-IM-2	**Wrong ASG input into MCDU and used for IM Operation**	5D (Low) 5B (Low)	None	5D (Low) 5B (Low)	Review Performance Data points to confirm no abnormal effects from OpEval Review ATSAP reports to confirm no abnormal	MORs Data cards from ACSS	AJM	Quarterly check in with ZAB/IM Team

Hazard ID	Hazard Description	Initial Risk	Safety Req	Res. Risk	Monitoring Task	Resource	Responsible Org	Due Date/ Freq.
					effects from OpEval			
I-IM-3	**Controller uncertain about speed adjustment during IM operation**	5D (Low) 5B (Low)	None	5D (Low) 5B (Low)	Review Performance Data points to confirm no abnormal effects from OpEval Review ATSAP reports to confirm no abnormal effects from OpEval	MORs Falcon Replays	AJM	Quarterly check in with ZAB/IM Team
I-IM-4	**Mismatch between IM state and controller awareness (whether internal to ZAB or external facilities) regarding IM Operation in effect**	5B (Low)	Briefing with adjacent facilities ZFW, ZLA, ZDV, P50	5B (Low)	Review Performance Data points to confirm no abnormal effects from OpEval Review ATSAP reports to confirm no abnormal effects from OpEval	MORs Falcon Replays	AJM	Quarterly check in with ZAB/IM Team
I-IM-5	**Additional coordination necessary for IM Operation across multiple sectors**	5A (Low)	Procedures need to incorporate coordination if controller manipulates an aircraft with an “L” or “T” in 4th Line	5A (Low)	Review Performance Data points to confirm no abnormal effects from OpEval Review ATSAP reports to confirm no abnormal effects from OpEval	MORs Falcon Replays	ZAB	Quarterly check in with ZAB/IM Team

4.10 SRM Panel Participants

An SRM Panel meeting convened May 24 and 25, 2022, to examine potential hazards and effects associated with the proposed operational evaluation. Attendance for each day is captured along with a column to identify those who had participated in SMS training (see Table 4-4).

Table 4-4: AIRS I-IM ZAB OpEval SRM Panel

Name	Organization	Title	Role	24-May	25-May	SMS Trained
Dave Surridge	AAL	Tech Pilot/AAL Management	SME	X	X	X
Jon Witten	AAL	Airbus Fleet Captain	SME	X	X	X
*Ric Babcock	APA	Safety Representative - Air Traffic Procedures	SME	X		X
Brian Townsend	APA	Safety Representative - Air Traffic and Procedures	Panel Member	X	X	X
*Andrew Benich	AAL	Airbus Technical Pilot	SME	X	X	X
Rick Ridenour	ACSS	Avionics SME	SME	X	X	X
Cam Morast	ACSS	PM for ACSS	SME	X	X	X
John Murdock	FAA/NATCA	Procedures Representative	Panel Member	X	X	X
Chris Aymond	FAA/NATCA	IM Representative/Terminal	SME	X	X	X
Tom Zarick	FAA/NATCA	IM Representative/En Route	SME	X	X	X
Dan Hess	ZAB	Traffic Management Supervisor	Panel Member	X	X	X
Christian Espinoza	ZAB	ATC Specialist	Panel Member	X	X	X
Derek Brey	ZAB	ATC Specialist	SME	X	X	X
Hershul Olloway	ZAB	ATC Specialist	SME	X	X	X
Albert Garcia	ZAB	ATC Specialist	SME	X	X	X
Travis Hatcher	ZAB	ATC Specialist	SME	X	X	X
*Aaron Pickett	ZAB	ATC Specialist	SME	X	X	X
Doug Arbuckle	FAA/SBS	Chief Scientist and Intl. Lead/	Change Proponent	X	X	X
Paul Von Hoene	FAA/AFS-400	Aviation Safety Inspector	Panel Member	X	X	X
*Mark Schumacher	FAA/AJT	ATC SME	Panel Member	X	X	
*Kelvin Courtney	FAA/AJT-2	ATC SME	SME	X	X	X
*Dilip Satheesan	FAA/AJV-P3	ATC SME	Panel Member	X	X	X
*Doug Boyson	FAA/AJV-P3	Terminal SME	SME	X	X	X
*Jeff Sparrow	FAA/SBS	ATC SME/Operational Description Author	SME	X	X	X
Lars Anderson	FAA/SBS	ATC SME	Observer	X	X	X
*Steve Anderson	FAA/SBS	ATC SME	SME	X	X	X
Brenda Perez	FAA/SBS	Interval Management SME	SME	X	X	X

*Mike Germain	FAA/SBS	Interval Management SME	SME	X	X	X
*Greg Comstock	FAA/SBS	Interval Management SME	SME	X	X	X
*Bridget Lewis	FAA/SBS	Interval Management SME	SME	X	X	X
*Randy Bone	FAA/SBS	Ops SME	SME	X	X	X
Ken Jones	FAA/SBS	Project Lead	SME	X	X	X
Angie Harris	FAA/SBS	Co-Facilitator	Co-Facilitator	X	X	X
Jamie Kirk	FAA/SBS	Facilitator	Co-Facilitator	X	X	X

*Attended remotely

5 Conclusion

Five new hazards with low risk were identified by this SRM Panel. The SRM Panel also identified safety recommendations to improve awareness and efficiency of the trial. The OpEval has a limited scope of one year within the ZAB airspace for AAL ACSS-equipped A321 aircraft. The AIRS team will use several parameters to determine the performance and success of the operation. Those parameters, along with specific items identified for monitoring the safety risk, will provide insight to the safety and efficiency of the operation. The data collected will provide input and guidance for future safety analyses to expand this type of operation to other airlines in the NAS, potentially adding to the ability to consistently maintain greater throughput.

Based on the five low risk hazards identified and the proposed management of the procedures involved in the I-IM Operational Evaluation, it is recommended that the proposed operational evaluation supported by this SRM document proceeds.

Appendix A – Acronym List

Acronyms Used in this Document	
A321	Airbus 321 series aircraft
AAL	American Airlines
ACSS	Aviation Communication & Surveillance Systems, LLC
ADS-B	Automatic Dependent Surveillance – Broadcast
AGD	ADS-B Guidance Display
AIRS	ADS-B In Retrofit Spacing
AFS	FAA Flight Standards Service
AJI	FAA Safety and Technical Training
AJM	FAA Air Traffic Program Management
AJT	FAA Air Traffic Services
AJV	FAA Mission Support Services
AJW	FAA Technical Operations
APA	Allied Pilots Association
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATO	Air Traffic Organization
ATPA	Automated Terminal Proximity Alert
ATSAP	Air Traffic Safety Action Program
CAMI	Confirm, Activate, Monitoring, Intervene
CAS-A	CDTI Assisted Separation on Approach
CAVS	CDTI Assisted Visual Separation
CDTI	Cockpit Display of Traffic Information
CP	Crossing Point
CSMM	Call Sign Mismatch
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
GA	Go Around
GIM-S	Ground-based Interval Management for Spacing
HAW	Hazard Analysis Worksheet
IFP	Instrument Flight Procedures
ILS	Instrument Landing System
IM	Interval Management
IMC	Instrument Meteorological Conditions
IOAA	IFP Operations and Airspace Analytics
JO	Joint Order
KPHX	Phoenix Sky Harbor International Airport
LOC	Localizer
LTA	Letter to Airmen
MCDU	Multi-Purpose Control Display Unit

Acronyms Used in this Document	
MIT	Miles-In-Trail
MOR	Mandatory Occurrence Report
NAS	National Airspace System
NATCA	National Air Traffic Controllers Association
NM	Nautical Miles
NORDO	No Radio
NOTAM	Notice To Air Missions
OpEval	Operational Evaluation
OTW	Out the Window
PCP	Planned Cancellation Point
PDARS	Performance Data Analysis and Reporting System
PF	Pilot Flying
PHL	Preliminary Hazard List
PM	Program Manager
POC	Point-of-Contact
RNAV	Area Navigation
SA	Situational Awareness
SBS	Surveillance and Broadcast Services
SM	Statute Mile
SME	Subject Matter Expert
SMS	Safety Management System
SOP	Standard Operating Procedures
SRM	Safety Risk Management
STARS	Standard Terminal Automation Replacement System
TCAS	Traffic Collision Avoidance System
TMU	Traffic Management Unit
TPFID	Third-Party Flight ID
TTF	Traffic-To-Follow
TRACON	Terminal Radar Control
VMC	Visual Meteorological Conditions
ZAB	Albuquerque Air Route Traffic Control Center

Appendix B – Reference Documents

B.1 Severity Definitions

Severity is the measure of how bad the effect of the hazard is predicted to be, considering the controls in place. The severity of an outcome is assessed independently of its likelihood. Table B-1 is a copy of the Severity definitions included in the ATO SMS manual used by this SRM Panel.

Table B-1: Severity Definitions

Effect On: ↓	***Hazard Severity Classification*** *Note: Severities related to ground-based effects apply to movement areas only.*				
	Minimal 5	**Minor 4**	**Major 3**	**Hazardous 2**	**Catastrophic 1**
	CONDITIONS RESULITING IN ANY ONE OF THE FOLLOWING:				
ATC Services	A minimal reduction in ATC services CAT D Runway Incursion[1] Proximity Event, Operational deviation, or measure of compliance greater than or equal to 66 percent[2]	Low Risk Analysis Event severity,[3] two or fewer indicators fail CAT C Runway Incursion	Medium Risk Analysis Event severity, three indicators fail CAT B Runway Incursion	High Risk Analysis Event severity, four indicators fail CAT A Runway Incursion	Ground collision[4] Mid-air collision Controlled flight into terrain or obstacles
Flight Crew	Pilot is aware of traffic (identified by Traffic Collision Avoidance System traffic alert, issued by ATC, or observed by flight crew) in close enough proximity to require focused attention, but o action is required Pilot deviation[9] where loss of airborne separation falls within the same parameters of a Proximity Event or measure of compliance greater than or equal to 66 percent Circumstances requiring a flight crew to initiate a go-around	Pilot deviation where loss of airborne separation falls within the same parameters of a Low Risk Analysis Event severity Reduction of functional capability of aircraft, but overall safety not affected (e.g., normal procedures as per Airplane Flight Manuals) Circumstances requiring a flight crew to abort takeoff (rejected takeoff); however, the act of aborting takeoff does not degrade the aircraft performance capability Near mid-air collision encounters with separation greater than 500 feet[10]	Pilot deviation where loss of airborne separation falls within the same parameters of a Medium Risk Analysis Event severity Reduction in safety margin or functional capability of the aircraft, requiring flight crew to follow abnormal procedures as per Airplane Flight Manuals Circumstances requiring a flight crew to reject landing (i.e., balked landing) at or near the runway threshold Circumstances requiring a flight crew to abort takeoff (i.e., rejected takeoff); the act of aborting takeoff degrades the aircraft performance capability Near mid-air collision encounters with separation less than 500 feet[10]	Pilot deviation where loss of airborne separation falls within the same parameters of a High-Risk Analysis Event severity Reduction in safety margin and functional capability of the aircraft requiring flight crew to follow emergency procedures as per Airplane Flight Manuals Near mid-air collision encounters with separation less than 100 feet[10]	Ground collision Mid-air collision Controlled flight into terrain or obstacles Hull loss to manned aircraft Failure conditions that would prevent continued safe flight and landing

Effect On: ↓	***Hazard Severity Classification*** *Note: Severities related to ground-based effects apply to movement areas only.*				
	Minimal 5	**Minor 4**	**Major 3**	**Hazardous 2**	**Catastrophic 1**
	CONDITIONS RESULITING IN ANY ONE OF THE FOLLOWING:				

1. Refer to the current version of Order 7050.1, *Runway Safety Program*.
2. Proximity Events and Operational Deviations are no longer used to measure losses of separation, but they are applicable when validating old data. The minimal loss of standard separation is now represented as a measure of compliance of greater than or equal to 66 percent.
3. Risk Analysis Event severity indicators are as follows:
   a. Proximity. Failure transition point of 50 percent of required separation or less.
   b. Rate of Closure. Failure transition point greater than 205 knots or 2,000 feet per minute (consider both aspects and utilize the higher of the two if only one lies above the transition point).
   c. ATC Mitigation. ATC able to implement separation actions in a timely manner.
   d. Pilot Mitigation. Pilot executed ATC mitigation in a timely manner.
4. An effect categorized as catastrophic is one that results in a fatality or fatal injury.
5. Ground Collision. An airplane on the ground collides with an object or person.
6. Minor Injury. Any injury that is neither fatal nor serious.
7. Serious Injury. Any injury that: a. Requires hospitalization for more than 48 hours, commencing within seven days from the date the injury was received.
   a. Results in a fracture of any bone (except simple fractures of fingers, toes, or nose).
   b. Causes severe hemorrhages, nerve, muscle, or tendon damage.
   c. Involves any internal organ; or
   d. Involves second or third-degree burns, or any burns affecting more than five percent of the body's surface.
8. Fatal Injury. Any injury that results in death within 30 days of the accident.
9. Refer to Order JO 8020.16, *Air Traffic Organization Aircraft Accident and Incident Notification, Investigation, and Reporting*, for more information about pilot deviations.
10. Near mid-air collision definitions are derived from FAA Order 8900.1, *Flight Standards Information Management System,* Volume 7, which defines the following categories: critical, potential, and low potential. Refer to Section 9 for the complete definitions of these categories.

B.2 Likelihood Definitions

Table B-2 is a list of the qualitative likelihood category definitions from the ATO SMS manual that were used to assess the hazard in this SRM document.

Table B-2: Likelihood Definitions

	Operations: Expected Occurrence Rate (Calendar-based)
	(Domain-wide: NAS-wide, Terminal, or En Route)
Frequent A	Equal to or more than once per week
Probable B	Less than once per week and equal to or more than once per three months
Remote C	Less than once per three months and equal to or more than once per three years
Extremely Remote D	Less than once per three years and equal to or more than once per 30 years
Extremely Improbable E	Less than once per 30 years

Appendix C – Hazard Analysis Worksheet

I-IM 2022 SRM Panel Preliminary Hazard Analysis for ZAB Operational Evaluation – Hazard Analysis Worksheet

Hazard ID	Hazard Description	Hazard Cause	System State	Controls	Control Justification	Effects	Severity	Severity Rationale	Likelihood	Likelihood Rationale	Initial Risk	Safety Requirement Description / Plan to Implement?	Organization Responsible/ Point of Contact	Predicted Residual Risk / Rationale	Safety Performance Target
I-IM-1	**Designate the wrong lead aircraft**	Controller provides wrong traffic Flight Crew hears/enters wrong ID Irregular use of IM Operation (Lack of proficiency) (Both pilots and ATC) Flight ID is incorrect (CSMM)	All	Flight Cross-checks MCDU list on avionics Hear-back/ Read-back ATC Radar Monitoring Conflict Alert TCAS Next Sector Check-on Team Brief Refresher	ATC Standard Operations Flight Crew Procedures	Loss of separation Additional workload (Loss of Assigned Spacing Goal or failure to meet ASG)	5-Minimal 5-Minimal	SME input	C-Remote B-Probable	SME input	5C-Low 5B-Low	N/A	N/A	5C-Low 5B-Low	Quarterly check in with ZAB/IM Team MORs
I-IM-2	**Wrong ASG input into MCDU and used for IM Operation**	Wrong ASG given to Controller Wrong ASG transmitted to Flight Crew Wrong ASG entered by Flight Crew	All	Flight Cross-checks Hear-back/ Read-back ATC Radar Monitoring Conflict Alert TCAS	ATC Standard Operations Flight Crew Procedures	Loss of separation Additional workload (Loss of Assigned Spacing Goal or failure to meet ASG)	5-Minimal 5-Minimal	SME input	D-Extremely Remote B-Probable	SME input	5D-Low 5B-Low	N/A	N/A	5D-Low 5B-Low	Quarterly check in with ZAB/IM Team MORs Data cards from ACSS

Hazard ID	Hazard Description	Hazard Cause	System State	Controls	Control Justification	Effects	Severity	Severity Rationale	Likelihood	Likelihood Rationale	Initial Risk	Safety Requirement Description / Plan to Implement?	Organization Responsible/ Point of Contact	Predicted Residual Risk / Rationale	Safety Performance Target
		Irregular use of IM Operation (Lack of proficiency) (Both pilots and ATC)		Collaborative decision on the static ASG between the TMU and the area/specialty Team Brief Refresher											
I-IM-3	Controller uncertain about speed adjustment during IM operation	IM Clearance Controller difficulty determining when time-based spacing is achieved Irregular use of IM Operation (Lack of proficiency) Pilot does not respond timely to speed commands Wrong speed entered by Flight Crew	All	Aircraft performance limits Avionics speed limits ATC Radar Monitoring Conflict Alert TCAS Team Brief Refresher	SME Input ATC Standard Operations Flight Crew Procedures	Loss of separation Additional workload (Loss of Assigned Spacing Goal or failure to meet ASG)	5-Minimal 5-Minimal	SME input	D-Extremely Remote B-Probable	SME input	5D-Low 5B-Low	N/A	N/A	5D-Low 5B-Low	Quarterly check in with ZAB/IM Team MORs Falcon Replays
I-IM-4	**Mismatch between IM state and controller awareness (whether internal to ZAB or external**	Deleting 4th Line, whether intentional or not (entering speed/heading)	All	ATC Radar Monitoring 4th Line data for ARTCCs	ATC Standard Operations	Additional workload	5 – Minimal	SME input	B- Probable	SME input	5B - Low	Briefing with adjacent facilities ZFW, ZLA, ZDV, P50	SBS	5B - Low	Quarterly check in with ZAB/IM Team MORs Falcon Replays

Hazard ID	Hazard Description	Hazard Cause	System State	Controls	Control Justification	Effects	Severity	Severity Rationale	Likelihood	Likelihood Rationale	Initial Risk	Safety Requirement Description / Plan to Implement?	Organization Responsible/ Point of Contact	Predicted Residual Risk / Rationale	Safety Performance Target
	facilities) regarding IM Operation in effect	NORDO Fail to cancel IM prior to ZAB boundary Controller fails to initiate IM Operation but enters on 4th Line													
I-IM-5	**Additional coordination necessary for IM Operation across multiple sectors**	Altitude stratum difference between multiple areas Lateral sector boundary design relative to traffic flows	All	4th Line Verbal Coordination	ATC Standard Operations	Additional Workload/ Distractions	5 – Minimal	SME input	A - Frequent	SME input	5A - Low	Procedures need to incorporate coordination if controller manipulates an aircraft with an “L” or “T” in 4th Line	ZAB – Dan Hess working with airspace office	5A - Low	Quarterly check in with ZAB/IM Team MORs Falcon Replays

Appendix D – TBFM SWIM-based ASG Tool Testing

D.1 Background

The FAA William J Hughes Technical Center (WJHTC) developed the TBFM SWIM-based ASG Tool to assist with future ADS-B In test programs and, more specifically, with IM. This tool uses TBFM data from SWIM to determine aircraft pairs for IM based on the Meter Reference Point (MRP) that the aircraft are scheduled to and whether the aircraft have frozen STAs. This tool will then calculate the time-based ASG by subtracting the frozen STAs and will output the IM aircraft pair with the calculated ASG to the display. The AIRS team requested modifications in order for the tool to only pair AAL A321 as the trail aircraft. Further functionality was requested by AIRS team and ZAB in order for the tool to be operationally usable and safe. For the AIRS I-IM SRM Panel and this SRMD, the functionality below is also assumed to be a part of the TBFM SWIM-based ASG Tool:

- New aircraft pairs are displayed at the top of the table;
- Properly removes old aircraft pairings from the display when updates occur;
- Log the data that is displayed with time stamps; and
- An indication will be provided when either the aircraft pair or the ASG are updated.

The TBFM SWIM-based ASG Tool had not been tested at the WJHTC before the AIRS I-IM SRM Panel due to scheduling constraints in the WJHTC Labs. Since this was not possible before the SRM Panel, this appendix describes the testing that will be conducted at WJHTC before releasing the tool to AIRS. The results of this testing will be provided in a report, where the AIRS team and ZAB can determine, if the TBFM SWIM-based ASG Tool's performance meets their expectations, and they deem that it is safe and operationally usable for the AIRS I-IM Trial.

D.2 Testing at WJHTC

The following sections describe the testing that the TBFM SWIM-based ASG Tool will undergo at the WJHTC before release to the AIRS Team. A report will be provided with the results from this testing, and the AIRS team and ZAB can use this to determine if the TBFM SWIM-based ASG Tool is acceptable for use during the AIRS I-IM Flight Trial.

The testing that the WJHTC is not at the same level as what would be required for full operational approval. The intent of this testing is to ensure that the TBFM SWIM-based ASG Tool functions as expected.

D.2.1 Endurance Test

The TBFM SWIM-based ASG Tool will undergo a 48-hour endurance test. This test will be executed to verify there are no severe memory leaks, and the tool can run for longer periods without crashing. This tool will be left to run connected to the live SWIM data feed for 48 hours. At the end of the test, the TBFM SWIM-based ASG Tool will be checked to make sure it is still usable, and it is correctly updating the aircraft pairs and ASG in real time.

D.2.2 Functionality Test

WJHTC Target Generation Facility (TGF) will develop a scenario where there are large number of aircraft pairings. This scenario will stress the TBFM SWIM-based ASG Tool and ensure that this tool will function appropriately for a large number of aircraft pairings. In order to feed this scenario to the TBFM SWIM-based ASG Tool, the SWIM data feed will be configured for the TBFM system in the lab instead of a live data feed. The following will be tested in this environment:

- Verify that all AAL Airbus A321 aircraft with a frozen STA in the scenario are flagged as candidate trail aircraft;
- Verify that ASGs are automatically generated and displayed with respect to what will be the lead aircraft determined by the MRP that it's scheduled to and that it's the aircraft before the trail aircraft;
- Verify that the sequence of eligible aircraft pairs for the MRP are displayed on the TBFM SWIM-based ASG Tool is the same sequence of aircraft that is on TBFM;
- Verify that the MRP can be dynamically changed while the TBFM SWIM-based Tool is running and that the aircraft pairings generated and displayed are appropriate for the MRP and the old aircraft pairings are removed;
- Verify that the ASGs generated by the tool are the same as subtracting the frozen STAs from the TBFM TGUI Aircraft Data panel of the same aircraft pairings;
- Validation of the following changes in the TBFM schedule result in appropriate changes to the ASGs and/or aircraft pairings:
    - Change runway configuration,
    - Manual STA Change of an aircraft in a candidate pairing, and
    - Swap;
- Verify that the TBFM Freeze Horizons enabled results in the ASG calculations on the TBFM SWIM-based ASG Tool;
- Verify that the TBFM SWIM-based ASG Tool data logging is functioning appropriately.

D.2.3 Multi-Client Test

This test will involve running multiple instances of the TBFM SWIM-based ASG Tool with different MRPs but using the same SWIM data feed. The test will verify that the aircraft pairings displayed are appropriate for each MRP and that each instance of the TBFM SWIM-based ASG Tool is running appropriately.

D.2.4 Recovery Test

This test will simulate a network outage, while the TBFM SWIM-based ASG Tool is running. The network connection on the TBFM in the lab will be disabled and restarted. The TBFM SWIM-based ASG Tool behavior will be documented and the steps a user will have to take if a network outage should occur.

D.3 Completion of Testing

Once testing is completed, a report will be provided with the results from this testing. The AIRS team and ZAB can use this to determine if the TBFM SWIM-based ASG Tool is acceptable for use during the AIRS I-IM Flight Trial.

For the purposes of this SRMD, the assumption is that testing results meets expectations from the AIRS Team and ZAB; and the TBFM SWIM-based ASG Tool is acceptable for use during the AIRS I-IM Trial.

Appendix E

See

https://www.faa.gov/air_traffic/technology/adsb/quicklinks/AIRS IM Operational Description v2.0_final for website.pdf