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Estimating the impact of increasing Pilot-Applied Separation on Approach

Potential Benefit for Cockpit Display of Traffic Information Assisted Separation

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Abstract— **The Federal Aviation Administration (FAA) is investigating the potential benefits of cockpit-based applications that receive Automatic Dependent Surveillance – Broadcast (ADS-B) information from other aircraft, more generally referred to as ADS-B In. This paper explores the benefit connecting ADS-B In to increased runway throughput by expanding the use of pilot-applied separation using a proposed application referred to as Cockpit Display of Traffic Information (CDTI) Assisted Separation (CAS). The analysis relies on the measured use and impact of visual approaches and pilot-applied visual separation using an analysis of transcript and trajectory data at 38 US airports. The measurements are then used as inputs in a runway queuing model that estimates delay reduction related to changing the frequency of pilot-applied visual separation. It is likely the results and modeling techniques presented in this paper will be used by the FAA as part of future investment analyses to justify funds for automation changes needed to fully take advantage of certain ADS-B In applications.**

Keywords-component; Benefits, ADS-B In, Cockpit Applications, Visual Approach, Visual Separation, Airport Throughput, Inter-arrival times

I. INTRODUCTION

The Surveillance and Broadcast Services (SBS) program provides the FAA with upgraded surveillance capabilities and services through currently available satellite-enabled technology. The primary tool for these improvements is Automatic Dependent Surveillance-Broadcast (ADS-B). The SBS program also bundles supporting technologies directed at lowering agency, operator and the National Airspace System (NAS) user operating costs, while enhancing safety, capacity, productivity, and efficiency.

The primary focus of the SBS program since 2007 has been in deploying a ground infrastructure and automation to support air traffic management surveillance using signals transmitted from the aircraft (ADS-B Out). To be an effective surveillance source for separation, all users in specified airspaces must be equipped. A major factor affecting equipage is an ADS-B Out equipage mandate for all users operating in airspace called out under 14 CFR 91.225 [1]. The ADS-B Out rule became effective in January 2020.

The overall strategy of the program has always been to deploy an infrastructure that can be leveraged for future operational improvements. One of the many proposed operational improvements is the use of information received into the cockpit on the ADS-B frequency (ADS-B In). ADS-B In applications have been developed for commercial and private users. So far, the most widespread use of ADS-B In (including Flight Information Surveillance-Broadcast and Traffic Information Surveillance-Broadcast systems that use the same frequency) has been by the general aviation community that primarily use safety and traffic situational awareness applications [2, 3]. Now that the transition to full ADS-B Out equipage is complete, there is a renewed interest in ADS-B In applications to improve efficiency for larger air transport operators. In particular, ADS-B In applications are an avenue for increased throughput being considered by the FAA [4] as well as industry. In 2020, the joint FAA/industry Equip 2020 group developed an ADS-B In Strategy Document [5] that included the following reasoning:

> "Air transport operators have invested in equipping their fleets with ADS-B Out equipment to meet the ADS-B Mandate in 2020. Operators are now looking forward to the benefits from ADS-B In applications to build on their ADS-B Out investments. ADS-B In applications provide opportunities for significant gains in efficiency, capacity, and safety in the U.S. National Airspace System (NAS), especially when integrated with Trajectory-Based Operations (TBO), which promises benefits in high-density operations." [5].

Currently, there is no ADS-B In mandate, so equipage will continue to be voluntary. Consequently, business decisions on the benefits of using ADS-B In applications as compared to the equipage costs need to be considered. Past business cases for ADS-B In were developed as part of previous FAA/industry activities [6, 7]. These analyses assumed a relationship between the ceiling and visibility thresholds and the use of visual approaches and pilot-applied visual separation.

The analysis presented in this paper uses transcript data to measure the current use of visual approaches and pilot-applied visual separation compared to ceiling and visibility thresholds at 38 US airports. The analysis also examines the measured impact of visual approaches and pilot-applied visual separation on runway inter-arrival time and throughput at the airports. The measurements are then used as inputs in a runway queuing model that estimates possible delay reduction related to changing the frequency of pilot-applied visual separation.

II. BACKGROUND

A. VISUAL APPROACH AND PILOT-APPLIED VISUAL SEPARATION

Historically, airports operate at their peak throughput and efficiency when air traffic controllers can utilize pilot-applied visual separation standards and visual approach clearances to maintain maximum runway capacity. Airport capacity is reduced as weather conditions approach the minimum requirements for conducting visual operations at a given facility, or when pilots are unable to apply visual separation.

Pilot-applied visual separation is when the pilot accepts responsibility for maintaining a safe distance from nearby traffic in visual conditions. When this occurs, the pilot is not responsible for managing any specific distance from the traffic, but must adhere to the “see and avoid” requirements of Code of Federal Regulations, Title 14, § 91.113. The controller will often instruct the pilot to “maintain visual separation” from or to “follow” such traffic. Although pilot-applied visual separation is in effect, ATC will continue to monitor the operation and instruct the flight crew as needed. These operations are often used in the approach environment at major U.S. airports.

Visual approach - A visual approach clearance is an air traffic management authorization for an aircraft on an instrument flight rule flight plan to proceed visually to the airport clear of clouds. [8] Prior to issuing a visual approach clearance, the controller must ascertain that the pilot has the airport and/or pertinent traffic to follow in sight. The controller may issue advisories to help the pilot find the airport or traffic. When the pilot confirms that the required entity (airport or traffic) is in sight, the controller can issue the visual approach clearance.

If the pilot has the airport in sight but cannot see the aircraft to be followed, Air Traffic Control (ATC) may clear the aircraft for a visual approach; however, ATC retains separation responsibility.

B. ADS-B IN APPLICATIONS RELATED TO PILOT-APPLIED SEPARATION

There are two near-term ADS-B In applications that both use a Cockpit Display of Traffic Information (CDTI) and relate directly to pilot-applied separation:

1. CDTI Assisted Visual Separation (CAVS),
2. CDTI Assisted Separation on Approach (CAS-A).

The CAVS application supports the flight crew when performing visual separation on approach to the same runway in Visual Meteorological Conditions (VMC). ATC issues the visual approach clearance and advises the flight crew to maintain visual separation from traffic. The flight crew must first visually acquire the traffic out the window (OTW) and then correlate that sighting with the traffic symbol on the CDTI. The flight crew is expected to operate at a safe distance behind the traffic-to-follow and will advise ATC if they are unable to maintain a safe distance for any reason. If runway separation is at risk, ATC will issue a go around as required. CAVS can be conducted in conjunction with existing visual arrival operations and does not require any additional infrastructure or modification to ATC procedures. The use of CAVS by the flight crew is unknown to ATC and doesn’t change controller-pilot separation responsibilities.

Once the traffic is designated in the CAVS equipment, the distance to traffic and the ground speed differential is displayed in the pilot’s forward field of view. Figure 1 presents an operational example of such a display. In addition, the flight crew gets a caution alert if the aircraft are 1.4 NM or closer. The additional information aids the flight crew in assessing the acceptability of spacing between ownship and designated aircraft.

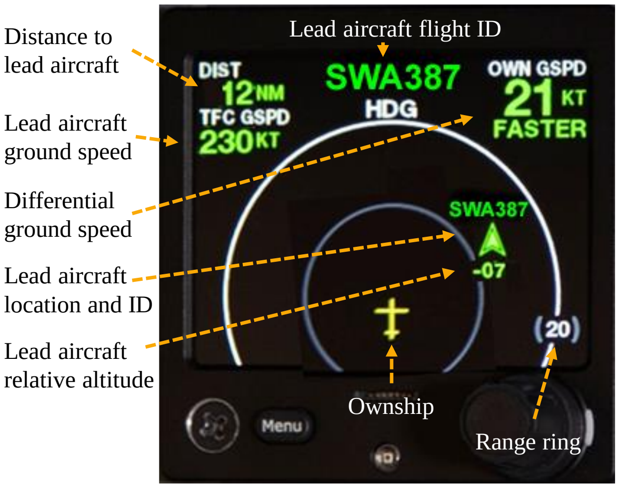


FIGURE 1. EXAMPLE OF CDTI WITH CAVS INFORMATION, PHOTO COURTESY OF ACSS, LLC.

The CAVS application allows the flight crew to lose out-the-window visual sight of traffic to follow and still maintain visual separation. The details are provided in FAA Advisory Circular 90-114B, Change 1 (Appendix B) [9]. This allows pilot-applied visual separation on approach to continue in conditions where it may be difficult, to impossible, to maintain visual contact throughout the approach. Examples include traffic being obscured by haze, bright sunlight, or city lights at night, or traffic blending into the ground.

CAVS has the potential to provide benefit on all visual operations on approach, not just those where traffic is obscured from view. CAVS is expected to provide traffic awareness, optimize the pilot’s visual separation task, and help the pilot maintain visual separation requirements during day and night VMC. It is expected that CAVS will reduce the number of go arounds and possibly increase arrival rates.

The objective of the CAS-A application [10] is to maintain pilot-applied visual-like separation safely and more efficiently from a lead aircraft via the CDTI during approach procedures. It is expected to recapture some of the runway capacity benefits of visual separation operations during weather conditions when identification of the lead aircraft OTW may be challenging.

CAS-A builds on the existing CAVS operation. The same flight deck tools are used for both CAS-A and CAVS.

The CAS-A operation is initiated by the controller, who provides an approach clearance and a CAS-A instruction that includes the Flight ID for the traffic-to-follow. The flight crew identifies the lead aircraft on the CDTI based on the Flight ID provided by the controller, and visual acquisition out-the-window is not required. After traffic identification by the flight crew and designation in the avionics, the flight crew uses the designated aircraft's information available on the CDTI to conduct pilot-applied separation operations.

CAS-A can only be used when both aircraft are approaching the same runway. CAS-A does not modify VMC or Instrument Meteorological Conditions (IMC) minima. CAS-A can be conducted when the airport of intended landing has a reported ceiling of 1000 feet or greater and visibility of 3 statute miles or greater. The aircraft conducting a CAS-A operation may enter IMC conditions when on an instrument approach but must remain clear of clouds when on a visual approach. Figure 2 presents a diagram of the CAS-A operation from [10].

CAS-A does not change any requirements for instrument or visual approach procedures. It allows the flight crew to use the CDTI alone to maintain separation from the designated aircraft when out-the-window visual contact is not possible or is lost. CAS-A does not change any controller or pilot procedures related to wake vortex limitations.

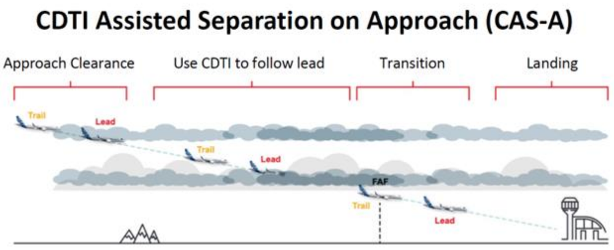


FIGURE 2. CAS-A OPERATION FROM [10]

C. VISUAL APPROACH AND PILOT-APPLIED VISUAL SEPARATION IN SIMULATION

Pilot-applied visual separation has long been recognized as a mechanism for increasing runway and airport throughput. However, visual approach clearances and visual separation instructions have not historically been recorded in available databases because they rely on voice communications. Without direct measurements on the number of visual approaches and/or visual separation operations, analysts have inferred their use by examining runway and airport throughput during various weather conditions. The weather conditions are often defined by recorded ceiling and visibility values. It is common practice to segregate the weather conditions into three distinct domains:

1. IMC occurs at an airport when the ceiling is below 1000 feet above ground level (AGL) and/or the visibility is less than 3 statute miles. The controller may not offer visual approaches or visual separation during IMC, and therefore rely on "radar" surveillance separation rules. When used by controllers, this term can mean surveillance via radar, multilateration, or ADS-B.

2. In VMC, full visual approaches and separation are possible, but not required and their use is at the discretion of the facility, the controller, and the pilots.

3. Analysts often define a third category, Marginal Meteorological Conditions (MMC), that is a subset of VMC where a mix of visual and radar separation and operations are used. Since MMC is a subset of VMC, the two categories can also be called High VMC and Low VMC.

Figure 3 presents a diagram showing nominal IMC, MMC, and VMC domains as a function of ceiling and visibility along with an indication what separation is used in each domain and the relationship between separation and throughput. A similar diagram has been used in other references [5,10,11]. Note Figure 3 just presents an example, the threshold between MMC and VMC can differ dramatically between airports.

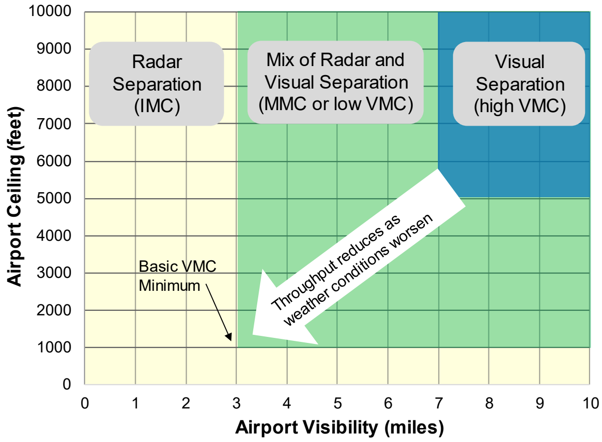


FIGURE 3. METEOROLOGICAL CONDITIONS AND APPROACHES

There are a common set of ceiling and visibility thresholds between MMC and VMC that have been used in many FAA and NextGen analyses [6,7,12]. The values are based on facility input and have not changed for several years. The Aviation System Performance Metrics (ASPM) database [13] lists these conditions as "Visual Approach" conditions [14]. Table I presents the MMC to VMC threshold conditions from ASPM as well as the resulting percent of hours in each meteorological condition when one applies these thresholds to historical ceiling and visibility data available at the selected airports. The frequency of historical ceiling and visibility were taken from a 30-year average at each airport from the National Climatic Data Center (NCDC) [15].

The definitions of IMC, MMC, and VMC, are used to further examine historical throughput data and help form (or sometimes validate) baseline arrival-departure curves that represent the maximum throughput that can be expected during those conditions (commonly referred to as pareto curves). [16,17] Figure 4 presents an example arrival-departure throughput curve for LAX assuming runways 24R and 25L are being used for arrivals and 24L and 25R are being used for departures.

TABLE I. ASPM MMC TO VMC THRESHOLD CONDITIONS AND PERCENT OF METEROLOGICAL CONDITIONS AT 38 US AIRPORTS

Airport	Ceiling (feet)	Visibility (miles)	Percent of hours		
			VMC	MMC	IMC
ATL	3600	7	73.2	14.3	12.5
BOS	2500	3	80.2	7.1	12.7
BWI	2500	5	74.1	10.9	15
CLT	3600	5	76.1	11.9	12
CVG	2900	3	75.5	12.6	11.9
DAL	2400	3	80.3	11.3	8.4
DCA	3000	4	82	9	9
DEN	2000	3	92.1	2.6	5.3
DFW	3500	5	81.9	12.1	6
DTW	3000	5	68.7	19.1	12.2
EWR	3000	4	77.4	10.8	11.8
FLL	4000	5	81.7	14.7	3.6
HOU	2100	3	81.8	8.8	9.4
HPN	3500	5	66.2	14.3	19.5
IAD	3000	7	75.1	13.6	11.3
IAH	4000	8	56.45	32.05	11.5
JFK	2000	4	81.4	6.5	12.1
LAS	5000	5	98.2	1.5	0.3
LAX	2500	3	72.4	11.8	15.8
LGA	3200	4	76.9	10.9	12.2
MCO	2500	3	90.3	3.9	5.8
MDW	1900	3	78.7	8.6	12.7
MEM	5000	5	67.3	22.1	10.6
MIA	2000	5	94.8	3.5	1.7
MSP	3500	8	72.4	19.2	8.4
ORD	5500	7	62.2	26.9	10.9
PHL	2300	4	77.4	9.6	13
PHX	3300	7	98.6	1.1	0.3
PIT	1800	3	80.7	5.7	13.6
SAN	2000	3	74.6	16	9.4
SAT	3000	5	70.6	17.2	12.2
SDF	3000	3	79.4	13	7.6
SEA	4000	3	62.3	27.2	10.5
SFO	3500	8	64.45	26.85	8.7
SLC	7500	10	75.1	19.2	5.7
STL	5000	5	70.5	19.7	9.8
TEB	3500	5	70.7	15.7	13.6
TPA	2100	3	92	2.6	5.4

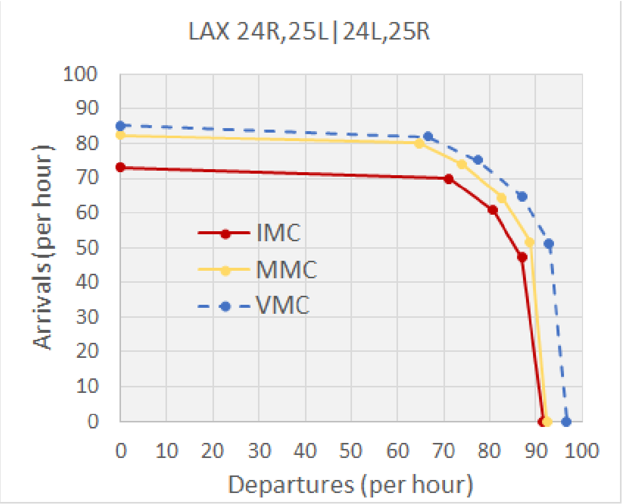


FIGURE 4. EXAMPLE ARRIVAL-DEPARTURE CURVES

D. Potential Issues

While being extremely useful for modeling, there are questions that arise when using the traditional values for the MMC to VMC threshold.

1. What mix of instrument and visual approaches is implied by the ASPM MMC to VMC threshold and is it consistent across airports?

Operational SMEs have indicated that the current ASPM MMC to VMC thresholds may not accurately reflect the reality of when visual separation is being used. If the threshold is too low, then the measured throughput during VMC may represent a significant mix of radar and visual separation and MMC is dominated by radar separation. If the threshold is too high, then the MMC throughput may be dominated by visual separation.

2. How often does visual approach imply pilot-applied visual separation?

As mentioned in the introduction, a visual approach clearance does not necessarily result in pilot-applied visual separation. If the pilot has the airport in sight but cannot see the aircraft to be followed, ATC may clear the aircraft for a visual approach; however, ATC retains separation responsibility.

3. Is there a measurable difference in throughput between visual approach and pilot-applied visual separation?

Presumably pilot-applied visual separation could result in higher throughput. If so, the throughput difference between pilot-applied visual separation, controller-applied visual separation, and radar separation during visual approaches should be measurable.

III. UPDATED DATA, ANALYSIS, AND BENEFITS MODELING APPROACH

A. Data Sources

Additional analysis of visual approaches and pilot-applied visual separation is made possible using the internal FAA Instrument Flight Procedures (IFP), Operations, and Airspace Analytics (IOAA) Tool [18] and the MITRE Transportation Data Platform (TDP)[19].

IOAA provides analysis capabilities to study flight operational metrics and implementation/use of instrument flight procedures (IFP). The capabilities enable analysis of fused operational usage metrics (e.g., arrival procedure usage), aircraft performance metrics (e.g., climb gradient distributions, final approach deviations), and weather conditions at various points of interest in the National Airspace System (NAS). Users can dynamically filter within the tool to quickly correlate between metrics and drill down to flights of interest. Further, the fused surveillance data used to derive operational usage, safety, and aircraft performance metrics is available for display and download.

IOAA Threaded Track data combines FAA radar, ASDE-X, and ADS-B data to create a fused end-to-end trajectory for each flight. The IOAA data includes indication of the approach being used (i.e., Visual, Instrument) using transcript data.

The IOAA threaded track and clearance data can be further enhanced using additional transcript data available through the TDP. Transcript data based on controller and pilot communications is gathered by facility and assigned to most flights in the National Airspace System (NAS). The transcript data allows examination of pilot-applied separation instructions.

To ensure some consistency with previous analyses, the IOAA data was also correlated with airport and weather data from ASPM [13]. ASPM is an FAA-maintained database that contains a variety of flight and airport information. Data comes from ARINC's Out-Off-On-In (OOOI), Traffic Flow Management System (TFMS), US Department of Transportation's Airline Service Quality Performance (ASQP) survey, weather data, airport logged arrival and departure rates, airport runway configurations, delays, and cancellations. Multiple data elements between the two sources (IOAA and ASPM) were checked for consistency; however, for this analysis the primary use of ASPM was to connect ceiling and visibility values measured at the airport to each arrival.

B. Data Analysis Approach

Individual arrival data were gathered from IOAA for 38 airports for Calendar Year (CY) 2022, The data for each flight included date, aircraft ID, arrival airport, runway used, time at the runway threshold (to the second), and approach clearance (derived by IOAA using transcript data). At each airport, there were several flights where IOAA was unsuccessful in assigning a clearance type. Landing times for all flights were included in the inter-arrival time calculations; however, no metrics were gathered for the unassigned flights since it was uncertain what clearance they were given.

As mentioned previously, a visual approach does not necessarily imply pilot-applied visual separation. Transcripts from the TDP allowed searching for terms during the approach that would indicate pilot-applied visual separation. The first step was limiting the transcripts to those used in the appropriate Terminal Approach Control (TRACON) for each airport. Then controller transcripts were queried for the search terms: "visual separation", "vis sep", "visual sep", "follow…visual", "maintain…visual". The controller transcript search terms also excluded some phrases like "follow the river", "helicopter", etc. The pilot transcripts were queried to find the phrase "traffic in sight." The querying of transcript data is somewhat complicated by the fact that pilot-applied visual separation is employed in other situations beyond the approach, including during taxiing and on takeoff. The analysis was limited to pilot-applied visual separation during approach operations.

The first part of the analysis examined the CY2022 frequency of visual approach and pilot-applied visual separation use at each airport. As mentioned previously, arrivals without assigned approach clearance data were excluded from the analysis.

Arrival date and threshold time were also correlated with ASPM weather data to assign an airport ceiling and visibility.

A second part of the analysis was performed to calculate an alternative MMC to VMC threshold at each airport. For this analysis, we chose the first ceiling and visibility where greater than 25 percent of the approaches were visual. The 25 percent value is somewhat arbitrary; however, it was applied consistently across the airports.

The data were then sorted by runway and threshold time and the time between the threshold time for an arrival and the previous flight threshold time on the same runway was calculated to examine the inter-arrival time (IAT).

A third part of the analysis then examined distributions of the IATs segregated into five different categories:

- IMC - arrivals when ceiling < 1000 feet AGL or visibility < 3 miles
- MMC – arrivals when ceiling or visibility are less than the MMC threshold derived in a previous step but greater than IMC
- VMC but not Visual – arrivals at or above the MMC threshold but without visual approach or pilot-applied visual separation
- Visual Approach (w/o Pilot-Applied Visual Separation) – arrivals with visual approach but no indication of pilot-applied visual separation
- Pilot-Applied Visual Separation – arrivals using pilot-applied visual separation

All IATs greater than five minutes were excluded to limit times of low demand. Distributions were examined at the airport level and individual runway level. Distributions with less than 50 observations in a year were excluded.

The most interesting parts of the IAT distributions are the smaller values which should indicate the minimum IAT, and consequently the potential maximum throughput available. To account for anomalous behavior in the data, the 10th percentile of each distribution was defined as a "reasonable" minimum IAT. The reasonable minimum IAT was then used to estimate any difference in expected maximum throughput.

C. Modeling and Simulation Description

The measurements in the data analysis were used as inputs in a runway queuing model. This model estimates possible delay reduction related to changing the frequency of pilot-applied visual separation.

Past cost-benefit cases have used a NAS-wide queuing model [20,21] that models capacity changes at the airport or airspace level. Advantages of the NAS-wide model methodology include the ability to add en route effects, dependencies between airports, and system-wide impacts. However, as the model is currently used, an airport is modeled across all runways as a set of arrival-departure curves (as opposed to at the runway-level) and it is sometimes difficult to segregate the proposed impact at a single airport because of all the system dependencies. Future studies may use the data analysis presented in this paper to modify airport-level capacity curves and weather assumptions.

The queuing model was developed in Python using a set of static and user-defined inputs. Some of the inputs are applied deterministically while a few are applied stochastically to introduce some variability. The model outputs include delays for a baseline and a test case based on user-defined inputs.

Static deterministic inputs for all baseline and test cases:

- Arrival schedule per runway on a per flight basis including aircraft type for every day in CY2022 for 38 airports
- Departure schedule per runway on a per flight basis for every day in CY2022 for 38 airports
- Ceiling in feet and visibility in statute mile for 15-minute bins for every day in CY2022 for 38 airports.

User-defined inputs can be set differently for the baseline and test cases:

- Interarrival Time (sec): IMC, VMC but not Visual Separation, Visual Separation
- MMC definition by ceiling and visibility (e.g. 3000 feet ceiling and 5 miles visibility)
- Percent of VMC arrivals that receive visual separation (applied stochastically)
- Aircraft types that can receive change in test case (All or one or more specific types)
- Carriers that can receive changes in test case (All or one or more specific airlines).

While the model primarily models the arrival queue, for mixed-use runways, the model protects the runway during scheduled departures (i.e., when a departure is scheduled to use the runway, an arrival is blocked.)

The primary output of the model is the arrival delay difference between the baseline and a test case. The results can be for a specific day where the percent of aircraft receiving visual separation is applied stochastically, or for all days in CY2022.

Multiple scenarios were run as part of the analysis:

- Considered 38 airports
- Modeled all runways with over 10% arrival traffic (138 runways across the airports)
- Ran each day in CY2022 to get yearly benefit; ran each day 50 times for the stochastic variable
- The baseline case used the recorded ceiling and visibility and the measured percent of VMC using visual separation.

Three test cases were examined for each scenario:

- Test case 1. Changed percent of arrivals that get visual separation in VMC from baseline value to 100%. This models a situation where weather cutoffs for VMC stay the same but a much larger percentage of aircraft receive visual separation.
- Test Case 2. Increased VMC times to IMC threshold (no more MMC) (but didn't change percent of VMC that get visual separation). This models a situation where visual separation is available for a wider range of conditions but there is no change in the percent of relevant arrivals receiving visual separation.
- Test Case 3. Increased VMC to IMC threshold AND changed percent of VMC that get Visual Separation to 100%.

IV. RESULTS

A. *Data Analysis Results- Use*

Table II presents the frequency of visual approach and pilot-applied visual separation in terms of number detected and percent of arrivals at 38 US airports in CY2022. The values are not additive; in each row the pilot-applied visual

TABLE II. THRESHOLFD FOR VISUAL APPROACHES AND PERCENT OF METEROLOGICAL CONDITIONS AT 38 US AIRPORTS

Airport	Visual Approaches	Percent of Arrivals with Visual Approach	Visual Separation	Percent of Arrivals with Visual Separation
ATL	256,802	80%	39,937	12%
BOS	40,588	27%	8,836	6%
BWI	71,835	83%	11,300	13%
CLT	155,795	78%	5,720	3%
CVG	34,542	69%	1,816	4%
DAL	74,461	87%	6,932	8%
DCA	96,165	75%	6,333	5%
DEN	206,034	79%	10,983	4%
DFW	226,354	89%	8,587	3%
DTW	82,283	84%	3,226	3%
EWR	12,692	9%	1,580	1%
FLL	26,771	26%	1,897	2%
HOU	47,189	75%	5,383	9%
HPN	23,379	64%	3,499	10%
IAD	85,056	81%	5,346	5%
IAH	88,705	59%	8,717	6%
JFK	16,883	10%	1,171	1%
LAS	147,548	79%	13,271	7%
LAX	157,993	68%	23,807	10%
LGA	62,678	45%	17,054	12%
MCO	106,623	71%	5,583	4%
MDW	12,939	17%	3,074	4%
MEM	73,838	83%	2,907	3%
MIA	27,456	16%	1,512	1%
MSP	85,274	72%	6,061	5%
ORD	114,453	38%	6,688	2%
PHL	70,008	65%	7,965	7%
PHX	172,588	98%	9,974	6%
SAN	21,132	36%	6,773	12%
SAT	38,309	71%	2,741	5%
SDF	47,108	74%	6,128	10%
SEA	59,313	38%	11,531	7%
SFO	119,903	78%	45,282	29%
SLC	85,810	95%	5,526	6%
STL	39,852	80%	5,196	10%
TEB	1,750	4%	206	0%
TPA	63,324	82%	4,656	6%

separation values are a subset of the visual approaches. At many airports, the use of visual approaches is greater than 50 percent, but the use of pilot-applied visual separation is much lower. It is unclear whether the lack of pilot-applied visual separation is simply due to low demand or other reasons. Use of both visual approaches and visual separation differs widely by facility based on other reasons besides weather including dependent or crossing runway concerns, airspace consideration, local facility policy, or controller comfort with procedure. Airports with a large mix of international traffic (JFK, EWR, MIA, IAH) may limit visual approaches because these approaches are not as commonly used outside the U.S.

The second part of the analysis was performed to calculate an alternative MMC to VMC threshold at each airport assuming the ceiling and visibility conditions when greater than 25 percent of the approaches were visual. Table III presents the MMC to VMC threshold used by ASPM (from facility data) as compared to the MMC to VMC threshold set using the transcript data 25 percent approach. In some cases (notably EWR, JFK, MDW, MIA, and TEB), there were no conditions where the percentage of visual approaches exceeded 25 percent (based on transcript data). In these cases, a value was chosen for the threshold where the visual approach percentage reached a local maximum. Additional details on visual approach and pilot-applied visual separation use have been separately documented [11].

TABLE III. MMC TO VMC THRESHOLD AND PERCENT OF METEROLOGICAL CONDITIONS AT 38 US AIRPORTS

Airport	ASPM		Transcript Data 25% CY2022	
	Ceiling (feet)	Visibility (miles)	Ceiling (feet)	Visibility (miles)
ATL	3600	7	2500	9
BOS	2500	3	6500	10
BWI	2500	5	2500	7
CLT	3600	5	3000	7
CVG	2900	3	3500	7
DAL	2400	3	2000	7
DCA	3000	4	3500	9
DEN	2000	3	3500	6
DFW	3500	5	2500	8
DTW	3000	5	2500	4
EWR	3000	4	5500	10
FLL	4000	5	7000	10
HOU	2100	3	2500	10
HPN	3500	5	2500	9
IAD	3000	7	2500	7
IAH	4000	8	3500	10
JFK	2000	4	4500	10
LAS	5000	5	4000	4
LAX	2500	3	3000	6
LGA	3200	4	3500	10
MCO	2500	3	2000	8
MDW	1900	3	10000	10
MEM	5000	5	2000	7
MIA	2000	5	6500	10
MSP	3500	8	3500	8
ORD	5500	7	5000	10
PHL	3000	10	3000	10
PHX	3000	5	3000	5
SAN	2000	3	8000	10
SAT	3000	5	3500	10
SDF	3000	3	3000	7
SEA	4000	3	6000	10
SFO	3500	8	3500	6
SLC	7500	10	2000	4
STL	5000	5	3000	8
TEB	3500	5	5000	10
TPA	2100	3	2500	4

In general, the 25 percent threshold results tend to pick a higher visibility than the ASPM results. Both methodologies result in a VMC domain that represents a large mix of visual and instrument approaches. Picking a lower threshold (e.g., 10% visual approaches) tends to make the calculated threshold look closer to the traditional but limits the MMC domain to be overwhelmingly dominated by instrument approaches. Picking a higher threshold (e.g., 80% visual approaches) results in many airports never reaching the VMC domain. The MMC to VMC threshold analysis was also repeated using data from CY2019 and CY2021 showing similar results

The differences in the traditional MMC to VMC threshold between facilities may depend on how the facility representatives interpreted the original inquiry about a visual approach threshold. Some facilities with lower thresholds may have picked values where they historically expected to first see visual approaches, while facilities with higher thresholds may have picked values where they expect nearly all arrivals to receive an visual approach.

B. Data Analysis Results – Inter-Arrival Time

The next set of analyses examined the impact of these defined categories (IMC, MMC, VMC but not Visual, Visual Approach w/o Pilot-Applied Vis Sep, Pilot-Applied Visual Separation) on minimum IAT and throughput. Analyses were performed at the runway and airport level.

Figure 5 examines the reasonable minimum (10th percentile) IAT by runway for each category at three sample airports: ATL, LAX, and SFO in bar charts. The number above each bar in Figure 5 is the percent of total airport arrivals using that runway. Figure 6 rolls up the runway data to show results by airport. In both Figures 5 and 6 a missing category (color) indicates an overlap in the data between categories.

In general, there is a noticeable difference in minimum IAT between the categories with a definite downtrend going from IMC to Pilot-Applied Visual Separation. This trend is different across runways and across airports. At some airports (e.g. ATL) there are distinct values for each category, while for others (e.g. DCA in Figure 6) many of the categories exhibit the same minimum IAT. Some airports have too few observation in a category to provide values (e.g. IMC at LAS). Across all cases, the IATs associated with Pilot-Applied Visual Separation are lower than Visual Approach (w/o Pilot-Applied Vis Sep) indicating a decrease in IAT when using pilot-applied visual separation. Additional details on IATs from this analysis have been separately documented [11].

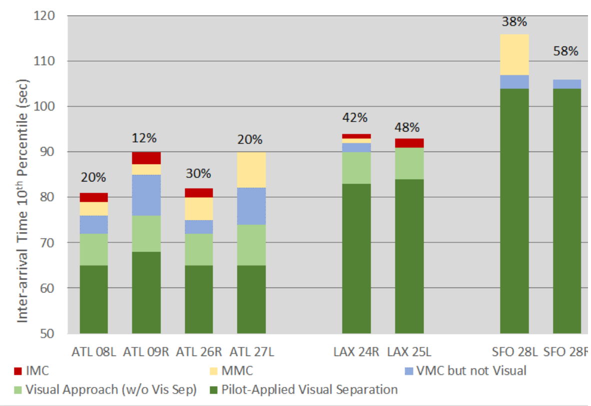


FIGURE 5. MINIMUM IAT PER RUNWAY EXAMPLES

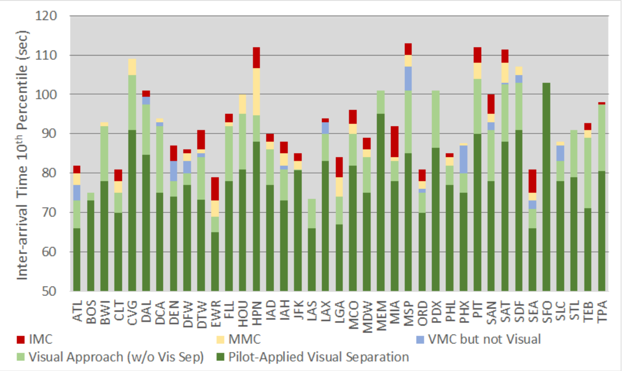


FIGURE 6. MINIMUM IAT PER AIRPORT

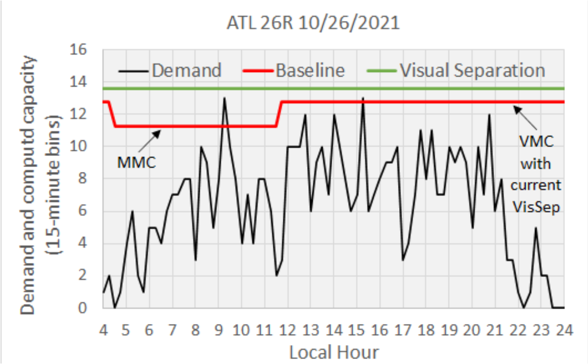
C. *Benefits Modeling Results*

In the queuing model, the demand and IAT are applied on an aircraft-by-aircraft basis.

Figures 7 and 8 show diagrams based on sample days at ATL runway 26R, the following data is aggregated in 15-minute bins:

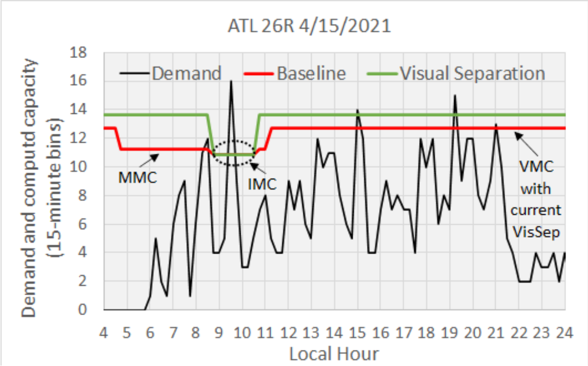
- Aggregated arrival demand
- Baseline capacity: historic MMC IAT during MMC, historic mix of Visual Separation IAT and VMC w/o Visual Separation IAT during VMC
- Test case 3 capacity: Visual Separation IAT in MMC and VMC.

A small table under each figure shows the resulting delay savings benefit (in minutes) for the day. In general, the opportunity for benefit occurs when the demand is higher than the baseline capacity curve. Figure 7 presents an example day (October 26, 2021) with some time in both VMC and MMC. Figure 8 presents an example day (4/15/2021) where IMC weather occurs with no increase in capacity for the test case. In scenarios similar to Figure 8, there is no benefit during IMC, but the recovery should be faster after the event, reducing delay.



ATL 26R 10/26/2021	Test Case 1	Test Case 2	Test Case 3
Delay Savings (minutes)	64.0	55.6	155.9

FIGURE 7. EXAMPLE ATL 26R 10/26/2021



ATL 26R 4/15/2021	Test Case 1	Test Case 2	Test Case 3
Delay Savings (minutes)	114.9	13.0	136.2

FIGURE 8. EXAMPLE ATL 26R 4/15/2021

Figure 9 shows the daily arrival delay in minutes for ATL runway 26R for both the Baseline and Test Case 3 across all days in CY2022. Figure 10 presents a similar graph showing the daily arrival delay savings in minutes (i.e., the difference between the Baseline and Test Case 3). Days with no arrival delay or delay savings represent days when ATL was operating in the opposite direction because of the winds.

On days when ATL runway 26R is in use, the overall baseline arrival delay ranges from 200 to 500 minutes in the model. Using ASPM delay metrics, the measured overall airborne arrival delay at ATL (mostly driven by delays during arrival) is on average ~1500 minutes a day. ATL often uses three arrival runways, suggesting that the per runway airborne arrival delay may average around 500 minutes a day, which is in a similar range to our estimates.

For comparison, the modeled delay savings when ATL 26R is operating, shown in Figure 10, is between 50 and 150 minutes per day.

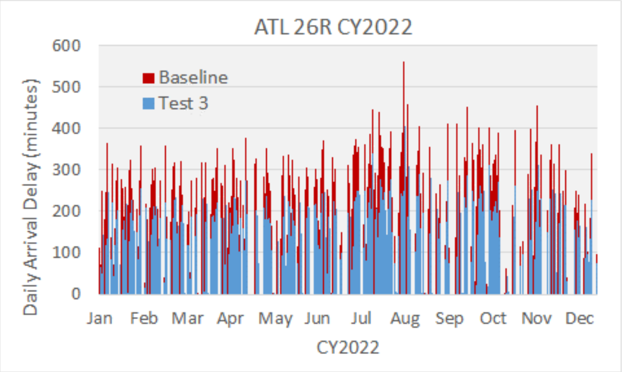


FIGURE 9. ARRIVAL DELAY BASELINE AND TEST CASE 3 BY DAY

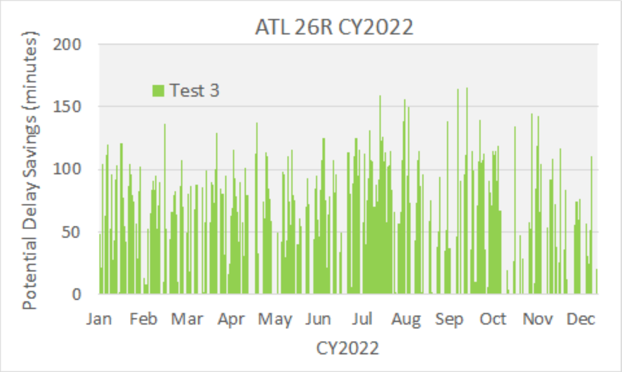


FIGURE 10. POTENTIAL TEST CASE 3 ARRIVAL DELAY SAVINGS BY DAY

The model was run 50 times for each day in CY2022 to allow for the stochastic variable to apply to different flights. The daily delay savings were aggregated by airport across all runways with at least 10 percent of the arrival traffic.

Figure 11 presents the annual potential delay savings results for Test Case 3 in hours per airport for 38 airports assuming CY2022 demand and weather.

Table IV presents the annual baseline delay and the delay savings for each test case in hours, as well as the percent of the baseline delay that could be mitigated. The results are presented across 38 airports.

The results shown in Figure 11 and Table IV indicate a total annual delay savings potential of greater than 10,500 hours, which would mitigate roughly 26 percent of the baseline arrival demand driven queuing delay in CY2022. A similar exercise and analysis using CY2021 data across the same 38 airports showed differences at the airport level; however, the result across the airports were roughly similar:12,000 hours of delay savings mitigating roughly 26 percent of queuing delay.

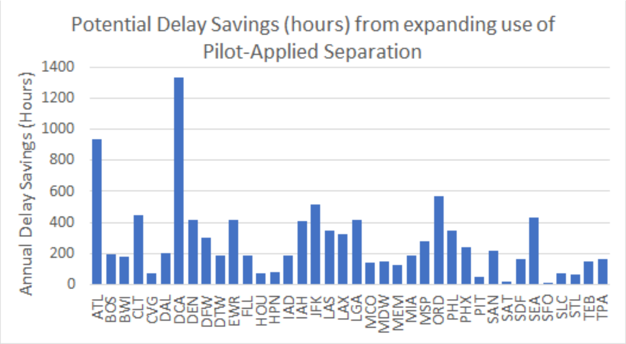


FIGURE 11. ANNUAL POTWNTIAL DELAY SAVINGS BY AIRPORT FOR TEST CASE 3 (IN HOURS)

TABLE IV. QUEUING MODEL RESULTS AT 38 US AIRPORTS

Airport	Baseline Delay (Hours)	Delay Savings (Hours)			Case 3 as a percent of Baseline
		Test Case 1	Test Case 2	Test Case 3	
ATL	2778	830	63	937	34%
BOS	1265	149	3	192	15%
BWI	574	161	3	175	31%
CLT	2387	388	22	444	19%
CVG	289	62	1	74	26%
DAL	795	192	2	205	26%
DCA	2950	1147	48	1329	45%
DEN	1826	391	6	415	23%
DFW	1791	266	16	300	17%
DTW	636	168	4	185	29%
EWR	1583	324	26	417	26%
FLL	670	139	1	188	28%
HOU	249	60	3	70	28%
HPN	343	67	6	79	23%
IAD	766	166	5	188	25%
IAH	1387	297	46	412	30%
JFK	2096	443	3	515	25%
LAS	1145	350	0	351	31%
LAX	1572	271	12	323	21%
LGA	1529	330	46	414	27%
MCO	639	134	1	140	22%
MDW	633	93	13	148	23%
MEM	577	116	1	122	21%
MIA	717	124	1	190	26%
MSP	771	218	22	279	36%
ORD	2451	366	81	567	23%
PHL	1393	300	12	350	25%
PHX	929	235	1	237	25%
PIT	169	37	1	46	27%
SAN	715	117	34	213	30%
SAT	70	13	1	17	25%
SDF	667	143	5	163	24%
SEA	1852	192	116	431	23%
SFO	909	3	11	15	2%
SLC	593	69	1	70	12%
STL	284	58	1	67	23%
TEB	435	106	14	150	35%
TPA	507	152	1	160	32%
Total	40940	8677	633	10577	26%

V. SUMMARY AND NEXT STEPS

The simulation results indicate that the CAVS/CAS ADS-B In applications have the potential to produce significant benefits.

This study presented an examination of the use of visual approaches and visual separation on approach operations at 38 US airports using a year of data. The data was also used to develop a consistent definition of the MMC to VMC threshold across airports and examine the impact of weather and visual approach and pilot-applied separation use on IAT and throughput. A major part of the study was examination of archived transcript data. Transcripts are a rich data source with several possibilities for new analysis.

Planned updates to the data analysis include:

- Comparing results across multiple years to understand differences
- Further examining sensitivity to the choice of MMC to VMC threshold
- Incorporating lead-follower aircraft wake categories to examine how wake spacing requirements impact the results
- Examining IAT as a function of demand (as opposed to limiting to arrivals < 5 min apart)
- Examining pilot-applied visual separation on departures.

Planned updates to the queuing model and results include:

- Incorporating wake category spacing impacts
- Examining different levels of equipage.

This work was done in support of the FAA Surveillance and Broadcast Services (SBS) office in support of a project examining the potential impacts of increasing the use of visual (or visual-like) separation using cockpit-based ADS-B In applications.

Another major part of this effort is an operational evaluation called the ADS-B In Retrofit Spacing (AIRS) project. The project includes partners from the FAA, American Airlines, the American Pilots Association (APA), and the National Air Traffic Controller Association (NATCA). American Airlines is equipping their entire Airbus A321 fleet with certified equipment from ACSS. American has been actively using CAVS starting in May 2020. In March 2023, Dallas Fort-Worth TRACON (D10) started using the CAS-A procedure for arrivals into Dallas-Fort Worth International Airport (DFW). Final data analysis and results are expected by summer of 2024.

It is likely the results and modeling techniques presented in this paper and the results from the AIRS project will be used by the FAA as part of future investment analyses to justify funds for automation changes needed to fully take advantage of certain ADS-B In applications.

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