Cockpit Display of Traffic Information (CDTI) Assisted Visual Separation (CAVS)

Benefits Analysis Report

Federal Aviation Administration, American Airlines and Aviation Communication & Surveillance Systems, LLC NextGen Project

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1 EXECUTIVE SUMMARY

Since January 13, 2009, the Federal Aviation Administration (FAA), American Airlines (at the time, US Airways), and Aviation Communication & Surveillance Systems (ACSS) have been conducting a Next Generation Air Transportation System (NextGen) Project implementing Automatic Dependent Surveillance – Broadcast (ADS-B) concepts and applications on American Airlines (AAL) A330 aircraft operating in and out of Philadelphia International Airport (PHL).

The project consists of three overlapping phases:

1) In Phase 1, American Airlines flight crews began using a Cockpit Display of Traffic Information (CDTI) for improved situational awareness and to familiarize American Airlines' flight crews with ADS-B traffic symbology, display controls, etc. Phase 1 flight operations began on July 10, 2013.
2) In Phase 2, American Airlines introduced the CDTI Assisted Visual Separation (CAVS) application into their A330 arrival operations. Phase 2 flight operations began on May 20, 2014.
3) Phase 3 implements the Merging and Spacing (M&S) application into their A330 arrival operations. Phase 3 data collection is ongoing and will be analyzed at a future date.

This report focuses on Phase 1 and 2 results; specifically, the paper-based pilot surveys on their use of the CDTI, pilot feedback discussions on CAVS, and the benefits analysis using data collected during Phase 1 and Phase 2 flight operations.

1.1 Pilot Surveys on the Use of the CDTI

The pilot surveys on the CDTI, although limited, were generally very positive with the following observations:

- The CDTI was often used in all phases of flight, with most uses occurring in Taxi and Arrival phases.
- Traffic situational awareness was very positively impacted.
- Flight operations were slightly to very positively impacted.
- Workload was generally not impacted.
- CDTI information was consistent with Air Traffic Control (ATC) and visual information.
- During half of the flights ATC was contacted, mainly for altitude changes.
- Most pilots found the CDTI easy to interpret and use.
- Problems consisted of non-optimal CDTI location and one instance where the database was out of date.

1.2 Informal Pilot Discussions on CAVS

Volpe held informal discussions with 25 American Airlines A330 pilots [5] on their use of CAVS approximately six months after CAVS approval. Although many of the pilots did not select an aircraft with which to perform CAVS, one pilot noted that the display allowed him to make quicker, yet confident, responses when following traffic. Outside of the CAVS procedure, pilots also found several uses for the ADS-B display and report using the traffic display to:

- Call the aircraft ahead, above, or below them using the displayed call sign to inquire about ride quality.
- Make more informed requests of ATC. Route changes and altitude requests have a greater chance of being approved when no conflicting traffic can be identified on the ADS-B-based CDTI.
- Identify a path for emergency descent in the event of an engine outage.
- See who might be ahead of them in Customs. While this might appear to be trivial, it actually has both practical and operational implications. If a large aircraft is ahead, then the lines in customs will be longer. Long wait times in customs lines result in disgruntled passengers and contribute to increased chances of missed connections. Depending on the circumstances crews might request an altitude with less headwind or increase their speed, attempting to arrive before the other aircraft.

1.3 CAVS Benefits Analysis

Benefits analysis consisted of three analysis types: 1) Time Between Consecutive Arrivals, 2) Time/Distance Flown from 25nm Radius to Runway, and 3) Fix-to-Runway.

The analyses looked for an improvement in time flown based on time periods (e.g., before and after CAVS flight operations began) and/or aircraft equipage (e.g., CAVS equipped and not CAVS equipped), depending on the analysis. Although most analyses also calculated the change in distance flown, the report focuses on changes in time flown as a time savings is much more easily translated into an improvement in operational efficiency versus an improvement in distance flown.

Each analysis used data from flights that arrived during the peak arrival period at PHL of 12:45 – 18:45 local time, only. Each analysis looked for improvements in each metric under weather conditions in which CAVS might be of most use (e.g., Instrument Meteorological Conditions (IMC), Marginal Meteorological Conditions (MMC)[1], deteriorating weather conditions[2]). Analysis was also conducted using flights arriving in Visual Meteorological Conditions (VMC).

A test for statistical significance[3] was performed on the results of each analysis. Results were also reported if "approaching significance".[4]

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[1]MMC is defined as visibility >= 5 statute miles (sm) and ceiling 2000 ft. – 3000 ft. Above Ground Level (AGL)

[2] Visibility varies between 3 – 7 sm and ceiling varies between 2000 – 6000 ft. AGL.

[3]Statistical significance (or a statistically significant result) is attained when a p-value (calculated probability) is less than the significance level (denoted α, alpha). The p-value of less than alpha indicates strong evidence that the results of the sample were not arrived at by chance. For the CAVS Benefits analysis, Mann-Whitney tests were performed where $\alpha = 0.05$ (a 5% significance level).

[4] Approaching significance is defined as $0.05 < p < 0.10$. Although not statistically significant, p values within this range *may* become statistically significant with additional data sets.

1.3.1 Time Between Consecutive Arrivals Analysis Results

The Time Between Consecutive Arrivals analysis compared the average time between consecutive aircraft arriving at PHL in the time period before CAVS flight operations began (i.e., Pre-CAVS) to the time period after CAVS flight operations began (i.e., CAVS). The analysis included the arrivals of all commercial airlines at PHL and differentiated between arrivals at each of the four PHL runways: 9L, 9R, 27L and 27R. Interval time comparisons were made in two separate weather conditions: MMC and VMC. The analysis also focused on AAL A330 arrivals only at the same four runways in MMC weather. Table 1 lists the conditions used in this analysis.

Table 1. Time Between Consecutive Arrivals Conditions: Time Period Comparison

Flights	Weather	Time Period Comparison		
All Flights	MMC	Pre-CAVS	vs.	CAVS
All Flights	VMC	Pre-CAVS	vs.	CAVS
AAL A330s	MMC	Pre-CAVS	vs.	CAVS

A second analysis was performed comparing all flights into PHL except for AAL A330 flights (i.e., Non-AAL A330s) and AAL A330 flights, in MMC, during the CAVS flight operations time period only. Table 2 lists the conditions used in this analysis.

Table 2. Time Between Consecutive Arrivals Conditions: Operator Flights Comparison

Time Period	Weather	Operator Flights Comparison		
CAVS	MMC	Non-AAL A330s	vs.	AAL A330s

When comparing all flights between Pre-CAVS and CAVS time periods, statistically significant results showed favorable improvements at runways 27L and 9R during MMC weather Arrivals at runway 27L showed an improvement of 41 seconds, or 22% less time flown. Arrivals at runway 09R showed an improvement of 6 seconds which was equivalent to 5% less time flown. There was no statistically significant improvement in time between arrivals for AAL A330s when comparing Pre-CAVS to CAVS.

The comparison of time between arrivals of Non-AAL A330s and AAL A330s had one statistically significant result: the time flown was greater for AAL A330s landing on 09R by 13 seconds, or 11.7%.

1.3.2 Time / Distance Flown from 25nm Radius to Runway Analysis Results

The Time / Distance Flown from 25nm Radius to Runway analysis contained three variants based on the conditions used:

1) The first used the same conditions as those in Time Between Consecutive Arrivals. See Table 3.

2) The second also used the same conditions as Time Between Consecutive Arrivals except it was limited to AAL's A330 arrivals only. See Table 3.
3) The third was a comparison between all flights into PHL except for AAL A330 flights (i.e., non-AAL A330s) and AAL A330 flights, in VMC and MMC, during the CAVS flight operations time period only. See Table 4.

The second and third analyses did not differentiate between AAL A330s equipped with CAVS and those not equipped with CAVS. Therefore, all AAL A330s (not just equipped aircraft) were used in both the Pre-CAVS and CAVS time periods.

Table 3. Time / Distance Flown from 25nm Radius to Runway Conditions; Time Period Comparison

Flights	Weather	Time Period Comparison		
All Flights	MMC	Pre-CAVS	vs.	CAVS
All Flights	VMC	Pre-CAVS	vs.	CAVS
AAL A330s	MMC	Pre-CAVS	vs.	CAVS
AAL A330s	VMC	Pre-CAVS	vs.	CAVS

Table 4. Time / Distance Flown from 25nm Radius to Runway Conditions; Operator Flights Comparison

Time Period	Weather	Operator Flights Comparison		
CAVS	MMC	Non-AAL A330s	vs.	AAL A330s
CAVS	VMC	Non-AAL A330s	vs.	AAL A330s

The analysis of time flown from a 25nm radius for all flights in MMC (Pre-CAVS vs. CAVS) had mixed results with two direction / runway pairs yielding positive statistically significant results (flights arriving from the East and landing on 27L (East 27L) or on 27R (East 27R)), one pair yielding a positive approaching significance result (West 27R) and two pairs yielding negative statistically significant results (East 09R and West 09R).

There were no statistically significant improvements when comparing the time flown of AAL A330s flights during the Pre-CAVS period and CAVS period. However, there was one set of conditions for which the difference in time flown for AAL A330s arrivals was positive and approached significance, at East 27R in MMC.

Time flown for AAL A330 flights showed statistically significant improvement over all other operator flights in the CAVS period, both in MMC and VMC weather. In MMC arrivals at East 27R and West 27R showed improvement of 14% and 28% in time flown, respectively.

1.3.3 Fix-to-Runway Analysis Results

The Fix-to-Runway analysis used a variety of conditions when comparing time and distance flown from a crossed arrival-fix on the flight path to the runway for American Airlines A330.

Unlike the previous analyses, the Fix-to-Runway analysis is limited to only AAL A330 flights but differentiates between American Airlines A330s equipped with CAVS and those not equipped with CAVS. The analysis groups the flights as follows:

- Non-CAVS Flight Ops refers to arrivals performed during the Pre-CAVS time period (i.e., before May 20, 2014) by any AAL A330 (CAVS-equipped and not CAVS-equipped), and arrivals performed during the CAVS time period (i.e., on or after May 20, 2014) by any AAL A330 not equipped with CAVS.
- CAVS Flight Ops refers to arrivals performed during the CAVS time period by AAL CAVS-equipped A330s, only.

The analysis differentiated between arrivals at each of the four PHL runways: 9L, 9R, 27L and 27R. The comparisons were made in MMC, IMC, VMC, deteriorating weather conditions, and all weather conditions. Table 5 shows the conditions used in this analysis.

Table 5. Time / Distance Flown Fix-to-Runway Conditions; Non-CAVS Flight Ops vs. CAVS Flight Ops

Flights	Weather	Time Period	Aircraft		Time Period	Aircraft
AAL A330s	MMC	Pre-CAVS	All AAL A330s	vs.	CAVS	Equipped AAL A330s
		CAVS	Non-equipped AAL A330s			
AAL A330s	IMC	Pre-CAVS	All AAL A330s	vs.	CAVS	Equipped AAL A330s
		CAVS	Non-equipped AAL A330s			
AAL A330s	VMC	Pre-CAVS	All AAL A330s	vs.	CAVS	Equipped AAL A330s
		CAVS	Non-equipped AAL A330s			
AAL A330s	Deterior-ating	Pre-CAVS	All AAL A330s	vs.	CAVS	Equipped AAL A330s
		CAVS	Non-equipped AAL A330s			
AAL A330s	All	Pre-CAVS	All AAL A330s	vs.	CAVS	Equipped AAL A330s
		CAVS	Non-equipped AAL A330s			

In MMC weather CHEAZ-09R showed an improvement in time flown of approximately 8% and in IMC weather WOJIK-27R showed an improvement in time flown of approximately 6%. Note that both of these statistical results were “approaching significance”.

In deteriorating weather conditions there were three Fix-to-Runway results that were statistically significant or approaching significance, all of which were positive indicating an improvement from the Non-CAVS Flight Ops to CAVS Flight Ops periods. The improvements in time flown ranged from 7% to 11.9%. In general, improvements were more apparent when ceiling conditions worsened.

A second Fix-to-Runway analysis was completed using only American Airlines CAVS-equipped A330 arrivals for the CAVS time period. It analyzed the same metrics for AAL A330 flights during which the flight crews used the CAVS application and the flights were coupled[5] below 9000' compared to AAL A330 flights where the CAVS application was not used or it was used but the flight did not remain coupled below 9000'. Flights coupled below 9000' served as a proxy for potential CAVS approaches, since confirmation of all CAVS approaches (via pilot surveys) were not available. See Table 6 for the conditions used in this analysis.

Table 6. Time / Distance Flown Fix-to-Runway Conditions; CAVS + Coupled Below 9000' Comparison

Flights	Weather	Time Period	CAVS / Coupled Comparison		
Equipped AAL A330s	MMC	CAVS	Not CAVS+Coupled<9K'	vs.	CAVS+Coupled<9K'
Equipped AAL A330s	IMC	CAVS	Not CAVS+Coupled<9K'	vs.	CAVS+Coupled<9K'
Equipped AAL A330s	VMC	CAVS	Not CAVS+Coupled<9K'	vs.	CAVS+Coupled<9K'
Equipped AAL A330s	Deteriorating	CAVS	Not CAVS+Coupled<9K'	vs.	CAVS+Coupled<9K'
Equipped AAL A330s	All	CAVS	Not CAVS+Coupled+9K'	vs.	CAVS+Coupled<9K'

When comparing Not CAVS+Coupled <9K' to CAVS+Coupled <9K' in VMC, MMC and IMC, only one fix pair was statistically significant: PSOUT-27R showed an improvement in time flown of over 12% in VMC weather.

No comparisons of fix pairs in deteriorating weather conditions were statistically significant.

One fix pairs' analysis of time flown in all weather conditions was statistically significant and positive; PSOUT-27R showed an improvement of almost 13%.

1.4 Analysis Limitations

While the benefits analyses did result in some improvements in the metrics measured, they were more limited than anticipated. This was likely due to several factors including:

- Limited number of potential CAVS flights.
- Limited ability to identify when CAVS was used by AAL flight crews.
- Activities resulting from the American Airlines/US Airways merger (e.g., contract negotiations, schedule integration) limiting the focus placed on performing CAVS operations

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[5] When performing CAVS, the flight crew of the CAVS-equipped aircraft "couples" to the aircraft it is following (i.e., preceding aircraft) so that the onboard system displays information needed for the CAVS procedure including the preceding aircraft flight ID, differential ground speed of the two aircraft, and the distance to the preceding aircraft. DO-317B, Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System, refers to the preceding aircraft as designated traffic when performing CAVS.

2 APPLICATION OVERVIEWS

In order to perform the tasks outlined in this project, American Airlines equipped a portion of their A330 fleet with the following:

- Two Class 3 Electronic Flight Bags (EFB) that host the CDTI application and interface with the traffic computer. The captain's EFB display is shown in the top of Figure 2-1, just above the captain's sidestick.
- CDTI hosted on the EFB providing integrated display of ADS-B and TCAS Traffic, CDTI and CAVS application controls, and ADS-B In system status and advisory messages. A sample CDTI screen is shown in the bottom left of Figure 2-1.
- Auxiliary Guidance Display (AGD) providing speed guidance, distance to coupled traffic, differential ground speed, and visual caution/warning alerts/advisory annunciators. The AGD is shown in the bottom right of Figure 2-1.

Figure 2-1. Captain's EFB, a CDTI and the AGD

2.1 Phase 1: Situational Awareness / CDTI Familiarization Overview

Cockpit Display of Traffic Information (CDTI) technology was added to the aircraft enhancing the flight crews' awareness of surrounding traffic while airborne and on or near the surface area. During Phase 1 flight crews became familiar with the location and use of the two CDTI displays. It is expected that the familiarization will improve the crew's situational awareness since other visually identified ADS-B equipped aircraft can be correlated to ADS-B aircraft shown on the CDTI, enabling crews to smoothly transition over to the CDTI (Cockpit Display of Traffic Information) Assisted Visual Separation (CAVS) application use in Phase 2.

2.2 Phase 2: CAVS Application Overview

CDTI (Cockpit Display of Traffic Information) Assisted Visual Separation (CAVS) [3] is a procedure in which controllers assign, and pilots accept, separation responsibility from another aircraft on a visual approach in a manner similar to visual separation today in order to achieve an operational advantage in the National Airspace System (NAS). ADS-B is the underlying technology being utilized; therefore, the aircraft performing the CAVS operation must have ADS-B In capability with an appropriate CDTI. Furthermore, the Traffic to Follow (TTF) must have ADS-B Out capability.

The concept of CAVS mirrors visual separation as known today, augmented with appropriate cockpit displays that provide a more complete set of information about the TTF aircraft than can be derived from out the window contact. Because CAVS is a visual separation procedure, the pilots are responsible for determining and maintaining safe separation from the assigned TTF aircraft. CAVS enables pilots to accept separation responsibility from other aircraft with the aid of a CDTI. In CAVS the flight crew is allowed to use the information provided by the CDTI for the TTF, after visual TTF acquisition and correlation on the CDTI, in addition to or as a substitute for out the window information. Therefore, once the TTF has been acquired by correlating the traffic on the CDTI, with a visual acquisition of the traffic out-the-window, CAVS can continue through the use of the traffic display (i.e., CDTI) when the traffic out-the-window is no longer immediately visible. The CDTI will aid in situational awareness, provide the pilots with the ability to more readily and more positively identify traffic to follow, and to help maintain visual separation requirements during day and night Visual Meteorological Conditions (VMC).

3 OPERATOR ASSESSMENT

3.1 Pilot Surveys on Use of the CDTI

Pilot surveys can be utilized to provide valuable insights into operations including frequency of use, when and how the CDTI was used, impact on situational awareness, impact on workload, etc. Unfortunately, pilot surveys can also be difficult to collect, especially paper-based ones.

American Airlines provided paper-based surveys to pilots on the CDTI-equipped A330s requesting voluntary feedback in three areas: 1) General use of the CDTI, 2) In-Trial Procedure (ITP), and 3) Surface Area Movement Manager (SAMM). The following will address only the first area, General use of the CDTI.

From October 2013 through October 2015 only 13 surveys were collected, with the majority collected in the early months (see Figure 3-1). The decline in collected surveys was expected, and perhaps exacerbated by activities associated with the US Airways/American Airlines merger.

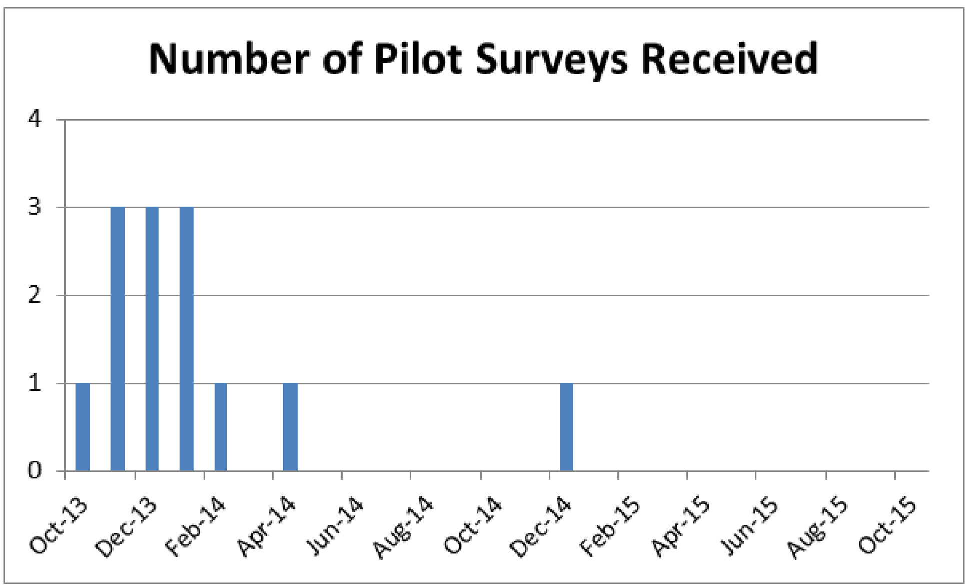

Figure 3-1. Number of Pilot Surveys Received

Although only 13 surveys were received (see Appendix E for survey summaries), some general observations can be made.

- The CDTI was often used in all phases of flight, with most uses occurring in Taxi and Arrival phases.
- Traffic situational awareness was very positively impacted.
- Flight operations were slightly to very positively impacted.
- Workload was generally not impacted.
- CDTI information was consistent with ATC and visual information.
- During half of the flights ATC was contacted, mainly for altitude changes; flight crews had a better awareness of available altitudes by using the CDTI.
- Most pilots found the CDTI easy to interpret and use.

- Problems consisted of non-optimal CDTI location and one instance where the database was out of date.

Given the difficulty in collecting paper surveys, American Airlines has been working to implement a version of the survey into an electronic format via their pilot iPads. This was completed in early 2016.

3.2 Pilot Feedback Discussions on CAVS

After approximately six months of CAVS operations Allied Pilots Association (APA) organized informal discussions with pilots that American Airlines hosted at their Flight Operations Office at PHL on December 1 and 2, 2014. The goals of these discussions were to solicit feedback on if and how the pilots were using the display, determine if they had ever completed a CAVS approach (i.e., a visual approach that would have been cancelled had the aircraft not been equipped), and describe what they see as benefits and limitations of the display. The APA representative approached pilots who were arriving from, or departing to, an international destination on CAVS-equipped A330 aircraft.

A total of 25 pilots (three of whom were First Officers) provided feedback to the APA representatives and three human factors specialists over the two-day period (all were present for each discussion). Conversations began with asking pilots if they use the display; and if so, for what purposes. If they had used the display, pilots were asked:

- Have you used it on approach to capture an aircraft to follow?
- Would you have had to cancel the visual approach if you weren't using CAVS?

Pilots were then invited to offer any other comments on the display or its uses, and recommendations for improvements to the equipment or training. The only other questions asked followed from the comments offered. The results of these discussions shed light on actions that might maximize the benefits of an ADS-B-based CDTI.

While only a few of the pilots said they had coupled with another aircraft, none of them had experienced conditions that would have involved losing sight of the lead aircraft and continuing the approach with CAVS. That did not mean, however, that the display afforded no benefits on visual approaches. One pilot said he is quick to report the airport in sight, but hesitates to report the aircraft (to follow) in sight until he has double-checked for accuracy; the display allows him to make a quicker, yet confident, response.

Outside of the CAVS procedure, pilots found several uses for the ADS-B display. Pilots reported using the traffic display to:

- Call the aircraft ahead, above, or below them using the displayed call sign to inquire about ride quality.
- Make more informed requests of ATC. Route changes and altitude requests have a greater chance of being approved when no conflicting traffic can be identified on the ADS-B-based CDTI.
- Identify a path for emergency descent in the event of an engine outage.
- See who might be ahead of them in Customs. While this might appear to be trivial, it actually has both practical and operational implications. If a large aircraft is ahead, then

the lines in customs will be longer. Long wait times in customs lines result in disgruntled passengers and contribute to increased chances of missed connections. Depending on the circumstances crews might request an altitude with less headwind or increase their speed, attempting to arrive before the other aircraft.

4 ANALYSIS OBJECTIVES

Following are the primary objectives used for developing the benefits analysis report:

- As appropriate, use the same data and benefits analysis methods as used in the ADS-B Benefits Basis of Estimate. [1]
- Determine if the estimated benefits are realized during American Airlines' flight operations at PHL.
- Tailor the benefits analysis to American Airlines by using their operations and cost data, where applicable.
- Use more than one benefits analysis methodology since the benefits may not be apparent in just one method due to the small number of equipped aircraft and the differences between how flight operations are described in the ADS-B Benefits Basis of Estimate versus those at PHL.
- Ensure that flights on which the applications were used can be identified by using more than one set of data and data sources.
- Protect any data or information considered sensitive by the project participants (e.g., FOQA data for US Airline Pilots Association (USAPA)).
- Collect data that supports performance analysis of ADS-B Out and the ADS-B In applications, as needed.

5 BENEFITS ANALYSIS

5.1 General Benefits Analysis Process

A major goal of the project is to determine and evaluate the benefits associated with each phase. The general approach includes identifying the desired new capability or procedure, determining required changes to the current operations, identifying the underlying metrics, and estimating and/or measuring the resulting benefits. See Figure 5-1 for process summary.

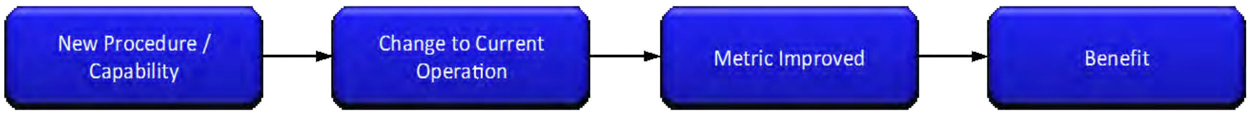

Figure 5-1. General Benefits Analysis Process

Once the metrics were identified the project determined the best methods by which to measure each metric and the potential sources of the data needed for each metric. The project then focused on a handful of measurement methods based on the availability of data, and performed the required analysis.

5.2 Benefits Metrics

The benefits of CAVS are expected to be derived by flight crews being able to maintain a visual approach in marginal conditions such as deteriorating weather conditions or conditions in which a flight crew's visibility is impaired by bright sunlight, haze or nighttime operations. Also, flight crews using new cockpit technologies, like the CDTI, can perform more efficient visual approaches while maintaining current safety standards. With the proper data, the resulting improvements may be measured in reduced flight time, fuel burn, and carbon emissions. These operational improvements may also be measured in a reduction in delays or overall delay times and perhaps in terms of increases in airport capacity.

This project focused on measuring improvements related to flight time, or time flown. One analysis measured the change in the interval of time between consecutive flights at the arrival runways. The other analyses measured the change in time flown from a fixed distance to the end of the arrival runway and the change in time flown from a fix on the arrival path to the end of the arrival runway. The change in distance flown was also measured with the results captured in Appendix G.

5.3 Benefits Data and Data Sources

Analysis of CAVS performance required the use of several data sources, depending on the analysis required. Data sources included Enhanced Traffic Management System, Compliance Monitor, Aviation System Performance Metrics, Flight Crew Comments Sheets, SafeRoute, and Flight Operations Quality Assurance.

5.3.1 Enhanced Traffic Management System (ETMS)

ETMS data is maintained by the FAA and contains track data for specific flights such as altitude, latitude, longitude, and time. ETMS data was used to determine the time between consecutive arrivals at PHL and the time / distance flown from a 25nm radius to PHL.

5.3.2 Compliance Monitor (CM)

CM data consists of various flight parameters captured by the FAA's ADS-B system including date, time of arrival (into PHL), aircraft ICAO address, aircraft ID, and several parameters at various points on the flight path such as time, aircraft latitude and longitude. CM data was used when measuring the time and distance flown by American Airlines A330s between fixes on their arrival paths and the runway.

5.3.3 Aviation System Performance Metrics (ASPM)

FAA's ASPM database contains weather data, airport arrival and departure rates (at 15-minute intervals), airport runway configurations, delays, cancellations and arrival/departure rates. ASPM data was used for selecting arrivals in ETMS based on the weather conditions at PHL (e.g., VMC, MMC). ASPM data was also used to determine the weather conditions at PHL for flights contained in the Compliance Monitor data.

5.3.4 Flight Crew Comments Sheets

Flight crew comments sheets were available for flight crews to provide feedback on the use of the CDTI and CAVS. They were originally intended to be the primary means of identifying flights during which a flight crew member used CAVS so those flights could be identified in the CM data.

5.3.5 SafeRoute

ACSS SafeRoute[6] data was also used for identifying flights on which CAVS was potentially performed. SafeRoute data are parameters recorded by the Traffic Alert Collision and Avoidance System (TCAS) surveillance processor including parameters related to surrounding ADS-B traffic, the host aircraft and the SafeRoute applications.

5.3.6 Flight Operations Quality Assurance (FOQA)

American Airlines' Flight Operations Quality Assurance (FOQA) was initially utilized, but was discarded in favor of the Compliance Monitor data as the CM data contained fewer errors and was easier to correlate with weather conditions than the FOQA data.

5.4 Data Analysis Periods and Methodologies

There are a handful of dates and timeframes that determine how the various data are categorized.

- New PHL RNAV arrivals were issued effective June 1, 2012, changing the arrival patterns into PHL. Therefore, data collected June 1, 2012 through September 30, 2015 was used in the analysis.
- CAVS flight operations began on May 20, 2014.
- Per the terms of their agreement with the FAA, American Airlines equipped twenty of twenty-four A330s between July 2013 and May 2015.

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[6] SafeRoute™ refers to ACSS' suite of ADS-B In applications that includes CAVS, M&S, Surface Area Movement Management (SAMM), and In-Trail Procedures (ITP).

Analyses using ETMS data do not differentiate between aircraft equipped with CAVS and aircraft not equipped with CAVS, using arrival data from non-AAL flights and from flights of AAL aircraft not equipped with CAVS. Therefore, all arrivals performed between June 1, 2012 and May 31, 2014 are categorized in the "Pre-CAVS" time period while the remaining are categorized as being in the "CAVS" time period. Reference sections 1.3.1and 1.3.2.

Analyses using CM data uses data only from AAL A330s and they _do_ differentiate between AAL A330s equipped with CAVS and AAL A330s not equipped with CAVS. Therefore, arrivals performed before May 20, 2014 by any AAL A330, CAVS-equipped and not CAVS-equipped, are categorized as Non-CAVS Flight Ops. Arrivals performed on May 20, 2014 or later by any AAL A330 not equipped with CAVS are also categorized as Non-CAVS Flight Ops. Arrivals performed on May 20, 2014 or later by CAVS-equipped aircraft are categorized as CAVS Flight Ops. Figure 5-2 shows the Non-CAVS Flight Ops period, CAVS equipage date, and the CAVS Flight Ops period for each of AAL A330 aircraft.

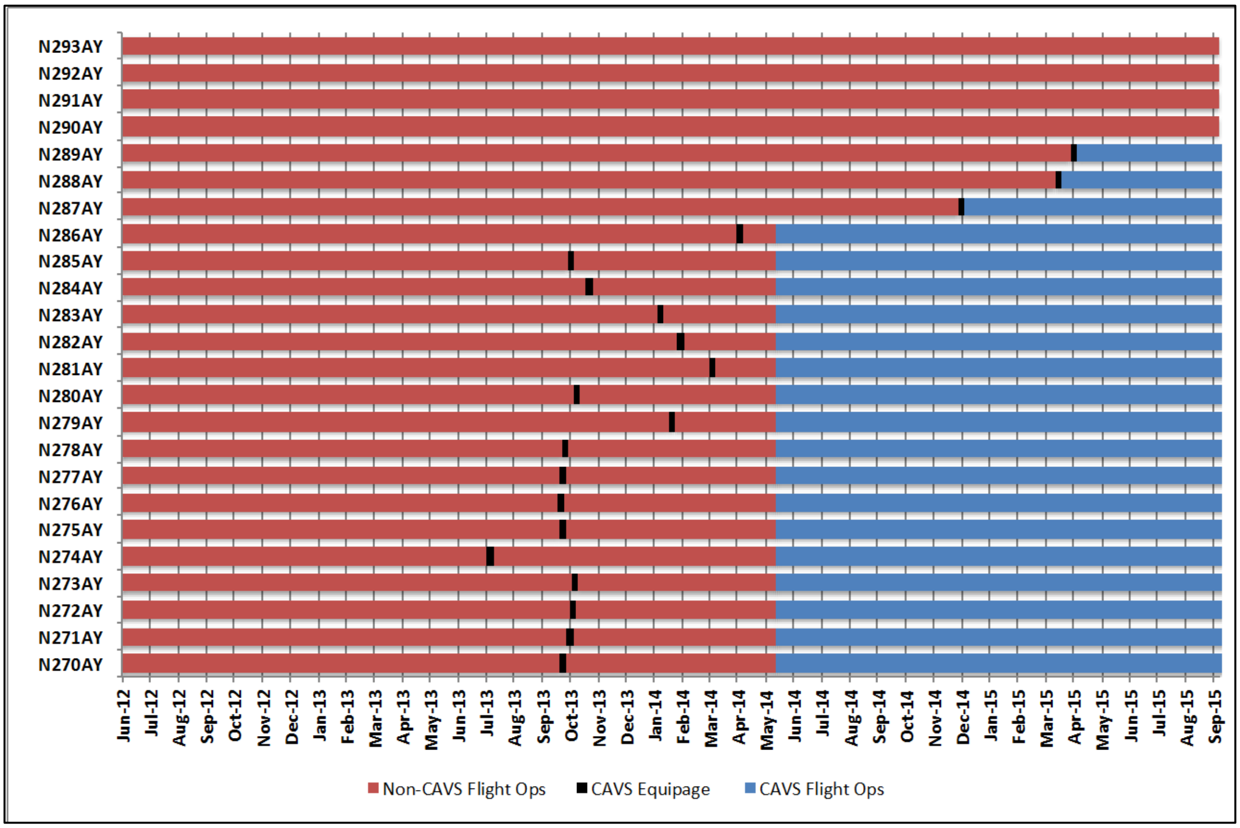

Figure 5-2. CM Data Analysis Periods

Each analysis used data from flights that arrived during the peak arrival period at PHL of 12:45 – 18:45 local time, only. Each analysis looked for improvements in each metric under different weather conditions (e.g., VMC, MMC).

Because a majority of the data was not Gaussian (i.e., normally distributed) a *Mann-Whitney test* was performed for determining if the results were statistically significant.

5.5 Situational Awareness Benefits Review

Unlike CAVS, no measurable benefits were anticipated during the Situation Awareness phase. This assumption was confirmed by a preliminary review comparing the data from three different periods: Pre-CDTI install, Post-CDTI install, and CAVS. The three time periods are equivalent to the time before CAVS Equipage, the time between CAVS Equipage and before CAVS Flight Ops, and the time after CAVS Flight Ops, respectively, in Figure 5-2. This review (not shown) indicated no improvements between the Pre-CDTI install and Post-CDTI install periods. Improvements were found between the Pre-CDTI install and CAVS periods however a comprehensive analysis could not be performed between the periods of concern as there was not enough data in each period for the comparative analyses.

5.6 CAVS Queuing Model Benefits Estimate

CAVS benefits at PHL were originally estimated with the queuing model used in the SBS Benefits Basis of Estimate [1] to be used as a “target” for comparison. However, the queuing model was not used in the analysis reported here because several of the model assumptions were too different for the results to be relevant (e.g., ADS-B equipage rates are lower than anticipated, CAVS installs were delayed, CAVS usage was not routine).

In the future, an updated queuing model, more aligned with current conditions, may prove to be valuable.

5.7 CAVS Benefits Analysis

Benefits analysis consisted of three analysis types: 1) Time Between Consecutive Arrivals, 2) Time/Distance Flown from 25nm Radius to Runway, and 3) Fix-to-Runway.

The analyses looked for an improvement in time flown based on time periods (e.g., before and after CAVS flight operations began) and/or aircraft equipage (e.g., CAVS equipped and not CAVS equipped), depending on the analysis. Although most analyses also calculated the change in distance flown, the report focuses on changes in time flown as a time savings is much more easily translated into an improvement in operational efficiency versus an improvement in distance flown.

Each analysis used data from flights that arrived during the peak arrival period at PHL of 12:45 – 18:45 local time. Each analysis looked for improvements in each metric under weather conditions in which CAVS might be of most use (e.g., IMC, MMC, deteriorating weather). Analysis was also conducted using flights arriving in Visual Meteorological Conditions (VMC).

Comparisons of less than 10 data points were discarded due to the inherent variability found in the flight paths as a result of ATC intervention (directs, etc.). Mann-Whitney tests were performed on the remaining results to determine if outcomes were “statistically significant” (probability that the result is from a random occurrence is less than 5%) or “approaching significance” (probability that the result is from a random occurrence is between 5-10%).

5.7.1 Time Between Consecutive Arrivals

ASPM data was used to identify blocks of time in which the weather was either VMC or MMC during the peak period of 12:45-18:45 local time. The average time between arrival aircraft to the runway was calculated using FAA ETMS data from flights arriving in those blocks of time. This resulted in data covering 274 hours over 65 days, or approximately 9,400 data points (i.e., pairs of PHL arrivals) from June 2012 -– Sept 2015. The data points are distributed into Pre-CAVS (June 2012 – Apr 2014) and CAVS (May 2014 – Sep 2015) and are classified by the weather (VMC or MMC).

The analysis focused on runways 9L, 9R, 27L, and 27R (see Appendix H); however, 9L is not included in the results because of the limited number of flights. Approximately 1,200 data points were excluded by eliminating consecutive arrival pairs whose spacing was greater than 4 minutes 26 seconds[7] accounting for instances where CAVS would have no impact. See Table 7 for the distribution of arrival pairs.

Table 7. Number of PHL Arrival Pairs Used in Analysis: By Period and Weather Conditions

Flights	Weather	Pre-CAVS	CAVS
All	VMC	2,777	2,443
All	MMC	1,872	987
AAL A330s	MMC	114	76
Non-AAL A330s	MMC	1,758	911

Table 8 contains the statistically significant results for all flights in each weather condition / runway combination (if available) in the Pre-CAVS versus CAVS comparison. There were no statistically significant results when comparing time between arrivals for AAL A330 in MMC weather. See Appendix G for complete test results.

Table 8. Average Time Between Arrivals For All Flights in VMC and MMC

			Pre-CAVS		CAVS		Difference (Positive = Improvement)		Statistically Significant?
Flights	Weather	Runway	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
All	MMC	27L	18	3:02	17	2:21	00:41	22.5%	Y
All	MMC	09R	1437	1:58	630	1:52	00:06	5.1%	Y

As is evident from the table, the average time between arrivals decreased between the Pre-CAVS and CAVS periods for runways 27L and 09R during MMC. In fact, the time between arrivals also improved for runway 27R during MMC (not shown above) although the results were not statistically significant at 95% significance level.

Table 9 contains the statistically significant results when comparing the time between arrivals for Non-AAL A330 flights and AAL A330 flights in the CAVS time period.

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[7] Assumes a 10nm separation at 135 knots.

Table 9. Average Time Between Arrivals: Non-AAL A330s vs. AAL A330s in MMC

			Non-AAL A330s		AAL A330s		Difference (Positive = Improvement)		Statistically Significant?
Time Period	Weather	Runway	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
CAVS	MMC	09R	579	1:51	61	2:04	(00:13)	(11.7%)	Y

Time flown for AAL A330 flights showed a statistically significant decline over all other flights in the CAVS Flight Ops period in MMC weather at runway 09R.

5.7.2 Time / Distance Flown from 25nm Radius to Runway

Similar to an estimating method used by the Surveillance and Broadcast Services (SBS) Benefits Basis of Estimate, the same ETMS data was used to calculate the average time flown and distance flown from a 25nm radius to a single point at PHL. Again, the analysis focused on runways 9L, 9R, 27L, and 27R (however 9L is not included because of lack of flights) during peak traffic periods and the results are categorized based on weather conditions at the time as well as the direction from which the flight is approaching PHL (East or West). The analysis included three comparisons: (1) flights of all operators between the two time periods, (2) flights of AAL A330s between the two time periods, and (3) flights of all operators to AAL A330s during the CAVS Flight Ops period, only (see Table 3 and Table 4). To reduce clutter the following tables contain results for Time Flown, only. See Appendix G for complete test results.

Per Table 10 the time flown by all operators in VMC was not improved in any direction / runway combination and improved at three of five direction / runway combinations in MMC.

Table 10. Time Flown from 25nm Radius to Runway for All Flights: VMC and MMC

		Pre-CAVS		CAVS		Difference (Positive = Improvement)		Statistically Significant?
Weather	Direction & Runway	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
VMC	West 27R	910	16:52	875	17:02	(00:11)	(1.0%)	Y
VMC	East 09R	295	15:04	114	15:23	(00:19)	(2.1%)	Y
VMC	West 09R	343	12:29	116	14:00	(01:31)	(12.2%)	Y
MMC	East 27L	41	10:44	31	08:58	01:46	16.4%	Y
MMC	East 27R	259	16:53	220	15:04	01:49	10.8%	Y
MMC	West 27R	182	17:40	154	16:51	00:49	4.6%	N*
MMC	East 09R	792	16:12	373	17:12	(01:00)	(6.2%)	Y
MMC	West 09R	704	14:38	279	15:41	(01:03)	(7.2%)	Y

* Approaching Significance

There were no statistically significant improvements when comparing the time flown of AAL A330s flights during the Pre-CAVS period and CAVS period. However, for AAL A330s arrivals at East 27R in MMC, the difference in time flown was positive and approached statistical significance. See

Table 11.

Table 11. Time Flown from 25nm Radius to Runway for AAL A330s: VMC and MMC

		Pre-CAVS		CAVS		Difference (Positive = Improvement)		Statistically Significant?
Weather	Direction & Runway	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
MMC	East 27R	31	16:14	25	13:05	03:09	19.4%	N*

* Approaching Significance

Time flown for AAL A330 flights showed statistically significant improvement over all other flights in the CAVS Flight Ops period, both in VMC and MMC weather.

Table 12 summarizes the statistically significant findings.

Table 12. Time Flown from 25nm Radius to Runway CAVS: Non-AAL A330s vs. AAL A330s in VMC and MMC

		Non-AAL A330s		AAL A330s		Difference (Positive = Improvement)		Statistically Significant?
Weather	Direction & Runway	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
VMC	East 27R	1226	13:42	148	12:49	00:52	6.4%	Y
VMC	West 27R	850	17:06	25	14:59	02:07	12.4%	Y
MMC	East 27R	195	15:19	25	13:05	02:14	14.6%	Y

5.7.3 Fix-to-Runway Analysis

Using CM data, two sets of analysis on approximately 12,800 American Airline A330 flights were performed on arrivals into PHL: Non-CAVS Flight Ops vs. CAVS Flight Ops and AAL non-coupled vs. AAL-coupled below 9000'. Flights with holding patterns or delay vectors were removed from the analysis as CAVS would not reduce their usage and they were considered outliers. Only flights that arrived during the peak period of 12:45 – 18:45 local time were used in the analysis. Each analysis examined the average time and distances from various approach fixes to various runways. Based on the available data the analysis focused specifically on the following fix-to-runway pairs in their respective RNAV arrivals (see Appendix I for approach charts):

- JIIMS TWO
  - CHEAZ-09R, STAYK-09R, PSOUT-27R, WOJIK-27R
- BOJID ONE
  - EXPRS-09R, KYILL-09R, EYRIE-27R, and HIFAL-27R

In addition, the arrivals in PHL were further divided between two approach directions: East and West. East refers to flights primarily coming from the east, heading north towards PHL (see Figure 5-3). West refers to flights primarily coming from the west, heading south towards PHL (see Figure 5-4).

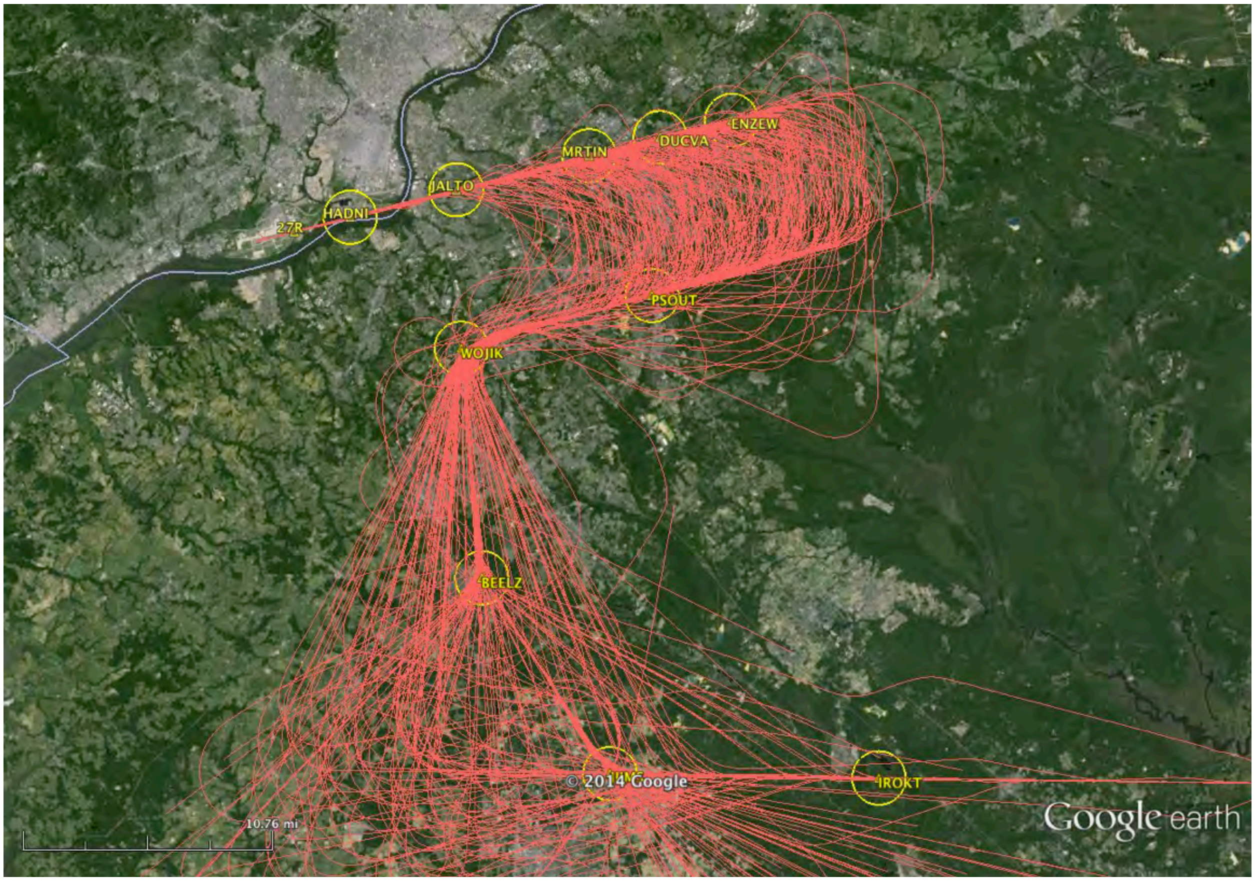


Figure 5-3. Example of the "East" Approaches on JIIMS Arrival to 27R

Figure 5-4. Example of the "West" Approaches on BOJID Arrival to 27R

5.7.3.1 Non-CAVS Flight Ops vs. CAVS Flight Ops

The average time and distance were calculated from selected fix-to-runway scenarios in various ceiling and visibility weather conditions at PHL to determine if potential benefits were apparent when comparing Non-CAVS Flight Ops to the CAVS Flight Ops. Each fix-to-runway analysis was run through three weather conditions, VMC, MMC and IMC, as well as through various weather scenarios where ceiling and visibility were adjusted. The resulting differences (positive and negative) between the Non-CAVS Flight Ops period and CAVS Flight Ops period were then tabulated. Figure 5-5 shows the distribution of flights in the analysis based on Non-CAVS Flights Ops, CAVS Flight Ops and weather condition (VMC, MMC, IMC).

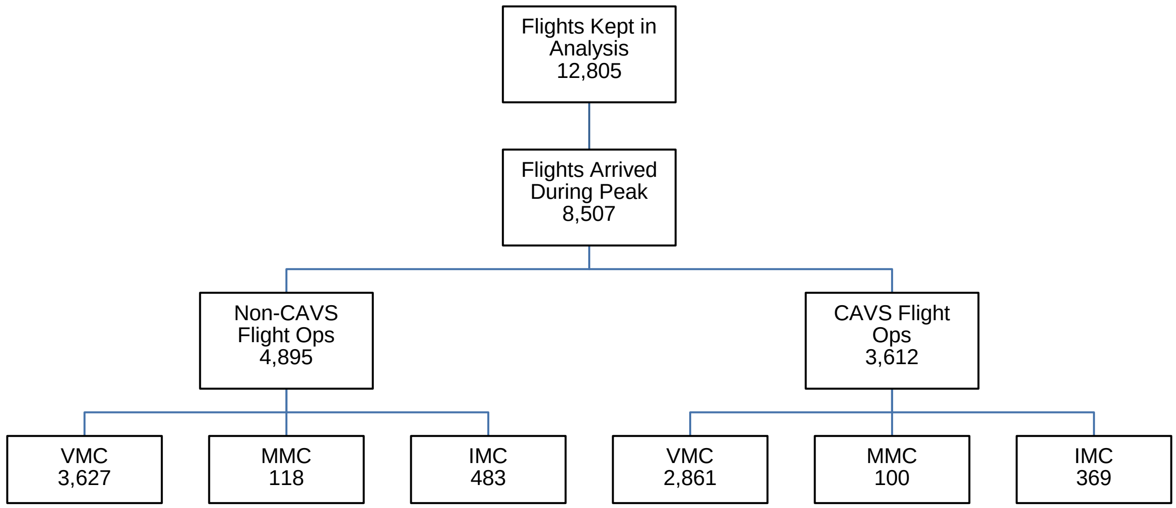


Figure 5-5. Flights Used in Analysis

Comparisons of less than 10 data points were discarded due to the inherent variability found in the flight paths as a result of ATC intervention (directs, etc.). Mann-Whitney tests were performed on the remaining results to determine if outcomes were "statistically significant" (probability that the result is from a random occurrence is less than 5%) or "approaching significance" (probability that the result is from a random occurrence is between 5-10%). To reduce clutter the following tables contain results for Time Flown only. See Appendix G for complete test results for Time Flown and Distance Flown.

In VMC weather EXPRS-09R, KYILL-09R and EYRIE-27R were found to have worsening results from the Non-CAVS Flight Ops to the CAVS Flight Ops case. However, in MMC and IMC weather CHEAZ-09R and WOJIK-27R, respectively, showed positive results. Note that the latter two were "approaching significance" (see Table 13).

Table 13. Non-CAVS Flight Ops vs. CAVS Flight Ops: VMC, MMC and IMC

		Non-CAVS Flight Ops		CAVS Flight Ops		Difference (Positive = Improvement)		Statistically Significant?
Weather	Fix Pair	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
MMC	CHEAZ-09R	57	10:39	31	09:46	00:53	8.3%	N*
IMC	WOJIK-27R	46	13:04	57	12:16	00:48	6.1%	N*
VMC	EXPRS-09R	73	07:39	62	08:41	(01:02)	(13.4%)	Y
VMC	KYILL-09R	41	10:06	39	11:39	(01:33)	(15.3%)	Y
VMC	EYRIE-27R	401	08:19	207	08:48	(00:29)	(5.7%)	Y

*Approaching significance

In *deteriorating* weather conditions all statistically significant and approaching significance results were positive, indicating an improvement from the Non-CAVS Flight Ops to the CAVS Flight Ops case (see Table 14).

Table 14. Non-CAVS Flight Ops vs. CAVS Flight Ops: Deteriorating Weather Conditions

			Non-CAVS Flight Ops		CAVS Flight Ops		Difference (Positive = Improvement)		Statistically Significant?
Ceiling	Visibility	Fix Pair	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
<=2200	All	WOJIK-27R	45	13:04	49	12:09	00:55	7.0%	Y
<=3000	<=5	WOJIK-27R	32	13:14	24	12:01	01:12	9.1%	N*
<=6000	All	HIFAL-27R	46	11:30	22	10:09	01:22	11.9%	Y

*Approaching significance

5.7.3.2 Not CAVS+Coupled below 9000' vs. CAVS+Coupled below 9000'

This analysis uses SafeRoute data to identify flights where CAVS was "coupled" on the SafeRoute application page and the coupling included altitudes below 9000'. Coupled flights only occurred for AAL PHL arrivals after CAVS flight operations began on May 20, 2014. These flights are compared to all other AAL A330 flights flown after May 20, 2014 for which SafeRoute data was available, or those not-coupled below 9000'. Note that the Not CAVS+Coupled below 9000' category contains flights designated as CAVS and coupled only *above* 9000', flights designated as M&S, and flights that were not coupled at all. Figure 5-6 shows the distribution of flights in the analysis for which SafeRoute data available, those that were during CAVS flight operations and kept in analysis, those that arrived during the peak period, and their coupled status.

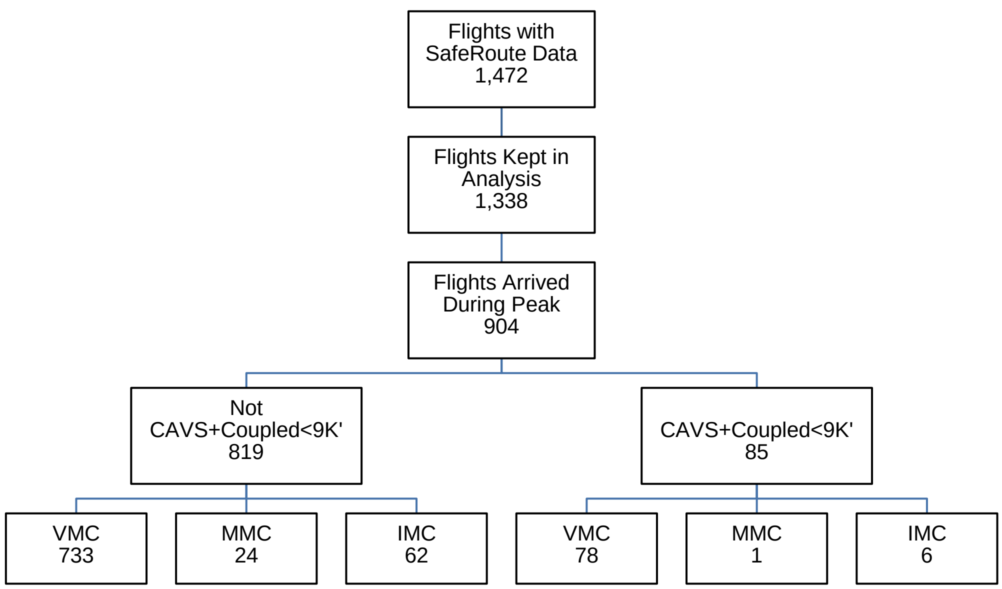


Figure 5-6. Flights Used for CAVS Proxy

When comparing Not CAVS+Coupled <9K' to CAVS+Coupled <9K' in VMC, MMC and IMC, only one fix pair was statistically significant; PSOUT-27R was positive in VMC (see Table 15). Very few arrivals in CAVS Flight Ops were identified as coupled below 9000' (2% - 3%), reducing the likelihood of having sufficient data for comparisons in MMC or IMC, which occur less often than VMC.

Table 15: Not CAVS+Coupled<9K' vs. CAVS+Coupled<9K': VMC, MMC, IMC

		Not CAVS+Coupled <9K'		CAVS+Coupled <9K'		Difference (Positive = Improvement)		Statistically Significant?
Weather	Fix Pair	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
VMC	PSOUT-27R	294	07:50	41	07:10	00:40	8.6%	Y

*Approaching significance

No comparisons of fix pairs in deteriorating weather conditions were statistically significant.

Only one fix pair, PSOUT-27R, turned out to be statistically significant in all weather conditions (see Table 16).

Table 16. Not CAVS / Coupled <9K' vs. CAVS / Coupled < 9K': Ceiling and Visibility All

CM Data			Not CAVS+Coupled <9K'		CAVS+Coupled <9K'		Difference (Positive = Improvement)		Statistically Significant?
Ceiling	Visibility	Fix Pair	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
All	All	PSOUT-27R	311	07:56	41	07:10	00:46	9.7%	Y

*Approaching significance

Even though the improvements experienced while coupled occurred mostly in weather conditions not associated with CAVS, it's possible that the improved situational awareness of using the CDTI and coupling enabled measurable benefits.

5.8 Analysis Limitations

While the benefits analyses did result in some improvements in the metrics measured, they were more limited than anticipated. This was likely due to several factors including:

- Limited number of potential CAVS flights
  - Of the 550 – 600 daily arrivals into PHL on average only 5 – 6 were performed by CAVS-equipped AAL aircraft. There are 10 – 15 AAL A330 daily arrivals at PHL depending on the time of year, approximately 72% of which arrive during the peak arrival period. Approximately 55% of AAL's daily A330 arrivals at PHL are A330-200s, of which 11 of 15 were CAVS-equipped. All nine A330-300s were CAVS equipped.
  - In order to perform CAVS the CAVS-equipped AAL aircraft required a "target" aircraft equipped with any version DO-260 ADS-B Out. While it is unknown what percentage of PHL arrivals were equipped with ADS-B Out, only a maximum of around 7% of all U.S. Air Carriers were equipped with DO-260B (i.e., Version 2) during the data analysis time periods.
  - From April 2015 to September 2015, AAL flight crews believed they could perform CAVS (i.e., couple to) with AAL aircraft only. This was due to an error/misinterpretation of the Merging & Spacing flight crew bulletin which restricts crews from coupling with non-AAL aircraft.
- Limited ability to identify when CAVS was used by AAL flight crews
  - Low response rate on voluntary paper-based surveys for pilots made identifying CAVS operations impractical.

  - SafeRoute data was available on approximately 25% of the flights in the CAVS Flight Ops period. Of those, approximately 85 flights were identified as potential CAVS flights (i.e., coupled below 9000') during the peak arrival period. The amount of SafeRoute data collected was limited due to the collection process not fully starting until after CAVS flight operations began as well as some of the SafeRoute data being overwritten when the compact flash cards remained on an aircraft too long.
- The American Airlines/US Airways merger, which became effective on March 27, 2013, may have been a "distraction" to performing CAVS operations
  - Crew contracts were renegotiated
  - Management priorities may have been refocused
- The Time / Distance Flown from 25nm Radius to the Runway analysis does not differentiate between aircraft equipped with CAVS and aircraft not equipped with CAVS. Therefore, all AAL A330s (not just equipped aircraft) were used in the CAVS time period. This could lead to underestimating the impact of CAVS.

Appendix A. Reference Documents

[1] Surveillance and Broadcast Services Benefits Basis of Estimate, August 2007, FAA

[2] Phasing Plan and Operational Description for Interval Management into PHL, Version 1.0, October 16, 2009, FAA

[3] CAVS Application Description, Version 1.0, June 19, 2012, American Airlines

[4] Merging and Spacing (M&S) Familiarization into PHL Application Description, Version 3.0, July 13, 2012, FAA

[5] Human Factors Considerations for Cockpit Display of Traffic Information (CDTI) – Assisted Visual Separation (CAVS), January 8, 2015, USDOT Volpe National Transportation Systems Center

[6] Data Collection and Benefits Analysis Plan, July 22, 2013, FAA

Appendix B. Glossary

Couple	A function in the CAVS application. When performing CAVS, the flight crew of the CAVS-equipped aircraft "couples" to the aircraft it is following (i.e., preceding aircraft) so that the onboard system displays information needed for the CAVS procedure including the preceding aircraft flight ID, differential ground speed of the two aircraft, and the distance to the preceding aircraft. DO-317B, Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications (ASA) System, refers to the preceding aircraft as designated traffic when performing CAVS.
Delay Vector	A method used by air traffic controllers to space and sequence flights to the arrival runway in congested airspace. In this analysis these took the form of "loops" in the arrival aircraft's flight path.
Deteriorating Weather Conditions	For the purpose of this report, meteorological conditions expressed in terms of visibility and ceiling where visibility varies between 3 – 7 statute miles and ceiling varies between 2000 – 6000 feet AGL.
Instrument Meteorological Conditions (IMC)	The meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling, less than the minima specified for visual meteorological conditions (VMC). For these analyses IMC conditions are visibility less than 5 statute miles or ceiling less than 2000 feet.
Marginal Meteorological Conditions (MMC)	The meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling in which use of the CDTI for situational awareness or the use of CAVS may increase visual approaches. For these analyses MMC conditions are visibility greater than or equal to 5 statute miles and ceiling greater than or equal to 2000 feet or less than 3000 feet.
Peak Arrival Period	The period of time during which arrivals into Philadelphia International Airport (PHL) are at their highest levels. For these analyses peak arrival period is 1245 to 1845 local time.
Visual Meteorological Conditions (VMC)	The meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling equal to or better than specified minima. For these analyses VMC conditions are visibility greater than or equal to 5 statute miles and ceiling greater than or equal 3000 feet.

Appendix C. Abbreviations

AAL	American Airlines
ADS-B	Automatic Dependent Surveillance – Broadcast
AGL	Above Ground Level
APA	Allied Pilots Association
ASA	Aircraft Surveillance Applications
ASG	Assigned Spacing Goal
ASPM	Aviation System Performance Metrics
ATC	Air Traffic Control
CAVS	CDTI Assisted Visual Separation
CDTI	Cockpit Display of Traffic Information
CM	Compliance Monitor
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FOQA	Flight Operations Quality Assurance
ICAO	International Civil Aviation Organization
IMC	Instrument Meteorological Conditions
ITP	In-Trail Procedure
M&S	Merging and Spacing
MMC	Marginal Meteorological Conditions
MOPS	Minimum Operational Performance Standards
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
PHL	Philadelphia International Airport
SAMM	Surface Area Movement Management
SBS	Surveillance and Broadcast Services
sm	statute miles
SRMD	Safety Risk Management Document
TCAS	Traffic Alert and Collision Avoidance System
TTF	Traffic To Follow
USAPA	US Airline Pilots Association
VMC	Visual Meteorological Conditions

Appendix D. Flight Crew Comment Sheet

Note: The Flight Crew Comment Sheet also contains questions on the ADS-B In application In-Trail Procedures (ITP). ITP is outside the scope of the Project, but was included in an effort to consolidate the comment sheets of separate American Airlines projects.

US AIRWAYS TRAFFIC DISPLAY (CDTI) PILOT DEBRIEF FORM (VERSION 0.22)

This questionnaire supports data collection on the use of CDTI and associated procedures. Your cooperation in filling out this form after each flight will assist evaluation and improvement of the equipment, procedure, and training. The information contained herein will not be released to the public in a manner which allows the identification of US Airways' flight crews.

Each Pilot: Please place a completed form in the FDML.
Maintenance: COMAIL to Ron Thomas PHX-FTC-FSS.

Date (DD/MM/YY): _____/ _____/_____ Flight Number: ____________

Aircraft: ☐ A330-200 ☐ A330-300 Number of flights you have used CDTI: ______________

General use of the CDTI

1. How often did you use the CDTI during the flight?
   ☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Very often

2. During what phase of flight did you use the CDTI? (check all that apply)
   ☐ Taxi ☐ Departure ☐ En route ☐ Approach ☐ Arrival

3. How did the CDTI impact your traffic situational awareness?
   ☐ Very negatively ☐ Slightly negatively ☐ No change ☐ Slightly positively ☐ Very positively

   Comments (specify possible influencing factors, e.g., visual conditions, airport runway configuration, traffic density, partial display of surrounding traffic):
   ____
   ____

4. How did the CDTI impact the flight operations? (e.g., safety, awareness of flight level changes, etc.)
   ☐ Very negatively ☐ Slightly negatively ☐ No change ☐ Slightly positively ☐ Very positively

   Comments:
   ____
   ____

5. How did the CDTI impact your workload? (specify possible influencing factors, e.g., phase of flight, weather conditions, partial display of surrounding traffic, airspace characteristics, traffic density, etc.)
   ☐ Very negatively ☐ Slightly negatively ☐ No change ☐ Slightly positively ☐ Very positively

   Comments:
   ____
   ____

6. Information provided by the CDTI was consistent with ATC and visual information.
   ☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

   Comments:
   ____
   ____

7. Did you ask ATC for information based on the CDTI? ☐ YES ☐ NO

If **YES**, what (e.g., clearance request, information on traffic, etc.):

____

____

8. Was the CDTI easy to interpret and use? (e.g., displayed information, traffic selection/highlighting, display setting)
☐ Easy ☐ Manageable, but could be improved ☐ Difficult

Comments:

____

____

9. Did you experience any problems while using the CDTI? ☐ YES ☐ NO

Comments (description of condition/problem):

____

____

10. Please provide any additional benefits or concerns regarding the CDTI and its use:

____

____

In-Trail Procedure (ITP) -- skip any questions that are not applicable

11. Was an ITP requested?
☐ YES ☐ NO (Reason: ______________________________)

12. If **YES**, why? (check all that apply)
☐ Altitude change based on the Operational Flight Plan
☐ More fuel-efficient flight level
☐ Weather (e.g., turbulence or thunderstorms)
☐ Other __________________________________

13. Was the ITP request approved?
☐ YES ☐ NO

If **YES**, how long did it take to receive the ITP clearance once requested?
☐ Less than 2 minutes ☐ Between 2 and 5 minutes ☐ Greater than 5 minutes

If **NO,** was it clear to you why the ITP request was not approved?
☐ NO ☐ YES (If **YES**, why: ______________________________)

Comments:

____

____

14. Please rate the difficulty/ease of **identifying** ITP opportunities:
☐ Easy ☐ Manageable, but could be improved ☐ Difficult ☐ Didn't try

15. Please rate the difficulty/ease of CPDLC communication **with ATC** about the ITP:
☐ Easy ☐ Manageable, but could be improved ☐ Difficult ☐ Didn't try

16. Please rate the difficulty/ease of **executing** the flight level change on the CDTI:
☐ Easy ☐ Manageable, but could be improved ☐ Difficult ☐ Didn't try

17. Please describe the nature of any difficulties with **identifying** ITP opportunities, **communicating with ATC** about the ITP, **executing** the flight level change or any other problems experienced.

____

____

18. Any other general comments/concerns on the ITP (including training, CRM)?

____

____

Surface Area Movement Manager (SAMM)

19. Airport(s) (4-letter ICAO ID) where SAMM was used: ☐ KPHL ☐ KCLT ☐ Other:_____

20. Your position: ☐ Captain (PF) ☐ First Officer (PM)

21. Was surface moving map available? ☐ YES ☐ NO

22. Conditions? ☐ Day VMC ☐ Day IMC ☐ Night IMC

23. How familiar were you with the taxi route? ☐ Not familiar ☐ Somewhat familiar ☐ Very familiar

24. How often did you refer to the surface moving map display? ☐ Not much ☐ Somewhat ☐ Frequently

25. How did SAMM impact your taxi/traffic situational awareness?
☐ Very negatively ☐ Slightly negatively ☐ No change ☐ Slightly positively ☐ Very positively
Comments:

____

____

26. How did SAMM impact your workload? (specify possible influencing factors, e.g., weather conditions, partial display of surrounding traffic, traffic density, etc.)
☐ Very negatively ☐ Slightly negatively ☐ No change ☐ Slightly positively ☐ Very positively

27. Please note any errors seen and/or any other general comments/concerns using SAMM during taxi.

____

____

Appendix E. Pilot Survey Summaries

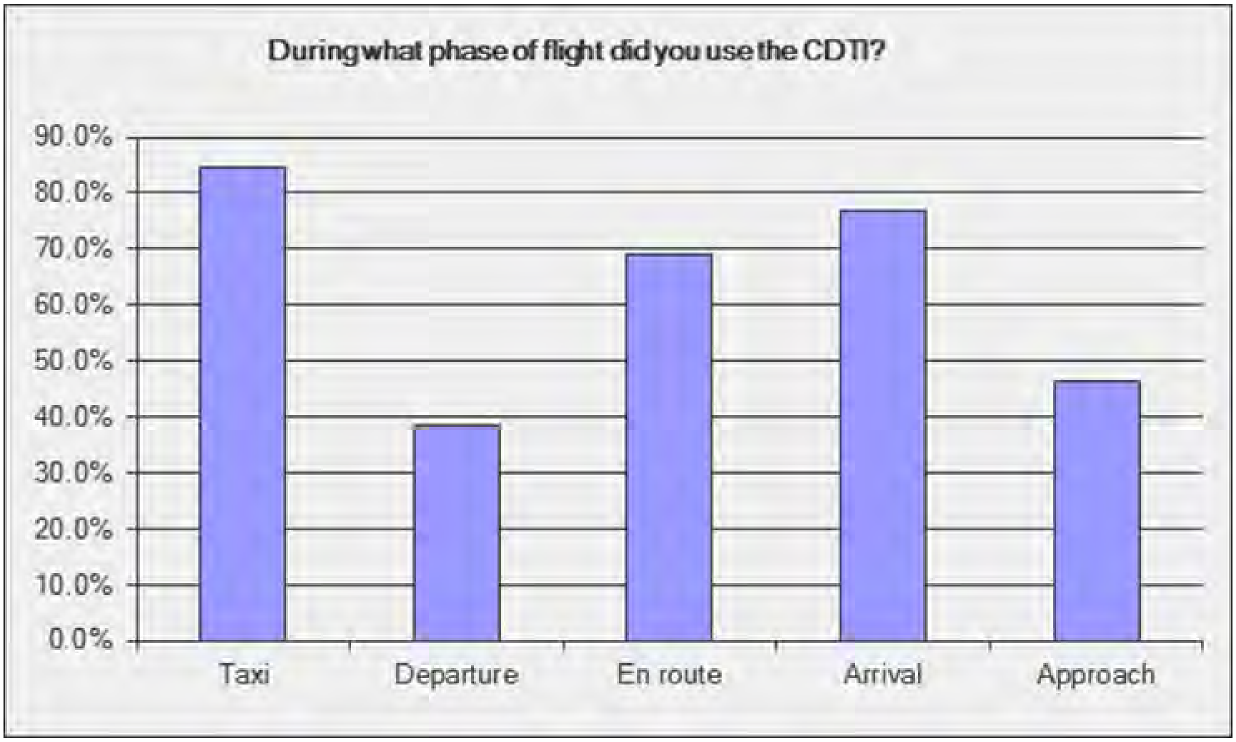
Question 1

How often did you use the CDTI during the flight?							
Answer Options	Never	Rarely	Sometimes	Often	Very often	Rating Average	Response Count
	0	0	7	4	2	3.62	13
						answered question	13
						skipped question	0

Question 2

During what phase of flight did you use the CDTI?		
Answer Options	**Response Percent**	**Response Count**
Taxi	84.6%	11
Departure	38.5%	5
En route	69.2%	9
Arrival	76.9%	10
Approach	46.2%	6
	answered question	**13**
	skipped question	**0**

Question 3



How did the CDTI impact your traffic situational awareness?							
Answer Options	Very negatively	Slightly negatively	No change	Slightly positively	Very positively	Rating Average	Response Count
	0	0	0	4	8	4.67	12
Comments (specify possible influencing factors, e.g., visual conditions, airport runway configuration, traffic density, partial							3
						answered question	12
						skipped question	1

Number	Response	Comments (specify possible influencing factors, e.g., visual conditions, airport runway configuration, traffic density, partial display of surrounding traffic):
1	Very positively	Planning for climb on tracks.
2	Very positively	Taxi surrounding aircraft
3	Slightly positively	Position of screen not good for taxi use by capt.

Question 4

How did the CDTI impact the flight operations?							
Answer Options	Very negatively	Slightly negatively	No change	Slightly positively	Very positively	Rating Average	Response Count
	0	0	0	6	7	4.54	13
Comments:							1
						answered question	13
						skipped question	0

Number	Response	Comments:
1	Slightly positively	Got us a higher alt.

Question 5

How did the CDTI impact your workload?							
Answer Options	Very negatively	Slightly negatively	No change	Slightly positively	Very positively	Rating Average	Response Count
	0	1	10	1	1	3.15	13
Comments:							1
						answered question	13
						skipped question	0

Number	Response	Comments:
1	Slightly negatively	More work, but not necessarily bad.

Question 6

Information provided by the CDTI was consistent with ATC and visual information.							
Answer Options	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Rating Average	Response Count
	0	0	0	6	6	4.50	12
Comments:							0
						answered question	12
						skipped question	1

Question 7

Did you ask ATC for information based on the CDTI?		
Answer Options	Response Percent	Response Count
Yes	50.0%	6
No	50.0%	6
If YES, what (e.g., clearance request, information on traffic, etc.):		6
	answered question	12
	skipped question	1

Number	If YES, what (e.g., clearance request, information on traffic, etc.):
1	Climb to 390 on track.
2	Altitude change request
3	Asked for ride reports of A/C on our route ahead of us - we could see their flight ID's and asked what kind of rides they were getting.
4	ITP Climb
5	Requested alt change FL380 to FL400.
6	Requested a ITP climb from F380 to 400. Worked great.

Question 8

Was the CDTI easy to interpret and use?					
Answer Options	Easy	Manageable, but could be improved	Difficult	Rating Average	Response Count
	10	2	1	1.31	13
Comments:					1
				answered question	13
				skipped question	0

Number	Response	Comments:
1	Difficult	But I am new at this.

Question 9

Did you experience any problems while using the CDTI?		
Answer Options	Response Percent	Response Count
Yes	15.4%	2
No	84.6%	11
Comments (description of condition/problem):		2
	answered question	13
	skipped question	0

Number	Response	Comments (description of condition/problem):
1	Yes	Location
2	Yes	Database out of date. Be nice to have up to date database.

Question 10

Please provide any additional benefits or concerns regarding the CDTI and its use:	
Answer Options	Response Count
	1
answered question	1
skipped question	12

Number	Response Text
1	The position (mount) of the EFB unfortunately is very poor, and will undoubtedly limit pilot use/data collection - especially for SAMM - during this study.

Appendix F. Data and Data Sources

Enhanced Traffic Management System (ETMS) Data

Enhanced Traffic Management System Counts (ETMSC) is an FAA-maintained database designed to provide information on traffic counts by airport or by city pair for various data groupings such as aircraft type or by hour of the day. ETMSC source data are created when pilots file flight plans and/or when flights are detected by the National Airspace System (NAS), usually via RADAR. ETMSC data used in the benefits analysis include track data for specific flights such as altitude, latitude, longitude, and time.

Compliance Monitor (CM) Data

Compliance Monitor is an FAA-maintained system which consists of various flight parameters captured by the FAA's ADS-B system. This data includes date, time of arrival (into PHL), aircraft ICAO address, aircraft ID, and several parameters at various points on the flight path such as time, aircraft latitude and longitude.

Aviation System Performance Metrics (ASPM) Data

ASPM is an FAA-maintained database. ASPM data falls into two categories: flight data containing information on individual flight performance and airport data containing information on airport efficiency. Data comes from ARINC's Out-Off-On-In (OOOI), ETMS, US Department of Transportation's Aviation's Airline Service Quality Survey (ASQP), weather data, airport arrival and departure rates (15-minute interval), airport runway configurations, delays, cancellations and arrival/departure rates.

American Airlines Flight Operations Quality Assurance (FOQA) Data

FOQA is a voluntary safety program designed to improve aviation safety through the proactive use of flight-recorded data. Data is used to identify and correct deficiencies in all areas of flight operations. FOQA data is comprised of various parameters such as the date, engine parameters, control input, fuel burn, speed, longitude, latitude, and surface positions. American Airlines' Flight Operations Quality Assurance (FOQA) was initially utilized, but was discarded in favor of the Compliance Monitor data as the CM data contained fewer errors and was easier to correlate with weather conditions than the FOQA data.

Flight Crew Comment Sheets

Flight crew comments sheets were provided to each flight crew of properly equipped A330 aircraft. The comment sheets asked specific questions regarding CDTI usage during each flight and flights during which CAVS was conducted. Questions included both objective (e.g., flight date, flight number) and subjective measures (e.g., ease of use, workload impact). The flight crew manually filled in the appropriate data on the comment sheet. See Appendix D for example comment sheet. Similar to FOQA data protections, flight crew comments sheets were de-identified prior to submitting to the FAA for analysis.

SafeRoute Data

SafeRoute data refers to parameters recorded by the Traffic Alert Collision and Avoidance System (TCAS) surveillance processor including parameters related to surrounding ADS-B traffic, the host aircraft and the SafeRoute applications. SafeRoute data was used to identify flights on which CAVS was used, for generating the CAVS Parameters of Interest files and for supplementing the flight crew comment sheets by identifying the FOQA data file associated with each CAVS flight. Similarly, the same process was followed for M&S application data resulting in the generation of the M&S Parameter of Interest files. Parameters for CAVS and M&S include flight arrival date/time, ownship latitude, ownship longitude, aircraft speed, traffic latitude, traffic longitude, range to traffic, spacing interval, etc. Similar to FOQA data protections, SafeRoute data was de-identified prior to providing to the FAA.

Appendix G. Data Analysis Mann-Whitney Test Summaries

Table 17. Average Time Between Arrivals in VMC and MMC

			Pre-CAVS		CAVS		Difference (Positive = Improvement)		Statistically Significant?
Flights	Weather	Runway	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
All	VMC	27L	158	2:35	184	2:36	(00:01)	(0.6%)	N
All	VMC	27R	2009	2:02	2034	1:59	00:03	2.5%	N
All	VMC	09R	610	1:55	225	1:56	(00:01)	(0.9%)	N
All	MMC	27L	18	3:02	17	2:21	00:41	22.5%	Y
All	MMC	27R	417	2:02	340	1:59	00:03	2.5%	N
All	MMC	09R	1437	1:58	630	1:52	00:06	5.1%	Y
AAL A330s	MMC	27R	32	2:01	25	2:13	(00:12)	(9.90%)	N
AAL A330s	MMC	09R	80	2:01	51	2:04	(00:03)	(2.40%)	N

*Approaching significance

Table 18. Average Time Between Arrivals: Non-AAL A330s vs. AAL A330s in MMC

			Non-AAL A330s		AAL A330s		Difference (Positive = Improvement)		Statistically Significant?
Time Period	Weather	Runway	Data Points	Avg Flight Time (mm:ss)	Data Points	Avg Flight Time (mm:ss)	Avg Flight Time (mm:ss)	Avg Flight Time (%)	Avg Flight Time
CAVS	MMC	09R	579	1:51	61	2:04	(00:13)	(11.7%)	Y
CAVS	MMC	27R	315	1:58	25	2:13	(00:15)	(12.70%)	N

*Approaching significance

Table 19. Time/Distance Flown from 25nm Radius to Runway: All Flights in VMC and MMC

		Pre-CAVS			CAVS			Difference (Positive = Improvement)		Statistically Significant?	
Weather	Direction & Runway	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time	Avg Distance Flown
VMC	East 27L	304	09:13	29.69	272	09:27	30.5	(00:14)	(0.77)	N	N
VMC	West 27L	176	14:23	47.49	213	13:49	46.7	00:35	0.79	N	N
VMC	East 27R	1308	13:34	45.01	1374	13:36	45.5	(00:02)	(0.53)	N	N
VMC	West 27R	910	16:52	56.53	875	17:02	58.4	(00:11)	(1.83)	Y	Y
VMC	East 09R	295	15:04	47.92	114	15:23	50.6	(00:19)	(2.64)	Y	Y
VMC	West 09R	343	12:29	38.93	116	14:00	48.3	(01:31)	(9.40)	Y	Y
MMC	East 27L	41	10:44	33.62	31	08:58	27.7	01:46	5.94	Y	Y
MMC	West 27L	32	14:08	46.52	26	15:24	49.0	(01:16)	(2.48)	N	N
MMC	East 27R	259	16:53	54.39	220	15:04	48.9	01:49	5.47	Y	Y
MMC	West 27R	182	17:40	58.82	154	16:51	56.1	00:49	2.70	N*	Y
MMC	East 09R	792	16:12	52.26	373	17:12	54.6	(01:00)	(2.34)	Y	Y
MMC	West 09R	704	14:38	45.94	279	15:41	48.0	(01:03)	(2.06)	Y	Y

*Approaching significance

Table 20. Time/Distance Flown from 25nm Radius to Runway: AAL A330s in VMC and MMC

		Pre-CAVS			CAVS			Difference (Positive = Improvement)		Statistically Significant?	
Weather	Direction & Runway	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time	Avg Distance Flown
VMC	East 27R	100	13:23	44.31	148	12:49	42.8	00:34	1.53	N	N
VMC	West 27R	36	12:52	44.69	25	14:59	57.8	(02:07)	(13.09)	N	N
VMC	East 09R	25	14:57	49.98	16	16:08	53.7	(01:10)	(3.75)	N	N
VMC	West 09R	13	14:44	46.78	2	17:06	60.2	(02:21)	(13.46)	N	N
MMC	East 27R	31	16:14	52.89	25	13:05	43.3	03:09	9.58	N*	N
MMC	West 27R	5	14:05	48.28	5	12:15	43.6	01:50	4.65	N	N
MMC	East 09R	75	16:58	56.09	50	16:08	54.2	00:50	1.87	N	N

*Approaching significance

Table 21. Time/Distance Flown from 25nm Radius to Runway CAVS: Non-AAL A330s vs. AAL A330s in VMC and MMC

		Non-AAL A330s			AAL A330s			Difference (Positive = Improvement)		Statistically Significant?	
Weather	Direction & Runway	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time	Avg Distance Flown
VMC	East 27R	1226	13:42	45.87	148	12:49	42.8	00:52	3.09	Y	Y
VMC	West 27R	850	17:06	58.37	25	14:59	57.8	02:07	0.60	Y	Y
VMC	East 09R	98	15:16	50.05	16	16:08	53.7	(00:52)	(3.68)	N	Y
MMC	East 27R	195	15:19	49.64	25	13:05	43.3	02:14	6.33	Y	Y
MMC	East 09R	323	17:22	54.66	50	16:08	54.2	01:14	0.44	N	N

*Approaching significance

Table 22. Time/Distance Flown from Fix-to-Runway, Non-CAVS vs. CAVS: Deteriorating Weather where Ceiling Varies and Visibility All

			Non-CAVS Flight Ops			CAVS Flight Ops			Difference (Positive = Improvement)		Statistically Significant?	
Ceiling	Visibility	Fix Pair	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time	Avg Distance Flown
<=6000	All	CHEAZ-09R	287	10:14	29.42	192	10:06	29.4	00:08	(0.02)	N	N
<=5000	All	CHEAZ-09R	275	10:18	29.61	176	09:57	28.9	00:21	0.66	N	N
<=4000	All	CHEAZ-09R	242	10:26	29.86	150	10:13	29.5	00:14	0.35	N	N
<=3000	All	CHEAZ-09R	196	10:41	30.48	112	10:19	29.6	00:22	0.86	N	N
<=2200	All	CHEAZ-09R	152	10:49	30.85	83	10:30	29.9	00:19	0.91	N	N
<=6000	All	STAYK-09R	308	08:36	24.13	189	08:28	23.9	00:08	0.23	N	N
<=5000	All	STAYK-09R	289	08:39	24.25	173	08:19	23.4	00:21	0.86	N	N
<=4000	All	STAYK-09R	255	08:47	24.52	149	08:30	23.8	00:18	0.76	N	N
<=3000	All	STAYK-09R	217	08:53	24.77	118	08:26	23.5	00:27	1.28	N	N
<=2200	All	STAYK-09R	171	09:03	25.29	89	08:30	23.5	00:33	1.79	N	N*
<=6000	All	PSOUT-27R	326	08:29	23.38	245	08:24	23.2	00:05	0.20	N	N
<=5000	All	PSOUT-27R	254	08:42	23.90	204	08:25	23.1	00:17	0.79	N	N
<=4000	All	PSOUT-27R	166	08:59	24.65	136	08:44	23.8	00:15	0.81	N	N
<=3000	All	PSOUT-27R	103	09:26	25.66	79	09:32	25.8	(00:06)	(0.11)	N	N
<=2200	All	PSOUT-27R	62	10:17	27.77	55	10:13	27.3	00:04	0.51	N	N
<=6000	All	WOJIK-27R	192	11:19	32.98	159	11:05	32.4	00:14	0.56	N	N
<=5000	All	WOJIK-27R	160	11:30	33.55	135	11:08	32.5	00:22	1.07	N	N
<=4000	All	WOJIK-27R	105	11:51	34.44	101	11:22	33.0	00:30	1.42	N	N
<=3000	All	WOJIK-27R	65	12:28	35.95	65	11:55	34.3	00:34	1.60	N	N
<=2200	All	WOJIK-27R	45	13:04	37.57	49	12:09	34.7	00:55	2.84	Y	Y
<=6000	All	EXPRS-09R	64	08:22	23.24	37	08:52	25.3	(00:30)	(2.04)	N	N
<=5000	All	EXPRS-09R	56	08:36	23.94	35	09:01	25.7	(00:25)	(1.78)	N	N
<=4000	All	EXPRS-09R	42	09:00	24.83	28	08:56	25.3	00:05	(0.46)	N	N
<=3000	All	EXPRS-09R	38	09:05	25.10	19	08:55	25.0	00:09	0.08	N	N
<=2200	All	EXPRS-09R	29	09:37	26.53	16	09:09	25.5	00:28	1.06	N	N
<=6000	All	KYILL-09R	33	11:09	31.89	23	11:52	34.7	(00:43)	(2.81)	N	N
<=5000	All	KYILL-09R	30	11:26	32.78	22	11:40	34.2	(00:14)	(1.41)	N	N
<=4000	All	KYILL-09R	24	11:47	33.71	17	11:39	33.8	00:09	(0.09)	N	N
<=3000	All	KYILL-09R	23	11:50	33.80	11	11:46	33.6	00:04	0.15	N	N
<=2200	All	KYILL-09R	19	12:19	34.88	10	11:54	33.9	00:25	0.98	N	N
<=6000	All	EYRIE-27R	74	09:28	26.86	34	08:47	24.6	00:40	2.21	N	N
<=5000	All	EYRIE-27R	56	09:42	27.51	18	09:30	27.0	00:11	0.49	N	N
<=4000	All	EYRIE-27R	21	10:28	29.31	13	09:54	27.8	00:34	1.47	N	N
<=6000	All	HIFAL-27R	46	11:30	33.67	22	10:09	29.6	01:22	4.04	Y	Y
<=5000	All	HIFAL-27R	32	11:40	34.19	12	10:52	31.9	00:47	2.29	N	N
<=4000	All	HIFAL-27R	16	11:38	33.67	11	11:02	32.2	00:36	1.44	N	N

*Approaching significance

Table 23. Time/Distance Flown from Fix-to-Runway, Non-CAVS vs. CAVS: Deteriorating Weather where Ceiling All and Visibility Varies

			Non-CAVS Flight Ops			CAVS Flight Ops			Difference (Positive = Improvement)		Statistically Significant?	
Ceiling	Visibility	Fix Pair	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time	Avg Distance Flown
All	<=7	CHEAZ-09R	129	10:29	30.06	87	09:52	28.3	00:37	1.76	N	N
All	<=6	CHEAZ-09R	105	10:40	30.55	59	10:15	29.3	00:25	1.27	N	N
All	<=5	CHEAZ-09R	79	10:41	30.53	41	10:30	30.0	00:11	0.52	N	N
All	<=4	CHEAZ-09R	67	10:30	30.03	33	10:36	30.4	(00:06)	(0.33)	N	N
All	<=3	CHEAZ-09R	49	10:00	28.79	25	10:20	29.6	(00:20)	(0.78)	N	N
All	<=7	STAYK-09R	135	09:01	25.32	75	08:32	23.8	00:29	1.57	N	N
All	<=6	STAYK-09R	113	09:03	25.36	56	08:41	24.2	00:23	1.20	N	N
All	<=5	STAYK-09R	90	08:55	24.99	43	08:48	24.5	00:07	0.48	N	N
All	<=4	STAYK-09R	70	08:54	24.95	38	08:33	23.9	00:21	1.05	N	N
All	<=3	STAYK-09R	48	08:12	23.41	28	08:10	23.0	00:02	0.40	N	N
All	<=7	PSOUT-27R	74	09:40	26.19	58	09:53	26.5	(00:13)	(0.28)	N	N
All	<=6	PSOUT-27R	55	10:14	27.62	45	10:13	27.6	00:01	0.02	N	N
All	<=5	PSOUT-27R	50	10:22	28.04	35	10:16	27.7	00:06	0.31	N	N
All	<=4	PSOUT-27R	35	09:52	27.01	23	10:09	27.5	(00:17)	(0.53)	N	N
All	<=3	PSOUT-27R	30	10:06	27.79	19	10:12	27.8	(00:06)	0.01	N	N
All	<=7	WOJIK-27R	52	12:30	36.18	49	12:11	35.0	00:19	1.15	N	N
All	<=6	WOJIK-27R	43	12:42	36.67	41	12:15	35.5	00:28	1.20	N	N
All	<=5	WOJIK-27R	39	12:53	37.22	32	12:17	35.5	00:37	1.70	N	N
All	<=4	WOJIK-27R	25	12:45	37.31	22	12:17	35.7	00:27	1.58	N	N
All	<=3	WOJIK-27R	23	13:07	38.39	17	12:42	37.0	00:24	1.35	N	N
All	<=7	EXPRS-09R	38	09:09	25.73	10	08:26	23.4	00:43	2.34	N	N
All	<=7	EYRIE-27R	13	10:39	28.69	10	09:44	26.7	00:54	2.01	N	N

*Approaching significance

Table 24. Time/Distance Flown from Fix-to-Runway, Non-CAVS vs. CAVS: Deteriorating Weather where Ceiling Varies and Visibility Varies

			Non-CAVS Flight Ops			CAVS Flight Ops			Difference (Positive = Improvement)		Statistically Significant?	
Ceiling	Visibility	Fix Pair	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Data Points	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time (mm:ss)	Avg Distance Flown (nm)	Avg Flight Time	Avg Distance Flown
<=5000	<=5	CHEAZ-09R	73	10:53	31.10	38	10:37	30.3	00:16	0.78	N	N
<=4000	<=5	CHEAZ-09R	72	10:49	30.85	36	10:44	30.6	00:04	0.24	N	N
<=3000	<=5	CHEAZ-09R	69	10:53	31.03	36	10:44	30.6	00:08	0.43	N	N
<=5000	<=4	CHEAZ-09R	62	10:41	30.56	31	10:40	30.5	00:01	0.04	N	N
<=4000	<=4	CHEAZ-09R	61	10:36	30.26	31	10:40	30.5	(00:04)	(0.27)	N	N
<=3000	<=4	CHEAZ-09R	58	10:40	30.44	31	10:40	30.5	(00:00)	(0.09)	N	N
<=5000	<=3	CHEAZ-09R	45	10:10	29.30	23	10:25	29.7	(00:15)	(0.42)	N	N
<=4000	<=3	CHEAZ-09R	45	10:10	29.30	23	10:25	29.7	(00:15)	(0.42)	N	N
<=3000	<=3	CHEAZ-09R	42	10:14	29.49	23	10:25	29.7	(00:11)	(0.23)	N	N
<=5000	<=5	STAYK-09R	81	09:07	25.46	41	08:52	24.7	00:15	0.74	N	N
<=4000	<=5	STAYK-09R	80	09:04	25.25	40	08:55	24.8	00:08	0.43	N	N
<=3000	<=5	STAYK-09R	77	09:08	25.45	40	08:55	24.8	00:12	0.63	N	N
<=5000	<=4	STAYK-09R	64	09:02	25.26	36	08:37	24.1	00:25	1.17	N	N
<=4000	<=4	STAYK-09R	63	08:57	24.99	36	08:37	24.1	00:20	0.91	N	N
<=3000	<=4	STAYK-09R	61	08:59	25.14	36	08:37	24.1	00:22	1.05	N	N
<=5000	<=3	STAYK-09R	45	08:10	23.30	26	08:14	23.2	(00:05)	0.10	N	N
<=4000	<=3	STAYK-09R	45	08:10	23.30	26	08:14	23.2	(00:05)	0.10	N	N
<=3000	<=3	STAYK-09R	43	08:11	23.43	26	08:14	23.2	(00:04)	0.23	N	N
<=5000	<=5	PSOUT-27R	49	10:17	27.84	30	10:18	27.8	(00:02)	0.06	N	N
<=4000	<=5	PSOUT-27R	47	10:24	28.16	30	10:18	27.8	00:05	0.39	N	N
<=3000	<=5	PSOUT-27R	44	10:32	28.48	26	10:23	27.9	00:09	0.56	N	N
<=5000	<=4	PSOUT-27R	35	09:52	27.01	18	10:11	27.6	(00:19)	(0.55)	N	N
<=4000	<=4	PSOUT-27R	35	09:52	27.01	18	10:11	27.6	(00:19)	(0.55)	N	N
<=3000	<=4	PSOUT-27R	33	10:02	27.49	14	10:17	27.8	(00:15)	(0.29)	N	N
<=5000	<=3	PSOUT-27R	30	10:06	27.79	15	10:21	28.2	(00:15)	(0.37)	N	N
<=4000	<=3	PSOUT-27R	30	10:06	27.79	15	10:21	28.2	(00:15)	(0.37)	N	N
<=3000	<=3	PSOUT-27R	29	10:12	28.08	11	10:33	28.6	(00:21)	(0.57)	N	N
<=5000	<=5	WOJIK-27R	38	12:48	37.01	27	12:04	34.8	00:44	2.20	N	N
<=4000	<=5	WOJIK-27R	36	12:59	37.55	27	12:04	34.8	00:56	2.74	N	N
<=3000	<=5	WOJIK-27R	32	13:14	38.21	24	12:01	34.6	01:12	3.63	N*	N*
<=4000	<=4	WOJIK-27R	25	12:45	37.31	17	11:58	34.7	00:47	2.64	N	N
<=3000	<=4	WOJIK-27R	23	13:05	38.29	14	11:52	34.3	01:12	4.02	N	N
<=5000	<=3	WOJIK-27R	23	13:07	38.39	13	12:29	36.3	00:38	2.09	N	N
<=4000	<=3	WOJIK-27R	23	13:07	38.39	13	12:29	36.3	00:38	2.09	N	N
<=3000	<=3	WOJIK-27R	22	13:17	38.93	10	12:31	36.2	00:47	2.71	N	N

*Approaching significance

Table 25. Time/Distance Flown from Fix-to-Runway, Non-CAVS vs. CAVS: VMC, MMC & IMC

		Non-CAVS Flight Ops			CAVS Flight Ops			Difference (Positive = Improvement)		Statistically Significant?	
Wx	**Fix Pair**	**Data Points**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Data Points**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Avg Flight Time**	**Avg Distance Flown**
VMC	CHEAZ-09R	305	08:53	26.00	241	09:05	26.9	(00:12)	(0.86)	N	N
MMC	CHEAZ-09R	57	10:39	30.34	31	09:46	28.3	00:53	2.04	N*	N
IMC	CHEAZ-09R	148	10:38	30.35	83	10:31	30.1	00:07	0.28	N	N
VMC	STAYK-09R	276	07:56	22.63	216	07:58	22.8	(00:02)	(0.12)	N	N
MMC	STAYK-09R	59	08:41	23.95	31	08:08	22.9	00:33	1.06	N	N
IMC	STAYK-09R	167	08:55	25.00	89	08:31	23.6	00:24	1.37	N	N
VMC	PSOUT-27R	1453	07:41	21.33	1110	07:46	21.8	(00:05)	(0.47)	N	Y
MMC	PSOUT-27R	43	07:53	21.65	25	07:55	22.2	(00:03)	(0.52)	N	N
IMC	PSOUT-27R	62	10:26	28.24	63	10:14	27.4	00:12	0.83	N	N
VMC	WOJIK-27R	875	10:07	29.86	722	10:08	30.1	(00:01)	(0.25)	N	N
MMC	WOJIK-27R	21	10:49	31.32	16	11:10	33.2	(00:21)	(1.85)	N	N
IMC	WOJIK-27R	46	13:04	37.64	57	12:16	35.2	00:48	2.40	N*	Y
VMC	EXPRS-09R	73	07:39	21.72	62	08:41	25.2	(01:02)	(3.44)	Y	Y
IMC	EXPRS-09R	36	09:32	26.56	16	09:09	25.5	00:23	1.09	N	N
VMC	KYILL-09R	41	10:06	29.65	39	11:39	34.7	(01:33)	(5.06)	Y	Y
IMC	KYILL-09R	21	12:08	34.57	10	11:54	33.9	00:14	0.67	N	N
VMC	EYRIE-27R	401	08:19	23.62	207	08:48	25.1	(00:29)	(1.48)	Y	Y
VMC	HIFAL-27R	239	10:22	30.48	131	10:40	31.5	(00:17)	(0.99)	N	N

*Approaching significance

Table 26. Time/Distance Flown from Fix-to-Runway, Not CAVS+Coupled <9K' vs. CAVS+Coupled <9K': Ceiling All and Visibility All

			Not CAVS+Coupled <9K'			CAVS+Coupled <9K'			Difference (Positive = Improvement)		Statistically Significant?	
Ceiling	**Visibility**	**Fix Pair**	**Data Points**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Data Points**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Avg Flight Time**	**Avg Distance Flown**
All	All	CHEAZ-09R	107	09:19	27.37	11	09:38	28.4	(00:19)	(1.05)	N	N
All	All	STAYK-09R	98	08:10	23.29	12	07:39	21.7	00:31	1.59	N	N
All	All	PSOUT-27R	311	07:56	22.16	41	07:10	19.9	00:46	2.26	**Y**	**Y**
All	All	WOJIK-27R	218	10:19	30.58	23	09:34	28.4	00:45	2.18	N	N

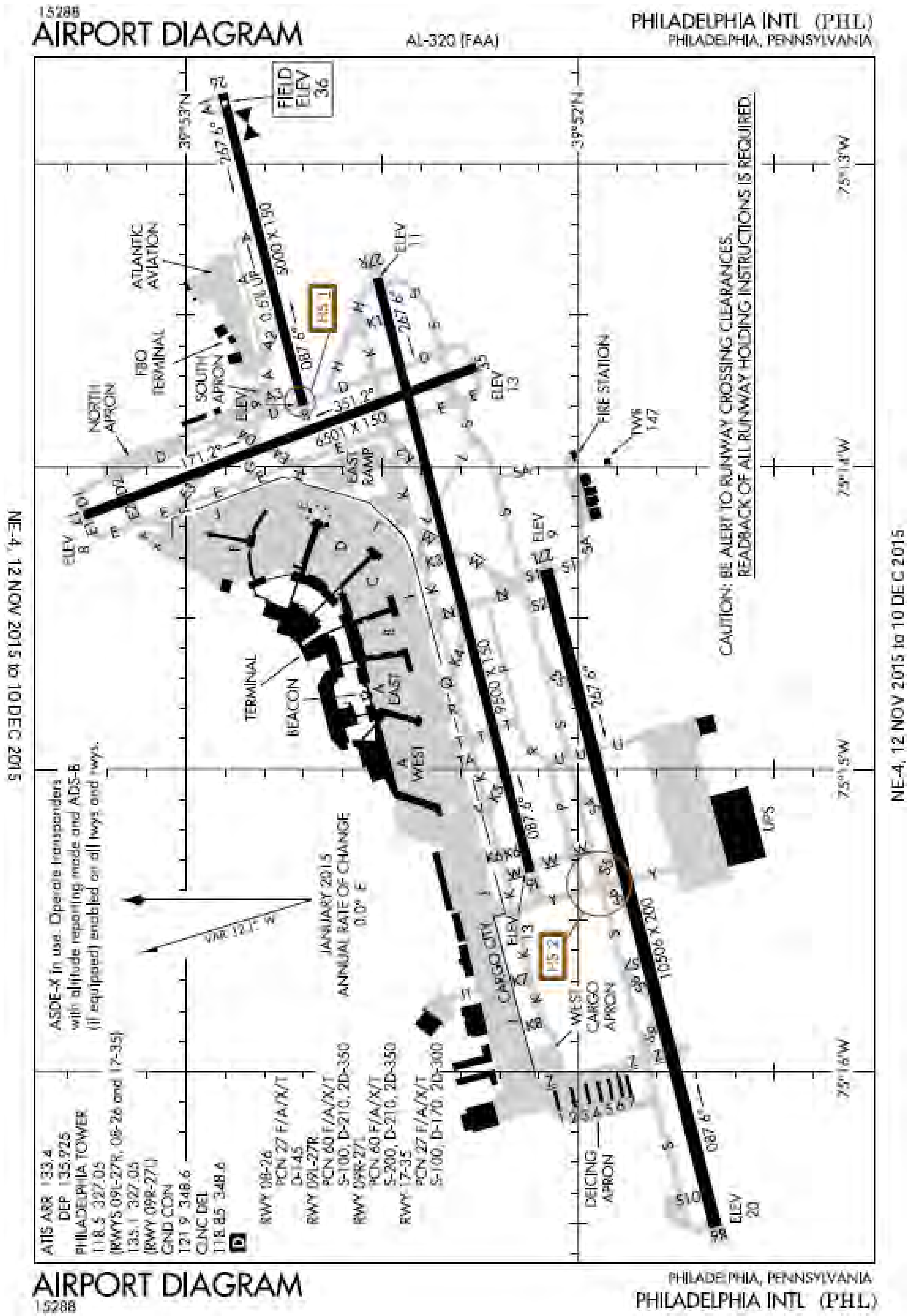
*Approaching significance

Table 27. Time/Distance Flown from Fix-to-Runway, Not CAVS+Coupled <9K' vs. CAVS+Coupled <9K': VMC, MMC and IMC

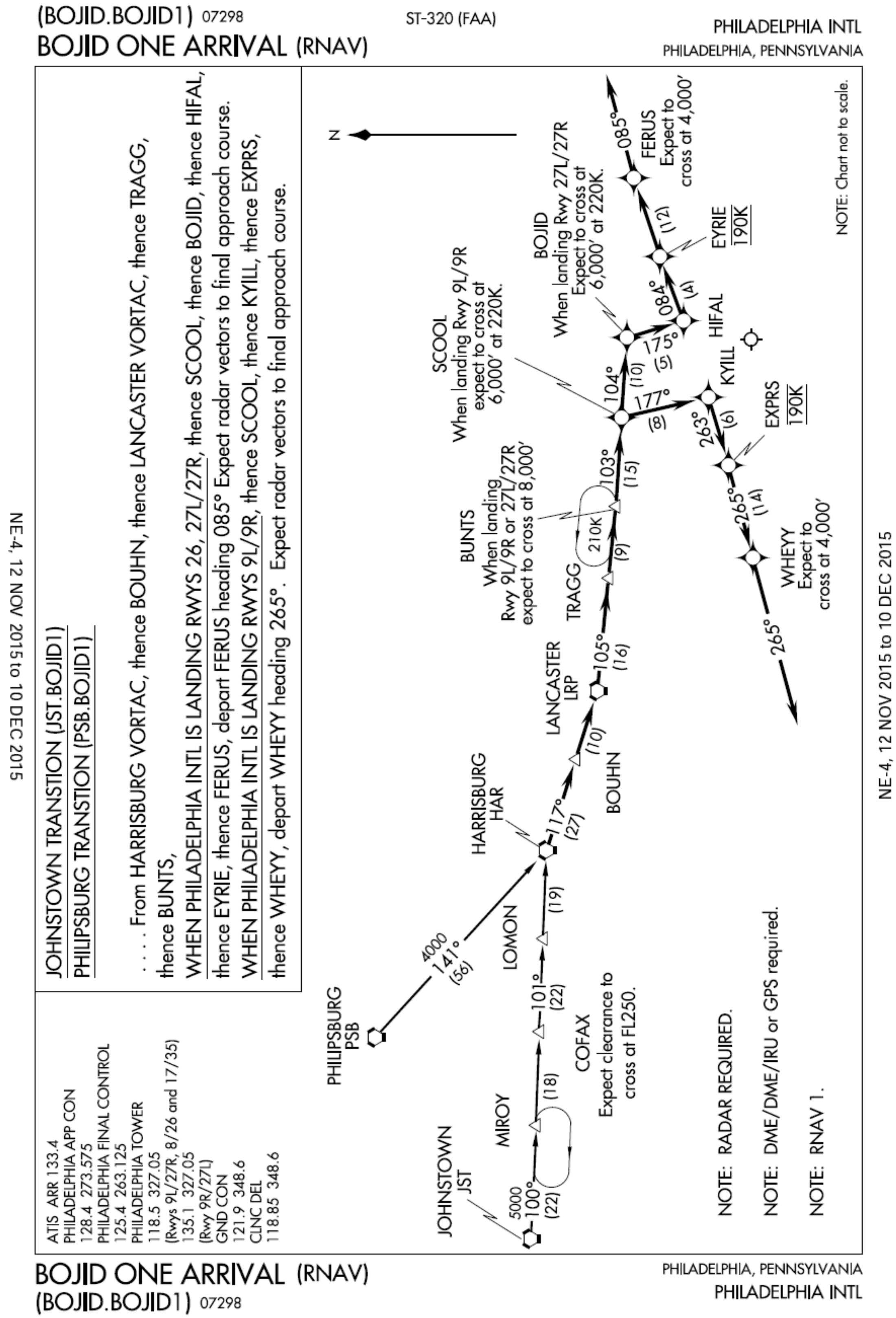
		Not CAVS+Coupled <9K'			CAVS+Coupled <9K'			Difference (Positive = Improvement)		Statistically Significant?	
Wx	**Fix Pair**	**Data Points**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Data Points**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Avg Flight Time (mm:ss)**	**Avg Distance Flown (nm)**	**Avg Flight Time**	**Avg Distance Flown**
VMC	PSOUT-27R	294	07:50	21.95	41	07:10	19.9	00:40	2.06	Y	Y
VMC	WOJIK-27R	205	10:14	30.37	23	09:34	28.4	00:39	1.97	N	N

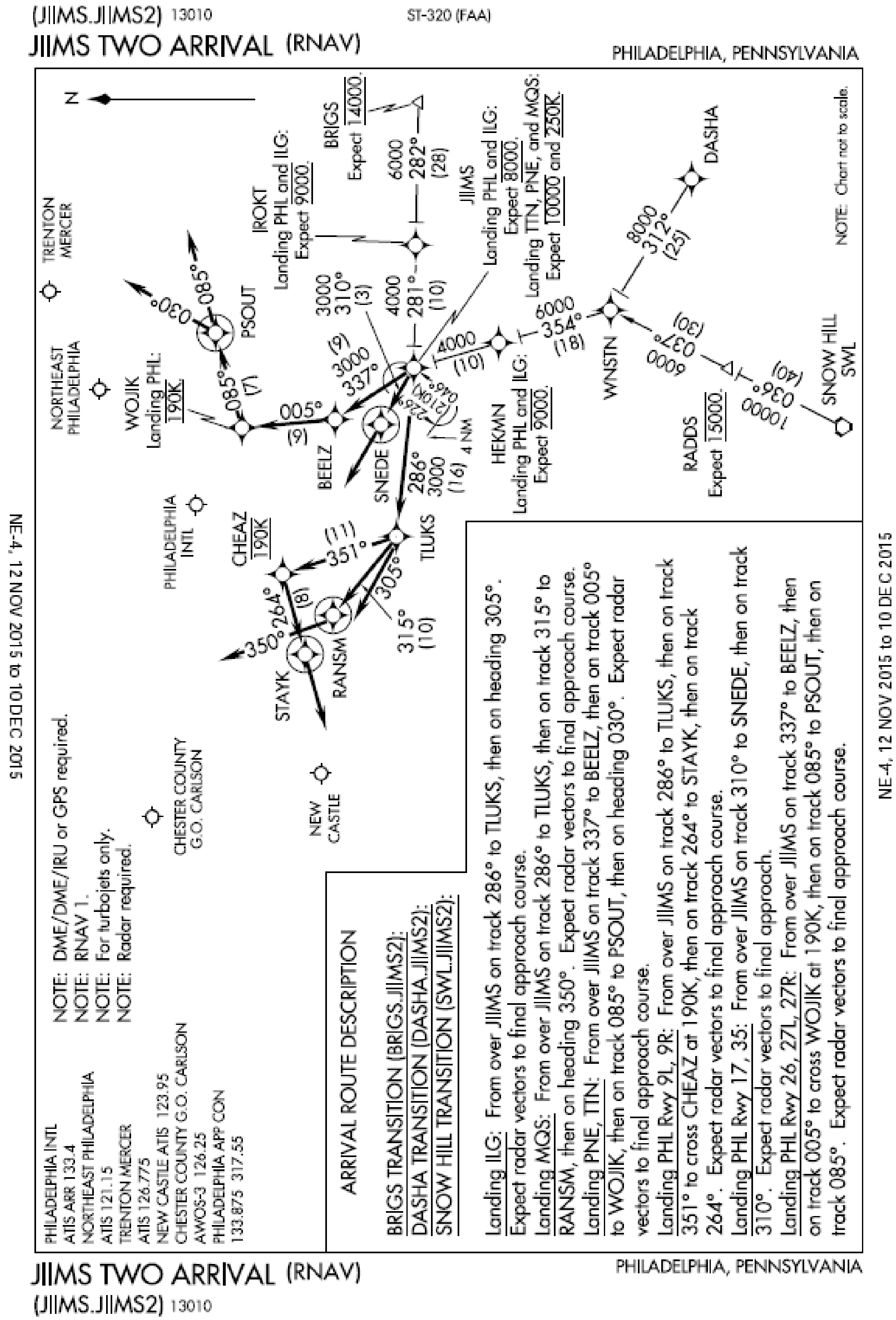
*Approaching significance

Appendix H. PHL Airport Diagram



Appendix I. BOJID ONE and JIIMS TWO RNAV Arrivals





(JIIMS.JIIMS2) 13010
ST-320 (FAA)
JIIMS TWO ARRIVAL (RNAV)
PHILADELPHIA, PENNSYLVANIA
NE-4, 12 NOV 2015 to 10 DEC 2015
PHILADELPHIA INTL
ATIS ARR 133.4
NORTHEAST PHILADELPHIA
ATIS 121.15
TRENTON MERCER
ATIS 126.775
NEW CASTLE ATIS 123.95
CHESTER COUNTY G.O. CARLSON
AWOS-3 126.25
PHILADELPHIA APP CON
133.875 317.55
NOTE: DME/DME/IRU or GPS required.
NOTE: RNAV 1.
NOTE: For turbojets only.
NOTE: Radar required.
ARRIVAL ROUTE DESCRIPTION
BRIGS TRANSITION (BRIGS.JIIMS2):
DASHA TRANSITION (DASHA.JIIMS2):
SNOW HILL TRANSITION (SWL.JIIMS2):
Landing ILG: From over JIIMS on track 286° to TLUKS, then on heading 305°. Expect radar vectors to final approach course.
Landing MQS: From over JIIMS on track 286° to TLUKS, then on track 315° to RANSM, then on heading 350°. Expect radar vectors to final approach course.
Landing PNE, TTN: From over JIIMS on track 337° to BEELZ, then on track 005° to WOJIK, then on track 085° to PSOUT, then on heading 030°. Expect radar vectors to final approach course.
Landing PHL Rwy 9L, 9R: From over JIIMS on track 286° to TLUKS, then on track 351° to cross CHEAZ at 190K, then on track 264° to STAYK, then on track 264°. Expect radar vectors to final approach course.
Landing PHL Rwy 17, 35: From over JIIMS on track 310° to SNEDE, then on track 310°. Expect radar vectors to final approach.
Landing PHL Rwy 26, 27L, 27R: From over JIIMS on track 337° to BEELZ, then on track 005° to cross WOJIK at 190K, then on track 085° to PSOUT, then on track 085°. Expect radar vectors to final approach course.
TRENTON MERCER
NORTHEAST PHILADELPHIA
WOJIK
Landing PHL: 190K
PSOUT
IROKT
Landing PHL and ILG: Expect 9000.
BRIGS
Expect 14000.
JIIMS
Landing PHL and ILG: Expect 8000.
Landing TTN, PNE, and MQS: Expect 10000 and 250K.
DASHA
WNSTN
HEKMN
Landing PHL and ILG: Expect 9000.
RADDS
Expect 15000.
SNOW HILL
SWL
BEELZ
SNEDE
TLUKS
CHEAZ
190K
PHILADELPHIA INTL
RANSM
STAYK
CHESTER COUNTY G.O. CARLSON
NEW CASTLE
NOTE: Chart not to scale.
JIIMS TWO ARRIVAL (RNAV)
PHILADELPHIA, PENNSYLVANIA
(JIIMS.JIIMS2) 13010