MTR 00W0000023
MITRE TECHNICAL REPORT

Analysis of Triple Arrivals to Hartsfield Atlanta International Airport

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Abstract

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) investigated new procedures that would improve arrival throughput at Hartsfield Atlanta International Airport (ATL) in marginal visual weather. The analysis focused on adding a third arrival stream to closely spaced parallel runways during periods of peak arrivals and measuring the impacts on operations and delays. Two of the procedures investigated in this study show promise for being implemented in a short timeframe, and have the potential for reducing arrival delay at the expense of some increase in departure delay. Two other procedures will require more equipment or development and are not likely to be available for implementation in the near future.

KEYWORDS: Air traffic control (ATC), Along Track Spacing (ATS), Atlanta, Federal Aviation Administration (FAA), Simultaneous Offset Instrument Approach (SOIA), Total Airspace and Airport Modeller (TAAM)

Acknowledgments

We would like to acknowledge the significant contributions of several study team members. Todd Waller of Delta Airlines provided the initial simulation baseline and other input information and worked closely with us throughout the analysis to model ground operations. The validation team—Scott Kirby (FAA Atlanta Traffic Management), David Scherer (FAA Atlanta Procedures), and Ron Weber (FAA Atlanta tower controller)—gave us valuable input throughout the modeling process and ensured that the final product was useful for the decision. Tom Denny (FAA Southern Region) provided direction and focus for the entire study. Frank Loy (FAA ATA-200, Office of Airspace Planning and Analysis) coordinated the efforts of the MITRE team with other FAA offices and provided input throughout the process. Finally, we thank Angela Signore for her help in document preparation.

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Section 1

Background and Motivation for Analyzing Triple Arrivals

The Air Traffic Control (ATC) system serving Hartsfield Atlanta International Airport (ATL) manages both arriving and departing aircraft very efficiently under visual weather conditions. The standard mode of operation at ATL during good weather is simultaneous visual arrivals, where ATC assigns two of the four parallel runways to arrivals and two runways to departures, as indicated in Figure 1-1. While there are some delays even in the best weather conditions, the operation is generally very efficient.

When the weather precludes simultaneous visual arrivals, arrival delays increase significantly. The Southern Regional Office (ASO) of the Federal Aviation Administration (FAA) and Delta Airlines initiated an effort to investigate new procedures that would improve arrival throughput in poor weather, at least in marginal visual conditions. They formed a study team of individuals from ATL tower, ATL approach control (TRACON), the Atlanta Air Route Traffic Control Center (ARTCC), and Delta Airlines to study adding a third arrival stream during periods of peak arrivals. The airfield configuration does not allow for three simultaneous approach streams, even with advanced surveillance equipment. Therefore, adding a third arrival stream would require a new procedure. FAA's Office of Airspace Planning and Analysis (ATA-200) supported the ATL study team by requesting The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) to outline potential new procedures and analyze the impacts on operations (both airspace and ground) and delays.

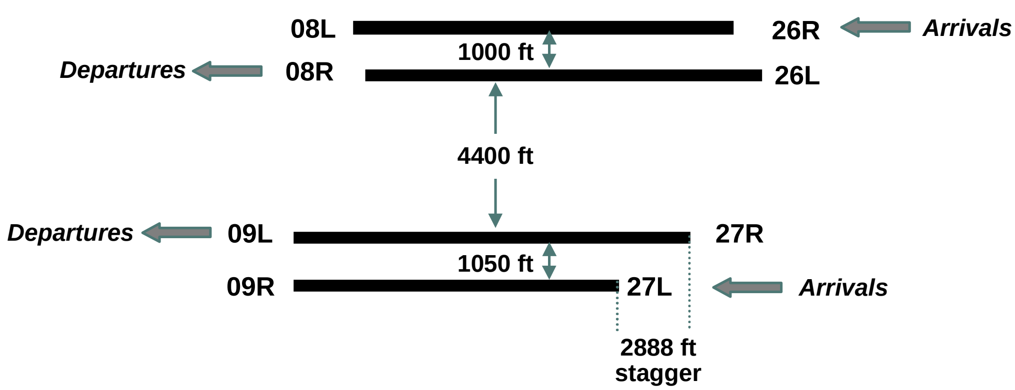

Figure 1-1. Current Runway Usage at ATL (West Flow Illustrated)

A new procedure allowing approaches to three parallel runways at ATL is viewed as an interim capacity enhancement until the fifth runway is available in 2004 or 2005. Since the location of the fifth runway provides adequate lateral separation for current simultaneous triple arrival procedures, there will be no need for the procedures analyzed in this study after the fifth runway is commissioned in 2005. Therefore, the study team focused on procedures that could be implemented in the very near term—within 1-2 years.

A third arrival stream could be applied to the north or south inboard runways, but only the south runway was studied here for two reasons. First, there is more protected airspace to the south of the airport, making it easier to add a third stream. Second, a third arrival stream to the south would more or less follow the path of the new routes being proposed for the fifth runway. Developing a procedure that follows existing planned routes minimizes the possibility of unanticipated environmental impacts.

In order to provide the best chance of near-term implementation, the new procedures build on the features of procedures to two and three parallel runways that have been proposed or implemented at other locations. These include dependent parallel approaches, simultaneous offset instrument approaches (SOIA) to two closely spaced runways, and simultaneous instrument approaches to three parallel runways. A fourth procedure, called along track spacing (ATS), has little chance for near-term implementation, but was analyzed for its potential for increasing capacity at many major airports. The approach procedures considered in this analysis combine simultaneous or dependent approach procedures with SOIA or ATS approaches to a third arrival runway.

Section 2

Study Overview

A primary objective of this study was to define four alternative triple parallel arrival procedures in enough detail to allow a preliminary analysis of the type of development, both internally and externally to FAA, that might be required to implement the procedures. Another objective was to quantify the delays (both arrivals and departures) and throughput associated with the new procedures and compare them with the delays and throughput obtained for current operations as modeled in the baseline scenario.

The ATL study team first met with ATA-200 and the CAASD analysis team in October 1999 to outline an approach for the study. It was agreed that CAASD would develop the four alternative procedures. FAA’s flight standards office supporting procedure development (AFS-420) provided guidance and analytical support for this effort. CAASD also agreed to analyze historical weather data to provide an indication of how often each of the procedures could be used.

It was agreed in October 1999 that CAASD would work cooperatively with Delta Airlines to model the procedures using the Total Airspace and Airport Modeller (TAAM), which would be used to provide estimates of delay and impacts on throughput. Delta provided critical information about their schedules for the year 2001, the year selected for the study baseline. Delta also contributed the TAAM model of ATL that was used as a starting point for the baseline simulation. CAASD revised this baseline model to reflect the weather conditions of interest in the study and implemented the new approach procedures in TAAM. CAASD and Delta worked collaboratively throughout the project to check for accuracy and completeness.

Details of the four procedures and preliminary simulation results were presented to the study team in January 2000. The study team decided to focus subsequent analysis on the two procedures that had the most potential for near-term implementation. The team also made changes at the January 2000 meeting in the assumptions concerning ground configuration and runway usage. These changes addressed problems in running the new procedures with existing taxi and departure queuing schemes.

CAASD and Delta incorporated these changes into the simulation model and presented new results in February 2000 to a group that included representatives from the Air Line Pilots Association (ALPA). Following that presentation, small additional refinements were made to the simulation model by both CAASD and Delta to further refine the operations. These modifications caused minor changes to the numerical results reported in February, but not to any of the conclusions. The results presented in Section 5 are the final results after all modifications.

Throughout the development of the simulation model, there has been a strong emphasis on validation of the assumptions and baseline results. The ATL study team assigned a small team of three individuals experienced in ATL tower, TRACON, and center operations to validate the modeling assumptions. In addition, CAASD has applied the guidelines for conducting an airspace study described in generic terms in RTCA SC-192, *Guidelines for Airspace Analysis*, and with more specificity in ATA-200's *Airspace Management Guidelines*. In accordance with these documents, CAASD supplemented the confirmation of assumptions and visual validation with an analysis that compared simulation results with operational data. Delay data were extracted from the Airline Service Quality Performance (ASQP) database; arrival rates and departure rates were extracted from ATL's Airport Resource Management System (ARMT) database.

Section 3

Procedures

Since the ATL study team was interested in implementing procedures in the near term, we emphasized defining the two procedures out of the initial four alternatives that could be applied without extensive equipment and procedure development. However, we also investigated the other two procedures, which provided greater capability but required more equipment or procedure development.

3.1 Simultaneous Offset Instrument Approaches (SOIAs)

Three of the procedures developed for this study used a technique called SOIA to the closely spaced parallel runways at ATL. This section discusses procedures and concerns inherent in all three of the SOIA procedures developed for ATL. Specifics for each of the procedures will be discussed in Sections 3.3.1, 3.3.2, and 3.3.3.

SOIAs to two parallel runways have been conducted successfully at the St. Louis International Airport (STL) since the mid-1980s, and have been tested at San Francisco International Airport (SFO). In the SOIA procedure, shown in Figure 3-1, parallel or near parallel streams of traffic are formed to two parallel runways. Since the runways are spaced closer than 2500 ft apart, two approach courses aligned with the runways would require standard wake turbulence separation between the approach streams, which would essentially reduce the arrival rate of the two runways to that of a single runway. To avoid this difficulty, one approach course is aligned with one runway, but the other approach course is offset at a distance greater than 2500 ft. Aircraft are arranged in pairs on the approaches using radar vectoring and speed control, with the aircraft on the offset approach behind the aircraft on the straight-in approach. Wake vortex separation need not be maintained between these two aircraft since the approach courses are separated by more than 2500 ft. The aircraft continue on the approach and fly down the glide path until visual conditions are encountered, which is labeled as the Clear of Clouds Point (CC) in Figure 3-1. The trailing aircraft (on the offset approach) must report visual contact with the leading aircraft (on the straight-in approach) and the landing runway to be issued a visual approach clearance. When the clearance is received, the trailing aircraft executes a sidestep maneuver to align with its runway and land. If the trailing aircraft does not acquire visual contact with the leading aircraft or cannot execute the SOIA for any reason prior to the Missed Approach Point (MAP), the trailing aircraft executes a missed approach that deviates away from the runways.

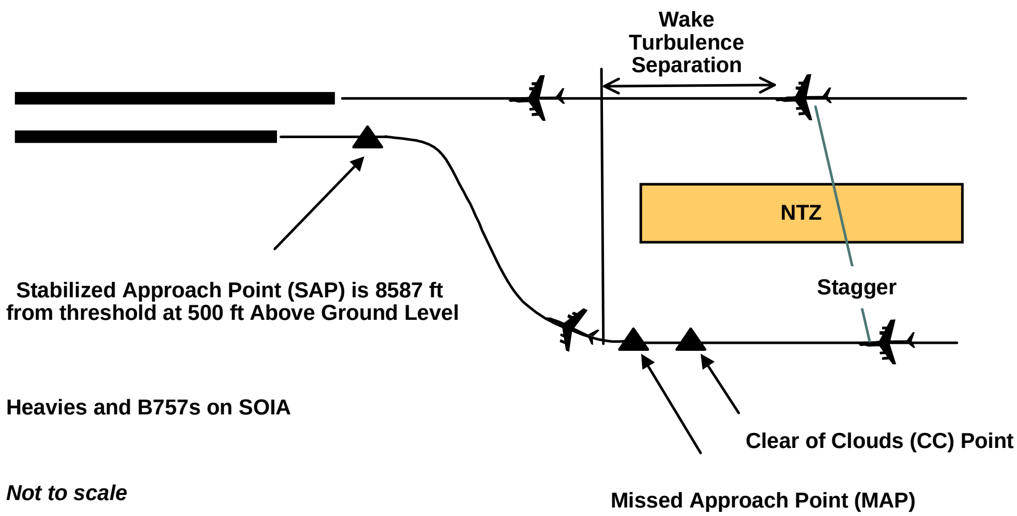

Figure 3-1. Simultaneous Offset Instrument Approach (SOIA)

Large aircraft following a heavy aircraft or B757, or small aircraft following any larger aircraft can safely fly with less than standard wake turbulence separation, but only if the trailing aircraft actively avoids wake turbulence by flying above the path of the leading aircraft. Since it could be difficult to implement a wake turbulence avoidance strategy during a SOIA due to limited maneuvering opportunity, the SOIA procedure generally requires that small and large aircraft fly as the leader on the straight-in approach. All heavy and B757 aircraft fly the offset approach as the trailing aircraft. With these restrictions, there should be no wake turbulence difficulties between the leading and trailing aircraft.

To avoid wake turbulence difficulties between pairs of aircraft, full wake turbulence separation is maintained between the trailing aircraft of one pair and the leading aircraft of the second pair.

Another concern is the requirement for the trailing aircraft to safely execute the sidestep maneuver at low altitude and reduced visibility. To ensure safety, the position of the MAP and CC point are set so that the sidestep maneuver can be accomplished from the MAP with less than 15 degrees of bank and less than 15 degrees of turn. There is sufficient distance to allow the aircraft to be wings level at greater than 500 ft above ground level (AGL) after the sidestep maneuver at the stabilized approach point (SAP). These requirements translate into higher ceiling and visibility requirements for larger sidesteps. Also, a glide path is provided for the SOIA to allow the trailing aircraft to maintain a constant rate of descent from the final approach fix to touchdown.

The position of the CC point and the ceiling requirement is set so that the trailing aircraft has approximately 30 seconds to acquire the leading aircraft before reaching the MAP. Visibility requirements are set so that the trailing aircraft can see the runway before reaching the MAP. Section 4 contains the results of ceiling and visibility calculations for each of the four procedures investigated in this study.

As an enhancement to safety, CAASD recommends that controllers be equipped with a Final Monitor Aid (FMA) to monitor SOIAs. The FMA is a color digital display with alerting algorithms and a 4:1 aspect ratio expansion designed to monitor parallel approaches. The FMA has been shown to significantly enhance safety by increasing the ability of the controller to monitor deviations from final by aircraft on simultaneous approaches (CTA Incorporated, 1992).

Procedures for the use of the Traffic Alert and Collision Avoidance System (TCAS) still need to be determined. If either the trailing or leading aircraft is above approximately 1100-1000 ft AGL when the sidestep maneuver is executed, TCAS is likely to generate a resolution advisory for one or both aircraft.

Additional development and testing are necessary for pilot training, phraseology, and ATC procedures before SOIA procedures can be implemented at ATL. Also, the specific approaches must be developed and tested for ATL, including flyability testing in aircraft or flight simulators.

Years of experience at STL and testing in flight simulators has shown that SOIAs can be executed safely, and their use at ATL can provide a means to increase arrival rates by using closely spaced parallel runways more effectively. SOIA has the potential to increase capacity, as indicated by the results of the simulation analysis reported in Section 5. However, SOIAs cannot generally be conducted with a visibility less than three miles or a ceiling of less than 1000 ft. Depending on the sidestep, the ceiling might have to be higher.

3.2 Along-Track Spacing

A recently developed concept for closely spaced approaches to dual runways involves the use of straight-in approaches to each runway. Deutsche Flugsicherung (DFS) has proposed using 1.5 nmi diagonal spacing between a leading aircraft on one runway and a trailing aircraft on the adjacent closely spaced parallel runway (DFS, 1999a). Wake turbulence protection is provided by displacing the threshold of the trailing aircraft by 1500 m (4921 ft), effectively raising the trailing aircraft's flight path by 80 m (262 ft). Since the trailing aircraft would be above the leading aircraft and would land farther down the centerline of the runway, the trailing aircraft should be protected from wake turbulence. The concept of relying on a displaced threshold for vertical separation is called the High Approach Landing System (HALS) (DFS 1999a).

For protection of the next pair of aircraft, DFS is testing a wake vortex prediction system that may allow the next pair of aircraft to follow at reduced wake turbulence spacing (DFS, 1999b). Since this concept is far from fully developed, we assumed in this analysis, similar to the SOIA, that full wake turbulence separation is maintained between the trailing aircraft of one pair and the leading aircraft of the second pair. See Figure 3-2.

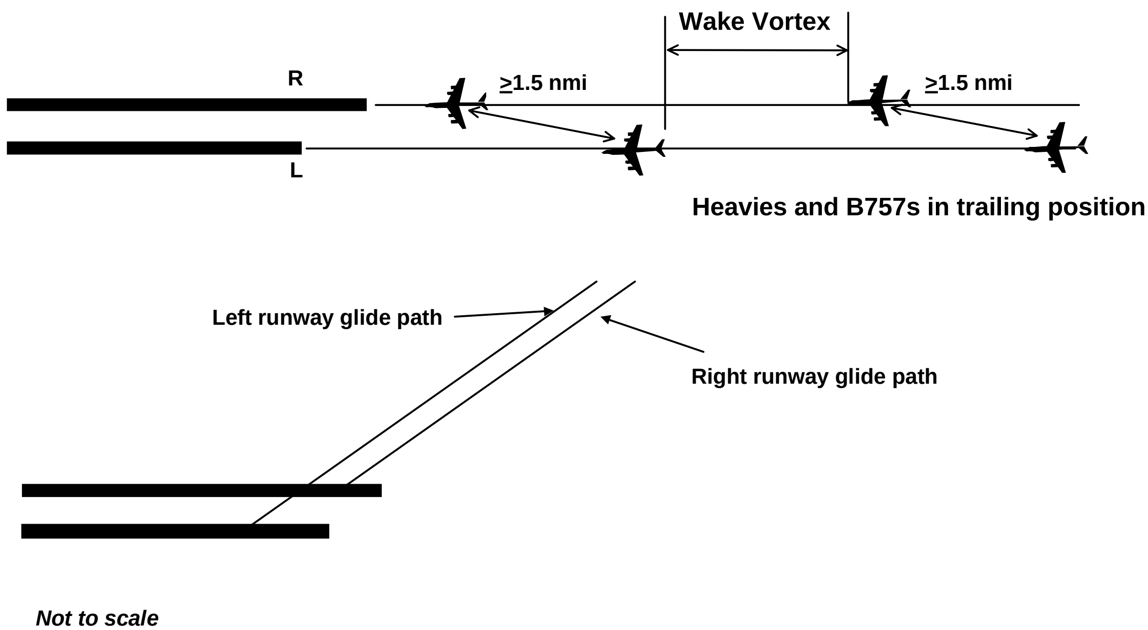

Figure 3-2. Along Track Spacing

ATS provides a capability to fly dual streams of aircraft to closely spaced runways (less than 2500 ft) in instrument meteorological conditions (IMC) down to Category I minima. This procedure is potentially more beneficial than SOIA since it can be applied when weather conditions are below the lowest minima permitted for SOIA operations. Also, there is no sidestep maneuver--all approaches are straight in. ATS has the potential to significantly increase capacity at a number of airports worldwide.

Current FAA wake turbulence standards allow a reduction of in-trail radar separation to 2.5 nmi under some conditions, but not to 1.5 nmi, even if the aircraft land on different runways. If the runways are less than 2500 ft apart, current rules consider this to be a single runway.

However, with adequate testing, it is possible that a reduced separation standard such as 1.5 nmi could be attained with restrictions on the leading and trailing aircraft.

Another difficulty with ATS is the Total Navigational System Error (TNSE) exhibited on final approach. TNSE represents path-following errors due to ground equipment, avionics, and pilot/autopilot technique. Measurements at Chicago O'Hare and Memphis show that this error has a standard deviation of approximately 20 ft per nmi from the localizer antenna. Thus, aircraft on a 10 nmi final would have an off-course error with a standard deviation of approximately 200 ft. For closely spaced runways, this could result in aircraft on adjacent runways crossing flight paths. Global Positioning System (GPS) course guidance would improve this performance, but due to the design of GPS precision approaches, the problem will still be significant.

Although ATS will require significant procedure development and testing, we included a proposed procedure with ATS to investigate the potential benefit for the procedure.

3.3 Approach Procedures for ATL

This section describes the four procedures with three approach streams developed for consideration by the ATL study team. While none of these procedures have been adequately tested for immediate implementation, we believe that two of these procedures—Independent SOIA Triples and Dependent SOIA Triples—could be implemented in the near term with dedicated effort by the FAA, industry, and pilots. The other two procedures considered—Independent Angled SOIA Triples and Triples Using Along Track Spacing—would require longer to implement.

3.3.1 Independent SOIA Triples

This procedure builds on the current standard that allows simultaneous/independent approaches to three parallel runways with a minimum of 5000 ft between runways, or as little as 4300 ft between runways if an FMA is used to monitor the approaches. Each approach stream requires its own monitor controller with a discrete frequency and an override capability. A 2000 ft No Transgression Zone (NTZ) is established between each pair of approach streams for simultaneous approaches. Each approach stream must turn onto final with at least 1000 ft vertical separation, as required in FAA Order 7110.65 (FAA 1998).

The north runways were fed by one stream to the outboard runway (08L/26R), similar to current procedures for simultaneous approaches to two runways at ATL. For the south runways, however, we established a straight-in approach to the inboard runway (09L/27R) and a SOIA to the outboard runway (09R/27L). The spacing between the SOIA and the straight-in approach was 5000 ft or greater. The trailing aircraft need only be slightly behind the leading aircraft to enhance visual acquisition, and the sidestep distance is approximately 3950 ft or more. Full wake turbulence spacing is maintained between the trailing aircraft and the leading aircraft of the next pair. See Figure 3-3.

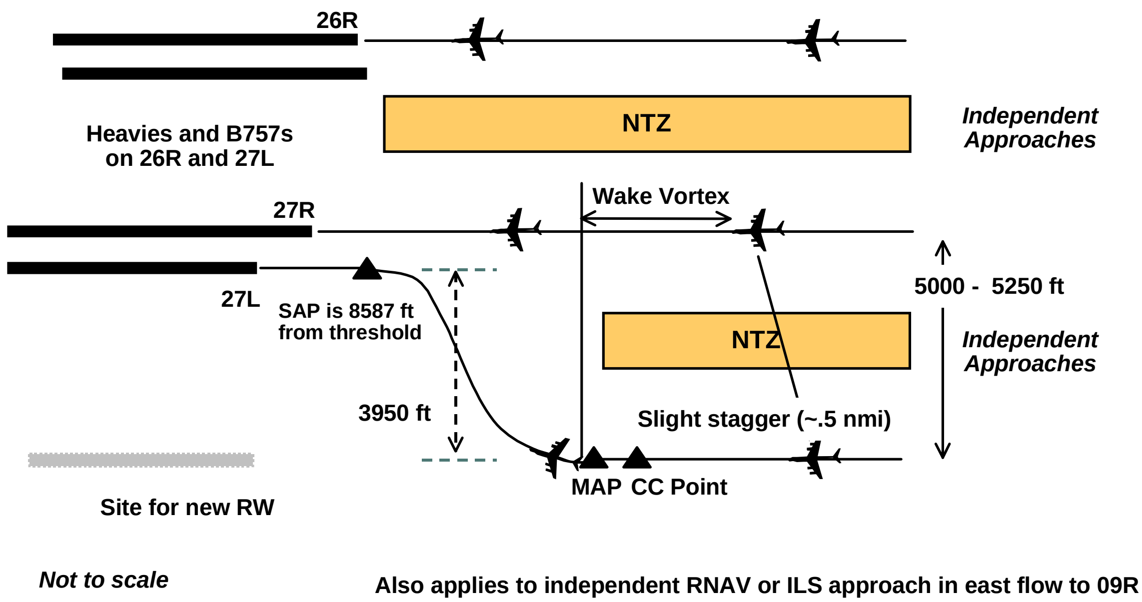

Figure 3-3. Independent SOIA Triples

Except for the actual sidestep maneuver, this procedure should require minimal development, since simultaneous approaches to three runways are already permitted. An FMA is recommended to enhance safety.

The SOIA should have lateral and vertical guidance, preferably by GPS or instrument landing system (ILS) precision approaches. However, use of an Area Navigation (RNAV) approach with vertical guidance would allow this SOIA to be implemented without installation of an ILS. This option should be investigated. If the lateral accuracy of an RNAV approach is insufficient, then use of an ILS localizer with RNAV vertical guidance could be tested.

3.3.2 Dependent SOIA Triples

This procedure builds on the current standard that allows dependent approaches to two parallel runways with a minimum of 2500 ft between runways and a diagonal separation of at least 1.5 nmi between aircraft (2 nmi if the distance between approach courses is 4300 ft or greater).

The north runways were fed by one stream to the outboard runway (08L/26R), similar to current procedures for simultaneous approaches to two runways at ATL. An NTZ was established between the north and south runway pairs to support the simultaneous approaches. For the south runways, however, we established a straight-in approach to the inboard runway (09L/27R) and a SOIA to the outboard runway (09R/27L). The spacing between the SOIA and the straight-in approach was 2500 ft or greater. The trailing aircraft follows the leading aircraft by a minimum of 1.5 nmi, and sidesteps approximately 1450 ft or more to line up with the runway. Full wake turbulence spacing is maintained between the trailing aircraft of one pair and the leading aircraft of the next pair. See Figure 3-4.

Although this procedure should not require a major development effort, some testing may be required since triple approaches consisting of dependent and simultaneous approaches have no regulatory approval, and some issues will need to be resolved. For example, dependent approaches to two runways require only one final controller, but simultaneous approaches require one controller for each approach stream. It is not clear if this procedure will require two or three final controllers.

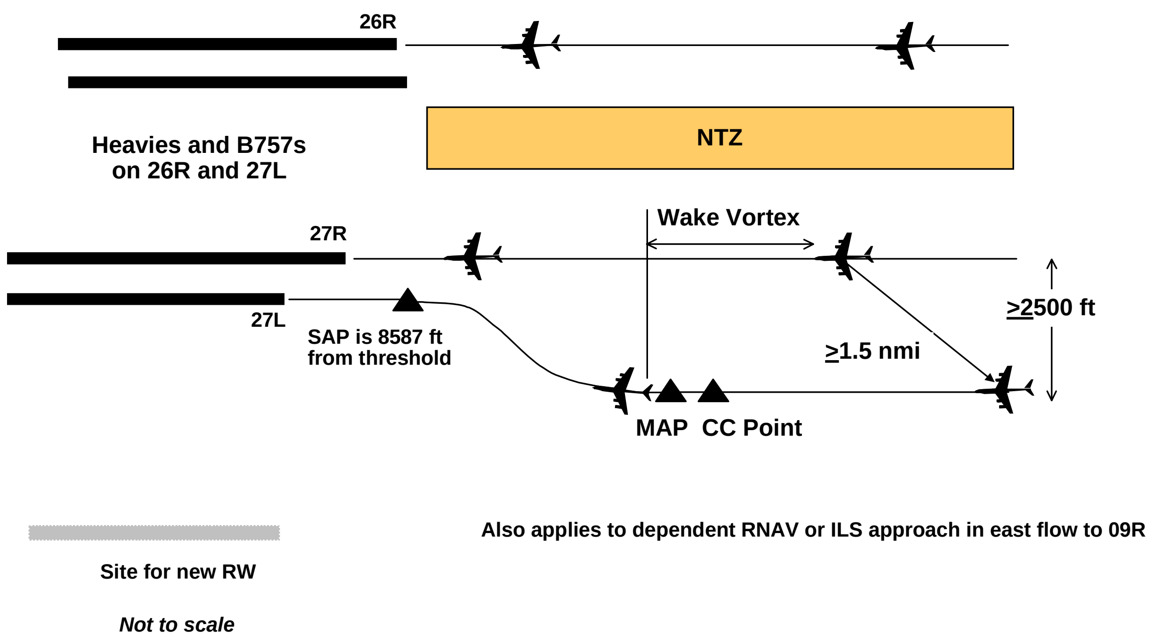

Figure 3-4. Dependent SOIA Triples

Similar to the Independent SOIA, FMA and vertical guidance is recommended to enhance safety, as is specific testing of the SOIA in aircraft or flight simulators. Also similar to the Independent SOIA, use of RNAV would be desirable for the SOIA.

Since the SOIA course is closer to the straight-in course than in the Independent SOIA Triples procedure previously described, the sidestep required of the SOIA aircraft is smaller, and the ceiling and visibility requirements are reduced, allowing greater applicability of this procedure. However, the requirement for the trailing aircraft to follow a minimum of 1.5 nmi diagonal spacing reduces the arrival rate, as reported in Section 5.

3.3.3 Independent Angled SOIA Triples

This procedure builds on the current standard that allows simultaneous/independent approaches to two parallel runways with a minimum of 3000 ft between runways and one localizer course offset by at least 2.5 degrees. A precision runway monitor (PRM) is required for these types of approach. PRM is a high-update-rate secondary surveillance radar with a color digital display designed for monitoring simultaneous approaches. Monitor controllers with discrete frequencies and override capability are required for each approach stream. A 2000 ft NTZ is established between each pair of approach streams. Also, each approach stream must turn onto final with at least 1000 ft vertical separation.

For ATL, we established three approach streams separated by NTZs. The north runways were fed by one stream to the outboard runway (08L/26R), similar to current procedures for simultaneous approaches to two runways at ATL. For the south runways we established a straight-in approach to the inboard runway (09L/27R) and a SOIA to the outboard runway (09R/27L) that was offset by approximately 3 degrees. The spacing between the SOIA and the straight-in approach was 3000 ft at the MAP. Full wake turbulence spacing is maintained between the trailing aircraft of one pair and the leading aircraft of the next pair. See Figure 3-5.

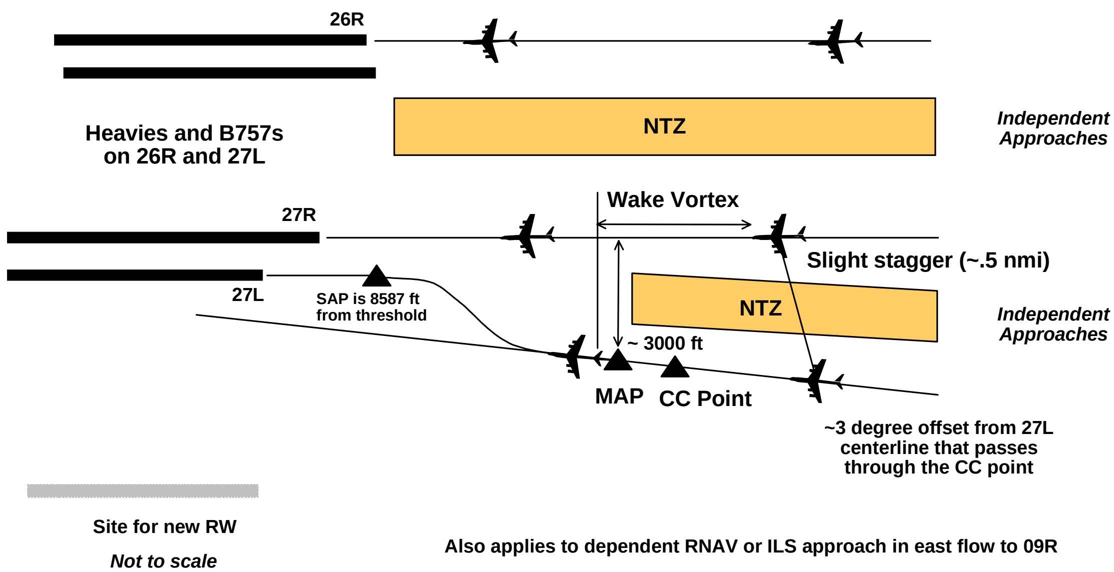

Figure 3-5. Independent Angled SOIA

This procedure will require some development, since no triple approach standards exist using the PRM. We believe that the separations between approach courses are sufficient, but this needs to be investigated and approved. Testing of the specific sidestep procedure also needs to be accomplished. Also, a PRM is required to implement this procedure, and vertical and horizontal guidance would have to be provided for the SOIA (similar to the Independent and Dependent SOIA procedures).

This procedure should provide lower minima than the Independent SOIA procedure since the sidestep distance is reduced. However, it will have slightly higher minima than the Dependent SOIA procedure. The arrival capacity of this procedure will be the same as that of the Independent SOIA procedure, which is slightly more than the Dependent SOIA procedure.

3.3.4 Triples Using Along Track Spacing

This procedure uses approaches to three runways using ATS concepts. For ATL, we again established three approach streams. The north runways were fed by one stream to the outboard runway (08L/26R), similar to current procedures for simultaneous approaches to two runways at ATL. An NTZ was established between the north and south pairs of runways. For the south runways we established a straight-in approach to both the inboard and outboard runways, with a diagonal spacing of 1.5 nmi spacing within pairs of aircraft. Full wake turbulence spacing is maintained between the trailing aircraft of one pair and the leading aircraft of the next pair. An FMA is recommended to enhance safety. An RNAV approach for runway 09R/27L would be desirable to reduce ground equipment requirements. See Figure 3-6.

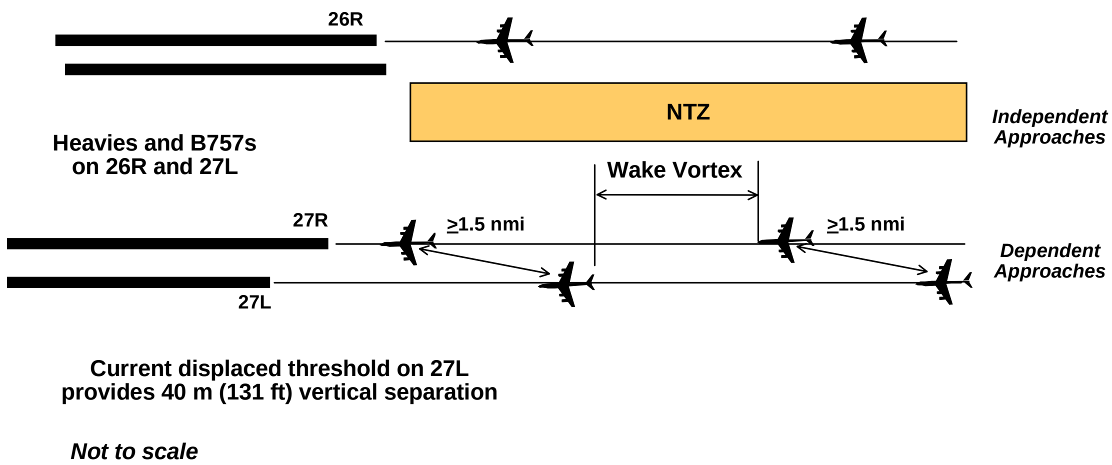

Figure 3-6. ATS Triples

This procedure will require considerable testing and development, since no ATS standards exist. However, this procedure could be used down to Category I minima, which is much better than any of the SOIA-based approaches. ATS should have an arrival capacity similar to that of the Dependent SOIA procedure.

3.4 Summary

The four procedures discussed above represent a range of capability and weather minima attained with varying degrees of equipment installation and procedure development. The results of the investigation of capacity enhancement benefits should be compared with the difficulties of implementation to determine which of the procedures should be fully tested and implemented.

Section 4

Approach Minima and Weather

4.1 Approach Minima

With any of the SOIA procedures, the aircraft on the SOIA must visually acquire the straight-in aircraft and the appropriate runway, and then must execute the sidestep maneuver. Experience with pilot groups investigating the application of SOIA at other airports indicates that there are two important constraints on the sidestep maneuver: it should not require excessive maneuvering, and the SOIA aircraft should be lined up with the landing runway in stabilized flight no lower than 500 ft above ground level. AFS-420 has the Airspace Simulation and Analysis for Terminal Enroute Radar Procedures (ASAT) and is using this tool to design SOIA procedures. The tool incorporates flight dynamics and has been benchmarked against simulator tests with pilots. It incorporates constraints on bank angle, degree of turn, and overshoots. AFS-420 applied the tool to each of the SOIAs under consideration to provide preliminary estimates of approach minima for the procedures. The ASAT results are shown in Table 4-1. Minima are also provided for Along Track Spacing, although these are extracted from the definition of conditions that require ILS approaches at ATL rather than obtained as analytical results from the AFS-420 model.

Table 4-1. Preliminary Approach Minima

Alternative	Ceiling*	Visibility*
Independent SOIA**	1800 ft	5 miles
Dependent SOIA**	1300 ft	3.25 miles
Independent Angled SOIA**	1400 ft	3.5 miles
Along Track Spacing	200 ft	2400 RVR***

* Ceiling is measured at the clear of clouds point and visibility is measured from the missed approach point.

** Source: ASAT design tool for SOIAs; additional testing will be required to determine exact minima.

*** Runway Visual Range

4.2 Analysis of Surface Observations Data

Since the approach minima are different for each of the alternative procedures, there will be a different window of applicability for each of them. We analyzed two data sets with information about weather to provide insight into how often the procedures could be used.

In the first analysis, we examined 24-hour surface aviation observations from October 1998 through September 1999. Ceiling and visibility data from 4,695 hourly and special reports were processed to estimate climatological conditions at the airport. Weather reports were considered to be valid for up to one hour unless superseded by another report. It was found that 72 percent of the time the weather conditions were officially V1 (better than 5000 ft ceiling and 5 miles visibility).

The V2 conditions were of particular interest since the alternative procedures are likely to be applicable during a significant portion of the V2 weather (less than 5000 ft ceiling and 5 miles visibility and better than 1000 ft ceiling and 3 miles visibility). As indicated in Table 4-2, it was found that ATL was in V2 conditions 15 percent of the time. The conditions for applying the Dependent SOIA (2500 ft) or the Independent Angled SOIA (3000 ft) would be met 14 percent of the time, or most of the time in V2. The conditions for applying the Independent SOIA (5000 ft) would be met 11 percent of the time, or about two-thirds of the time in V2.

Table 4-2. Analysis of Surface Observations at ATL

<table>
<tr><th>Ceiling</th><th>Visibility</th><th>Percentage of Time from Surface Observations</th><th>Applicability of Alternative Procedures</th></tr>
<tr><td colspan="2">V1</td><td>72%</td><td>None</td></tr>
<tr><td>5000 ft</td><td>5 miles</td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="4">V2</td><td rowspan="4">15%</td><td>Independent SOIA: 11%</td></tr>
<tr><td>Dependent SOIA: 14%</td></tr>
<tr><td>Independent Angled SOIA: 14%</td></tr>
<tr><td>Along Track Spacing: 15%</td></tr>
<tr><td>1000 ft</td><td>3 miles</td><td colspan="2"></td></tr>
<tr><td colspan="2">I1</td><td>12%</td><td>Along Track Spacing: 12%</td></tr>
<tr><td>200 ft</td><td>2400 RVR</td><td colspan="2"></td></tr>
<tr><td colspan="2">I2</td><td>1%</td><td>None</td></tr>
</table>

I1 conditions (less than 1000 ft ceiling and 3 miles visibility and better than 200 ft ceiling and 2400 runway visual range [RVR]) are not candidates for application of the SOIA procedures, but ATS could be applied under these conditions. The analysis of surface observations indicates that ATL is in I1 conditions 12 percent of the time. None of the alternative procedures examined in this study could be applied in I2 conditions (less than 200 ft ceiling and 2400 RVR).

The results of the analysis of surface observations were presented to the ATL study team in January 2000, and the team observed that it did not provide a complete picture of the opportunity for applying SOIA at ATL. In particular, they pointed out that visual approaches are not always possible in V1 conditions due to haze or fog, and that the alternative procedures are likely to be helpful in such cases. The study team also noted that in some cases visual approaches can be run in V2 conditions. Since it was not possible to determine from the surface observations how often visual approaches were not possible during V1 conditions or how often visual approaches were possible during V2 weather, we performed a second analysis using another source of information that recorded both weather conditions and type of approach.

4.3 Analysis of Data from Airport Resource Management Tool

The results of the analysis of surface observations were presented to the ATL study team in January 2000, and the team observed that it did not provide a complete picture of the opportunity for applying SOIA at ATL. In particular, they pointed out that visual approaches are not always possible in V1 conditions due to haze or fog, and that the alternative procedures are likely to be helpful in such cases. The study team also noted that in some cases visual approaches can be run in V2 conditions. Since it was not possible to determine from the surface observations how often visual approaches were not possible during V1 conditions or how often visual approaches were possible during V2 weather, we performed a second analysis using another source of information that recorded both weather conditions and type of approach.

ATL collects operational data about every arrival push in its ARMT. We extracted the weather conditions and type of approach for all arrival pushes from November 1998 through October 1999. The results of the analysis of that data are shown in Table 4-3.

Table 4-3. Analysis of ARMT Weather Data at ATL

Weather Conditions	Type of Approaches	Percentage of Arrival Pushes	
		East	West
V1	Visual	51%	62%
	Split visual/instrument	5%	9%
	Instrument	7%	8%
V2	Visual	1%	2%
	Split visual/instrument	1%	3%
	Instrument	13%	8%
I1	Instrument	18%	8%
I2	Instrument	3%	0%

The conditions that are most likely to benefit from the SOIA procedures are shaded in gray in Table 4-3: instrument approaches combined with V1 or V2 weather conditions. In east operations, these conditions occur for 20 percent of the arrival pushes, while in west operations they occur for 16 percent of the pushes. Operations at ATL were split almost evenly between east and west during the evaluation period. This view of weather and operational data indicates an even greater opportunity for the application of SOIA procedures than implied by the surface observation data. Note that it was not possible to determine from the ARMT data which portion of 16–20 percent of the arrivals pushes would be impacted by each of the three different SOIA procedures.

SOIA procedures would not be needed when visual approaches are possible, nor would they be possible in I1 or I2 weather conditions. The conclusion that SOIA procedures could be applied to 16-20 percent of the arrival pushes does not include any consideration of split operations (one runway with visual approaches, one with instrument approaches). It is possible that the SOIA procedures might be applied during some of the split operations, but there is no information in the ARMT database to indicate if the instrument approaches are conducted to the north or south runway. The validation team stated that the usual configuration is for the north runway to be operating with instrument approaches while the south runway operates with visual approaches during split operations. In this case, there would be no need for SOIA procedures, which are only modeled as being applied to the south runways.

ATS can be applied in the same conditions that apply to SOIA. In addition, ATS could be applied in I1 conditions, increasing the overall percentage of arrival pushes that could benefit from ATS to 38 percent for east operations and 24 percent for west operations.

Section 5

Delay and Throughput Analysis

5.1 Scenarios

Various scenarios were constructed to make it possible to validate the models and isolate the effects of the changes in procedures. The scenarios for the preliminary analysis included the baseline dual operations and all four triple arrival procedures: Independent SOIA (5000 ft), Dependent SOIA (2500 ft), Independent Angled SOIA (3000 ft), and Along Track Spacing. The study team focused the remaining portion of the study on two of these procedures: Independent SOIA and Dependent SOIA. The final results in this section are reported only for those two procedures.

The critical factor influencing delay and throughput in this analysis is the separation between the leading and trailing aircraft in a pair on two closely spaced parallel runways. Other important factors, such as wake turbulence separation from the trailing aircraft of one pair to the leading aircraft of the next pair, are common to all the procedures considered. Since the Independent Angled SOIA has the same separation within pairs as the Independent SOIA (approximately 0.5 miles), the capacity results for the Independent Angled SOIA would be the same as for the Independent SOIA. Similarly, ATS has the same separation within pairs as the Dependent SOIA (1.5 miles), so those capacity results would be the same. Of course, the weather conditions during which the procedures could be conducted are different, so the overall effect of the procedures would be different. However, when the procedures are in operation, the Independent SOIA and the Independent Angled SOIA would have the same capacity, as would the Dependent SOIA and the ATS.

The baseline and the two SOIA procedures were modeled in east and west flows, resulting in six separate models. Each of the six models was run with all the ground operations active and again without taxiways or gates acting as constraints. This approach was helpful in isolating the source of problems with new procedures to the airspace or ground operations.

5.2 Assumptions

Scope. The scope of the simulation model was ATL airport, TRACON, and Atlanta ARTCC within 200 miles of ATL. It was assumed that there are no impacts to or from areas outside this boundary. No satellite airports or traffic were included.

Weather. It was assumed that there is sufficient visibility and ceiling at the airport (see runway dependencies) to support the procedures tested, but that the ceiling and/or visibility is poor enough to require full wake turbulence separation between aircraft on the same runway (visual separations are not in effect).

Traffic. The study team agreed to use estimates of the traffic in 2001 as the basis for the study. The traffic file consisted of 2,684 flights, both arrivals and departures, over a 24-hour period. This traffic file included both air carrier and general aviation operations. The total count is consistent with FAA forecasts (FAA, 1998) and reflected the consensus of the participants. We drew on two sources of data to build the complete traffic file: Delta Airlines and the ATA-200 Airspace Laboratory. Delta provided future operations estimates for their flights and for Atlantic Southeast Airlines, other associates, and United Parcel Service for a total of 1,910 flights. Schedules for the remaining 774 flights (other scheduled carriers and general aviation) were built using Enhanced Traffic Management System (ETMS) data from the Airspace Laboratory on a recent busy day and extrapolated to the 2001 number of operations. The new traffic file reflects equipment as specified by Delta or ETMS with one exception. The fleet mix for AirTran was modified to replace 44 DC9s with B717s, as per their schedule through 2001.

Airspace Operations. The routes through center airspace are unchanged, although the flow rates will be different during triple operations. All traffic segregation was done in TRACON airspace. The turn onto the SOIA and ATS final approaches was at 18 nmi from the runway threshold. The maximum length of any final approach was 25 nmi.

Triple Arrivals. It was assumed that there are no obstacles to switching between dual and triple arrivals. This implies that tower, TRACON, and center can make adjustments in a timely manner. The timing for triples was not determined a priori since it was found that slight shifts in the timing could have large negative impacts on delay and throughput. The timing was derived experimentally by selecting an interval, applying it, and observing the effects on throughput and delays for both arrivals and departures. The process was repeated until a set of optimal times was found for each of the scenarios.

Runway Usage. We experimented with various schemes for assigning traffic to runways during triple arrivals to improve landing efficiency and taxi operations once on the ground. As described in Section 1, the study team made a number of changes in this strategy at the January 2000 briefing of preliminary results. The final models included these assumptions about runway usage during triple arrivals:

- Move as many departures as possible from the south departure runway to the north runway during triple arrivals. Rebalance the two departure runways during departure pushes and dual arrival operations.
- Move as many heavy jet and B757 arrivals as possible to the north arrival runway during triple arrivals.
- Restrict all heavy jet and B757 arrivals on the closely spaced arrivals to the southernmost runway (09R/27L). This reduces the concern about wake turbulence for the following aircraft, which may not be able to execute wake turbulence avoidance maneuvers during the sidestep.

- Restrict small aircraft to the north runway or to the straight-in approach (09L/27R) on the south runways.
- Require any aircraft on a SOIA (09R/27L) to be RNAV equipped.

Runway Dependencies. The assumption of clear weather (V1 or V2) at the airport implies that departures on either of the inboard runways can be launched independently of arrivals to the outboard runways. Similarly, arrivals to the outboard runways can land with no consideration of aircraft departing on the inboard runways. During triple arrivals, there will be both arrivals and departures on 09L/27R. In this case, arrivals on 09L/27R cannot touch down until departures on the same runway are 6000 ft down the runway and airborne. Departures on 09L/27R cannot launch until a previous arrival to the same runway has turned off. Two arrivals to the closely spaced parallel runways follow the separation requirements detailed in the SOIA procedure of interest (spacing within a pair and between pairs).

Ground Operations. The Delta ground model was used as a starting point for the baseline and SOIA analyses. Modifications were made to gate assignments to account for different airlines in the traffic file. Other modifications were made to address problems that arose with the new traffic file and runway usage. The study team directed that some ground improvements be included in the final models, including high-speed exits from 09L/27R and an additional taxi for arrivals to 09R/27L to cross 09L/27R. Priorities for 09L/27R are assigned as follows: arriving aircraft on 09L/27R have the highest priority; aircraft arriving on 09R/27L have priority to cross 09L/27R before departures on 09L/27R; departures on 09L/27R have the lowest priority.

5.3 Validation

There were several phases of validation in this study. First, the starting point for the baseline TAAM model was developed by Delta and validated in various studies by teams of controllers from the ATL tower and TRACON. In a separate effort, the National Aeronautics and Space Administration (NASA) did an independent study using the Delta model. This study compared the taxi out times obtained in TAAM with those obtained from ASQP, making adjustments to account for the fact that ASQP does not cover all the airlines. The NASA study also compared arrival and departure rates throughout the day with radar track data and touchdown and takeoff times. Some adjustments were made to the rules in the original Delta model to improve the correspondence between the data and the TAAM results.

All of this earlier validation work served as a starting point for the analysis of triple arrivals. Modifications had to be made to the arrival and departure rates to align this study with the appropriate weather conditions (instrument landing conditions as opposed to visual landing conditions, the assumption in the Delta and NASA analyses). The new arrival and departure rates were extracted from ARMT data over the past year, restricting the data to pushes with V1 or V2 weather and instrument landings. Details about arrival pushes were available from October 1998 through November 1999. There were 361 arrival pushes recorded for this period with the specified weather and type of arrival. Figure 5-1 shows how many times arrival rates at various levels were recorded. For instance, the figure indicates that in east operations, there were 37 reported pushes with an arrival rate of approximately 85 aircraft per hour. The figure indicates that 85 to 90 aircraft per hour was experienced with some regularity in both east and west flows. Values higher than that have only been reported five times over the past year, and are not considered for the purpose of validating the baseline. The final baseline simulation model was adjusted to deliver peak arrival rates of 85 to 90 aircraft per hour.

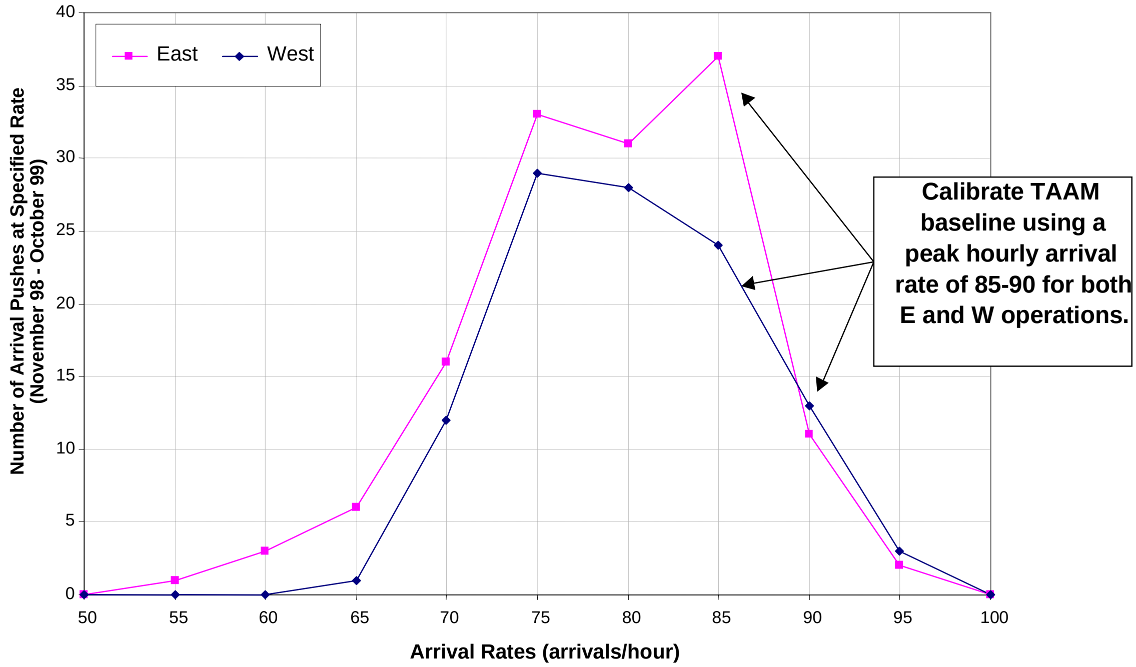

Figure 5-1. Arrival Rates from ARMT for ILS Arrivals in V1 or V2 Conditions

Departure rates were determined using a similar process, although there was less data to support the operationally achievable rates. ARMT has collected departure data only since March 1999. There were 230 departure pushes recorded from March through October 1999 as being in V2 weather. The reported departure rates are shown in Figure 5-2. This figure indicates that rates of up to 100 aircraft per hour are regularly experienced in V2 weather in both east and west operations. The final baseline simulation model was adjusted to deliver comparable peak departure rates.

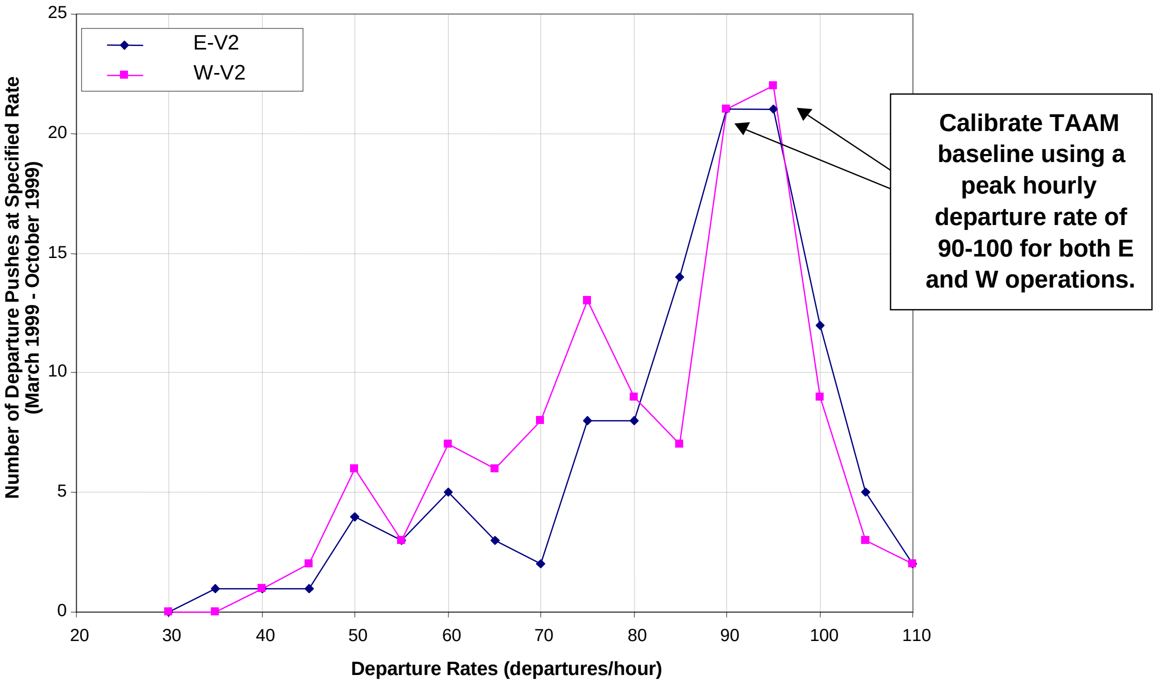

Figure 5-2. Departure Rates from ARMT for Departures in V2 Conditions

The assumptions for the new baseline were checked repeatedly with the validation team, which included controllers and staff from the tower, TRACON, and center. There were two meetings in Atlanta with this team to review the assumptions and to view the operation of the model.

One additional validation step was taken for the final model. Delays were extracted from ASQP and compared with the delays generated in TAAM. ARMT data was used to find a single day reporting V2 weather throughout the day. 19 October 1999 reported 10 departure pushes in V2 weather and 5 arrival pushes with V2 and instrument approaches. Arrival and departure delays as reported in ASQP for 19 October 1999 are shown in Figures 5-3 and 5-4. The average delays from this day of data were calculated to be 15 minutes of arrival delay per aircraft and 10 minutes of departure delay per aircraft. Note that it was not possible to make a direct comparison with TAAM results since the ASQP values are based on scheduled arrival and departure times, which are adjusted by the airlines to include expected delays. This can be seen in the figures, which show a large number of negative delays, especially for arrivals. The delays reported in TAAM are not calculated on the same basis. They are computed as the difference between the unimpeded arrival time and the actual arrival time, with no consideration of scheduled arrival times. Thus, any direct comparison of TAAM and ASQP results is flawed. However, it may be useful to examine the relative values of arrival and departure delays. The average delays from TAAM are 14 minutes for arrivals and 8 minutes for departures. This is comparable to the relative values from ASQP, 15 minutes for arrivals and 10 minutes for departures.

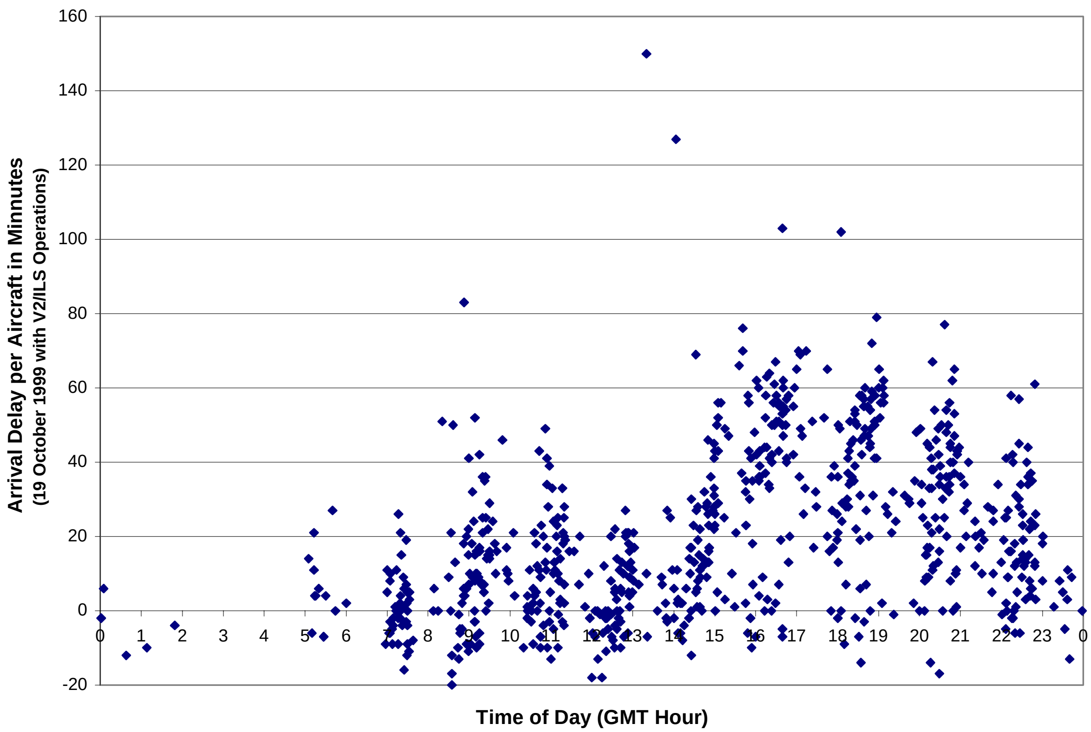

Figure 5-3. ASQP Arrival Delays on 19 October 1999

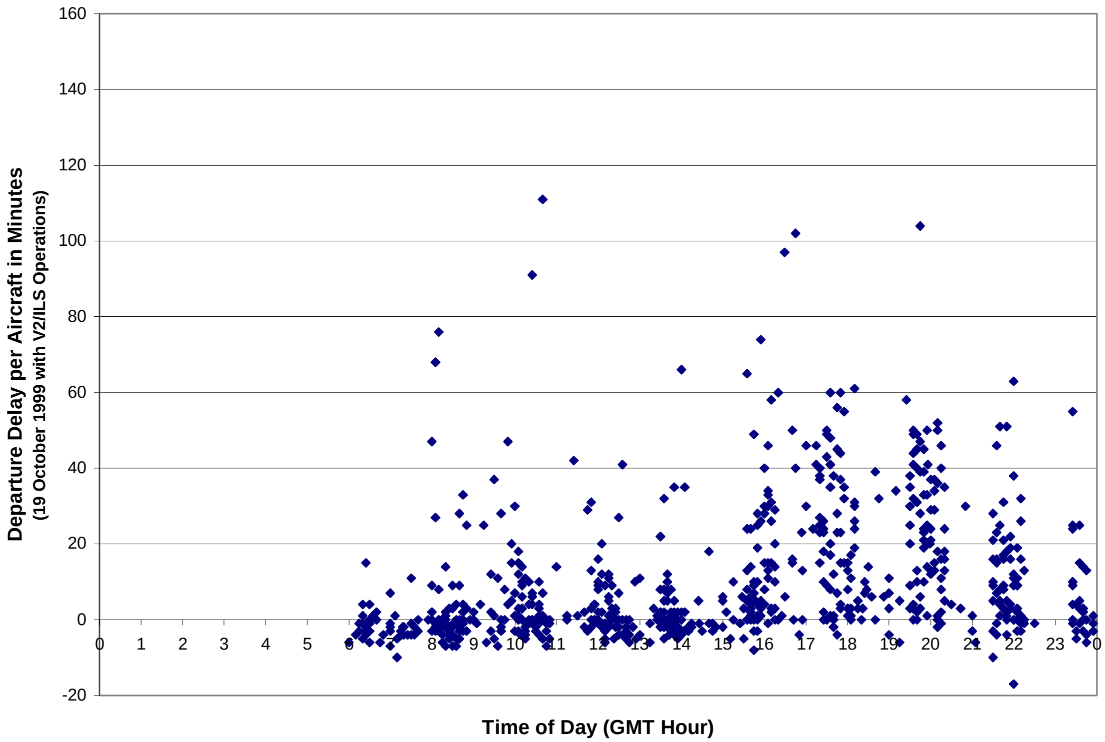

Figure 5-4. ASQP Departure Delays on 19 October 1999

5.4 Simulation Model

The TAAM baseline model was refined until it adequately represented airspace and ground operations for a typical day in V2 weather conditions. Numerous adjustments were made to adapt the model to triple arrival operations. The greatest challenge was in getting the separations between aircraft on different runways to precisely match the requirements of the alternative procedures. It was not possible to model the separations exactly with TAAM's current parameter settings and rule capabilities. Specifically, TAAM was not able to enforce the minimum spacing between aircraft in two arrival streams, so any two aircraft can be closer or farther apart than specified in the procedure. TAAM was not able to close the spacing by speeding up an aircraft to arrive before its scheduled arrival time. As a result, the aircraft were not always paired exactly as specified in Section 3. However, it was possible to ascertain that, on the average, the spacing was correct. We developed a post-processing routine to review the spacing as the aircraft crossed the runway threshold and adjusted model parameters until the averages were in close agreement with the requirements. While this approach is not ideal for visual inspection, it does deliver fairly accurate delay and throughput results.

Another challenge in developing the TAAM model was in switching between dual and triple approaches. The initial plan was to trigger triple approaches dynamically inside TAAM when heavy arrival demand was combined with light departures. It was not possible to implement this approach due to the time at which it was necessary to select the type of approach. In order to get the separation as close as possible, it is necessary to activate TAAM's sequencing algorithms 30–45 minutes before the scheduled arrival time. At this time, an arrival route is selected after checking the rules. TAAM cannot look ahead to anticipate departures in the future, so the rule could only check the number of aircraft currently taxiing to departure or waiting in a departure queue. This number would not be relevant to the conditions at the airport when the arriving aircraft lands. The workaround for this problem was to select the timing for the triple approaches before starting the simulation model. After running the model, the results were checked to see if the timing had an adverse impact on departures. This involved a substantial amount of trial-and-error experimentation rather than the application of a few simple rules, but it was effective in accomplishing the objectives. The final result was a finely tuned schedule for application of triple approaches. It was closely matched to the specific traffic file in this study and cannot be automatically applied to other traffic patterns. In fact, the triple/dual schedule had to be changed between east and west operations. On west flow with this traffic schedule, the arrival pushes overlap with the departure pushes to a greater extent than on east flow, limiting the length of time for triple operations. The total time in triple arrivals for west flow was only 7 hours, 45 minutes while triple arrivals can be applied for 8 hours, 10 minutes in east flow.

The other major challenge was in balancing traffic among runways, both departures and arrivals, to get the best performance from the alternative procedures. As described in Section 1, the preliminary model runs showed very poor performance when ground operations were activated. Many of these problems were ultimately resolved by shifting traffic to different runways depending on the type of operation (triple or dual), type of aircraft and equipage, and arrival and departure fix.

5.5 Results

Delays. The delay results for east and west flows are shown in Figures 5-5 and 5-6. Compared with the baseline, the Dependent SOIA offers some improvement in average arrival delays, resulting in a reduction of up to 0.9 minutes (west operations) or seven percent. The Independent SOIA offers an even larger improvement, reducing average arrival delays by 1.8 minutes (west operations) or 13 percent with respect to the baseline. These results are not unexpected. The Dependent SOIA closes the separation within a pair to a minimum of 1.5 miles (compared with the full wake turbulence separation that would be required without a special procedure), while the model of the Independent SOIA uses a separation of approximately 0.5 miles. As the separation within pairs decreases, we expect to see greater reductions in arrival delay.

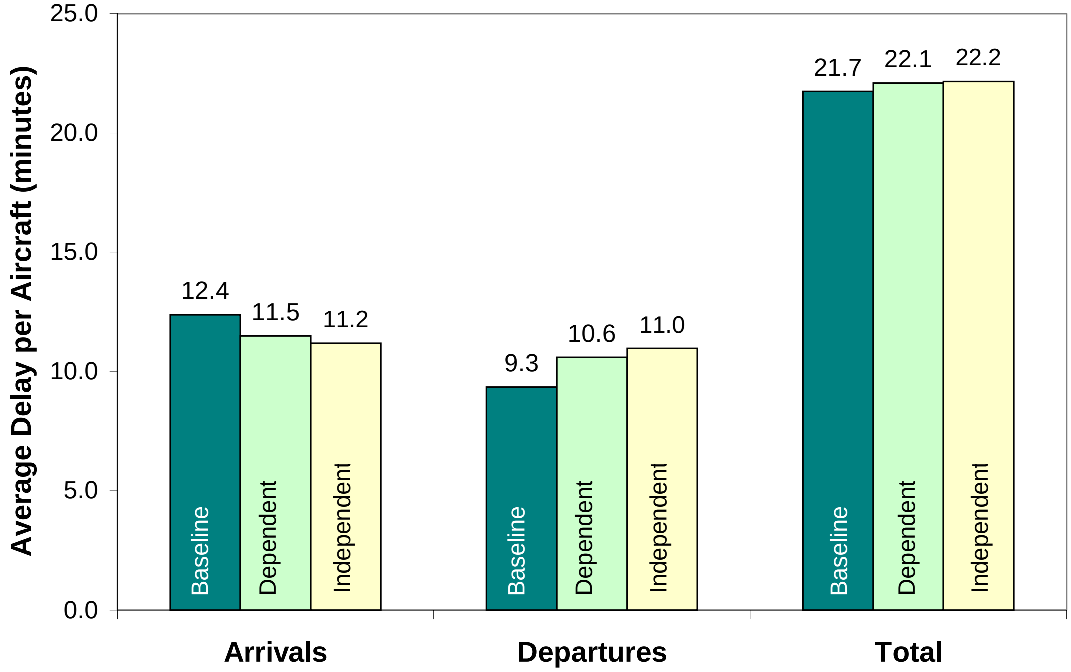

Figure 5-5. Delays for West Flow with Taxi and Gates

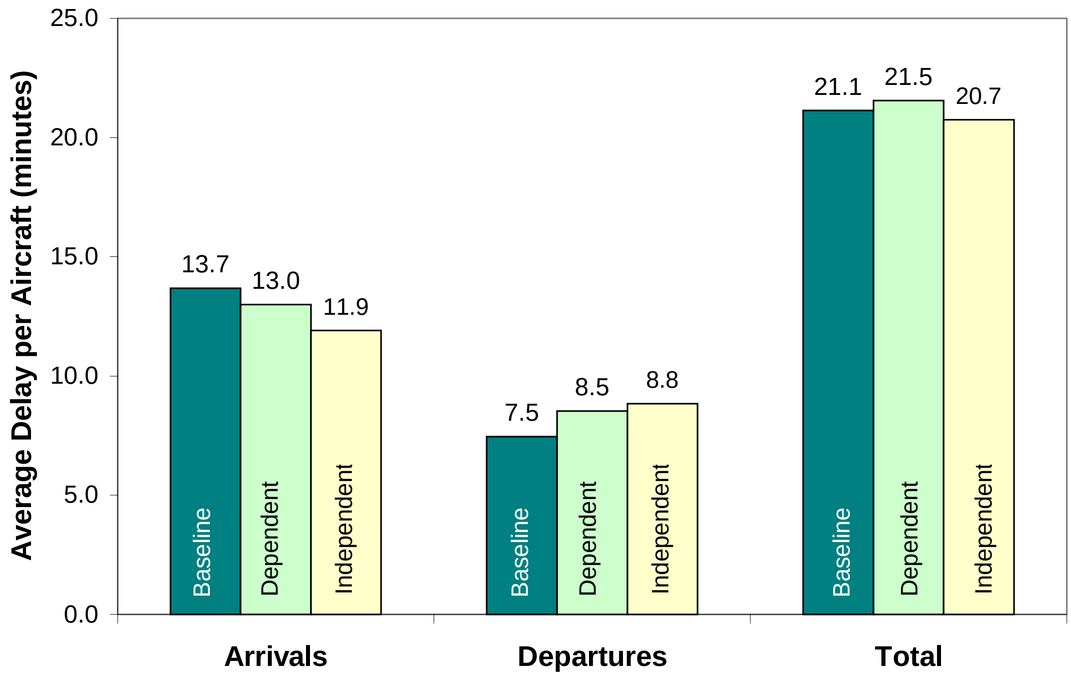

Figure 5-6. Delays for East Flow with Taxi and Gates

The delay picture reverses for departures. Departure delays increase relative to the baseline for the Dependent SOIA. The average departure delay increases by up to 1.3 minutes (west operations), or 13 percent increase (any apparent discrepancies between the numbers in the text and those in the figures are due to round off errors). For the Independent SOIA, the average delay increases by up to 1.7 minutes (also for west operations), or 17 percent. As described in the assumptions above, there are two ways in which departures are affected during triple arrival operations. First, more departures are shifted to the north runway, resulting in longer queues and greater delays. Second, the departures from the south runway are given lower priority than the arrivals to that runway. Departures are also held when arrivals to 09R/27L line up to cross 09L/27R.

Figures 5-5 and 5-6 show that departure delay offsets all or nearly all of the decrease in arrival delay. This trade between arrival and departure delay could be economical since arrival delay is taken in airborne holding and vectoring while departure delay is taken at the gate or in a departure lineup, where fuel consumption is lower.

Delays were also calculated without taxis and gates as constraints (that is, without ground operations activated in TAAM). These results indicate that after all the changes to tune runway usage to the new procedures, there isn’t a large effect from ground operations. Although all the values without ground operations are smaller than those in Figures 5-5 and 5-6 (with ground operations activated), the same trends are evident.

Throughput. The implementation of triple arrivals resulted in increased arrival throughput for both of these procedures, with the magnitude of the increase varying with the particular conditions of the arrival push. In the first 30 minutes of an arrival push, a minimum of two and a maximum of ten additional aircraft landed with triple arrivals.

Sensitivity of Results. The delay and capacity results were very sensitive to two key factors: the timing of the triple arrivals and the traffic distribution across runways. In the case of the timing of the triple arrivals, greater arrival benefits are seen with longer periods of application. However, if triple arrivals are applied during departure pushes, very large departure delays or gridlock on the airport can result. The benefits of triple arrivals at ATL are very sensitive to the timing of arrival and departure pushes, and they will change with different traffic scenarios. These procedures will require tight coordination among tower, TRACON, and center to set up the traffic for dual and triple approaches.

Traffic distribution among runways was also a sensitive and important factor for these procedures. The arrival benefits of the triple arrivals depend on the ability to load the center runway—and this depends on the relative mix of RNAV equipped, heavy, and small aircraft. Departure delays are sensitive to the distribution of departures between the north and south runways. Too many on either one can cause gridlock. Thus, segregation of both arriving and departing traffic among the runways was important, and it will be more complex than in the current operation. In this analysis, an additional 70-140 aircraft need to be shifted from the north to the south runways to implement the alternative procedures.

Other Results. In the original version of the simulation model, only the current taxiway crossings to runways 09L/27R were included. During the analysis of triple arrivals, it was discovered that there were large delays from holding departing aircraft on 09L/27R while aircraft landing on 09R/27L crossed the inboard runway. Based on guidance from the study team, additional taxiway crossings were built into the model, resulted in decreased departure delays. These additional runway crossings reduced delay during dual operations as well. There was a 12 percent decrease in departure delay with the two extra runway crossings, and virtually no change to arrival delay.

Section 6

Summary

Two of the procedures investigated in this study—Independent SOIA and Dependent SOIA—show promise for being implemented in a short time frame, although they will require some additional development and testing. The other two procedures—Independent Angled SOIA and ATS—would require even more equipment or development and are not likely to be available for implementation in the near future. Safety would be enhanced for the Independent SOIA, Dependent SOIA, and ATS procedures with the addition of a FMA display to assist in controlling the final approaches.

The Independent SOIA and Dependent SOIA have different sidestep maneuvers, and hence different weather minima. Both have the potential to improve arrival throughput for a significant fraction of the operations at ATL. The Dependent SOIA could be applied through much of the 15-20 percent of the time that visual approaches are not possible in V1 or V2 weather. The Independent SOIA could be applied less frequently due to its higher minima, but might be used approximately 10-15 percent of the time.

Both the Independent SOIA and Dependent SOIA have the potential for reducing arrival delay, with the Independent SOIA providing the larger impact. Both procedures also increase departure delay to some extent. For east operations, the increase in departure delay was greater than the improvement in arrival delay, while the west operations show much less impact on departure delay.

This analysis of delays and throughput can be used to support airline analyses of the economic benefits of the alternative procedures. Additional consideration also needs to be given to the workload on center, TRACON, and tower controllers to segregate traffic in more complex patterns and to provide for separation on closely spaced approaches.

List of References

CTA Incorporated, 1992, *Comparison of Controller Performance Using the Final Monitor Aid and the ARTS/DEDS Display Systems*, Pleasantville, N.J.

Deutsche Flugsicherung, 1999a, *The Frankfurt Capacity Program: Wake Vortex Considerations for Paired Approaches*.

Deutsche Flugsicherung, 1999b, *Wake Vortex Warning System*.

Federal Aviation Administration, 1991, *Aircraft Wake Turbulence*, AC 90-23E, Washington, D.C.

Federal Aviation Administration, 1998, 7110.65L, *Air Traffic Control*, Department of Transportation, Washington, D.C.

Federal Aviation Administration, 1998, *Terminal Area Forecasts: Fiscal Years 1998-2015*, FAA-APO-98-10, Washington, D.C.

Federal Aviation Administration, 1999, *Airspace Management Handbook*, Department of Transportation, Washington, D.C.

RTCA, 1998, *Government and Industry Guidelines and Concepts for NAS Analysis and Redesign*, RTCA/DO-224, RTCA SC-192, Washington, D.C.

RTCA, 1999, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, RTCA/DO-229B, RTCA SC-159, Washington, D.C.

Glossary

AGL	Above Ground Level
ALPA	Air Line Pilots Association
ARMT	Airport Resource Management System
ARTCC	Air Route Traffic Control Center
ASAT	Airspace Simulation and Analysis for TERPS (Terminal Enroute Radar Procedures)
ASQP	Airline Service Quality Performance
ATC	Air Traffic Control
ATL	Hartsfield Atlanta International Airport
ATS	Along Track Spacing
CAASD	Center for Advanced Aviation System Development
CC	Clear of Clouds Point
DFS	Deutsche Flugsicherung
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FMA	Final Monitor Aid
GPS	Global Positioning System
HALS	High Approach Landing System
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MAP	Missed Approach Point
NASA	National Aeronautics and Space Administration
NTZ	No Transgression Zone
PRM	Precision Runway Monitor
RNAV	Area Navigation
RVR	Runway Visual Range
SAP	Stabilized Approach Point
SFO	San Francisco International Airport
SOIA	Simultaneous Offset Instrument Approach
STL	St. Louis International Airport
TAAM	Total Airspace and Airport Modeller
TCAS	Traffic Alert and Collision Avoidance System
TNSE	Total Navigational System Error
TRACON	Terminal Radar Approach Control