ANALYSIS OF POTENTIAL BENEFITS OF WIND DEPENDENT PARALLEL ARRIVAL OPERATIONS

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Abstract

This paper documents the results of fast-time simulations evaluating potential capacity benefits of procedure concepts developed for parallel approaches to Closely Spaced Parallel Runways (CSPR) at airports with runway spacing less than 2,500 feet. Currently, simultaneous arrival operations at CSPR airports rely on visual meteorological conditions (VMC). In inclement weather when visual procedures can no longer be applied, simultaneous arrivals must be discontinued. Application of standard aircraft separations based on Instrument Flight Rules (IFR) effectively results in the loss of arrival operations on one of the two runways, significantly reducing the arrival capacity of CSPR airports. Proposed wind-dependent parallel approach concepts promise improvements in arrival capacity at CSPR airports by enabling continued operations of dual arrival streams in instrument meteorological conditions (IMC). The concepts permit dependent parallel arrival operations when meteorological conditions are determined to render approach paths free of wake vortices from preceding aircraft. The operations are expected to increase capacity during IMC and decrease weather-related delays at CSPR airports. Simulation results for 9 CSPR airports in the National Airspace System (NAS) suggest significant potential capacity benefits ranging from 2 to 18 additional arrival operations per hour depending upon the concept and airport. The paper outlines the proposed wake independent straight-in parallel approach concept and 12 procedural derivatives. It describes the model developed to visualize the operations and the Monte Carlo approach taken to quantify potential capacity benefits.

Introduction

The Federal Aviation Administration (FAA) Operational Evolution Plan (OEP) identifies the need to develop operational procedures that enable the continued use of CSPRs in inclement weather conditions on parallel runways whose centerlines are spaced as close as 1,000 feet [1]. In the OEP's Terminal Area Congestion quadrant, the scope of the Reduced Separation Standards initiative (TERM-5) includes the goals of identifying procedures for wake-independent procedures, validating safety assessments, and addressing training issues.

The FAA and the National Aeronautics and Space Administration (NASA) currently undertake a multi-phased research and development program to develop and implement wake vortex avoidance solutions that can safely reduce separations and improve capacity at airports in the National Airspace System (NAS) [2,3]. As part of this program, a Conops Evaluation Team (CET) investigated candidate dependent approach concepts and identified five approach geometries for approaches to CSPRs including straight-in parallel approaches [4,5]. The proposed operational concepts rely on knowledge of the dynamics of wake vortices within the wind field along the approach paths and require Instrument Landing Systems (ILS) serving each one of the CSPRs.

The research reported in this paper was carried out to support the CET and provides an analysis of the potential capacity benefits of the wind-dependent straight-in arrival concept. It presents results of Monte Carlo model simulation analyses of dependent parallel runway operations at 9 CSPR airports and 12 procedural variants with authorized minimum diagonal separation of 1.5 nautical miles (NM).

Parallel Runway Operations

Current Dependent Operations

In IMC, conducting dependent arrival operations with a minimum of 1.5 NM diagonal separation applied between arrivals on adjacent parallel runways is currently authorized if the runways are separated by at least 2,500 feet [6]. If parallel runways are closely spaced (i.e. separated by less than 2,500 feet), current Air Traffic Control (ATC) procedures require treating parallel runways operationally as a single runway. In this case, standard radar or wake turbulence separation must be applied between consecutive arrivals regardless of whether aircraft conduct approaches to the same runway or adjacent parallel runways. Minimum separation requirements currently applicable to aircraft approaching CSPRs are summarized in Table 1.

Table 1. Current Separation Requirements

Current Minimum Arrival Separation Requirements at CSPR Thresholds with a Runway Centerline Spacing Less Than 2,500 ft.				
Leading Aircraft Category	**Trailing Aircraft Category**			
	Small	**Large**	**B757**	**Heavy**
Small	2.5/3.0	2.5/3.0	2.5/3.0	2.5/3.0
Large	WT	2.5/3.0	2.5/3.0	2.5/3.0
B757	WT	WT	WT	WT
Heavy	WT	WT	WT	WT

Applicable 2.5 or 3.0 NM depending upon runway occupancy time at selected airport, WT = Wake Turbulence Separation

Proposed Dependent Operations

Wind-dependent parallel approach concepts promise improvements in arrival capacity of CSPR airports with runway centerline separation of less than 2,500 to 1,000 feet [7,8]. The concepts rely on the presence of specified wind fields that render one or both approach paths free of wake vortices of preceding aircraft and authorize continued operations of dual arrival streams in IMC. If yet to be defined meteorological conditions are met to support wake-free approaches, the proposed concepts permit conducting dependent parallel arrival operations requiring a minimum of 1.5 NM diagonal separation applied between arrivals on adjacent parallel runways for aircraft following Large or Small category aircraft. Standard wake turbulence separation requirements would remain unchanged and continue to apply to arrivals following B757 or Heavy category aircraft. Minimum separation requirements applicable to wake-free approach operations conducted under the proposed wind-dependent concept are summarized in Table 2.

Table 2. Proposed Separation Requirements

Minimum Arrival Spacing Requirements for Proposed Dependent Dual Operations at CSPR Thresholds with a Runway Centerline Spacing of 1,000 to 2,499 ft.				
Leading Aircraft Category	**Trailing Aircraft Category**			
	Small	**Large**	**B757**	**Heavy**
Small	1.5	1.5	1.5	1.5
Large	1.5	1.5	1.5	1.5
B757	WT	WT	WT	WT
Heavy	WT	WT	WT	WT

1.5 NM diagonal separation of Trailer from Leader on dependent parallel approach, WT = Wake Turbulence Separation

Procedural Variants of Proposed Dependent Operations

Twelve procedural variants of the proposed dual wind-dependent approach concept were modeled. While all modeled operations were straight-in arrival operations characterizing approaches along the extended centerlines of the arrival runways, procedural variants of the wind-dependent concept investigated the potential impact of additional operational restrictions on capacity benefits.

The operations were divided into two categories. Approach operations in the first category assumed that prevailing winds render only the upwind approach of the two parallel approach paths wake free. The approach geometry is illustrated in Figure 1 for the case of St. Louis Lambert International Airport (STL). Approach procedures in this category are subsequently referred to as **upwind wake free** procedures. The second category of approach operations assumed that both upwind and downwind approach paths are wake free. Approach procedures in the latter category are referred to as **upwind and downwind wake free** procedures. While the minimum separation requirements listed in Table 2 were applied to wake free approaches, the separation requirements of Table 1 were applied whenever

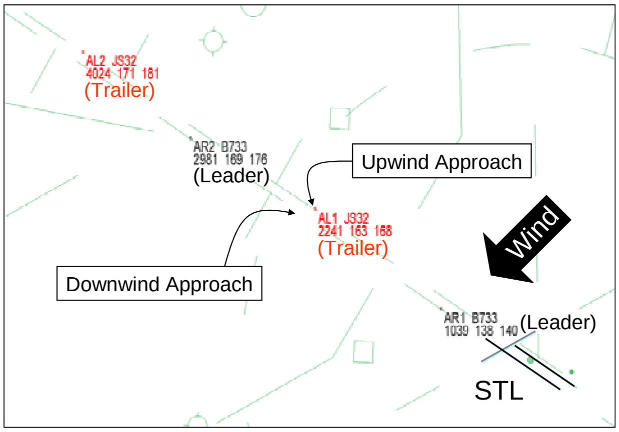

Figure 1. Plan View of Approach Geometry

approaches were not considered wake free. For each of the upwind wake free as well as upwind and downwind wake free approach categories, six procedural variants were evaluated for pairs of aircraft approaching the parallel runways in a staggered fashion. The procedural variants employed two types of additional restrictions. The first type of restriction required that aircraft in the leading position (Leader) be of certain wake category for aircraft in the trailing position (Trailer) to conduct wake-free approaches. The second type of restriction prohibited assigning B757 and Heavy category aircraft to the upwind approach and required these category aircraft be assigned the downwind approach only. The definitions of the procedural variants are presented in Table 3.

Each procedural variant was assigned and is subsequently referred to by a Scenario number also shown in the table. For example, in Scenario 3, Trailers conduct wake-free approaches only if their associated Leaders are B757, Large, or Small category aircraft. In this case, a Trailer paired with a Leader of Heavy category requires application of the minimum separations listed in Table 1. Also in this case, aircraft of all wake categories are assigned to both upwind and downwind approaches. As another example, in Scenario 12, B757 and Heavy category aircraft are assigned the downwind approach only.

It is important to note that all procedure variants employed dependent approaches comprising Leader-Trailer pairs and that all wake-free procedures authorized application of 1.5 NM diagonal separation between Leader-Trailer pairs on adjacent parallel approaches if Leaders are Small or Large category aircraft only (see Table 2). The simulation approach and the fast-time model developed to evaluate potential capacity benefits are described in the following section.

Table 3. Definitions of Procedural Variants of Proposed Dependent Wake Free Operations

Scenario	**Current Approach Operations**				
1	Single Runway Arrivals (Baseline)				
Wind Dependent Approach Operations					
Upwind Wake Free			**Upwind and Downwind Wake Free**		
Scenario	**Leader Aircraft Category**	**Approach Assigned to H, B757**	**Scenario**	**Leader Aircraft Category**	**Approach Assigned to H, B757**
2	ALL	UW and DW	8	ALL	UW and DW
3	S, L, B757	UW and DW	9	S, L, B757	UW and DW
4	S, L	UW and DW	10	S, L	UW and DW
5	ALL	DW	11	ALL	DW
6	S, L, B757	DW	12	S, L, B757	DW
7	S, L	DW	13	S, L	DW

UW = upwind, DW = downwind; B757 = Boeing B757; S = Small, L = Large, H = Heavy category aircraft

Benefit Analysis Model

The complexity of operations generally inhibits complete modeling of the full range of possible activities in the airport terminal area. The modeling in this study restrictively aimed to capture the key elements of actual operations that are considered relevant in constraining arrival capacity associated with the proposed wind-dependent straight-in arrival operations to CSPR runways.

MITRE's SLX Aviation Model (SAM) was chosen and adapted to model paired arrival operations to evaluate the impact of wind-dependent procedures on **airfield capacity**. A highly flexible general simulation programming language, the Simulation Language with eXtensibility (SLX) was used to construct the model [9]. The model includes animation capabilities for visualization as well as analysis capabilities to calculate benefit metrics. SLX is an object-based programming language which lends itself to flexible modeling of novel ATC procedures. Controller behavior is conveniently modeled through object classes whose actions are designed to mirror selected ATC control activities **in the presence of constraints**. The model is supported by SLX's tools for generating stochastic variations of modeling parameters that are used to vary model input when performing Monte Carlo simulation runs, and tools for collecting and analyzing output metrics.

Model Constraints

The capacity-limiting constraints that govern the wind-dependent arrival operations evaluated in this study can be divided into two categories: (1) operational constraints and (2) procedural constraints.

1) Operational constraints arise from separation requirements that are applied to meet minimum standards as well as ATC operational practice that typically results in larger than minimum separation between aircraft. Standard separation requirements and ATC operational practice were assumed to remain unchanged in the modeling of wind-dependent arrival procedures and the same operational constraints were applied uniformly to all procedure scenarios modeled.

2) Procedural constraints include those that arise from procedural restrictions. For example, a wind-dependent arrival procedure may authorize only certain aircraft types to approach on the upwind approach. As procedural restrictions generally vary from one scenario to another, varying procedural constraints were applied in the modeling of the various procedure scenarios.

A key modeling requirement in the present study is the capability to adequately capture applicable capacity-limiting constraints. The main features of the model developed to evaluate capacity benefits and key model input are outlined in the following sections.

Modeling Assumptions

In order to facilitate comparisons between capacity benefit estimates obtained for the nine airports evaluated in this study, certain assumptions were considered to apply uniformly to arrival operations at all airports. At all airports, approaching aircraft were assumed to join the localizer of the ILS about 16 NM from the threshold. All Leader aircraft were assigned to the downwind approach and all Trailer aircraft were paired on the upwind approach (see Figure 1). When joining the localizer, Trailer aircraft on the upwind approach were assigned an intercept altitude that was 1,000 feet higher than the intercept altitude assigned to Leader aircraft on the downwind approach.

Model Input

Fleet Mix. All modeled aircraft were assigned performance types that were drawn from an empirical aircraft type distribution. For each of the 9 airports modeled, the aircraft type distribution was obtained from analyses of Enhanced Traffic Management System (ETMS) data representing one year (2004) of arrival and departure operations. Each fleet mix was found to typically consist of a few hundred aircraft types as identified by International Civil Aviation Organization (ICAO) aircraft type designators. The distributions obtained for each airport specified each aircraft type's relative probability to operate at the airport. Aircraft types that represented the top 97.5 percent of all operations were considered in the model.

Such truncating of the aircraft type distribution was found to remove those aircraft types whose individual probability to operate at an airport was typically less than 0.1 percent. The types of all modeled aircraft were randomly drawn from the distributions of the top 97.5 percent of observed aircraft types. Consequently, a random arrival demand sequence of aircraft types was assumed and, if no other procedure restrictions (see Table 3) required otherwise, directly applied in the model. When modeling procedures that required restricting B757 and Heavy category aircraft to the downwind runway, the sequence of aircraft types was adjusted in order to meet the procedural restriction. Such targeted adjustments only affected the sequence of aircraft types and did not impact the overall distribution of modeled aircraft types. When grouped by aircraft wake category, Large category aircraft were observed to dominate the fleet mix at all modeled airports. The fractions of aircraft of Heavy category and of type B757 were found to vary significantly from airport to airport. Figure 2 summarizes the percentages of aircraft comprising the four wake categories at each airport.

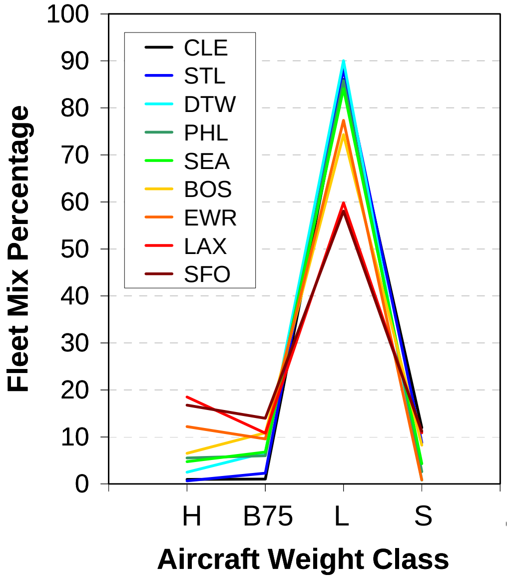

Figure 2. Model Fleet Mix Summary

Aircraft performance. SAM is a highly flexible discrete-event aviation modeling tool that provides 4D flight trajectories and enables the modeling of ATC decision-making processes under operational and procedural constraints for large numbers of flight operations [10]. Aircraft flight performance is based on Eurocontrol's Total Energy Model which, in its Base of Aircraft Data, provides performance parameters for 84 aircraft types commonly used in commercial air carrier operations [11]. The data base also supports 180 additional aircraft types by assigning each additional type to one of the 84 directly modeled types with similar performance characteristics.

Approach profiles. Trajectories of approaching aircraft were modeled to begin at points that are located about 23 NM from the runway thresholds and aligned with one of the extended centerlines of the parallel runways. All approaching aircraft capable of maintaining an airspeed of 170 KIAS were assigned this speed when intercepting the localizer. The assigned airspeed was subjected to stochastic variations within a uniform ±1 percent range around the assigned intercept airspeed. The resulting variability in modeled approach speed was assumed to capture minor speed variability in actual operations. It should be noted that assigned approach speeds when expressed in units of KTAS differed slightly between aircraft on the two approaches because the intercept altitude on the upwind approach exceeded that on the downwind approach by 1,000 ft. Furthermore, it is important to note that no ground speed effects due to wind or changes in wind were considered in the modeling of the procedures.

While established on the localizer, all aircraft maintained their assigned altitude until intercepting a 3.0-degree ILS glideslope. Due to the 1,000-foot difference in assigned altitudes between aircraft on the upwind (higher) and downwind (lower) approaches, aircraft on the upwind approach intercepted the glideslope farther out than aircraft on the downwind approach. All aircraft maintained the localizer intercept airspeed in terms of KIAS until reaching a point about 6 NM from the threshold. At this point, aircraft were modeled to decelerate to their aircraft type-specific final approach speeds in landing configuration (given in units of KIAS) which was attained when reaching an altitude of 1,000 feet above ground level (AGL) and maintained until touch-down. Sample altitude and speed profiles of the model are illustrated in

Figure 3 for the case of an aircraft of type B733 approaching STL's runways 12R and 12L. In order to account for variability in final approach and landing speeds, the aircraft type-specific speed was subjected to stochastic variations within a uniform ±5 percent range around the airspeed specified by the model for a given aircraft type at reference weight. The resulting variability in aircraft type-specific speeds was assumed to capture the variability in aircraft weights and landing speeds in actual operations.

Aircraft separation. The model's Controller ensured that approaching aircraft are spatially separated from preceding aircraft. Separation was achieved by imposing applicable diagonal, radar, or wake turbulence separation between aircraft as presented in Tables 1 and 2. In addition to these applicable minimum separation values, another temporal separation value was added that was randomly drawn from a distribution. This distribution served to buffer applicable separation minima and was selected to be identical to the buffer distribution commonly used in airfield capacity modeling [12]. It is important to note that the application of additional temporal separations drawn from the buffer distribution does not exclude situations in which minor deviations from separation rules may occasionally occur. Application of the composite separation values by the model Controller consisting of discrete standard minimum separations (Tables 1 or 2) plus normally distributed separation buffer values resulted in model aircraft separations that are considered to be consistent with those realistically achieved by ATC in actual arrival operations.

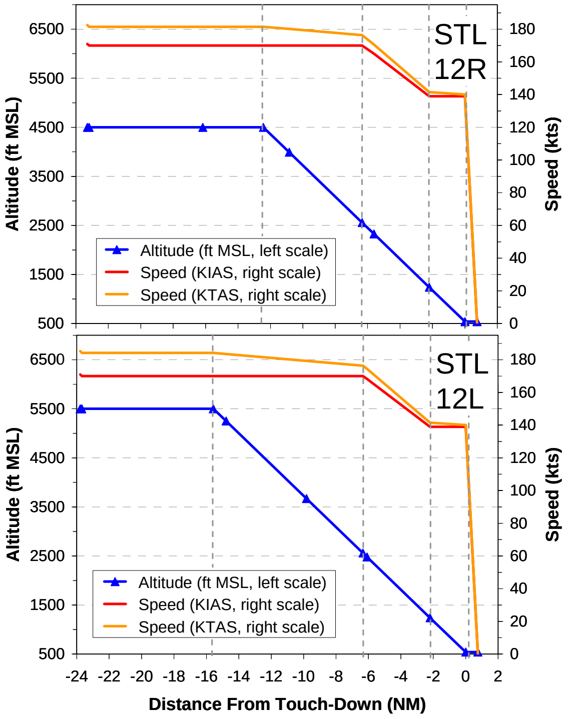

Figure 3. Sample Approach Profiles (STL)

The model Controller applied the required temporal separation to ensure that approaching aircraft were spatially separated from preceding aircraft at two geometric locations on the approach. Separation from preceding aircraft was ensured when an aircraft joined the localizer and at the runway threshold when a preceding aircraft crossed the threshold. Joining the localizer was modeled to occur for all aircraft at a distance of approximately 16 NM from the runway threshold. At each constraint location (joining the localizer and approaching the threshold), the model Controller evaluated in-trail separation requirements (preceding approach to the same runway) as well as applicable diagonal separation requirements (preceding parallel approach to the adjacent runway) for the specific types of approaching aircraft and the procedure scenario modeled. Of the two separation requirements, the separation requirement that called for application of the larger temporal separation (referred to as the limiting constraint) was chosen by the Controller at each constraint location. The Controller then determined which constraint location (joining the localizer of approaching the threshold) yielded the limiting overall constraint and applied the associated temporal separation to each flight when joining the localizer. The resulting separation between aircraft anywhere else on the approach from joining the localizer to crossing the threshold was dependent upon the speed assigned to aircraft when joining the localizer and the speed profiles flown during the final descent to the runway.

Model Capacity Analysis

The scope of the evaluation of the proposed procedural variants of wind-dependent arrival procedures was to estimate the impact of additional procedural restrictions on arrival capacity benefits at CSPR airports. Procedural constraints were adapted to reflect the requirements of the various candidate procedures studied (see Table 3). Operational constraints were assumed to remain unchanged and were applied uniformly to all modeling scenarios (see Tables 1 and 2).

All modeling scenarios of proposed procedures employed randomly selected aircraft types based on empirical aircraft type distributions and randomized flight performances. Where procedural restrictions allowed, the modeling scenarios employed the same random sequences of arriving flights.

Wind-dependent arrival operations were modeled by performing multiple replicates of Monte Carlo simulation runs. Each simulation run modeled 500 Leader aircraft approaching and landing on the downwind runway and an equal number of Trailer aircraft on the upwind approach and landing on the upwind runway. Monte Carlo runs were replicated 100 times. The modeling of each procedure scenario comprised 50,000 simulated arrivals on approach to each runway. The modeling results are based on a total of 11.3 million simulated operations.

In the modeling approach presented here, arrival **capacity** is defined as the **maximum average arrival throughput**, on a long-term basis, given sustained arrival demand [13]. This definition of arrival capacity recognizes the possibility of temporarily achieving greater throughput during time periods in which arrival demand is characterized by favorable sequences of aircraft types.

For a given airport and distribution of aircraft types, arrival **capacity benefit** is defined as the difference between IMC capacities modeled for single-runway operations and for each kind of paired arrival operation (see Table 3). At each airport under investigation, operations on runways other than the parallel runways were assumed to remain unchanged. Consequently, improvements in arrival capacity were assumed to represent potential arrival capacity benefits of the respective airfields.

Model Validation

For each airport evaluated, modeled arrival capacities of single-runway operations served as Baseline capacities and were compared to modeled arrival capacities of the various procedure variants of paired, wind-dependent operations. Measured differences in capacities then served to estimate the potential capacity benefits of the proposed procedures. Both, Baseline and procedure models were subjected to extensive testing to ensure proper model behavior. At each model analysis step, inspection of key model output including distributions of modeled aircraft separations and throughput representing large numbers of simulated operations allowed efficient validation of operational and procedural constraints and performance randomization applied in the model. Figure 4 illustrates model output distributions of inter-arrival separations measured in 1,000 model execution replicates of 500 Baseline operations on STL’s runway 12R. It presents separation values of an approaching aircraft from a preceding aircraft when the latter crosses points at various distances from the threshold as well as when the preceding aircraft crosses the threshold. At and outside of the ILS outer marker (5.4 NM from the threshold), the most likely separation of consecutively arriving aircraft is seen to be close to 5 NM (dark blue curves) whereas compression effects during deceleration reduce the most likely observed separation to about 4 NM close to the threshold (red curve). The distributions presented in Figure 4 comprise about 3.5 million separation

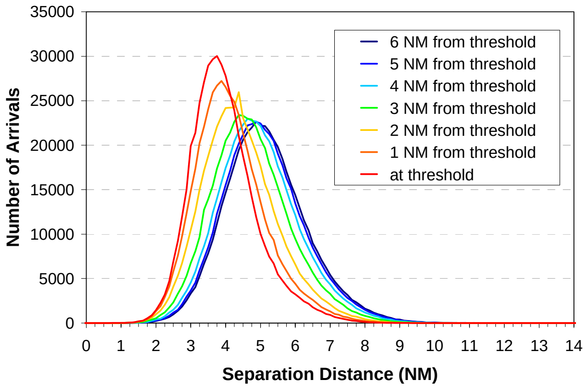

Figure 4. Modeled Distributions of STL Baseline Separations

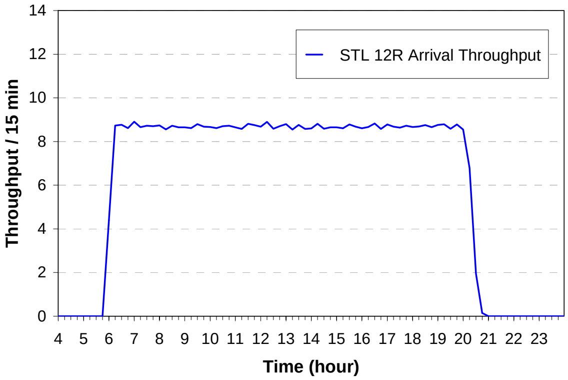

Figure 5. Modeled Average Baseline Throughput (STL)

Table 4. Modeled Baseline Capacities

Airport	Modeled Single-Runway Arrival Capacity (ops/hr, (StdDev))
CLE	33.4 (0.4)
STL	34.9 (0.3)
DTW	34.6 (0.4)
PHL	33.2 (0.4)
SEA	32.7 (0.4)
BOS	32.3 (0.4)
EWR	30.4 (0.3)
LAX	31.2 (0.3)
SFO	29.3 (0.2)

measurements performed during execution of the model. Illustrating the statistics gathered in a typical set of Monte Carlo runs of the model, Figure 5 presents the average throughput distribution resulting from 100 model execution replicates of 500 Baseline arrival operations to STL's runway 12R. The throughput shown represents a total of 50,000 simulated operations and the average number of arrivals measured per 15-min time interval. The resulting throughput of 34.9 arrivals per hour served as Baseline capacity when determining potential capacity benefits of wind-dependent procedure variants at STL. This capacity and Baseline capacities that were similarly derived for all other airports are presented in Table 4. The observed differences in capacity are largely due to differences in the aircraft type distributions of the various airports (see section Model Input). These Baseline capacity values were found to be consistent with single-runway arrival capacities commonly determined for IMC operations.

Capacity Sensitivity Analysis

Sensitivity analyses were carried out in order to evaluate the sensitivity to which capacity results depend upon the approach geometry and speed parameter ranges chosen in this study. The analyses were found to indicate that capacity results are little sensitive to whether Leader aircraft are assigned to the downwind or upwind runway and to variations in runway stagger distance for the range of possible stagger values at the nine airports under investigation. For STL's approaches to runways 12R and 12L, capacity results were observed to lie within 0.5 percent of one another when comparing runway geometries with and without runway stagger. In order to facilitate comparisons between capacity benefit estimates for all airports and possible runway geometries, no runway stagger was assumed in the modeling of all other airports.

Capacity Benefit Results

The modeling results presented in Figures 6 to 9 suggest potential capacity benefits associated with all wind-dependent procedures of arrival operations to CSPRs evaluated in this study. The legends of the figures identify the airports as well as the minimum arrival separation values (2.5 or 3.0 NM) applied in the modeling (see Table 1).

Upwind Wake Free Procedures

Results of unrestricted upwind wake free procedures (Scenarios 2, 3, and 4) are shown in Figure 6. These procedures impose no additional restrictions on B757 and Heavy category aircraft and all aircraft types were assigned to both upwind and downwind approaches (see Table 3). These procedure variants were seen to potentially yield 3 to about 8 additional arrival operations depending upon the procedure variant and airport. The largest capacity gains were observed for Scenario 2 in which aircraft of all wake categories served as Leaders and 1.5 NM diagonal separation could be applied to all Trailers following Small or Large category Leader aircraft (see Table 2). In this case, capacity benefits were seen to be greatest at airports

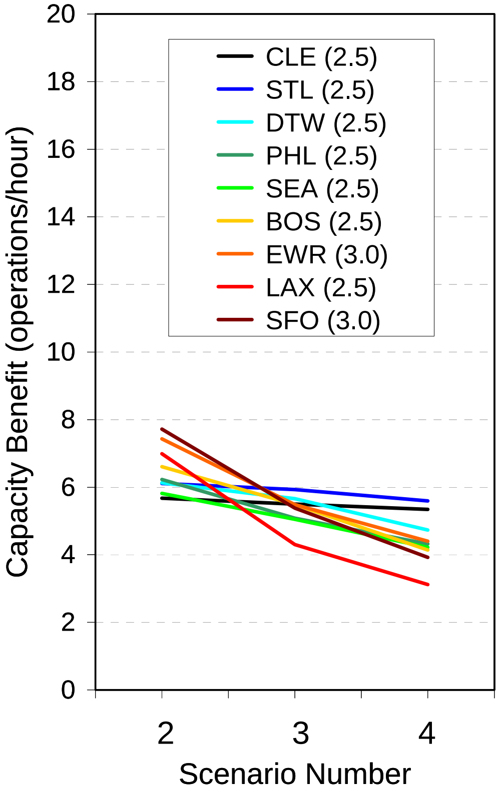

Figure 6. Modeled Capacity Benefits of Upwind Wake-Free Procedures (Scenarios 2, 3, and 4)

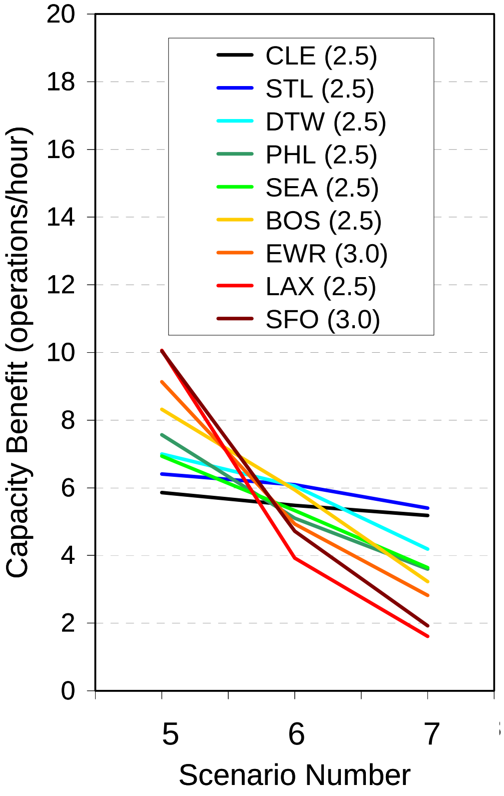

Figure 7. Modeled Capacity Benefits of Upwind Wake-Free Procedures (Scenarios 5, 6, and 7)

with larger percentages of B757 and Heavy category aircraft in their fleet mix and that currently apply minimum arrival separations of 3.0 NM (see Figure 2). Furthermore, benefits at airports with a fleet mix that includes small percentages of B757 and Heavy category aircraft were impacted only little by additional restrictions on Leader aircraft and capacity benefit results obtained for CLE and STL essentially remained unchanged.

Results of upwind wake free procedures that required assigning B757 and Heavy category aircraft to the downwind approach only (Scenarios 5, 6, and 7) are presented in Figure 7. These procedures were found to yield larger benefits at airports with larger percentages of B757 and Heavy category aircraft in their fleet mix provided aircraft of all wake categories served as Leaders (up to 10 additional arrival operations in Scenario 5). If restrictions were imposed on Leader aircraft, significant benefit reductions were observed especially for those airports with larger percentages of B757 and Heavy category aircraft in their fleet mix. Not surprisingly, benefits at airports with a fleet mix comprising small percentages of B757 and Heavy category aircraft were seen to be impacted little by restricting these aircraft to the downwind approach or imposing additional restrictions on Leader aircraft. Specifically, capacity benefit results obtained for CLE and STL differed only little from those found in Scenarios 2, 3 and 4.

Upwind and Downwind Wake Free Procedures

The modeling results for upwind and downwind wake free procedures presented in Figures 8 and 9 indicate potential capacity benefits that exceed those obtained for all corresponding procedure variants presented above that assumed wake free arrival operations on the upwind approach only.

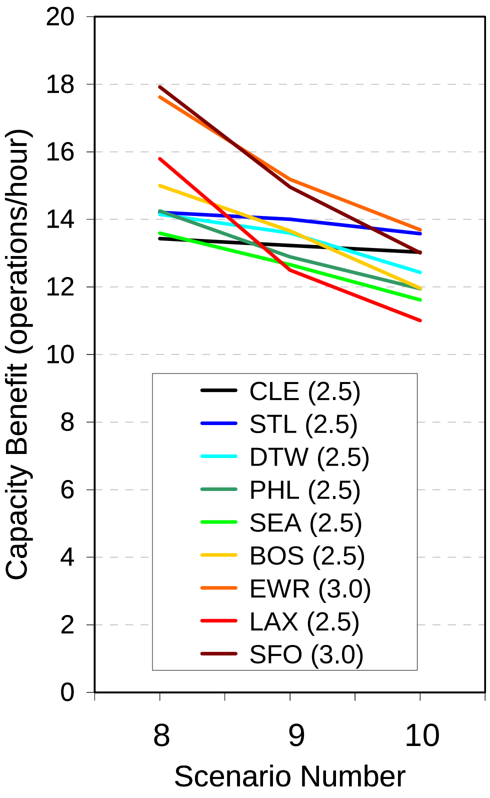

Figure 8. Modeled Capacity Benefits of Upwind and Downwind Wake-Free Procedures (Scenarios 8, 9, and 10)

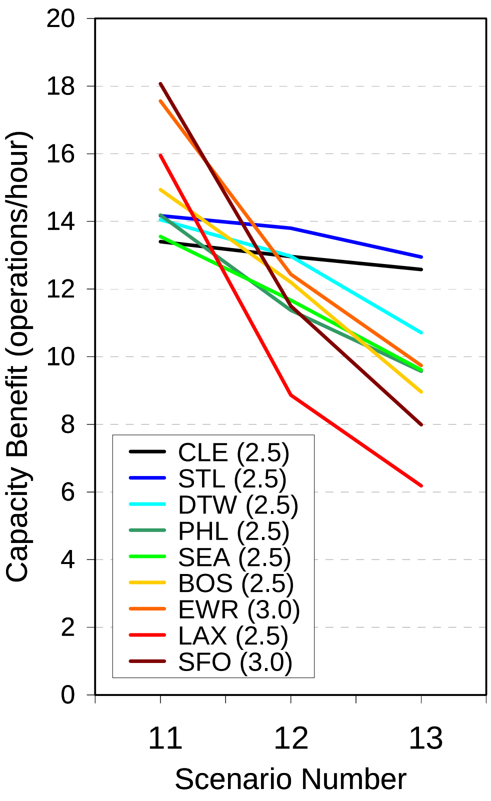

Figure 9. Modeled Capacity Benefits of Upwind and Downwind Wake-Free Procedures (Scenarios 11, 12, and 13)

Results of unrestricted upwind and downwind wake free procedures (Scenarios 8, 9, and 10) are presented in Figure 8. These procedure variants impose no additional restrictions on B757 and Heavy category aircraft and all aircraft types were assigned to both upwind and downwind approaches. The procedure variants were seen to potentially yield 11 to 18 additional arrival operations depending upon the procedure variant and airport. The largest capacity gains were observed for Scenario 8 in which aircraft of all wake categories served as Leaders and 1.5 NM diagonal separation could be applied to all Trailers following Small or Large category aircraft (see Table 2). As before in the case of upwind wake free procedures, capacity benefits were seen to be greatest at airports with larger percentages of B757 and Heavy category aircraft in their fleet mix and that currently apply minimum arrival separations of 3.0 NM. While benefits at airports with a fleet mix comprising larger percentages of B757 and Heavy category aircraft were again seen to be impacted significantly by additional restrictions on Leader aircraft (Scenarios 9 and 10), benefits at airports with a fleet mix comprising small percentages of B757 and Heavy category aircraft were impacted only little by these additional restrictions.

Results of upwind wake free procedures that required assigning B757 and Heavy category aircraft to the downwind approach only (Scenarios 11, 12, and 13) are presented in Figure 9. When compared to Scenarios 8, 9, and 10, these procedures were found to yield similar benefits if no additional restrictions on Leader aircraft applied. However, the capacity benefit results were found to display a greater dependence on additional restrictions imposed on Leader aircraft. If restrictions were imposed on Leader aircraft, significant benefit reductions were observed especially for those airports with larger percentages of B757 and Heavy category aircraft in their fleet mix. As seen in results obtained for upwind wake free procedures (Figures 6 and 7), benefits at airports with a fleet mix that includes small percentages of B757 and Heavy category aircraft were impacted only little by restricting B757 and Heavy category aircraft to the downwind approach or imposing additional restrictions on Leader aircraft. For example, capacity benefit results obtained for CLE and STL differed only little from those found in Scenarios 8, 9 and 10.

The modeling results suggest potential capacity benefits associated with all wind-dependent procedures of arrival operations to CSPRs at all airports investigated in this study. Evaluation of the various procedure categories indicated that assigning B757 and Heavy category aircraft to the downwind approach does not negatively impact its benefit potential provided no additional restrictions on Leader aircraft are imposed. In this case, it is interesting to note that upwind wake free procedures were observed to benefit from assigning Heavy and B75 category aircraft to the downwind runway at airports with larger percentages of B757 and Heavy category aircraft.

In all four groups of modeled scenarios, capacity benefits were found to display a dependence on additional restrictions imposed on Leader aircraft. While significant reductions in modeled benefits were observed within each group and for airports with larger percentages of B757 and Heavy category aircraft in their fleet mix, little to no significant impact was seen for airports with small such percentages in their fleet mix.

Summary

The FAA and NASA currently conduct a multi-phased research and development program to develop and implement wake vortex avoidance solutions that can safely reduce separations and improve capacity at airports in the NAS. As part of this program, candidate wind-dependent parallel operational concepts to CSPRs were identified. These concepts rely on knowledge of the dynamics of wake vortices within the wind field along the approach paths. The concepts are designed to permit dependent parallel arrival operations when meteorological conditions render approach paths free of wake vortices from preceding aircraft.

Potential capacity benefits of wind-dependent straight-in arrival concepts were evaluated using Monte Carlo model simulation analyses of dependent parallel runway operations with authorized minimum diagonal separation of 1.5 nautical miles (NM) at 9 CSPR airports.

Two categories of procedures were evaluated. Arrival operations in the category comprising procedures in which only the upwind approach is considered wake free were found to yield potential capacity benefits ranging from about 2 to 10 additional arrival operations per hour. Greater potential capacity benefits were identified to be associated with procedures where both approaches are considered wake free. In this category of procedures, potential capacity benefits were found to range from about 6 to 18 additional arrival operations per hour.

While capacity benefits were seen to be largely dependent upon the category of procedure, significant differences were also observed within each category for operations at airports characterized by a fleet mix with varying fractions of B757 and Heavy category aircraft. Procedure capacity benefits at airports with a fleet mix comprising small percentages of B757 and Heavy category aircraft were found to be impacted little by additional restrictions on Leader aircraft or when B757 and Heavy category aircraft were restricted to the downwind runway. Conversely, procedure capacity benefits at airports with a fleet mix comprising larger percentages of B757 and Heavy category aircraft were significantly reduced when additional restrictions on Leader aircraft were imposed.

The modeling results were also found to suggest that airports currently conducting arrival operations requiring the application of a minimum arrival separation of 3.0 NM could generally benefit most from wake free procedures especially if no additional restrictions on Leader aircraft are imposed.

This fast-time simulation analysis of wind-dependent parallel approach procedures firmly establishes their potential capacity benefits that result from extended use of dual arrival streams in IMC. The results promise reductions in weather-related delays at CSPR airports and support continued pursuit of defining and implementing wake-independent procedures, validating safety assessments, and addressing training issues.

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