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Vertical Navigation Requirement for Simultaneous Independent Parallel Instrument Approaches to Closely Spaced Parallel Runways

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12. Abstract
A 2011 technical report titled, *Comparative Evaluation of Lateral Flight Technical Error for Instrument Landing System and Localizer Only Approaches*, presented the risk of collision between aircraft flying dual simultaneous independent approaches to parallel runways in the event that the lead aircraft deviates from its course toward the path of the adjacent aircraft. The runway separation was 4,300 feet (ft). One aircraft was flying an instrument landing system (ILS) approach and the other aircraft was flying a localizer only approach (LOC) without high update rate (HUR) surveillance. The 2011 report showed that the risk of collision for the dual ILS-LOC operation was less than 1.0×10^{-9}. Since the 2011 report was written, the minimum runway separation standard for dual simultaneous independent parallel instrument approaches without HUR surveillance has been reduced from 4,300 ft to 3,600 ft, for offset approach operations, the standard has been reduced to 3,000 ft, and for triple approach operations, the standard has been reduced from 5,000 ft to 3,900 ft. This study extends the analysis to examine risk of collision for ILS and LOC approaches during dual, offset, and triple operations at the new runway separation minimums and also to include lateral navigation/vertical navigation (LNAV/VNAV/RNAV Required Navigation Performance (RNP)) and LNAV approaches. Lateral and vertical performance data from the Established on RNP data collection efforts were included in the extended analysis.

All combinations of dual and triple approaches that were examined in this analysis resulted in collision risks less than the vertical guidance baseline case. The results of this report do not counter the inherent safety advantages of using vertical guidance. The use and availability of vertical guidance is encouraged as a recognized substantial safety enhancement during all instrument approach operations.

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Table of Contents

List of Figures

List of Tables

Executive Summary

A 2011 technical report titled, *Comparative Evaluation of Lateral Flight Technical Error for Instrument Landing System and Localizer Only Approaches*, [4] presented the risk of collision between aircraft flying dual simultaneous independent approaches to parallel runways in the event that one of the aircraft deviates from its course toward the path of the adjacent aircraft at the then-current minimum runway separation of 4,300 feet (ft). This report covers the scenario in which one aircraft was flying an instrument landing system (ILS) approach and the other aircraft was flying a localizer only approach (LOC). The 2011 report showed that the risk of collision for the dual ILS-LOC operation was less than 1.0×10^{-9}. Since that report was written, additional closely spaced parallel operations studies have supported the extension of the navigation systems approved for dual and triple approach operations to include Ground-Based Augmentation System Landing System (GLS), Localizer Performance with Vertical Guidance (LPV), Global Positioning System based Area Navigation (RNAV), and Global Positioning System based RNAV Required Navigation Performance (RNP), RNAV RNP. Each of these navigation systems required vertical guidance and were to be flown either with flight director or while coupled to an autopilot. The minimum runway separation standard for closely spaced parallel operations without high update rate surveillance operations has been reduced from 4,300 ft to 3,600 ft. Additionally, the minimum runway separation standard for offset approach operations has been reduced to 3,000 ft and the standard for triple approach operations has been reduced from 5,000 ft to 3,900 ft. This present study extends the previous ILS to LOC only analysis to examine the risk of collision for dual, offset, and triple approach operations using all approved navigation systems, but without vertical guidance. This study also applies to the localizer type directional aid precision runway monitor approach for Simultaneous Offset Instrument Approaches (SOIA). Lateral and vertical performance data from the Established on RNP (EoR) data collection efforts were included in this extended analysis.

All combinations of dual, offset, and triple approaches that were examined in this analysis resulted in collision risks less than vertical guidance baseline cases. Those simultaneous approach operations that require vertical guidance to mitigate wake turbulence, such as operations authorized under Federal Aviation Administration (FAA) Order JO 7110.308 [5], were not considered in this safety analysis and are therefore outside the scope of this report. The results of this report do not counter the inherent safety advantages of using vertical guidance. The use and availability of vertical guidance is recognized as a substantial safety enhancement during all instrument approach operations.

1 Introduction

1.1 Background

In 2011, the Air Traffic Safety Oversight Service (AOV) and the Air Traffic Organization (ATO) requested an evaluation of the risk of conducting dependent and simultaneous independent approaches with an inoperative glideslope to one runway. To support this request, a technical report [4] was published in August 2011 that evaluated the risk of collision between two aircraft conducting simultaneous independent approach operations, in which one aircraft had the full capabilities of the ILS, but the other aircraft had only the localizer available (ILS-LOC). The LOC instrument approach chosen for that evaluation contained several stepdown fixes between the final approach fix and the minimum descent altitude in order to test a case where the crew workload increased. This type of approach is commonly referred to as a dive-and-drive approach, in which the crew will descend (dive) to the altitude of a stepdown fix, then level off (drive) until they cross that fix, and so forth until the minimum descent altitude is reached.

The 2011 report results were based on data obtained from a pilot human-in-the-loop (HITL) simulation study utilizing the FAA Boeing 737-800 and Airbus A330 level D qualified flight simulators. The HITL results showed that pilots experienced an increase in workload during dive-and-drive approaches that degraded lateral performance. Most HITL test pilot subjects stated that they seldom flew dive-and-drive approaches, noting that their aircraft were equipped with baro-VNAV (vertical navigation) to calculate a smooth vertical path even when a glideslope was not available. In addition, their company standard operating procedures required them to extract the RNAV procedure with lateral navigation (LNAV)/VNAV/RNAV(RNP) minima from the navigation database and, if available, execute and monitor it while flying either an ILS or LOC approach.

The 2011 study made use of a Flight Technologies and Procedures Division (AFS-400) fast-time simulation tool to evaluate the risk of collision. Due to complexity of aircraft design and their corresponding geometry of flight, collision between two aircraft was modeled by a test criterion violation (TCV). The TCV in the 2011 report was defined as the penetration by the center of gravity of one aircraft into the volume of space representing the other aircraft, a cylinder with a 265 ft radius and 160 ft height (±80 ft). Figure 1-1 depicts this TCV volume, which represents the worst case aircraft size, the Airbus A380.

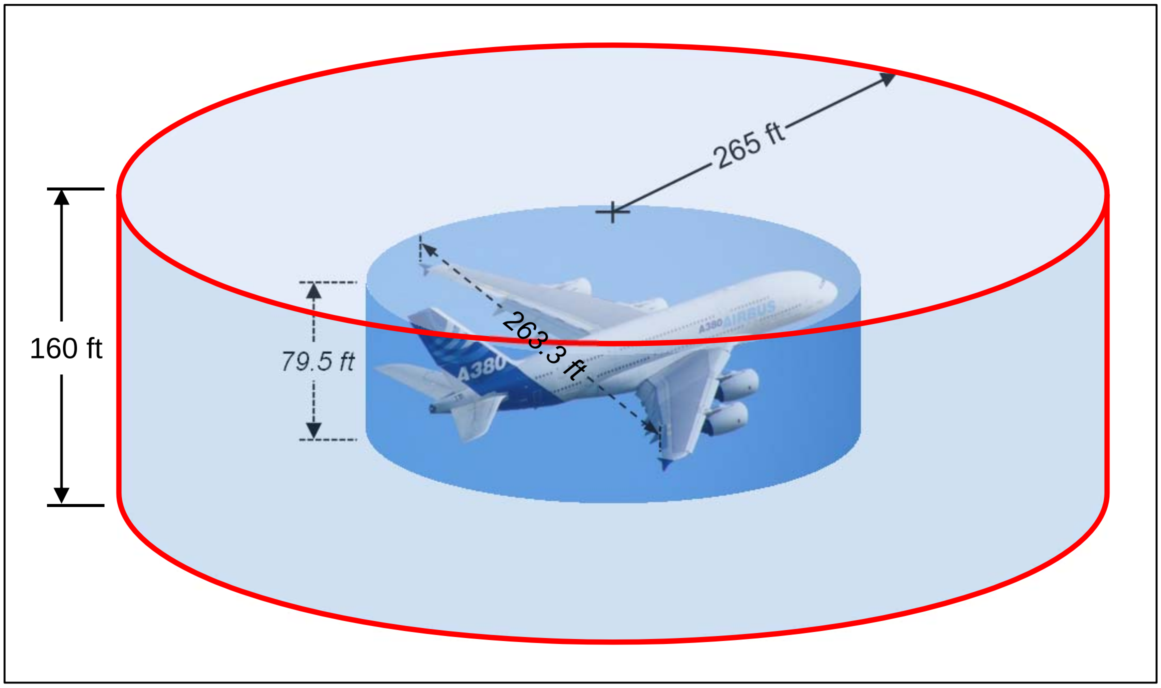

Figure 1-1: TCV Volume Dimensions

The fast-time simulation tool used input options including lateral/vertical track distributions, fleet mix, aircraft dynamics, surveillance, air traffic control monitoring systems, pilot response times (PRT), controller response times (CRT), and environmental conditions. The tool created thousands of runs per scenario, such as an ILS-LOC simultaneous independent approach combination with 3,600 ft Runway Centerline Spacing (RCLS) to produce results that were used to calculate the probability of a TCV.

The specific lateral and vertical deviation distributions derived from the 2011 ILS-LOC HITL were used as input into the fast-time simulations to determine the collision risk in an ILS-LOC scenario in which there was a course deviation. The 2011 report showed the collision risk of the ILS-LOC combination to be approximately 2% greater than that of the ILS-ILS combination given the higher lateral error of the LOC approaches. The overall collision risk for both of those combinations was less than 1×10^{-9} per operation.

This present safety study expands the evaluation of collision risk in the event of a deviation of one aircraft into the path of the other aircraft during simultaneous independent approach operations to runways with an RCLS at the current minimum runway separation of 3,600 ft for dual approaches, 3,000 ft for offset approaches, and 3,900 ft for triple approaches. Additionally, SOIA operations are covered by this analysis as they are identical to simultaneous offset independent dual instrument approach lateral separation operations analyzed in this study prior to the transition to visual separation. At that 3,000 ft lateral separation point, the SOIA operation requires the pilot on the offset approach to visually acquire and maintain separation from the lead aircraft on the straight-in approach. This study does not support any changes to the current requirements of this visual separation portion of the SOIA operation as lateral separations less than 3,000 ft were not analyzed. This includes the vertical guidance requirement for the straight-in approach and for the visual segment portion of the offset approach, both of which provide wake mitigation benefits.

1.2 Purpose

The purpose of this document is to present an evaluation of the risk of collision for dual, offset, and triple simultaneous independent approach operations due to a deviation by the lead aircraft into the path of an adjacent trailing aircraft when both aircraft have lateral navigation, but one or more aircraft do not have vertical navigation. While this analysis evaluates the risk of collision in the case of a course deviation, it is not meant to discourage the use and availability of vertical guidance capabilities as they are recognized to add safety to instrument approach operations.

2 Objectives and Scope

The objective of this study was to examine the collision risk sensitivity for aircraft conducting dual, offset, and triple simultaneous independent approach operations without vertical navigational guidance. The scope of this report is limited to collision risk and therefore does not address vertical guidance benefits for wake turbulence separation standards or controlled flight into terrain.

3 Methodology

3.1 Fast Time Simulation

The primary analysis tool for this safety study was the Flight Systems Laboratory (AFS-450) Airspace Simulation and Analysis Tool – New Generation ($ASAT^{ng}$). $ASAT^{ng}$ is a multifaceted fast-time simulation tool for aviation related safety assessments. $ASAT^{ng}$ uses high fidelity models of all components of an aviation scenario to evaluate the overall risk of the operation. A wide range of parameters covering operational aspects, such as aircraft performance, atmospheric conditions, navigation system performance, air traffic control monitoring and surveillance equipment, PRT, and CRT enable very efficient and realistic modeling of complex operational scenarios. $ASAT^{ng}$ also uses official FAA databases of navigation and surveillance facilities, runways, fixes, etc. Additionally, $ASAT^{ng}$ allows the aircraft fleet mix for the area of interest to be incorporated into the simulations.

3.2 Test Design and Scenarios

For the dual, offset, and triple approach operations, the airport field elevations were at 2,000 ft and the runway spacings were at the minimum allowable separation of 3,600 ft, 3,000 ft, and 3,900 ft respectively. Assumptions were kept consistent with the 2011 technical report titled, *Simultaneous Independent Close Parallel Approaches - High Update Radar Not Required*. [3]

The fleet mix utilized 20% heavy aircraft, 40% large aircraft, and 40% small aircraft. Half of the heavy aircraft (i.e. 10% of the fleet mix) were represented by the Airbus 330 (A330) and half by the Boeing 747-400 (B744). The large aircraft were all represented by the Boeing 737-800 (B738) and the small aircraft were all represented by a generic Embraer Regional Jet. The aircraft in the mix each have different approach speeds and dynamics in response to pilot inputs appropriate for the aircraft type.

In each $ASAT^{ng}$ simulation run, the closest point of approach was recorded along with the position of the deviating aircraft relative to the evading aircraft. If the deviating aircraft's center of gravity penetrated the TCV volume of the endangered aircraft then a TCV occurred and was considered to result in a collision.

Each combination of runway spacing and field elevation has 4 fundamental scenarios of interest, i.e., 20° and 30^{o} level and descending course deviations. No determination has been made of the prevalence of a descending or level course deviation, and therefore the choice was made to cover the two equally. All scenarios used CRT distributions increased by a two second delay by the controller prior to noticing the course deviation. Based on the analysis described in the October 2010 report, *Pilot and Controller Response Times from the July 2009 Human in the Loop Data Collection Project*, DOT-FAA-AFS-450-61 [2], there were 2 CRT distributions utilized in this study, one for 20° course deviations and one for 30° course deviations.

According to the 2011 LOC pilot HITL, pilots experienced increased workload during dive-and-drive approaches which would have a negative effect on situational awareness during simultaneous approach operations. [4] Consistent with previous AFS-400 closely spaced parallel operations safety studies, the PRTs that were used in this analysis did not reflect the increased workload of dive-and-drive approaches, but instead reflected the workload associated with a smooth vertical path. If dive-and-drive approaches during simultaneous approach operations were desired, additional data collection would be required to determine the appropriate PRTs for those operations.

For the study of dual and offset simultaneous independent approach operations, a total of eight combinations were investigated. These eight combinations did not include all of the possible combinations of traffic with and without vertical guidance, but were a representative selection of those combinations where at least one runway was without vertical guidance. These eight combinations were compared to a vertical guidance baseline case in which all aircraft utilized vertical guidance. All cases were comprised of four fundamental scenarios of turn angles and descent/non-descent for each of the approach procedures as shown in tables 3-1 and 3-2. For triples, a total of eight combinations were investigated. They were also comprised of four fundamental scenarios of turn angles and descent/non-descent for each of the approach procedures as shown in table 3-3. Before considering descending or level path deviations, there are three basic possibilities for path deviations during triple approaches that could result in a TCV. An aircraft on an outside approach path can deviate toward the aircraft on the center approach, an aircraft on an outside approach can also deviate all the way across the center toward the aircraft on the opposite outside approach, or an aircraft on the center approach can deviate toward an aircraft on an outside approach. Since each of these three potential events can occur with a level or descending course deviation, the result is six possibilities. As is also shown in tables 3-1, 3-2, and 3-3, aircraft with ILS, GLS, or LPV navigation systems are modeled equivalently based on available data. The same modeled equivalency also exists with LOC and Localizer Performance (LP) approaches.

Table 3-1: Tested Combinations of Dual Approaches

First Runway	Second Runway
ILS, GLS, or LPV	ILS, GLS, or LPV
ILS, GLS, or LPV	LOC or LP
LOC or LP	LOC or LP
LNAV	LOC or LP
LNAV/VNAV/RNAV(RNP)	LOC or LP
ILS, GLS, or LPV	LNAV
LOC or LP	LNAV
LNAV	LNAV
LNAV/VNAV/RNAV(RNP)	LNAV

Table 3-2: Tested Combinations of Offset Approaches

First Runway Straight-In Approach	Second Runway Offset Approach
ILS, GLS, or LPV	ILS, GLS, or LPV
ILS, GLS, or LPV	LOC or LP
LOC or LP	LOC or LP
LNAV	LOC or LP
LNAV/VNAV/RNAV(RNP)	LOC or LP
ILS, GLS, or LPV	LNAV
LOC or LP	LNAV
LNAV	LNAV
LNAV/VNAV/RNAV(RNP)	LNAV

Table 3-3: Tested Combinations of Triple Approaches

First Runway	Second Runway	Third Runway
ILS, GLS, or LPV	ILS, GLS, or LPV	ILS, GLS, or LPV
ILS, GLS, or LPV	ILS, GLS, or LPV	LOC or LP
ILS, GLS, or LPV	LOC or LP	LOC or LP
ILS, GLS, or LPV	LNAV	LOC or LP
LOC or LP	LOC or LP	LOC or LP
LNAV	LNAV	LNAV
ILS, GLS, or LPV	LNAV	LNAV
LNAV/VNAV/RNAV(RNP)	LNAV	LNAV
LNAV/VNAV/RNAV(RNP)	LOC or LP	LNAV

There was a 2,000 ft wide no transgression zone equidistant between any 2 given approach paths for both dual and triple approaches. Based on previous analyses that have evaluated runway stagger and shown increased runway stagger to lessen collision risk, these scenarios were conservatively tested without runway stagger.

The temperature profile was a linear decrease from the International Standard Atmosphere temperature of 15°C at the surface to -36.5°C at 36,090 ft, with no wind. The release positions of the two aircraft were distributed uniformly between 2 and 14 nautical miles (NM) out from the threshold in such a way to ensure that the deviating aircraft could reach the other aircraft prior to its landing. Each pair was released at the same distance from the runway threshold (i.e. side-by-side) and "at-risk" for a collision in the event that the controller and/or pilot did not intervene with the deviation. At-risk is a condition for the release of the aircraft specified within the ASAT^{ng} simulation that ensures the 2 aircraft will pass somewhere within the minimum possible range which, for this study, was inside the 265 ft radius of the TCV volume.

Aircraft on ILS, GLS, or LPV approaches were simulated with the Collision Risk Model (CRM) for Category II with Flight Director at a glide slope of 3°, and as noted in table 3-4, the vertical error distribution for the LNAV/VNAV/RNAV(RNP) scenario used the CRM vertical error distribution. [7] Consistent with previous studies not only by the FAA, but by other civil aviation agencies and in International Civil Aviation Organization panels, it is accepted that vertical flight technical error is the predominant contributor to vertical total system error in vertically guided approaches for altitude acquisition and maintenance. Therefore, it was assumed in this study that flight technical error is the primary factor contributing to vertical errors in the vertical guidance cases. This represents a conservative assumption as uncompensated baro-VNAV would have the potential to increase vertical separation from adjacent approaches as the glideslope angle would effectively increase and decrease with changing atmospheric conditions. The distributions for non-vertical guidance approaches were based on previous data collection efforts. In the case of LOC, LP, and LNAV approaches, the EoR HITL data indicated that the vertical errors associated with non-vertical guidance approaches could be represented with a normal distribution having a mean of 0 ft and a standard deviation of 175 ft. [1] In the case of LOC approaches, the 2011 localizer study indicated that the HITL pilots that participated in the 2011 study had lateral deviations for LOC approaches that were approximately 33% greater than lateral deviations for ILS approaches. [4] Based on this data, a 33% increase in lateral deviation was incorporated into the fast-time simulations of LOC and LP approaches. Table 3-4 shows the lateral and vertical deviation distributions that were used as inputs to the corresponding fast-time simulation scenarios.

Table 3-4: Lateral and Vertical Deviation Distributions

	ILS, GLS, LPV	LOC, LP	LNAV/VNAV/RNAV(RNP)	LNAV
Lateral	CRM	CRM plus 33%	Normal (0, 0.04NM)	Normal (0, 0.04NM)
Vertical	CRM	Normal (0, 175ft)	CRM	Normal (0, 175ft)

3.3 Test Assumptions

This operation meets all the requirements of Order JO 7110.65W, *Air Traffic Control*, paragraph 5-9-7 Simultaneous Independent Approaches – Dual & Triple [6];

3.4 Independent Variables

A wide range of parameters were used to realistically model these complex operational scenarios. These parameters include:

- Aircraft fleet mix;
- Approach type;
- PRT distribution;
- CRT distribution;
- Airport field elevation;
- Runway spacing;
- Approach deviation rate;
- Aircraft performance;
- Atmospheric conditions;
- Navigation system performance; and
- Surveillance and monitoring equipment.

3.5 Dependent Variables

The dependent variable is the TCV rate.

4 Data Analysis

4.1 Collision Risk

Tables 4-1, 4-2, and 4-3 show the results of the analysis for all tested combinations of dual and triple approaches. The results show that all combinations where at least one aircraft does not have vertical guidance resulted in collision risk probabilities that are less than the vertical guidance baseline case.

Table 4-1: Risk of TCV for Dual Approaches

First Runway	Second Runway	Risk of TCV
ILS, GLS, or LPV	ILS, GLS, or LPV	9.96E-10
ILS, GLS, or LPV	LOC or LP	9.12E-10
LOC or LP	LOC or LP	9.23E-10
LNAV	LOC or LP	9.16E-10
LNAV/VNAV/RNAV(RNP)	LOC or LP	9.65E-10
ILS, GLS, or LPV	LNAV	8.98E-10
LOC or LP	LNAV	9.16E-10
LNAV	LNAV	8.77E-10
LNAV/VNAV/RNAV(RNP)	LNAV	9.12E-10

Table 4-2: Risk of TCV for Offset Approaches

First Runway Straight-In Approach	Second Runway Offset Approach	Risk of TCV
ILS, GLS, or LPV	ILS, GLS, or LPV	5.45E-10
ILS, GLS, or LPV	LOC or LP	5.05E-10
LOC or LP	LOC or LP	4.99E-10
LNAV	LOC or LP	4.85E-10
LNAV/VNAV/RNAV(RNP)	LOC or LP	5.11E-10
ILS, GLS, or LPV	LNAV	4.87E-10
LOC or LP	LNAV	4.70E-10
LNAV	LNAV	4.77E-10
LNAV/VNAV/RNAV(RNP)	LNAV	4.90E-10

Table 4-3: Risk of TCV for Triple Approaches

First Runway	Second Runway	Third Runway	Risk of TCV
ILS, GLS, or LPV	ILS, GLS, or LPV	ILS, GLS, or LPV	9.98E-10
ILS, GLS, or LPV	ILS, GLS, or LPV	LOC or LP	9.24E-10
ILS, GLS, or LPV	LOC or LP	LOC or LP	8.87E-10
ILS, GLS, or LPV	LNAV	LOC or LP	8.89E-10
LOC or LP	LOC or LP	LOC or LP	8.68E-10
LNAV	LNAV	LNAV	8.86E-10
ILS, GLS, or LPV	LNAV	LNAV	8.86E-10
LNAV/VNAV/RNAV(RNP)	LNAV	LNAV	8.80E-10
LNAV/VNAV/RNAV(RNP)	LOC or LP	LNAV	9.10E-10

5 Conclusions

This study examined risk of collision during dual, offset, and triple simultaneous independent approach operations at the associated current runway separation minimums. The results of the fast-time simulations indicate that all of the tested combinations of dual and offset approaches examined in this study resulted in collision risks that were less than the vertical guidance baseline cases. Additionally, the results of the fast-time simulations indicate that all combinations of triple approaches examined in this study also resulted in collision risks of less than the vertical guidance baseline case. Therefore, the results of this study support the allowance of simultaneous independent approach operations for dual approaches with a RCLS as low as 3,600 ft, offset approaches with a RCLS as low as 3,000 ft, and triple approaches with a RCLS as low as 3,900 ft when all aircraft have lateral guidance, but 1 or more aircraft do not have vertical guidance.

SOIA lateral separation is identical to simultaneous offset independent dual instrument approach lateral separation analyzed in this study prior to the transition to visual separation. Therefore, the allowance of SOIA without vertical guidance for the offset precision runway monitor approach is supported by this analysis. The vertical guidance requirement for the straight-in approach during SOIA is not affected by this study since it is required during the visual segment of the SOIA operation.

Those simultaneous approach operations that require vertical guidance to mitigate wake turbulence, such as operations authorized under FAA Order JO 7110.308 [5], were not considered in this safety analysis and are therefore outside the scope of this report. The results of this report do not counter the inherent safety advantages of using vertical guidance. This study is not meant to discourage the use and availability of vertical guidance as a substantial safety enhancement during all instrument approach operations.

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