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Safety Study Report on San Francisco International Airport Simultaneous Offset Instrument Approach (SOIA) Wake Vortex Re-evaluation

April 2005

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12. Abstract

In order to increase capacity at San Francisco International Airport during periods of inclement weather, the FAA has implemented a SOIA operaion. The SOIA operation consists of a straight-in Instrument Landing System (ILS) approach to runway 28L and a Localizer Directional Aid (LDA) approach with glide slope to runway 28R. Since the runways in question are separated by only 750,' one of the primary safey concerns, as reported in Volume I, was that of wake turbulence. Volume I recommended a wake turbulence mitigation strategy based on the concept of an "operational window." The SOIA operation calls for the RWY 28L aircraft to lead and the RWY 28R to trail while approaching to land at SFO. In order to avoid wake vortex encounters, the trailing aircraft must remain within an "operational window" behind the leading aircraft. In Volume I, the size of the operational window was determined to be 0.6 NM for a heavy aircraft following a heavy aircraft. Since Volume I was published, actual wake vortex data has been collected and analyzed at SFO runways 28 L and R. This study concludes that the size of the operational window can be increased to approximately 1 NM (depending on the speed of the leading aircraft) based on the SFO wake vortex data collection and analysis.

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San Francisco International Airport Simultaneous Offset Instrument Approach (SOIA) Wake Vortex Re-evaluation

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Executive Summary

In order to increase capacity at San Francisco International Airport (SFO) during periods of inclement weather, the FAA has implemented a Simultaneous Offset Instrument Approach (SOIA) operation. The SOIA operation consists of a straight-in Instrument Landing System (ILS) approach to runway 28L (RWY 28L) and a Localizer Type Directional Aid (LDA) with glide slope approach to runway 28R (RWY 28R). The LDA final approach course to RWY 28R is offset approximately 2.5° from RWY 28R extended centerline. After the LDA Missed Approach Point (MAP), the aircraft on RWY 28R must perform a sidestep maneuver to align the aircraft for landing. Planning and support efforts for the SOIA operation involved not only the FAA but also industry partners such as United Airlines and pilot organizations. The safety aspects of these efforts were reported in an extensive study by the FAA's Flight Procedures Standards Branch (AFS-420), titled "San Francisco International Airport Simultaneous Offset Instrument Approach Procedures (SOIA), Volume I", and dated March 2000 (reference 1).

Since RWY 28L and RWY 28R are separated by only 750 feet, one of the primary safety concerns, as reported in reference 1, was that of wake turbulence. The SOIA operation, by design, mitigates wake turbulence encounters prior to the RWY 28R Missed Approach Point (MAP) by keeping the aircraft separated laterally by at least 3,000 feet. However, after the MAP, during the visual segment of the approach, the aircraft get closer to one another as they line up to land on the closely spaced parallel runways. It is during this portion of the approach, especially near the runway thresholds, that the potential for wake turbulence encounters is at its greatest and therefore, must be minimized.

Reference 1 recommended a wake turbulence mitigation strategy for the SFO SOIA operation: 1) smaller aircraft in the lead, 2) lead aircraft on the downwind runway, and 3) trailing aircraft stays within an "operational window" behind the lead aircraft. This study presents a reevaluation of the operational window as reported in Reference 1 based on additional data. (The other two wake mitigation strategies are still applicable and any one of the three is sufficient for wake mitigation.). Under the operational window concept, the aircraft on the left is leading and landing on RWY 28L and the aircraft on the right is trailing and landing RWY 28R. The RWY 28R aircraft must stay within the boundaries of an operational window. The front window boundary was determined by a collision risk analysis and the rear window boundary was determined by a wake turbulence analysis. The length of the operational window as originally recommended in reference 1 was 0.6 NM for a heavy/B757 following a heavy/B757.

The wake turbulence analysis used to determine the size of the original operational window was solely based on analytical assumptions and modeling. However, since the publication of reference 1, actual wake vortex data has been collected at SFO. Wake turbulence data has been collected and analyzed from over 250,000 landings at SFO on RWY 28R and RWY 28L. The results reported in this study, performed by the FAA's Flight Operation Simulations and Analysis Branch, AFS-440, update the size of the operational window based on the data collection and analysis results. This study concludes that the size of the operational window can be increased to approximately 1 NM (depending on speed of leading aircraft) for an aircraft following a heavy aircraft.

Table of Contents

List of Tables

List of Figures

1.0. Introduction

In order to increase capacity at San Francisco International Airport (SFO) during periods of inclement weather, the FAA has implemented a SOIA operation. The SOIA operation consists of a straight-in Instrument Landing System (ILS) approach to runway 28L (RWY 28L) and a Localizer Type Directional Aid (LDA) with glide slope approach to runway 28R (RWY 28R). The LDA final approach course to RWY 28R is offset approximately 2.5° from RWY 28R extended centerline. After the LDA Missed Approach Point (MAP), the aircraft on RWY 28R must perform a sidestep maneuver to align the aircraft for landing. Planning and support efforts for the SOIA operation involved not only the FAA but also industry partners such as United Airlines and pilot organizations. The safety aspects of these efforts were reported in an extensive study by the FAA's Flight Procedures Standards Branch, AFS-420, titled "San Francisco International Airport Simultaneous Offset Instrument Approach Procedures (SOIA), Volume I," dated March 2000 (reference 1).

Since RWY 28L and RWY 28R are separated by only 750 feet, one of the primary safety concerns, as reported in reference 1, was that of wake turbulence. The SOIA operation, by design, mitigates wake turbulence encounters prior to the RWY 28R Missed Approach Point (MAP) by keeping the aircraft separated laterally by at least 3,000 feet. However, after the MAP, during the visual segment of the approach, the aircraft get closer to one another as they line up to land on the closely spaced parallel runways. It is during this portion of the approach, especially near the runway thresholds, that the potential for wake turbulence encounters is at its greatest and therefore, must be minimized.

Reference 1 identified three wake mitigation strategies for the SFO SOIA operation: 1) smaller aircraft in the lead, 2) lead aircraft on the downwind runway, and 3) trailing aircraft stays within an "operational window" behind the lead aircraft. This study presents a reevaluation of the operational window as reported in Reference 1. (The other two wake mitigation strategies are still applicable and any one of the three is sufficient for wake mitigation.) Figure 1 shows the operational window in graphic form. The aircraft on the left is leading and landing on RWY 28L and the aircraft on the right is trailing and landing RWY 28R. The RWY 28R aircraft must stay within the boundaries of the operational window as shown. The front window boundary was determined by a collision risk analysis based on a blunder scenario, while the rear window boundary was determined by a wake turbulence analysis. The length of the operational window as originally recommended in reference 1 was 0.6 NM for a heavy/B757 following a heavy/B757.

The wake turbulence analysis used to determine the size of the original operational window was solely based on analytical assumptions and modeling. However, since the publication of reference 1, actual wake vortex data has been collected at SFO. Reference 2 provides an analytical summary of the wake turbulence data collected from over 250,000 landings at SFO on RWY 28R and RWY 28L. The results reported in this study, performed by the FAA's Flight Operations Simulation and Analysis Branch, AFS-440, update the size of the operational window based on the information available in reference 2.

2.0. Description of the Model

2.1. San Francisco International Airport

Figure 2 depicts an aerial view of SFO and identifies some of the parameters of interest such as the geometry of the runways, the leading (RWY 28L) and trailing (RWY 28R) aircraft approach paths, and the direction of the critical crosswind. Since the trailing aircraft was on the starboard (or right) side of the leading aircraft, this analysis focuses only on crosswinds that transport the wake vortices of the leading aircraft towards the direction of the trailing aircraft namely a left crosswind as shown in Figure 2. One of the constraints placed on the SFO SOIA operation is a maximum crosswind of 10 knots.

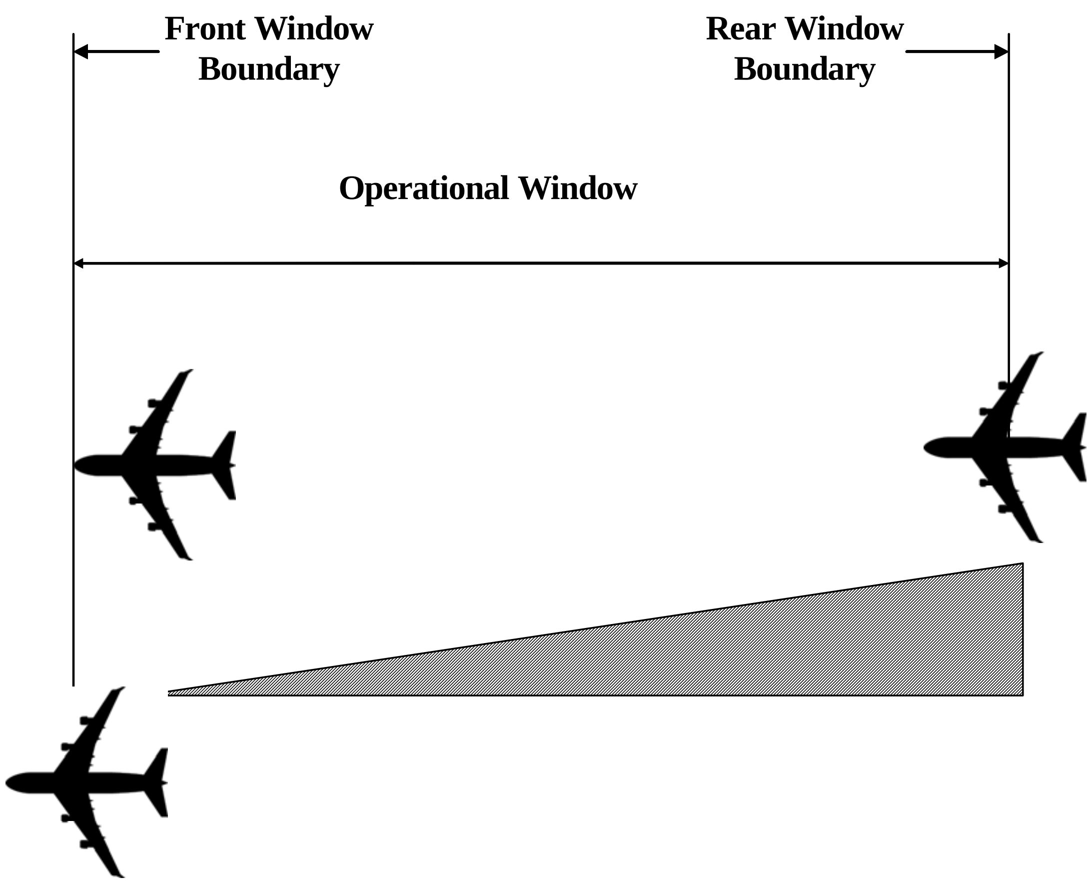

Figure 1: Operational Window Concept

2.2. Wake Turbulence Aircraft Classes

Wake turbulence separation minima for Air Traffic Control (ATC) purposes are provided in reference 3. For wake turbulence purposes, reference 3 classifies aircraft as Heavy, Large, and Small as follows:

a. Heavy - aircraft capable of takeoff weights of more than 255,000 pounds whether or not they are operating at this weight during a particular phase of flight.

b. Large - aircraft of more than 41,000 pounds, maximum certificated takeoff weight, up to 255,000 pounds. (While technically a large aircraft, the B757 has been shown to exhibit wake vortex generation properties more akin to heavy aircraft. Therefore, for all practical purposes, the B757 is treated as a heavy aircraft for wake turbulence separation minima.)

c. Small - Aircraft of 41,000 pounds or less maximum certificated takeoff weight.

Figure 2: Aerial View of SFO

2.3. SFO Wake Turbulence Data Collection

The primary wake turbulence measurements at SFO were obtained using three lines of anemometers (called wind lines) installed between and perpendicular to RWY 28L and RWY 28R. Wind line 1 was placed very near the runway thresholds where aircraft were typically at an altitude of 65 feet. The other two wind lines were placed further down the runways where the aircraft altitude was sufficiently low enough that the vortex wakes interacted with the ground and subsequently decayed rapidly. Therefore, only data from wind line 1 was considered meaningful in the context of this study. A vortex signature was required to be registered within the first 18 seconds after aircraft passage or else any wind changes were assumed to be from a gust and not a wake vortex. In addition, in keeping with the SOIA imposed crosswind constraint of 10 knots, only landings when the crosswind component was 10 knots or less were considered relevant to this study. For a more complete description of the SFO data collection program, the reader is directed to reference 2.

Between March 2000 and October 2002, a total of 261,416 landings with vortex data at wind line 1 were documented. Figure 6 of reference 2 is reproduced below as Figure 3. Figure 3 shows the 261,416 landings at SFO by aircraft type and wake turbulence class.

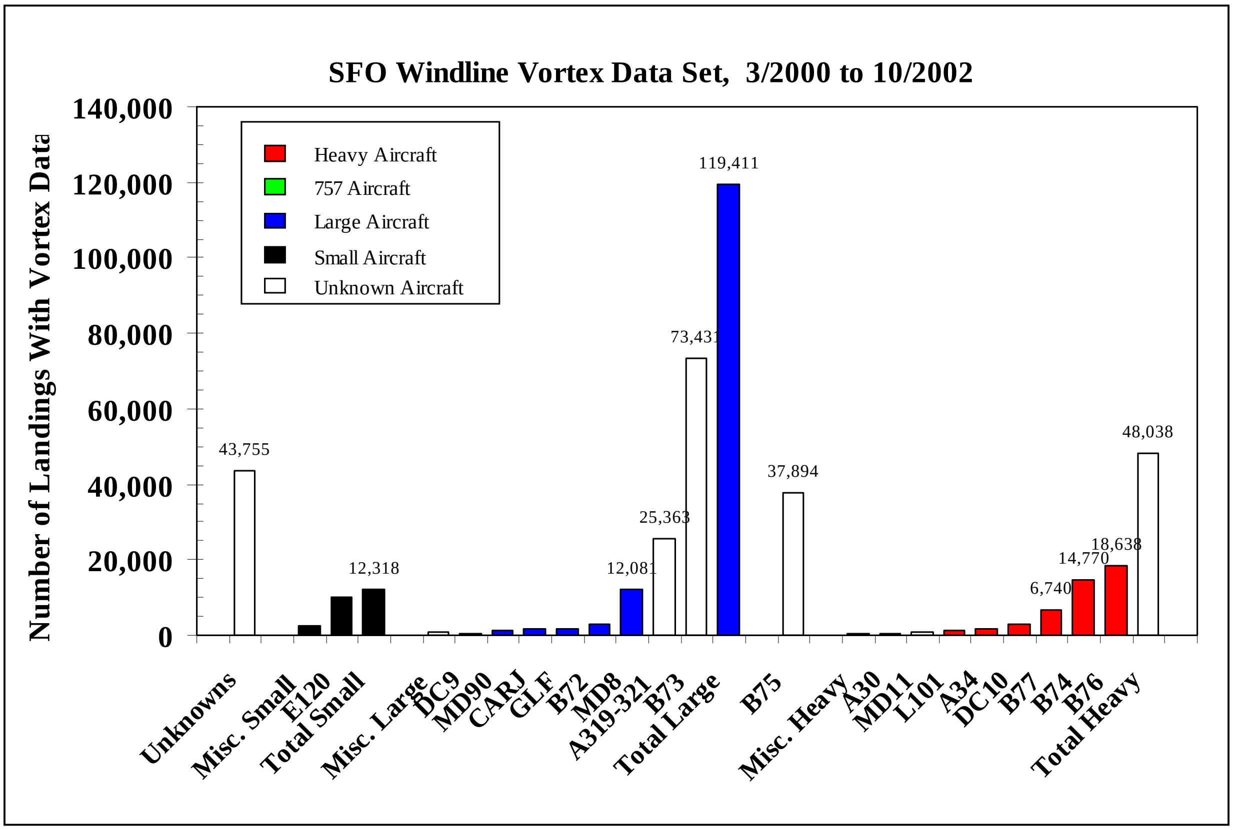

Figure 3. SFO Wake Vortex Landings by Aircraft Type

Of the 261,416 landings with wind line 1 vortex data, 229,234 had a crosswind component of 10 knots or less. Crosswind information was obtained from time matched Automated Surface Observing System (ASOS) data. A total of 106,716 landings were on RWY 28L (40.8%) while 154,700 landings were on RWY 28R (59.2%).

3.0. Summary of Data Analysis

Figure 12 from reference 2 is reproduced below as Figure 4. Figure 4 shows the percent of landings with a vortex exceeding 750 feet lateral transport distance vs. the time after passage over the wind line. The Figure 4 analysis considered only landings with crosswinds of 10 knots or less. As Figure 4 shows, a total of 178,464 landings (42,223 heavy, 33,586 B757, and 102,655 large) were analyzed. Small aircraft were not included because in the entire measurement period only 4 wakes out of 12,318 landings traveled 750 feet or more with the minimum travel time of 58 seconds. In the SOIA scheme, 58 seconds is not operationally feasible between leading and trailing aircraft.

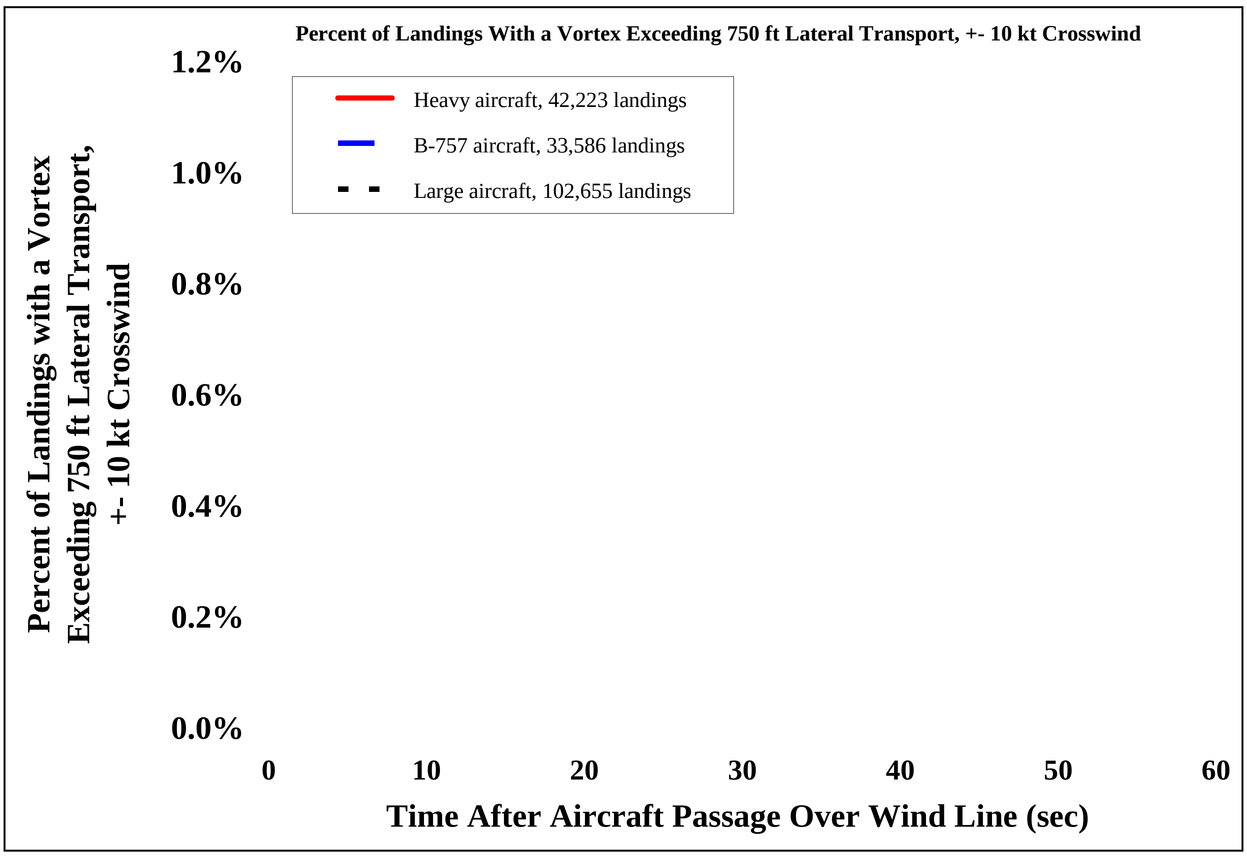

Figure 4: Percentage of Vortices Transported 750 Feet or More vs. Aircraft Class

As Figure 4 shows, the highest percentage of wakes transported 750 feet or more is attributed to heavy aircraft. Therefore, the case of an aircraft following a heavy will be considered the limiting case for determining the size of the operational window based on wake turbulence.

As depicted in Figure 4, the data shows that under all operational environmental conditions measured, no wakes were transported 750 feet in less than 28 seconds for a heavy aircraft. If we were only concerned with wakes propagating the 750 feet between RWY 28L and RWY 28R centerlines, a wake travel time of 28 seconds would seem appropriate for our analysis. However, as reference 2 points out, wakes that travel only 675 feet, i.e. to the edge of RWY 28R, could pose a potential problem. Therefore, assuming a constant wake transport velocity, a scale factor of .9 (675/750) will be applied, resulting in a wake transport time of 25.2 seconds to cover 675 feet.

To avoid a wake encounter, the operational window concept introduced and described earlier calls for the trailing aircraft to land within 25.2 seconds of the leading aircraft's landing. While useful in our analysis here, the 25.2 second maximum spacing between leading and trailing aircraft has little practical use in an ATC environment. In order to give ATC a useable metric to assess the SOIA aircraft spacing, the 25.2 seconds must be converted to a distance. Since all aircraft will not be at the same speed, a speed range will be used as shown in Table 1. Table 1 shows the 25.2 seconds spacing parameter converted to a distance across a range of groundspeeds representative of Category C and D aircraft operating at SFO.

Groundspeed (Knots)	Operational Window (NM)
130	0.91
135	0.95
140	0.98
145	1.02
150	1.05
155	1.09
160	1.12

Table 1: Operational Window Length vs. Leading Aircraft Groundspeed (Based on 25.2 second wake transport time)

Results and Conclusions

The operational "wake free" window that was determined to be 0.6 NM for a heavy aircraft trailing a heavy aircraft, as reported in reference 1, can be expanded to the values shown in Table 1. From a practical ATC standpoint, Table 1 results indicate that the trailing aircraft should remain within 1 NM of the leading aircraft during SOIA operations at SFO.

5.0. List of References

1. Lankford, D. N., McCartor, G., Hasman, F., Greene, G. C., Yates, J., Ladecky, S., and Templeton, D., "San Francisco International Airport Simultaneous Offset Instrument Approach Procedures (SOIA), Volume I," DOT-FAA-AFS-420-84, March 2000.

2. DOT-VNTSC-FA27-PM-04-13: Summary Results from Long-Term Wake Turbulence Measurements at San Francisco International Airport. J. N. Hallock and F. Y. Wang, July 2004.

3. FAA Order 7110.65, Air Traffic Control, 2/19/2004.