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Flight Procedure Standards Branch
Flight Technologies and Procedures Division
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SAN FRANCISCO INTERNATIONAL AIRPORT SIMULTANEOUS OFFSET INSTRUMENT APPROACH PROCEDURES (SOIA)

VOLUME I

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Final Report

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12. Abstract

This study is based on a United Airlines/Air Line Pilots Association (UAL/ALPA) joint concept of operations proposal that introduces a Simultaneous Offset Instrument Approach (SOIA) procedure with an ILS straight in to runway 28L and an LDA with glide slope and a side step to runway 28R at the San Francisco International (SFO) Airport. Proponents believe an offset LDA with electronic glide slope usable throughout the visual approach segment, a Precision Runway Monitor (PRM) system, Distance Measuring Equipment (DME), and a MAP located 3,000 feet to 3,400 feet abeam of the parallel localizer course will have significantly enhanced flying qualities and provide increased operational efficiency and safety. The Flight Procedure Standards Branch (AFS-420) was asked to evaluate LDA approaches using a 3° offset LDA with glide slope; i.e., non-precision instrument approaches, to runway 28R. The proponents have suggested a MAP, denoted LDA_D, from which the visual transition to the landing runway, runway 28R, can be suitably performed by all current air carrier airplanes, including heavy aircraft, such as the Boeing 747-400 while simultaneously approaching with landings to runway 28L. Three test approaches, identified as LDA_A, D, and E, using a 3° offset LDA with glide slope and DME were designed and tested using a qualified, level C flight simulator. Statistical analysis indicated that LDA_A and LDA_D, should be the preferred approaches among the three tested and that the criteria for success, as stated in the test plan, were all met or exceeded by LDA_A and LDA_D. Because of the similarity in flyability qualities and the lower minimums provided by LDA_D, LDA_D is the preferred procedure. LDA_D is recommended for implementation with several operational requirements.

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EXECUTIVE SUMMARY

This study is based on a United Airlines/Air Line Pilots Association (UAL/ALPA) joint concept of operations proposal that introduces a Simultaneous Offset Instrument Approach (SOIA) procedure with an ILS straight in to runway 28L and a localizer type directional aid (LDA) approach with glide slope and a sidestep to runway 28R at the San Francisco International (SFO) Airport. The proposal is supported by the SFO airport authority and the Federal Aviation Administration (FAA).

Since the spacing of runways 28L and 28R is only 748.9 feet, parallel operations are not approved for instrument flight conditions. In order to improve capacity at SFO, an LDA approach with a side-step maneuver for alignment with runway 28R, but without vertical guidance, was developed and tested approximately seven years ago. The approach featured a missed approach point (MAP) located 4,900 feet abeam the extended runway center line of runway 28R, but because of flyability problems the approach was not commissioned.

Proponents believe an offset LDA with electronic glide slope usable throughout the visual approach segment, a Precision Runway Monitor (PRM) system, distance measuring equipment (DME), and a MAP located 3,000 feet to 3,400 feet abeam of the parallel localizer course will have significantly enhanced flying qualities and provide increased operational efficiency and safety. In addition, the elimination of stepdowns that are normally associated with an LDA would provide other benefits such as more noise abatement and a more stabilized approach.

As a means to safely increase airport capacity at SFO, the Flight Procedure Standards Branch (AFS-420) was asked to evaluate LDA approaches using a 3° offset LDA with glide slope; i.e., nonprecision instrument approaches, to runway 28R. With the installation of a PRM system at SFO, the instrument portion of an LDA approach with a 3° offset could be designed with a MAP located as close as 3,000 feet perpendicular distance to the extended center line of runway 28L. The proponents have offered their suggested MAP as the point from which the visual transition to the landing runway, runway 28R, can be suitably performed by all current air carriers, including heavy aircraft, such as the Boeing 747-400 while simultaneously approaching with landings to runway 28L. The LDA approach suggested by the proponents is labeled LDA_D in this document.

In order to determine an optimal placement of the MAP relative to the runway threshold, three types of LDA procedures to runway 28R were tested. The approaches were designed to evaluate the significance of the distance of the MAP from the 500-foot, height above threshold (HAT) Stabilized Approach Point (SAP*), relative to the flyability of the approach. A minimum representation of simulated landing traffic on the adjacent runway was incorporated to aid in the evaluation and quantification of the stagger distance between the leading aircraft on runway 28L and the trailing aircraft on runway 28R. Three experimental control approach procedures were included to minimize the effects of a possible test learning factor, but were not included in the statistical analysis.

*** SAP is SOIA terminology**

The test simulator used for data acquisition was a FAA qualified, level C flight simulator. The United Airlines B747-400 simulator, located at Denver, Colorado, was used for the test flights. Line pilots, current and qualified in the B747-400, were enlisted to fly the flight simulator. Ten United Airlines, three Air Canada, and one Northwest Airlines flightcrews participated in the simulation.

Three test approaches, identified as LDA_A, D, and E, using a 3° offset LDA with glide slope and DME were designed. The test MAPs were located along the extended runway center line of runway 28R at 20,182.9 feet from the runway threshold and plus and minus 3,000 feet from 20,182.9 feet and 2,251.1 feet abeam, (3,000-748.9 feet runway separation). The angles formed by the extended runway centerline and the threshold to MAP lines are 7.5°, 6.4°, and 5.5°. Therefore, the approaches are classified as LDA approaches; i.e., nonprecision approaches.

To be considered successful, the analysis of the data from the test should show that the proposed LDA operation, aided by glide slope augmentation, assisted the crews in maneuvering the aircraft during the visual segment after leaving the LDA to a safe airline acceptable approach and landing by providing the following:

a. During the lateral transition the aircraft parameters should be in accordance with airline operating guidelines for terminal operations at published minimums and at maximum gross landing weight.

b. A stabilized visual approach in the lateral transition segment from the MAP to threshold.

c. A successful, normal landing.

d. Sustained bank angles during the visual segment shall not be excessive; i.e., not greater than 25° for terminal, low level operations.

e. Sustained rates of descent will not exceed acceptable standard practice for safe terminal, low level, visual transitions and landing operations; i.e., not greater than 1,200 feet per minute.

f. Overshoots beyond the extended runway centerline should not exceed acceptable turbojet/air carrier practices and Target Level of Safety (TLS). **NOTE**: For SFO operations the target limit is on the order of 200 feet.

g. Resolution of cockpit/crew procedures should be established prior to the visual segment.

Statistical analysis confirmed LDA_A and LDA_D, should be the preferred approaches among the three tested. The statistical analysis also indicated the criteria for success, as stated in the test plan, were all met or exceeded by LDA_A and LDA_D. Additionally, the pilots indicated their preference for LDA_A and LDA_D. Because of the similarity in flyability qualities and the lower minimums provided by LDA_D, LDA_D is the preferred procedure. LDA_E is not recommended because of inferior flyability qualities and lack of pilot support.

The Airspace Simulation and Analysis for TERPS (ASAT) computer system was modified to conform to the conditions of LDA_D. The purpose of the simulation was to determine the forward boundary of an operational window of alignment of the two approaching aircraft at the MAP for runway 28R. The operational window of alignment is an alignment interval, relative to the aircraft approaching runway 28L, that the aircraft approaching runway 28R can safely be in at the MAP. The forward boundary is determined by collision risk considerations while the rear boundary is determined by wake encounter considerations.

Three scenarios were designed whose only difference was the trailing distance of aircraft approaching runway 28R when it crossed the MAP. Three trailing distances were simulated, 0.0 NM, 0.25 NM, and 0.50 NM. Each of the three scenarios was performed 50,000 times. During the simulation of each scenario, no TCVs were observed. The smallest CPA observed was 650 feet during the simulation of the 0.0 NM scenario. Each scenario met the TLS established for the simulation. Therefore, the forward boundary of the operational window could be 0.0 NM.

A three-dimensional computer simulation was performed by the ASAT Wake Turbulence Risk Analysis module to determine the rear boundary of the operational window. This module was created by modifying ASAT to include wake turbulence formulae provided by the Research Division, NASA Langley Field Office (AAR-210) to characterize the wake turbulence based on the aircraft type and approach speed. The test criterion used for this simulation was the Wake Vortex Encounter (WVE). A wake protection circle, with center on the longitudinal axis of the trailing aircraft is constructed in a geometric plane perpendicular to the longitudinal axis with radius equal to the semi-span of the aircraft. If a wake vortex circle of the wake producing aircraft intersects the protection circle about the trailing aircraft, then a WVE is said to have occurred.

The rear boundary of the operational window was found to be 0.6 NM at the MAP, given a heavy aircraft following a heavy aircraft and a crosswind component of 10 knots at the surface increasing to 20 knots at 2,000 feet. For a large following a large the rear boundary is 0.7 NM and for a small following a small the rear boundary is unrestricted for the same crosswind conditions.

The study indicated that the implementation of LDA_D must include the following operational requirements:

a. Pilots of trailing aircraft will be instructed not to pass the leading aircraft inside the MAP.

b. The crosswind component of the total wind is 10 knots or less.

c. To ensure flyability and safety, aircraft on adjacent approach courses will be paired to mitigate potential wake vortex effects. The pairing of aircraft will be based on any one of the following mitigation strategies:

(1) The lead aircraft is downwind from the trailing aircraft; or

(2) The leading aircraft is a smaller category aircraft than the trailing aircraft; or

(3) A small aircraft is paired with another small aircraft, or

(4) A large aircraft is paired with another large aircraft and the paired aircraft are spaced within 0.7 NM longitudinally at the MAP; or

(5) A heavy aircraft or Boeing B757 aircraft is paired with another heavy aircraft (or B757) and the paired aircraft are spaced within 0.6 mile longitudinally at the MAP. When there is a size disparity, the smaller/slower aircraft should lead. For example, if a Boeing B757 is paired with a Boeing B747, the B757 should lead.

d. If none of the above wake mitigation strategies are employed, standard wake turbulence separation, as specified in Order 7110.65, shall be applied.

e. The FAA will continue its data collection at SFO to determine if the actual wind and wake conditions support an increase in the 0.6 NM longitudinal interval between heavy aircraft/B757.

f. During a defined period of time when conducting SOIA operations with ceilings above 2,400 feet and visibility greater than 4 statute miles, an evaluation will be performed prior to full SOIA approval.

g. The results and conclusions of the FAA's analysis of the SFO PRM-SOIA concept are based on the specific runway spacing and configuration, airspace, procedure design and design minima, aircraft mixes, and other criteria particular to SFO. Accordingly, there is no assurance that any part of the SFO PRM-SOIA analysis can be applied directly to any other location or situation, without additional study and analysis required.

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1.0 INTRODUCTION

This study is based on a United Airlines/Air Line Pilots Association (UAL/ALPA) joint concept of operations proposal which is supported by the San Francisco International (SFO) Airport authority and the Federal Aviation Administration (FAA). The study was conducted and analyzed to determine flyability, collision risk, and wake turbulence factors associated with conducting Precision Runway Monitor (PRM) procedures to SFO runways 28L and 28R. The UAL/ALPA concept of operations proposal introduces a Simultaneous Offset Instrument Approach (SOIA) procedure with an ILS straight in to runway 28L and a localizer directional aid (LDA) with glide slope and a sidestep to runway 28R. This report presents the results of the study, which validates, with the application of specific criteria, the ability to conduct PRM-SOIA at SFO.

The two primary runways used for approach and departure operations at SFO are closely spaced, parallel runways. Independent parallel ILS approaches have been approved by the FAA for runways spaced at least 3,400 feet apart, but less than 4,300 feet apart when the approach surveillance radar is a PRM system. Since the runway spacing at SFO is only 748.9 feet, parallel operations are not approved for instrument flight conditions. In order to improve capacity at SFO, an LDA approach with a side-step maneuver for alignment with the runway was developed and tested approximately seven years ago. The missed approach point (MAP) of this LDA approach was located about 4,900 feet abeam of the extended center line of runway 28R and did not include electronic vertical guidance. Because of flyability problems, the LDA approach was not commissioned.

Proponents believe an offset LDA with electronic glide slope usable throughout the visual approach segment, a PRM system, distance measuring equipment (DME), and a MAP located 3,000-3,400 feet abeam of the parallel localizer course will have significantly enhanced flying qualities and provide additional operational efficiency and safety. In addition, the elimination of stepdowns that are normally associated with an LDA would provide other benefits such as noise abatement.

The PRM is a system that provides air traffic controllers with high precision secondary surveillance radar data for aircraft on final approach to closely spaced parallel runways. High resolution color monitoring displays with visual and audible alerts, called Final Monitor Aids (FMA), are required to present surveillance track data to controllers along with detailed maps depicting approaches and the no transgression zone (NTZ), a critical 2,000-foot wide zone between parallel runways that aircraft are prohibited from entering. According to FAA Order 8260.39A, simultaneous independent ILS approaches are authorized for dual parallel runways whose extended center lines are separated by at least 3,400 feet, but less than 4,300 feet, and having a PRM system. In addition, runway separation may be decreased to 3,000 feet if the localizer courses are aligned at least 2-1/2° to 3° divergent to each other.

As a means to safely increase airport capacity at SFO, the Flight Procedure Standards Branch (AFS-420) was asked to evaluate LDA approaches using a 3° offset LDA with glide slope; i.e., nonprecision instrument approaches, to runway 28R. With the installation of a PRM system at SFO, the instrument portion of an LDA approach with a 3° offset could be designed with a MAP located as close as 3,000 feet perpendicular distance from the extended center line of runway 28L. The proponents have offered their suggested MAP as the point from which the visual transition to the landing runway, runway 28R, can be suitably performed by all current air carriers, including heavy aircraft, such as the Boeing 747-400 while simultaneously approaching with landings to runway 28L. This point is referred to in this report as DICKI.

The results of the evaluation conducted by AFS-420 are contained in two volumes. This volume, Volume I, describes and documents major issues such as flyability of the proposed procedure, wake turbulence, and collision risk. Volume II contains track plots from the B747-400 simulator tests. The track plots are grouped by missed approach points and each plot depicts data such as scenario number, wind, altitude, indicated airspeed, bank angles, aileron deflection, and position and speed of adjacent aircraft.

2.0 STATEMENT OF PROBLEM

During the instrument portion of the proposed LDA approach, with glide slope, the approach will be conducted as a closely spaced parallel approach with an offset angle of 3 degrees. With the addition of a glide slope, the instrument portion of the approach would be essentially an ILS approach. This type of approach has been thoroughly tested by the FAA and, with the installation of a PRM, is approved under Order 8260.39A. After passage of the Clear of Clouds point, defined by the intersection of the glide slope with the ceiling, the pilot must visually acquire traffic on the adjacent approach, perform a side-step maneuver to align the aircraft with the extended runway center line, and then perform a normal landing. Because the localizer is not aligned within 3° of the runway center line, the approach is a nonprecision LDA approach.

The basic problem was to evaluate whether an LDA, improved by the addition of a glide slope and DME, could be designed with satisfactory flying qualities along the visual segment after leaving the LDA. In addition, because of the close proximity of the parallel runways it was necessary to evaluate collision risk and the risk imposed by wake vortices during the visual segment of the approach. Although proponents suggested a possible MAP called DICKI, it was obvious the MAP point of the LDA approach could be placed in several different positions relative to the runway threshold. Therefore, the flight test was designed to compare several different possible positions of the MAP. The primary focus of the flight test was to determine an optimal position of the MAP. The test criteria included the flying qualities of the visual segment of the approach, the magnitude of overshoots of the extended runway, collision risk, wake vortex risk, and whether normal landings were the expected result.

2.1 DESCRIPTION OF THE EVALUATION

In order to determine an optimal placement of the MAP relative to the runway threshold, three types of LDA procedures to runway 28R were tested. The approaches were designed to evaluate the significance of the distance of the MAP from the 500-foot, height above threshold (HAT)

Stabilized Approach Point (SAP*), relative to the flyability of the approach. A minimum representation of simulated landing traffic on the adjacent runway was incorporated to aid in the evaluation and quantification of the stagger distance between the leading aircraft on runway 28L and the trailing aircraft on runway 28R. Three experimental control approach procedures were included to minimize the effects of a possible test learning factor, but were not incorporated into the evaluation.

The test simulator used for data acquisition was a FAA qualified, level C flight simulator. The United Airlines B747-400 simulator, located at Denver, Colorado, was used for the test flights. The simulator has active traffic alert and collision avoidance system (TCAS) displays that respond appropriately according to current TCAS algorithms for both traffic alert (TA) and resolution advisory (RA) modes. The TCAS was set in the TA/RA mode during the evaluation. Air traffic control, during the simulator test, was provided by FAA Bay TRACON.

Three test approaches, identified as LDA_A, D, and E, using a 3° offset LDA with glide slope and DME were designed. The LDA approach course (294.81° T, 277.81° M) was intercepted at approximately 12 NM DME from the LDA/DME facility from a 30° intercept course (264.81° T, 247.81 ° M) 3 miles from the LDA course, at an altitude of 4,000 feet. The test MAPs were located along the extended runway center line of runway 28R at 20,182.9 feet from the runway threshold and plus and minus 3,000 feet from 20,182.9 feet and 2,251.1 feet abeam, (3,000-748.9 feet runway separation), see figure 1. The positions of the test MAPs were computed using a computer design tool developed by AFS-420. The angles formed by the extended runway center line and the threshold to MAP lines are 7.5°, 6.4°, and 5.5°. Since these angles are greater than the 3° difference allowed by Order 8260.3 and do not meet localizer siting criteria, the approaches are classified as LDA approaches; i.e., nonprecision approaches.

The distance of 20,182.9 feet was derived from the given decision altitude of 1,126 feet mean sea level (MSL) the runway 28R touchdown zone elevation of 11 feet, the 3° glide slope for runway 28R, and the runway 28R glide slope point of intersection of 973.1 feet. The three test MAPs to threshold distances for SFO are 3.3 NM, 3.8 NM and 2.9 NM. Test MAP altitudes for SFO are 1,126 feet, 1,282 feet, and 970 feet MSL, respectively. **NOTE**: These are not consistent (that is, rounded to the next higher 20 feet) with current FAA practice and directives for precision approaches since an LDA, with glide slope, is a nonprecision approach having vertical guidance not an ILS.

In addition, three experimental control approach procedures were also designed. These procedures are identified in this test as LDA_B, C, and F. The experimental control scenarios were conducted at the discretion of the test conductor. The arrangement of the approaches is depicted in figure 1 and summarized in table 2.1.

*** SAP is SOIA terminology**

Procedure	Runway	Separation	MAP to Threshold	Offset Angle	Magnetic Course
LDA_A	28 R	3000'	3.8 NM	-3 °	278°
LDA_B*	28 R	4300'	3.7 NM	-3 °	278°
LDA_C*	28 R	4300'	3.4 NM	-3 °	278°
LDA_D	28 R	3000'	3.3 NM	-3 °	278°
LDA_E	28 R	3000'	2.9 NM	-3 °	278°
LDA_F*	28 R	3400'	3.4 NM	-3 °	278°

Table 2.1: LDA TEST APPROACHES

SFO Approach Course
Runway 28R

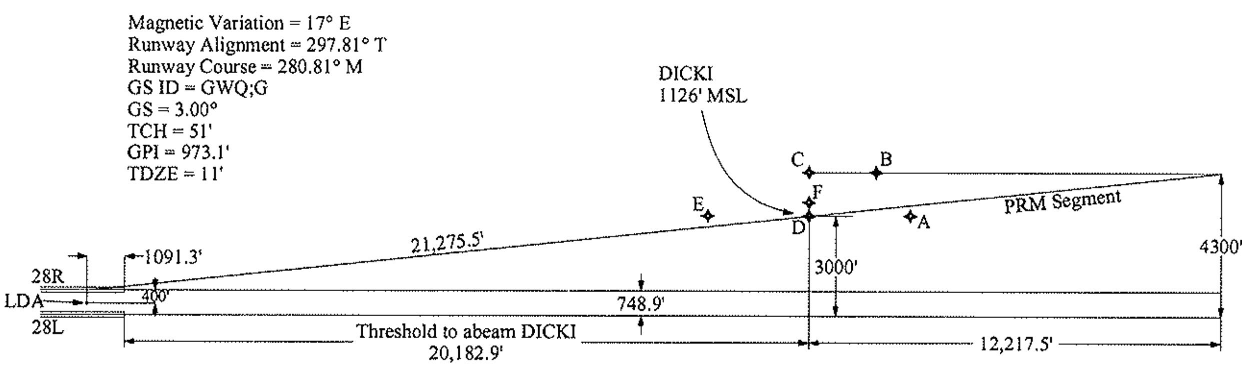


Figure 1: DIAGRAM OF SFO WITH LDA MAPS

LDAs A, D, and E were the basic test LDA scenarios. According to the test plan, only flight test data from LDAs A, D, and E were to be included in the statistical analysis. Various surface winds, ceilings and visibility were included to simulate as accurately as possible weather conditions that may engender the use of an LDA approach during actual operations. The winds used were (1) 072°/15 knots, (2) 162°/15 knots, (3) 258°/15 knots, and (4) 342°/15 knots. The winds were designed to test the effects of quartering tailwinds and headwinds. The atmospheric conditions used during the test are listed in table 2.2.

*** Denotes experimental control scenario**

Procedure	Ceiling	Visibility	Altimeter	Temperature	Turbulence
LDA_A	1700’	5 sm.	29.92	90° F	5 %
LDA_B*	1700’	5 sm	29.92	90° F	5 %
LDA_C*	1600’	4 sm	29.92	90° F	5 %
LDA_D	1600’	4 sm	29.92	90° F	5 %
LDA_E	1500’	4 sm	29.92	90° F	5 %
LDA_F*	1600’	4 sm	29.92	90° F	5 %

Table 2.2: SIMULATION ATMOSPHERIC CONDITIONS

AFS-420 computed the LDA localizer test positions, LDA magnetic course alignments, test DME positions, and test MAPs utilizing Instrument Approach Procedures Automation (IAPA) geodetic calculations and submitted them to United Air Lines for inclusion in the simulator run-time software and to Flight Technologies, Inc., for test approach procedure charting.

The National Resource Specialist for Simulator Engineering (AFS-408) assisted in the configuration of the flight simulator. The simulator provided a night visual presentation with adequate lighting and background for visual reference of the runways used at SFO in the testing.

2.2 RECORDED DATA PARAMETERS

Data logging began 1 NM prior to the glide slope intercept point for all LDA approaches. The data parameters recorded during each test run of this evaluation were:

a. LDA Aircraft position, X (longitudinal distance) referenced to the landing runway threshold, Y (lateral distance) referenced to the landing runway center line extended, and Z (height above runway threshold).

b. Runway 28L traffic aircraft position, X (longitudinal distance) referenced to the landing runway threshold, Y (lateral distance) referenced to the landing runway center line extended, and Z (height above runway threshold).

c. LDA course deviation.

d. Glide slope course deviation throughout entire data logging period.

e. Indicated airspeed in knots.

f. Bank angle.

g. Aircraft heading.

h. Rate of descent.

*** Denotes experimental control scenario**

i. Time.

j. Wind direction and speed.

k. Flap position.

l. Gear position.

m. Aileron deflection.

n. Elevator deflection.

o. Rudder deflection.

p. Radar altitude.

q. Scenario number/LDA designation (Letter).

r. Initial stagger distance of runway 28L traffic aircraft.

s. Auto pilot, On/Off.

2.3 SUBJECT CREWS

Line pilots, current and qualified in the B747-400, were enlisted to fly the flight simulator. Ten United Airlines, three Air Canada, and one Northwest Airlines flight crews participated in the simulation. Flight crews were briefed and familiarized with the simulator prior to data acquisition runs. Differences in simulator equipment were identified for the participating crews. During the evaluation, the pilot flying the simulator filled out a short questionnaire after each run. A post evaluation questionnaire was administered at the conclusion of each session (see section 12.0).

Project pilot's notes and subject pilot comments on their assessment of each completed approach were obtained and evaluated.

2.4 CRITERIA FOR SUCCESS

To be considered successful, the analysis of the data from the test should show the proposed LDA operation, aided by glide slope augmentation, assisted the crews in maneuvering the aircraft during the visual segment after leaving the LDA to a safe airline acceptable approach and landing by providing the following:

a. During the lateral transition the aircraft parameters should be in accordance with airline operating guidelines for terminal operations at published minimums and at maximum gross landing weight.

b. A stabilized visual approach in the lateral transition segment from the MAP to threshold.

c. A successful, normal landing.

d. Sustained bank angles during the visual segment shall not be excessive; i.e., not greater than 25° for terminal, low level operations.

e. Sustained rates of descent will not exceed acceptable standard practice for safe terminal, low level, visual transitions and landing operations; i.e., not greater than 1,200 feet per minute.

f. Overshoots beyond the extended runway centerline should not exceed acceptable turbojet/air carrier practices and target level of safety. **NOTE**: For SFO operations the target limit is on the order of 200 feet.

g. Resolution of cockpit/crew procedures should be established prior to the visual segment.

2.5 RESPONSIBILITIES

The participating organizations and their responsibilities are as follows:

a. AFS-420 provided the test plan, test and data acquisition, data analysis, and program management.

b. AFS-408 provided assistance for the simulators used in the project.

c. SFO Bay TRACON provided the air traffic personnel as required for this test.

d. Product Team for Secondary Surveillance (AND-450) provided oversight for the project. Funding was provided through AND-450 and by the SFO Airport. This included:

(1) Simulator time and compensation for all pilots, required simulator operator personnel and FAA personnel necessary to complete scenario setup, validation, and data collection activities.

(2) Travel for FAA personnel to accomplish simulator setup, validation, and data collection activities.

(3) Funding for the preparation of the procedure approach plates to be used in the test.

(4) Funding for contract technical support for the preparation of the final report.

3.0 DATA ANALYSIS

3.1 DATA REDUCTION

Upon receipt of the recorded data from the flight simulator, the data was converted to a form suitable for analysis. Since the primary criterion for comparison of the three scenarios was the degree of stability during the approach and the amount of lateral dispersion past the extended center line of runway 30L, data was extracted which would serve to measure those parameters. The data extracted for analysis were as follows:

a. THR500: The distance from threshold where the perpendicular distance of the aircraft from the extended centerline first became less than 500 feet.

b. THR300: The distance from threshold where the perpendicular distance of the aircraft from the extended centerline first became less than 300 feet.

c. THR100: The distance from threshold where the perpendicular distance of the aircraft from the extended centerline first became less than 100 feet.

d. THR50: The distance from threshold where the perpendicular distance of the aircraft from the extended centerline first became less than 50 feet.

e. BANK_LEF: The maximum left-bank angle.

f. LEFT_ALT: The altitude of the maximum left-bank angle.

g. BANK_RT: The maximum right-bank.

h. RIGHT_ALT: The altitude of the maximum right-bank angle.

i. OVR_SHT: The maximum lateral distance across the extended centerline (overshoot).

j. CPA: The minimum distance between the center of gravity is called the closest point of approach (CPA).

k. UNDER_GS: The maximum deviation below the glideslope.

l. MAP2SAP: The average rate of descent from the MAP to the SAP.

m. SAP2THR: The average rate of descent from the SAP to a point 1,000 feet short of the threshold. The rate of descent was not computed to the threshold to eliminate anomalies caused by the flaring action of the aircraft.

The variables listed above as (a) through (d) provide a measure of the distance from threshold where the aircraft became aligned with the extended centerline of the runway. Large distances are desirable since they indicate the aircraft achieved a more stabilized approach farther from the runway threshold. Variable (e) and (g) provide measures of the maximum bank angles that were required to perform the approach. Small values are preferred since they would indicate a more stabilized approach. Variable (f) and (h) provide measures of the altitude of the aircraft when the maximum left or right-bank was achieved. Larger values of these variables are preferred since they would indicate the turning maneuver took place at a higher altitude. Variable (i) represents the maximum lateral distance the aircraft flew across the extended centerline of runway 28R toward runway 28L, called the overshoot. A small value of this variable is preferred. Variable (j) represents the minimum distance between the centers of gravity, called the CPA. A large value of this variable is preferred. Variable (k) represents the maximum vertical deviation below the glide slope during the visual segment of the approach. This variable provides an indication of the vertical stability of the approach. Variable (l) and (m) provide measures of the average rate of descent during the visual segment of the approach. Values of approximately 900 feet per minute are expected because of the speed of the approaching aircraft and the 3° glideslope. All the variables, (a) through (m), provide a measure of the stability of the aircraft during the visual segment of the approach.

3.2 STATISTICAL TESTS

The primary statistical analysis procedures used were the Analysis of Variance test (ANOVA), Tukey's B test, and Spearman's rank correlation coefficient. The ANOVA test is designed to compare the means of several groups of data. The data can be grouped according to one or more variables. The ANOVA test assumes the groups of data are all normally distributed with equal variances. In most cases, violations of these assumptions do not significantly affect the outcome of ANOVA. At most, they tend to give a slightly erroneous significance level. ANOVA tests the null hypothesis, H_0: the means are equal, against the alternate hypothesis, H_1: two or more means are different.

Tukey's B test is based on ANOVA and has the same assumptions regarding the data as ANOVA. Tukey's B test is designed to provide pair wise comparisons of means for several groups of data. Therefore, Tukey's B test groups the means into significantly different groups and arranges them in order from smallest to largest. The Tukey's B test tables presented in this report indicate the groupings as separate columns. The means are ranked within the columns to indicate the rankings within the groups.

The Spearman rank correlation coefficient is often used when it is necessary to determine whether a correlation exists between two variables. The Spearman rank correlation coefficient, often called RHO (ρ), is found by sorting the observations in an ascending list and then ranking them. Of all the statistics based on ranks, the Spearman RHO was the earliest and probably the best known. Spearman's rank correlation coefficient is used to test the null hypothesis, H_0: there is no association between the two variables, against the alternate hypothesis, H_1: there is an association between the two variables.

3.3 GROUPING VARIABLES

As indicated in section 2.1, four wind directions at 15 knots were simulated in the flight test. The data was separated into four groups according to the wind direction used in the conduct of the test flight. The wind cases had to be numbered in order to carry out the analysis. They were numbered 1 through 4 as follows:

a. Wind case 1: 15 knots from 072°; a right-quartering tailwind.

b. Wind case 2: 15 knots from 162°; a left-quartering tailwind.

c. Wind case 3: 15 knots from 258°; a left-quartering head wind.

d. Wind case 4: 15 knots from 342°; a right-quartering head wind.

The six approach scenarios represent six more grouping variables although only three scenarios were used in the data analysis. The approach scenarios had to be numbered in order to carry out the analysis. They were numbered 1 through 6 as follows:

a. LDA_A: number 1.

b. LDA_B: number 2.

c. LDA_C: number 3.

d. LDA_D: number 4.

e. LDA_E: number 5.

f. LDA_F: number 6.

Thus, the flight test data forms a two-way experiment with wind case and scenarios being the two independent variables. The number of data in each wind case and approach scenario is presented in matrix form in table 3.1. Note that for scenarios 1, 4, and 5, the number of runs are nearly equal. In addition, the number of runs, per wind direction are, also nearly equal. The number of runs of scenario 6 (LDA_F) was too small for analysis; however, scenario 6 was not intended to be included in the analysis.

Scenario	Wind Direction				Totals by Scenario
	1	2	3	4	
1	13	9	14	12	48
2	4	5	5	7	21
3	12	3	5	3	23
4	10	13	11	13	47
5	12	12	13	12	49
6	1	1	0	2	4
Totals by Wind	52	43	48	49	**Total** 192

Table 3.1: MATRIX OF SCENARIOS vs WINDS

4.0 ANALYSIS OF LATERAL DATA

A two-way ANOVA was performed on each of the variables, (a) through (f), which represent lateral stability on the extended runway center line, using the approach scenarios and the wind cases as grouping or independent variables. Because the test plan specified only LDAs A, D, and E, numbered 1, 4, and 5, were to be included in the analysis, the experiment is a 3 × 4 factorial design. The two-way ANOVA indicated significant differences at the 0.05 significance level for each of the variables, (a) through (f). The two-way ANOVA also indicated no interactions between the two independent variables, scenario number and wind case. This will permit an analysis of the data by either scenario or wind case. Table 4.1 presents the results of the two-way ANOVA for interaction for each variable (a) through (f). The degree of freedom, the

F-values, and the significance or probability of each F is shown. If the value of the significance of F, in the table, is less than 0.05 then a significant interaction is present. Note that none of the values of significance of F is less than 0.05.

Variable	Degrees of Freedom	F-Value	Significance of F
THR500	6	.629	.707
THR300	6	.807	.566
THR100	6	.913	.487
THR50	6	.403	.876

Table 4.1: INTERACTION OF LATERAL VARIABLES

4.1 ANOVA OF LATERAL VARIABLES BY WIND DIRECTION

Since there are no interactions of the independent variables, the dependent variables can be analyzed relative to each independent variable. The analysis continued by considering each wind case separately. For example, a one-way ANOVA was performed on wind case 1 data using the approach scenario as the dependent variable and THR500 as the independent variable. This analysis will show if, for those runs flown during wind case 1, the means of THR500 are significantly different. For wind case 1, significant differences between the approach scenarios were found for THR500, THR300, and THR100. Note that a significant difference for THR50 with a right-quartering tailwind is not present. Therefore, the means of THR50, when grouped by scenario are considered equal.

Significant differences indicate the means of the dependent variables can be considered to be different. Therefore, since the significance of THR500 is .000, we can infer that it is extremely likely that one or more of the mean values of THR500 when grouped by approach scenario are different. The results of the ANOVA analyses are presented in tables 4.2, 4.3, 4.4, and 4.5. In each table, the result is considered significant if the value of Sig. is less than or equal to 0.05.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
THR500	Between Groups	1.3E+08	2	65561541.37	38.231	.000
	Within Groups	5.5E+07	32	1714896.257		
	Total	1.9E+08	34			
THR300	Between Groups	1.3E+08	2	65137690.41	30.399	.000
	Within Groups	6.9E+07	32	2142786.380		
	Total	2.0E+08	34			
THR100	Between Groups	9.9E+07	2	49744451.81	15.163	.000
	Within Groups	1.0E+08	32	3280688.883		
	Total	2.0E+08	34			
THR50	Between Groups	1.2E+07	2	5830749.162	1.505	.237
	Within Groups	1.2E+08	32	3873887.758		
	Total	1.4E+08	34			

TABLE 4.2: ANOVA, WIND CASE 1, RIGHT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
THR500	Between Groups	4.6E+07	2	23225348.73	6.342	.005
	Within Groups	1.1E+08	31	3662017.483		
	Total	1.6E+08	33			
THR300	Between Groups	3.5E+07	2	17536365.54	4.482	.020
	Within Groups	1.2E+08	31	3912679.142		
	Total	1.6E+08	33			
THR100	Between Groups	7574232	2	3787115.880	.967	.391
	Within Groups	1.2E+08	31	3916505.590		
	Total	1.3E+08	33			
THR50	Between Groups	2.8E+07	2	14010501.06	4.854	.015
	Within Groups	8.9E+07	31	2886351.140		
	Total	1.2E+08	33			

Table 4.3: ANOVA, WIND CASE 2, LEFT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
THR500	Between Groups	9.7E+07	2	48351426.33	21.935	.000
	Within Groups	7.7E+07	35	2204306.767		
	Total	1.7E+08	37			
THR300	Between Groups	8.4E+07	2	42196116.90	11.233	.000
	Within Groups	1.3E+08	35	3756413.941		
	Total	2.2E+08	37			
THR100	Between Groups	6.5E+07	2	32264803.41	5.897	.006
	Within Groups	1.9E+08	35	5471831.414		
	Total	2.6E+08	37			
THR50	Between Groups	5.4E+07	2	27079675.16	4.855	.014
	Within Groups	2.0E+08	35	5577573.068		
	Total	2.5E+08	37			

Table 4.4: ANOVA, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
THR500	Between Groups	1.0E+08	2	51980751.21	35.599	.000
	Within Groups	5.0E+07	34	1460173.843		
	Total	1.5E+08	36			
THR300	Between Groups	1.0E+08	2	51607079.69	30.519	.000
	Within Groups	5.7E+07	34	1691004.925		
	Total	1.6E+08	36			
THR100	Between Groups	6.5E+07	2	32469184.44	7.163	.003
	Within Groups	1.5E+08	34	4533133.003		
	Total	2.2E+08	36			
THR50	Between Groups	4.1E+07	2	20509076.12	4.214	.023
	Within Groups	1.7E+08	34	4866829.667		
	Total	2.1E+08	36			

Table 4.5: ANOVA, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

4.2 TUKEY'S B TEST OF LATERAL VARIABLES FOR WIND CASE 1

The ANOVA tests determine whether significant differences are present, but they do not indicate which scenarios may be causing the significant differences. To determine the ranking of the approach scenarios and the significant pairs of approach scenarios, the Tukey B test was performed by wind case. The results of the Tukey B test for wind case 1 are presented in tables 4.6, 4.7, and 4.8. The test was not necessary for THR50 since ANOVA indicated there was no significant difference between the means of the scenarios. However, Tukey's B test was performed so the ranking of the means could be observed. The result of Tukey's B test for THR50 is shown in table 4.9.

THR500

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05		
		1	2	3
5	12	9624.583		
4	10		11543.40	
1	13			14183.08

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.527.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.6: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND, AND THR500 DEPENDENT

THR300

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05		
		1	2	3
5	12	8716.583		
4	10		10455.00	
1	13			13238.46

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.527.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.7: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND, AND THR300 DEPENDENT

THR100

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	6625.500	
4	10	8256.500	
1	13		10591.69

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.527.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.8: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND, AND THR100 DEPENDENT

THR50

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05
		1
5	12	5443.083
4	10	6369.300
1	13	6788.462

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.527.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.9: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND, AND THR50 DEPENDENT

Tables 4.6, 4.7, 4.8, and 4.9 indicate, as expected, the distance from threshold to MAP is increased, and the distance from threshold where the aircraft becomes stabilized on the approach is also increased. From the tables, the mean for LDA_A is significantly larger than for LDA_E except for THR50. The mean for LDA_D is significantly larger than LDA_E for THR300 and THR500. This indicates the aircraft performing LDA_A and LDA_D were within 500 and 300 feet abeam the extended runway center line farther from the runway threshold than were the aircraft performing LDA_E when a right-quartering tailwind was present. The means were not significantly different for THR50, but the means were again ranked LDA_E, LDA_D, and LDA_A. Although not significantly different, the flights from the two LDAs farthest from the threshold tended to be aligned with the runway center line farther from the threshold.

4.3 TUKEY'S B TEST OF LATERAL VARIABLES FOR WIND CASE 2

The results of Tukey's B Test for wind case 2 are shown in tables 4.10, 4.11, 4.12, and 4.13. All three scenarios were tested using the conditions of wind case 2.

THR500

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	8504.833	
4	13	9912.769	9912.769
1	9		11506.33

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.10: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND, AND THR500 DEPENDENT

THR300

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	7541.750	
4	13	8736.923	8736.923
1	9		10151.44

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.11: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND, AND THR300 DEPENDENT

THR100

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05
		1
5	12	5941.667
4	13	6134.385
1	9	7095.222

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.12: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND, AND THR100 DEPENDENT

THR50

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	3236.750	
4	13	4525.615	4525.615
1	9		5540.333

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.13: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND, AND THR50 DEPENDENT

The results of Tukey's B test for wind case 2 are very similar to those for wind case 1. Again, as expected, when flying the approach with MAP farthest from the threshold, the aircraft tend to align with the runway center line farther from the threshold.

4.4 TUKEY'S B TEST OF LATERAL VARIABLES FOR WIND CASE 3

The results of Tukey's B Test for wind case 3 are shown in tables 4.14, 4.15, 4.16, and 4.17. All three scenarios were tested using the conditions of wind case 3, a left-quartering headwind.

THR500

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05		
		1	2	3
5	13	9722.385		
4	11		11302.91	
1	14			13488.71

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.14: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND, AND THR500 DEPENDENT

THR300

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	13	8655.769	
4	11	10083.27	
1	14		12168.57

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.15: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND, AND THR300 DEPENDENT

THR100

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	13	6222.000	
4	11	7387.000	7387.000
1	14		9282.500

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.16: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND, AND THR100 DEPENDENT

THR50

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	13	4300.000	
4	11	5578.727	5578.727
1	14		7127.357

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.17: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND, AND THR50 DEPENDENT

The results of Tukey's B test for wind case 3 are very similar to those for wind cases 1 and 2. Again, as expected, when flying the approach with MAP farthest from the threshold, the aircraft tend to align with the runway center line farther from the threshold.

4.5 TUKEY'S B TEST OF LATERAL VARIABLES FOR WIND CASE 4

The results of Tukey's B Test for wind case 4 are shown in tables 4.18, 4.19, 4.20, and 4.21. All three scenarios were tested using the conditions of wind case 4, a right-quartering headwind.

THR500

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05		
		1	2	3
5	12	10777.67		
4	13		12961.62	
1	12			14938.42

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.18: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND, AND THR500 DEPENDENT

THR300

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05		
		1	2	3
5	12	9947.833		
4	13		12205.31	
1	12			14089.50

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.19: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND, AND THR300 DEPENDENT

THR100

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	7844.667	
4	13	9008.692	
1	12		11089.33

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.20: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND, AND THR100 DEPENDENT

THR50

Tukey B[a,b]

		Subset for alpha = .05	
SCENARIO	N	1	2
5	12	5859.750	
4	13	6666.308	6666.308
1	12		8414.167

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.21: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND, AND THR50 DEPENDENT

The results of Tukey's B test for wind case 4 are very similar to those for wind cases 1, 2, and 3. Again, as expected, when flying the approach with MAP farthest from the threshold, the aircraft tend to align with the runway center line farther from the threshold.

4.6 ANOVA OF LATERAL VARIABLES BY SCENARIO

In the previous analysis of the lateral variables, the wind direction was held constant in order to determine which scenario or LDA was affected the most by the given wind direction. In this analysis, the scenario is held constant to determine which wind direction had the most effect on the given scenario. For example, if scenario 1 is constant and a one-way ANOVA is performed on THR500, then it may indicate which wind case had the most effect or caused the largest values of THR500. Tables 4.22, 4.23, and 4.24 present the results of the ANOVA.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
THR500	Between Groups	6.5E+07	3	21773892.43	5.757	.002
	Within Groups	1.7E+08	44	3781854.607		
	Total	2.3E+08	47			
THR300	Between Groups	8.8E+07	3	29470585.03	6.126	.001
	Within Groups	2.1E+08	44	4810552.179		
	Total	3.0E+08	47			
THR100	Between Groups	9.7E+07	3	32327236.73	5.338	.003
	Within Groups	2.7E+08	44	6055656.375		
	Total	3.6E+08	47			
THR50	Between Groups	4.4E+07	3	14603911.27	2.035	.123
	Within Groups	3.2E+08	44	7175886.321		
	Total	3.6E+08	47			

Table 4.22: ANOVA, LDA_A, FARTHEST MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
THR500	Between Groups	6.1E+07	3	20242665.39	13.599	.000
	Within Groups	6.4E+07	43	1488519.086		
	Total	1.2E+08	46			
THR300	Between Groups	7.9E+07	3	26477723.26	13.636	.000
	Within Groups	8.3E+07	43	1941688.183		
	Total	1.6E+08	46			
THR100	Between Groups	5.8E+07	3	19424256.44	5.305	.003
	Within Groups	1.6E+08	43	3661670.566		
	Total	2.2E+08	46			
THR50	Between Groups	3.5E+07	3	11519874.52	3.374	.027
	Within Groups	1.5E+08	43	3414756.887		
	Total	1.8E+08	46			

Table 4.23: ANOVA, LDA_D, CENTER MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
THR500	Between Groups	3.1E+07	3	10356209.36	7.193	.000
	Within Groups	6.5E+07	45	1439732.141		
	Total	9.6E+07	48			
THR300	Between Groups	3.5E+07	3	11600778.14	6.239	.001
	Within Groups	8.4E+07	45	1859421.892		
	Total	1.2E+08	48			
THR100	Between Groups	2.6E+07	3	8512053.263	2.586	.065
	Within Groups	1.5E+08	45	3291858.319		
	Total	1.7E+08	48			
THR50	Between Groups	5.1E+07	3	16846468.93	6.796	.001
	Within Groups	1.1E+08	45	2479000.343		
	Total	1.6E+08	48			

Table 4.24: ANOVA, LDA_E, NEAREST MAP WITH WIND CASE INDEPENDENT

4.7 TUKEY'S B TEST OF LATERAL VARIABLES FOR LDA_A

The ANOVA tests determine whether significant differences are present, but they do not indicate which scenarios may be causing the significant differences. To determine the ranking of the approach scenarios and the significant pairs of approach scenarios, the Tukey B test was performed by scenario. The results of the Tukey B test for LDA_A are presented in tables 4.25, 4.26, 4.27, and 4.28.

THR500

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	9	11506.33	
3	14		13488.71
1	13		14183.08
4	12		14938.42

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.669.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.25: TUKEY'S B TEST, LDA_A, FARTHEST MAP, AND THR500 DEPENDENT

THR300

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	9	10151.44	
3	14	12168.57	12168.57
1	13		13238.46
4	12		14089.50

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.669.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.26: TUKEY'S B TEST, LDA_A, FARTHEST MAP, AND THR300 DEPENDENT

THR100

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	9	7095.222	
3	14	9282.500	9282.500
1	13		10591.69
4	12		11089.33

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.669.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.27: TUKEY'S B TEST, LDA_A, FARTHEST MAP, AND THR100 DEPENDENT

THR50

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05 1
2	9	5540.333
1	13	6788.462
3	14	7127.357
4	12	8414.167

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.669.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.28: TUKEY'S B TEST, LDA_A, FARTHEST MAP, AND THR50 DEPENDENT

The variables THR500, THR300, THR100, and THR50 measure the distance from threshold where the aircraft stays within the indicated lateral distance of the extended runway center line. For example, THR500 measures the distance from threshold where the aircraft comes within 500 feet of center line and stays within 500 feet of center line. A large value is preferable since it indicates the aircraft is stabilized on the approach farther from the threshold. Tukey's test indicated wind case 2 and wind case 3, both left-quartering winds, had significantly smaller values of THR500, THR300, and THR100. This result could be expected since both winds would tend to move the aircraft away from the center line. However, no significant difference was detected for THR50. Thus, by the time the aircraft came within 50 feet of center line, the distances from threshold were not significantly different.

4.8 TUKEY'S B TEST OF LATERAL VARIABLES FOR LDA_D

The ANOVA tests determine whether significant differences are present, but they do not indicate which scenarios may be causing the significant differences. To determine the ranking of the approach scenarios and the significant pairs of approach scenarios, the Tukey B test was performed by scenario. The results of the Tukey B test for LDA_D are presented in tables 4.29, 4.30, 4.31, and 4.32.

THR500

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05		
		1	2	3
2	13	9912.769		
3	11		11302.91	
1	10		11543.40	
4	13			12961.62

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.602.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.29: TUKEY'S B TEST, LDA_D, CENTER MAP, AND THR500 DEPENDENT

THR300

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05		
		1	2	3
2	13	8736.923		
3	11	10083.27	10083.27	
1	10		10455.00	
4	13			12205.31

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.602.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.30: TUKEY'S B TEST, LDA_D, CENTER MAP, AND THR300 DEPENDENT

THR100

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	13	6134.385	
3	11	7387.000	7387.000
1	10		8256.500
4	13		9008.692

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.602.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.31: TUKEY'S B TEST, LDA_D, CENTER MAP, AND THR100 DEPENDENT

THR50

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05 1	2
2	13	4525.615	
3	11	5578.727	5578.727
1	10	6369.300	6369.300
4	13		6666.308

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.602.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.32: TUKEY'S B TEST, LDA_D, CENTER MAP, AND THR50 DEPENDENT

The results of Tukey's B test for LDA_D, with centered MAP, are very similar to that of LDA_A. The left-quartering tailwind, wind case 2, and the left-quartering headwind, cause the aircraft to align with the center line significantly closer to the threshold than the other two wind cases. Note that, on average, the aircraft flying LDA_D are within 50 feet of the center line about 4,525 feet from the threshold.

4.9 TUKEY'S B TEST OF LATERAL VARIABLES FOR LDA_E

The ANOVA tests determine whether significant differences are present, but they do not indicate which scenarios may be causing the significant differences. To determine the ranking of the approach scenarios and the significant pairs of approach scenarios, the Tukey B test was performed by scenario. The results of the Tukey B test for LDA_E are presented in tables 4.33, 4.34, 4.35, and 4.36.

THR500

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05 1	2
2	12	8504.833	
1	12	9624.583	9624.583
3	13	9722.385	9722.385
4	12		10777.67

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.235.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.33: TUKEY'S B TEST, LDA_E, NEAREST MAP, AND THR500 DEPENDENT

THR300

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	12	7541.750	
3	13	8655.769	8655.769
1	12	8716.583	8716.583
4	12		9947.833

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.235.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.34: TUKEY'S B TEST, LDA_E, NEAREST MAP, AND THR300 DEPENDENT

THR100

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05
		1
2	12	5941.667
3	13	6222.000
1	12	6625.500
4	12	7844.667

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.235.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.35: TUKEY'S B TEST, LDA_E, NEAREST MAP, AND THR100 DEPENDENT

THR50

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	12	3236.750	
3	13	4300.000	4300.000
1	12		5443.083
4	12		5859.750

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.235.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4.36: TUKEY'S B TEST, LDA_E, NEAREST MAP, AND THR50 DEPENDENT

The results of Tukey's B test for LDA_E are very similar to those LDA_A and LDA_D. The left-quartering winds seem to delay the alignment of the aircraft with the runway center line.

4.10 SUMMARY OF LATERAL DATA ANALYSIS

It was the purpose of this analysis to determine which approach scenario aligned most rapidly with the extended runway center line by ranking the means of THR50, THR100, THR300, and THR500 for the four wind cases. Since these variables measure the distance from threshold where the aircraft approached within 50, 100, 300, or 500 feet of the extended runway center line, larger values indicate the aircraft becomes stabilized on the center line further from threshold.

For each wind case and for each lateral variable it was found that LDA_A became laterally stabilized significantly farther from the threshold than the other two. LDA_D, with means smaller than those for LDA_E, also exhibited better lateral stabilization than LDA_E. Therefore, the LDA approaches with MAP farthest from the runway threshold became laterally stabilized farthest from the runway threshold regardless of the wind condition.

In addition, an objective of this analysis was to determine the effect of wind direction on alignment with the runway center line. It was found that the left-quartering winds had the most effect. The smallest values of the variables THR500, THR300, THR100 and THR50 occurred for wind cases 2 and 3. In most cases, the differences were significant.

5.0 ANALYSIS OF AIRCRAFT BANK DATA

A two-way ANOVA was performed on each of the variables, (e) and (g), which represent the maximum bank angle achieved during the left and right turns using the approach scenarios and the wind cases as grouping or independent variables. The two-way ANOVA indicated significant differences at the 0.05 significance level for each of the variables, (e) and (g). The two-way ANOVA also indicated no interactions between the two independent variables. This allows an analysis of the data by either scenario or wind case. The following table presents the results of the ANOVA test for interactions. The degrees of freedom, the F-value, and the significance or probability of F is shown. If the value of the significance of F, in the table, is less than 0.05 then a significant interaction is present. Note that none of the values of significance of F is less than 0.05.

Variable	Degrees of Freedom	F-Value	Significance of F
BANK_LEF	6	.932	.474
BANK_RT	6	.617	.716

Table 5.1: INTERACTION OF AIRCRAFT BANK VARIABLES

5.1 ANOVA OF AIRCRAFT BANK DATA BY WIND DIRECTION

Since there are no interactions of the independent variables, the dependent variables can be analyzed relative to each independent variable. The analysis continued by considering each wind case separately. For example, a one-way ANOVA was performed on wind case 1 data using the approach scenario as the dependent variable and BANK_LEF as the independent variable. The data for wind case 1 showed no significant differences. Significant differences between the approach scenarios were only found for BANK_LEF for wind case 2 and wind case 3. The results of the ANOVA analyses are presented in tables 5.2, 5.3, 5.4, and 5.5.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
BANK_RT	Between Groups	28.265	2	14.132	1.344	.276
	Within Groups	326.068	31	10.518		
	Total	354.333	33			
BANK_LEF	Between Groups	13.306	2	6.653	.584	.564
	Within Groups	364.573	32	11.393		
	Total	377.879	34			

Table 5.2: ANOVA, WIND CASE 1, RIGHT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
BANK_RT	Between Groups	48.267	2	24.133	2.941	.068
	Within Groups	254.379	31	8.206		
	Total	302.646	33			
BANK_LEF	Between Groups	67.016	2	33.508	4.544	.019
	Within Groups	228.605	31	7.374		
	Total	295.621	33			

Table 5.3: ANOVA, WIND CASE 2, LEFT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
BANK_RT	Between Groups	19.348	2	9.674	.439	.648
	Within Groups	770.731	35	22.021		
	Total	790.080	37			
BANK_LEF	Between Groups	71.167	2	35.583	3.361	.046
	Within Groups	370.556	35	10.587		
	Total	441.722	37			

Table 5.4: ANOVA, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
BANK_RT	Between Groups	18.175	2	9.088	.725	.492
	Within Groups	426.097	34	12.532		
	Total	444.272	36			
BANK_LEF	Between Groups	48.567	2	24.283	2.663	.084
	Within Groups	310.074	34	9.120		
	Total	358.641	36			

Table 5.5: ANOVA, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

To determine the ranking of the approach scenarios and the significant pairs of approach scenarios, the Tukey B test was performed by wind case.

5.2 TUKEY'S B TEST OF BANK VARIABLES FOR WIND CASE 1

It is not necessary to perform Tukey's B test of the bank variables for wind case 1 since it was shown by ANOVA that no significant differences were present. However, the results of Tukey's B test are presented in tables 5.6 and 5.7 in order to show the ranking of the LDAs. The tables show that the LDAs are always ranked, from smallest bank angle to largest, LDA_A, LDA_D, and LDA_E.

BANK_LEF

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05 1
1	13	9.9808
4	10	10.2160
5	12	11.3667

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.527.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.6: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND, AND BANK_LEF DEPENDENT

BANK_RT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05 1
5	13	-11.6046
4	11	-10.2645
1	14	-10.0014

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.7: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND, AND BANK_RT DEPENDENT

5.3 TUKEY'S B TEST OF BANK VARIABLES FOR WIND CASE 2

To determine the ranking of the bank variables by approach scenario and the significant pairs by approach scenarios, the Tukey B test was performed by wind case. The results of the Tukey B test for wind case 2 are presented in tables 5.8 and 5.9.

BANK_LEF

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
1	9	7.7167	
4	13	8.2508	
5	12		10.9367

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.8: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND, AND BANK_LEF DEPENDENT

BANK_RT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	-12.8350	
4	13	-11.4154	-11.4154
1	9		-9.7744

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.9: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND, AND BANK_RT DEPENDENT

For each of the variables, BANK_LEF and BANK_RT, the smallest bank angles are produced by LDA_A and LDA_D. In each case, the bank angles for LDA_E are significantly smaller than those of the LDA_A.

5.4 TUKEY'S B TEST OF BANK VARIABLES FOR WIND CASE 3

The results of the Tukey B test for wind case 3 are presented in tables 5.10 and 5.11. Multiple columns indicate significant differences. Those scenarios that are statistically equivalent are listed in the same column.

BANK_LEF

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05 1
4	11	8.3482
1	14	8.9471
5	13	11.5231

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.10: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH BANK_LEF DEPENDENT

BANK_RT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05 1
5	13	-11.6046
4	11	-10.2645
1	14	-10.0014

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.11: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH BANK_RT DEPENDENT

In this case, Tukey's B test did not indicate any significant differences. However, it is clear from the tables that the largest bank angles, although not significantly different, were those of LDA_E.

5.5 TUKEY'S B TEST OF BANK VARIABLES FOR WIND CASE 4

The results of the Tukey B test for wind case 4 are presented in tables 5.11 and 5.12.

BANK_LEF

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05 1
1	12	9.4083
5	12	11.8392
4	13	11.8708

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.12: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH BANK_LEF DEPENDENT

BANK_RT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05 1
4	13	-13.6562
5	12	-12.7783
1	12	-11.9508

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.13: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH BANK_RT DEPENDENT

5.6 ANOVA OF AIRCRAFT BANK DATA BY SCENARIO

In the previous analysis of the aircraft bank variables, the wind direction was held constant in order to determine which scenario or LDA was affected the most by the given wind direction. In this analysis, the scenario is held constant to determine which wind direction had the most effect on the given scenario. For example, if scenario 1 is constant and a one-way ANOVA is performed on THR500, then it may indicate which wind case had the most effect or caused the largest values of THR500. Tables 5.13, 5.14, and 5.15 present the results of the ANOVA.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
BANK_RT	Between Groups	64.127	3	21.376	1.916	.141
	Within Groups	490.918	44	11.157		
	Total	555.045	47			
BANK_LEF	Between Groups	28.769	3	9.590	1.100	.359
	Within Groups	383.473	44	8.715		
	Total	412.242	47			

Table 5.14: ANOVA, LDA_A, FARTHEST MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
BANK_RT	Between Groups	74.405	3	24.802	2.573	.067
	Within Groups	404.798	42	9.638		
	Total	479.203	45			
BANK_LEF	Between Groups	111.324	3	37.108	5.043	.004
	Within Groups	316.438	43	7.359		
	Total	427.762	46			

Table 5.15: ANOVA, LDA_D, CENTER MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
BANK_RT	Between Groups	27.220	3	9.073	.463	.709
	Within Groups	881.560	45	19.590		
	Total	908.780	48			
BANK_LEF	Between Groups	5.084	3	1.695	.133	.940
	Within Groups	573.897	45	12.753		
	Total	578.981	48			

Table 5.16: ANOVA, LDA_E, NEAREST MAP WITH WIND CASE INDEPENDENT

No significant differences were detected for LDA_A and LDA_E. Therefore wind direction has little effect on the size of the maximum bank angle for those two scenarios. Significant differences were detected for LDA_D during the left bank.

5.7 TUKEY'S B TEST OF AIRCRAFT BANK DATA FOR LDA_D

Since significant differences were not detected for LDA_A and LDA_E, Tukey's B test was only conducted for LDA_D. The results of the test are presented in tables 5.16 and 5.17.

BANK_RT

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05
		1
4	13	-13.6562
2	13	-11.4154
1	9	-11.3489
3	11	-10.2645

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.240.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.17: TUKEY'S B TEST, LDA_D, CENTER MAP WITH BANK_RT DEPENDENT

BANK_LEF

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	13	8.2508	
3	11	8.3482	
1	10	10.2160	10.2160
4	13		11.8708

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.602.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 5.18: TUKEY'S B TEST, LDA_D, CENTER MAP WITH BANK_LEF DEPENDENT

Tukey's B test of LDA_D, with BANK_LEF independent, indicates the largest left bank angles occurred during quartering tailwinds from the right. However, Tukey's B test of LDA_D, with BANK_RT independent, has no indication of significant differences. Visual examination of the means of BANK_RT shows little difference in the right bank angle regardless of wind direction.

5.8 DESCRIPTIVE STATISTICS OF AIRCRAFT BANK DATA

One of the criteria for the success of the LDA approaches is the bank angles should not be excessive; i.e., should not exceed 25 degrees. The variables BANK_LEF and BANK_RT represent the largest bank angles, left and right, that were recorded during the approach. Tables 5.18, 5.19, and 5.20 are tables of standard statistics for BANK_LEF and BANK_RT by scenario or LDA. The values of BANK_LEF are negative to indicate they are in the opposite direction to BANK_RT. The tables indicated the maximum bank, left or right, never exceeded 25 degrees.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
bank_lef	45	-19.30	-5.52	-11.1940	3.4841
bank_rt	45	4.66	17.55	9.2024	3.0277
Valid N (listwise)	45				

Table 5.19: BANK STATISTICS FOR LDA_A

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
bank_lef	44	-19.45	-4.65	-11.7575	3.3711
bank_rt	44	4.67	16.50	9.6886	3.1223
Valid N (listwise)	44				

Table 5.20: BANK STATISTICS FOR LDA_D

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
bank_lef	46	-22.51	-2.63	-12.7661	4.4603
bank_rt	46	4.20	18.63	11.3667	3.5603
Valid N (listwise)	46				

Table 5.21: BANK STATISTICS FOR LDA_E

5.9 SUMMARY OF AIRCRAFT BANK DATA ANALYSIS

The first purpose of this analysis was to determine which approach scenario exhibited the most stabilized approach by ranking the means of BANK_LEF and BANK_RT for the four wind cases. It was found that for wind cases 1, 3, and 4 there were no significant differences for BANK_LEF or BANK_RT between the three flight scenarios. Significant differences were only found for wind case 2. In six of the eight tables, the largest average angles were recorded by LDA_E, the LDA with MAP nearest the threshold. In one case, wind case 4, the largest angles were recorded by LDA_D; however, they were not significantly larger. This is a further indication that the aircraft were more stable when performing the approaches with MAP farthest from the runway threshold.

The second purpose of this analysis was to determine the effect the four wind cases had by scenario. For LDA_A, the LDA with MAP located farthest from the threshold, no significant differences were detected. Therefore, the left and right bank angles did not differ by wind direction for LDA_A. For LDA_D, the LDA with MAP located centrally, the only significant difference was for BANK_LEF. An examination of Tukey's B test of BANK_LEF indicated the largest bank angles occurred during wind case 1 and wind case 4. Therefore, the largest left bank angles occurred during right-quartering winds. For LDA_E, the LDA with MAP located nearest the threshold, no significant differences were detected.

One of the stated criteria for success is that maximum bank angles should not exceed 25 degrees. These variables, BANK_LEF and BANK_RT represent the largest bank angles during the approach. It was shown that the bank angles, regardless of scenario or wind case, never exceeded 25 degrees.

In summary, the analysis showed the choice of scenario had much more effect on maximum bank angle than wind direction. Maximum bank angles never exceeded 25 degrees, which met one of the criteria for success.

6.0 ANALYSIS OF ALTITUDE-AT-MAXIMUM-BANK DATA

A two-way ANOVA was performed on each of the variables, (f) and (h), which represent the altitude at which the maximum bank angle was achieved during the left and right turns using the approach scenarios and the wind cases as grouping or independent variables. The two-way ANOVA indicated significant differences at the 0.05 significance level for each of the variables, (f) and (h). The two-way ANOVA also indicated no interactions between the two independent variables. This allows an analysis of the data by either scenario or wind case. The following table presents the results of the ANOVA test for interactions. The degrees of freedom, the F-value, and the significance or probability of F are shown. If the value of the significance of F, in the table, is less than 0.05 then a significant interaction is present. Note that none of the values of significance of F is less than 0.05.

VARIABLE	DEGREES OF FREEDOM	F-VALUE	SIGNIFICANCE OF F
LEFT_ALT	6	1.384	.226
RT_ALT	6	.321	.925

Table 6.1: INTERACTION OF AIRCRAFT BANK VARIABLES

6.1 ANOVA OF ALTITUDE-AT-MAXIMUM-BANK DATA BY WIND DIRECTION

Since there are no interactions of the independent variables, the dependent variables can be analyzed relative to each independent variable. The analysis continued by considering each wind case separately. For example, a one-way ANOVA was performed on wind case 1 data using the approach scenario as the dependent variable and LEFT_ALT as the independent variable. The data for all four of the wind cases showed significant differences for both RT_ALT and LEFT_ALT. The results of the ANOVA analyses are presented in tables 6.2, 6.3, 6.4, and 6.5

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RT_ALT	Between Groups	275929.1	2	137964.562	12.465	.000
	Within Groups	354177.9	32	11068.061		
	Total	630107.1	34			
LEFT_ALT	Between Groups	455861.0	2	227930.515	26.556	.000
	Within Groups	274653.4	32	8582.918		
	Total	730514.4	34			

Table 6.2: ANOVA, WIND CASE 1, RIGHT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RT_ALT	Between Groups	191226.2	2	95613.086	5.830	.007
	Within Groups	508441.2	31	16401.330		
	Total	699667.4	33			
LEFT_ALT	Between Groups	242991.7	2	121495.872	10.342	.000
	Within Groups	364182.3	31	11747.816		
	Total	607174.0	33			

Table 6.3: ANOVA, WIND CASE 2, LEFT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RT_ALT	Between Groups	228762.3	2	114381.152	13.847	.000
	Within Groups	289103.0	35	8260.086		
	Total	517865.3	37			
LEFT_ALT	Between Groups	47393.90	2	23696.949	.445	.644
	Within Groups	1863785	35	53250.998		
	Total	1911179	37			

Table 6.4: ANOVA, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RT_ALT	Between Groups	181364.2	2	90682.103	11.806	.000
	Within Groups	261151.8	34	7680.935		
	Total	442516.0	36			
LEFT_ALT	Between Groups	365966.9	2	182983.462	42.547	.000
	Within Groups	146225.1	34	4300.739		
	Total	512192.0	36			

Table 6.5: ANOVA, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

6.2 TUKEY' B TEST OF ALTITUDE-AT-MAXIMUM-BANK DATA FOR WIND CASE 1

Each ANOVA indicated significant differences between the scenarios for all four of the wind cases. Tukey's B test is used to rank the scenarios for wind case 1.

LEFT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	894.5583	
4	10	977.2100	
1	13		1158.462

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.527.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.6: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND WITH LEFT_ALT DEPENDENT

RT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	465.4000	
4	10	544.1500	
1	13		673.3231

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.527.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.7: TUKEY'S B TEST, WIND CASE 1, RIGHT-QUARTERING TAILWIND WITH RT_ALT DEPENDENT

As expected, the average altitudes where the maximum left and right bank angles occurred is highest for LDA_A, the LDA with MAP farthest from the threshold.

6.3 TUKEY' B TEST OF ALTITUDE-AT-MAXIMUM-BANK DATA FOR WIND CASE 2

Tukey's B test was used to rank the means for the altitude at maximum bank data for wind case 2. The ANOVA test indicated significant differences. Tukey's B test confirms that result. The results are presented in tables 6.8 and 6.9.

LEFT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	860.6333	
4	13		973.3385
1	9		1076.533

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.8: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND WITH LEFT_ALT DEPENDENT

RT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	397.7833	
4	13	498.2538	498.2538
1	9		589.2333

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.055.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.9: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND WITH RT_ALT DEPENDENT

In wind case 2, the highest average altitudes are still recorded by LDA_A, but LDA_D is grouped with LDA_A, indicating no significant difference between the two.

6.4 TUKEY' B TEST OF ALTITUDE-AT-MAXIMUM-BANK DATA FOR WIND CASE 3

Tukey's B test was used to rank the means for the altitude at maximum bank data for wind case 3. The ANOVA test indicated significant differences for RT_ALT. Tukey's B test confirms that result. The results are presented in tables 6.10 and 6.11.

LEFT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05
		1
5	13	936.7308
4	11	945.5182
1	14	1013.614

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.10: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH LEFT_ALT DEPENDENT

RT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	13	471.7000	
4	11		595.9182
1	14		653.0286

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.539.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.11: TUKEY'S B TEST, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH RT_ALT DEPENDENT

In this case, the LDA with the highest altitude for the turns was LDA_A with the MAP farthest from the threshold. However, for the left turn, the means were not significantly different.

6.5 TUKEY' B TEST OF ALTITUDE-AT-MAXIMUM-BANK DATA FOR WIND CASE 4

In this case ANOVA indicated significant differences. Tukey's B test confirms ANOVA by dividing the LDAs into three groups for LEFT_ALT. The results are shown in tables 6.12 and 6.13.

LEFT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05		
		1	2	3
5	12	906.1417		
4	13		1052.008	
1	12			1151.583

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.12: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH LEFT_ALT DEPENDENT

RT_ALT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05	
		1	2
5	12	526.7333	
4	13	595.4077	
1	12		699.3333

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.316.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.13: TUKEY'S B TEST, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH RT_ALT INDEPENDENT

As expected, the average highest altitude for the turns was recorded by LDA_A, the LDA with MAP farthest from the threshold. The average lowest altitude for the turns was recorded by LDA_E, the LDA with MAP nearest the threshold.

6.6 ANOVA OF ALTITUDE-AT-MAXIMUM-BANK DATA BY SCENARIO

Since there are no interactions of the independent variables, the dependent variables can be analyzed relative to each independent variable. The analysis continued by considering each scenario separately. For example, a one-way ANOVA was performed on LDA_A data using the approach scenario as the dependent variable and wind case as the independent variable. Only two significant differences were found. Both significant differences occurred in the tests of RT_ALT. The first significant difference was from the grouping by LDA_D. The second significant difference was from the grouping by LDA_E. The results of the ANOVA analyses are presented in tables 6.14, 6.15, and 6.16.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RT_ALT	Between Groups	66458.46	3	22152.819	1.644	.193
	Within Groups	592870.6	44	13474.333		
	Total	659329.1	47			
LEFT_ALT	Between Groups	185755.8	3	61918.614	2.292	.091
	Within Groups	1188603	44	27013.703		
	Total	1374359	47			

Table 6.14: ANOVA, LDA_A, FARTHEST MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RT_ALT	Between Groups	82327.13	3	27442.378	3.411	.026
	Within Groups	345920.6	43	8044.666		
	Total	428247.8	46			
LEFT_ALT	Between Groups	76977.76	3	25659.253	.960	.420
	Within Groups	1149072	43	26722.597		
	Total	1226049	46			

Table 6.15: ANOVA, LDA_D, CENTER MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
RT_ALT	Between Groups	100520.6	3	33506.868	3.180	.033
	Within Groups	474082.7	45	10535.172		
	Total	574603.3	48			
LEFT_ALT	Between Groups	36940.02	3	12313.339	1.781	.164
	Within Groups	311171.1	45	6914.913		
	Total	348111.1	48			

Table 6.16: ANOVA, LDA_E, NEAREST MAP WITH WIND CASE INDEPENDENT

6.7 TUKEY'S B TEST OF ALTITUDE-AT-MAXIMUM-BANK DATA FOR LDA_D

Although the ANOVA indicated a significant difference for RT_ALT by LDA_D, Tukey's B test did not indicate a significant difference. The result of Tukey's B test is presented in table 6.16.

RT_ALT

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05
		1
2	13	498.2538
1	10	544.1500
4	13	595.4077
3	11	595.9182

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.602.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.17: TUKEY'S B TEST, LDA_D, CENTER MAP WITH RT_ALT DEPENDENT

From table 6.16, the average altitude of the right turn was about 100 feet lower for wind case 2 than that of wind case 3. This was expected since wind case 2 represents a right-quartering tailwind while wind case 3 is a left-quartering head wind.

RT_ALT

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
2	12	397.7833	
1	12	465.4000	465.4000
3	13	471.7000	471.7000
4	12		526.7333

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 12.235.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 6.18: TUKEY'S B TEST, LDA_E, NEAREST MAP WITH RT_ALT DEPENDENT

In this case Tukey's B test indicated a significant difference. As expected, wind case 2, a quartering tailwind, had the lowest altitude corresponding to the maximum right turn.

6.8 SUMMARY OF ALTITUDE-AT-MAXIMUM-BANK DATA ANALYSIS

It was expected the LDA with MAP farthest from the threshold would have the highest average altitudes at the maximum bank angles. This was reinforced by the fact that LDA_D, with MAP located 3,000 feet nearer the threshold, had the second highest average altitudes at the maximum bank angles. LDA_E, with MAP located 3,000 feet nearer the threshold than LDA_D, had the lowest average altitudes at the maximum bank angles.

It was also expected that wind case 2, a quartering tailwind, would have the most effect on altitude. This was shown to be the case for LDA_D and LDA_E. The ANOVA indicated a significant difference for LDA_D during the right turn, but Tukey's B test did not indicate a significant difference. Both the ANOVA and Tukey's B test indicated significant differences for LDA_E during the right turn. In both cases, the average altitude was on the order of 100 feet.

7.0 ANALYSIS OF AIRCRAFT CPA AND OVERSHOOT DATA

A two-way ANOVA was performed on the variables (i) OVR_SHT, which represents the overshoot distance across the extended center line, and (j) CPA, which represents the closest point of approach of the two aircraft, using the approach scenarios and the wind cases as grouping or independent variables. The two-way ANOVA indicated significant differences at the 0.05 significance level. The two-way ANOVA also indicated no interactions between the two independent variables. This allows an analysis of the data by either scenario or wind case. The following table presents the results of the ANOVA test for interactions. The degrees of freedom, the F-value, and the significance or probability of F is shown. If the value of the significance of F, in the table, is less than 0.05 then a significant interaction is present.

VARIABLE	DEGREES OF FREEDOM	F-VALUE	SIGNIFICANCE OF F
CPA	6	.090	.997
OVR_SHT	6	1.021	.414

Table 7.1: INTERACTION OF OVERSHOOT AND CPA

Since there are no interactions of the independent variables, the dependent variables can be analyzed relative to each independent variable.

7.1 ANOVA OF CPA AND OVERSHOOT DATA BY WIND CASE

The analysis was continued by considering each wind case separately. For example, a one-way ANOVA was performed on wind case 1 data using the approach scenario as the independent variable and OVR_SHT and CPA as the dependent variables. The only significant difference was detected for OVR_SHT during wind case 2. The results of the ANOVA analyses are presented in tables 7.2, 7.3, 7.4, and 7.5.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OVR_SHT	Between Groups	5048.013	2	2524.006	.776	.469
	Within Groups	97521.77	30	3250.726		
	Total	102569.8	32			
CPA	Between Groups	1044422	2	522211.133	.238	.790
	Within Groups	6.6E+07	30	2194805.593		
	Total	6.7E+07	32			

Table 7.2: ANOVA, WIND CASE 1, RIGHT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OVR_SHT	Between Groups	3054.989	2	1527.495	3.624	.039
	Within Groups	12221.79	29	421.441		
	Total	15276.78	31			
CPA	Between Groups	1175431	2	587715.468	.164	.850
	Within Groups	1.0E+08	29	3584231.191		
	Total	1.1E+08	31			

Table 7.3: ANOVA, WIND CASE 2, LEFT-QUARTERING TAILWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OVR_SHT	Between Groups	939.829	2	469.914	.554	.580
	Within Groups	27138.34	32	848.073		
	Total	28078.17	34			
CPA	Between Groups	338152.5	2	169076.241	.080	.923
	Within Groups	6.7E+07	32	2102215.078		
	Total	6.8E+07	34			

Table 7.4: ANOVA, WIND CASE 3, LEFT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OVR_SHT	Between Groups	3821.545	2	1910.772	.379	.688
	Within Groups	156416.2	31	5045.683		
	Total	160237.7	33			
CPA	Between Groups	938711.1	2	469355.566	.229	.797
	Within Groups	6.4E+07	31	2051636.048		
	Total	6.5E+07	33			

Table 7.5: ANOVA, WIND CASE 4, RIGHT-QUARTERING HEADWIND WITH APPROACH SCENARIO INDEPENDENT

From tables 7.2, 7.3, 7.4, and 7.5, it is clear that wind direction has little effect on closest point of approach or overshoot. The only significant difference was during wind case 2. Since the other wind cases had no significant differences, this significant difference could be attributed to chance.

7.2 TUKEY'S B TEST OF CPA AND OVERSHOOT DATA FOR WIND CASE 2

Since the only significant difference of OVR_SHT occurred during wind case 2, Tukey's B test was only performed for this one case. Although ANOVA indicated a significant difference, Tukey's B test did not indicate a significant difference. Refer to table 7.6.

OVR_SHT

Tukey B[a,b]

SCENARIO	N	Subset for alpha = .05 1
4	12	9.4750
1	9	10.8889
5	11	30.6182

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.513.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 7.6: TUKEY'S B TEST, WIND CASE 2, LEFT-QUARTERING TAILWIND WITH OVR_SHT DEPENDENT

7.3 ANOVA OF CPA AND OVERSHOOT DATA BY SCENARIO

The analysis was continued by considering each scenario or LDA separately. For example, a one-way ANOVA was performed on LDA_A data using the wind case as the independent variable and CPA or OVR_SHT as the dependent variable. Significant differences were detected for OVR_SHT during LDA_A and LDA_D. The results of the ANOVA analyses are presented in tables 7.7, 7.8, 7.9, and 7.10.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OVR_SHT	Between Groups	34339.17	3	11446.390	6.903	.001
	Within Groups	67982.62	41	1658.113		
	Total	102321.8	44			
CPA	Between Groups	6784835	3	2261611.537	.847	.476
	Within Groups	1.1E+08	41	2670627.351		
	Total	1.2E+08	44			

Table 7.7: ANOVA, LDA_A, FARTHEST MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OVR_SHT	Between Groups	46704.61	3	15568.204	6.735	.001
	Within Groups	92457.21	40	2311.430		
	Total	139161.8	43			
CPA	Between Groups	1.1E+07	3	3575712.675	1.430	.248
	Within Groups	1.0E+08	40	2500076.547		
	Total	1.1E+08	43			

Table 7.8: ANOVA, LDA_D, CENTER MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
OVR_SHT	Between Groups	11491.29	3	3830.431	1.182	.328
	Within Groups	132858.2	41	3240.445		
	Total	144349.5	44			
CPA	Between Groups	4449878	3	1483292.649	.667	.577
	Within Groups	9.1E+07	41	2223407.050		
	Total	9.6E+07	44			

Table 7.9: ANOVA, LDA_E, NEAREST MAP WITH WIND CASE INDEPENDENT

7.4 TUKEY'S B TEST OF OVERSHOOT DATA FOR LDA_A

Since ANOVA detected no significant difference for CPA, it is only necessary to perform Tukey's B test for OVR_SHT. The result is shown in table 7.10.

OVR_SHT

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05 1	2
2	9	10.8889	
3	13	25.1538	
1	12		71.2167
4	11		76.1727

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.041.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 7.10: TUKEY'S B TEST, LDA_A, FARTHEST MAP WITH OVR_SHT DEPENDENT

From table 7.10, there are two significantly different groups. Overshoot is least for wind cases 2 and 3. This is not surprising since wind cases 2 and 3 are quartering winds from the left and tend to drift the aircraft away from runway 28L.

7.5 TUKEY'S B TEST OF OVERSHOOT DATA FOR LDA_D

Since ANOVA detected no significant difference for CPA, it is only necessary to perform Tukey's B test for OVR_SHT. The result is shown in table 7.11.

OVR_SHT

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05 1	2
2	12	9.4750	
3	10	12.5300	
1	10	42.3400	42.3400
4	12		88.2667

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.909.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 7.11: TUKEY'S B TEST, LDA_D, CENTER MAP WITH OVR_SHT DEPENDENT

The result shown in table 7.11 is very similar to table 7.10. The overshoot for wind cases 2 and 3 are significantly smaller than for wind case 4.

7.6 CORRELATION OF CPA AND OVERSHOOT DATA

ANOVA and Tukey's test are tests that determine whether the mean or average values of the data sets seem to be different. However, in regard to overshoot and CPA data, and because of the important safety implications associated with overshoots and CPA, it is advisable to also examine the extreme values of the distributions and investigate the correlation of the two. When investigating the correlation of two variables we attempt to discover whether some relationship exists between the two. Is it possible that large values of overshoot lead to small values of CPA? Do large values of CPA go with small values of overshoot? Table 7.12 displays the ten largest overshoot values along with the corresponding CPA, the scenario, and the wind case. Table 7.13 displays the ten smallest CPA values along with the corresponding overshoot, the scenario, and the wind case.

RANK	SCENARIO	WIND	CPA	OVR_SHT
1	LDA_E	4	3524	290.70
2	LDA_D	4	3706	231.20
3	LDA_E	1	3524	184.60
4	LDA_A	1	3220	177.90
5	LDA_D	4	3767	176.40
6	LDA_D	1	3038	172.90
7	LDA_D	4	5712	170.90
8	LDA_D	4	2370	170.90
9	LDA_A	1	3828	167.90
10	LDA_E	1	4739	140.80

Table 7.12: TEN LARGEST OVERSHOOTS, WITH CPA, SCENARIO, AND WIND

Table 7.12 indicates the largest overshoot was 290.7 feet. The scenario was LDA_E, with MAP nearest the threshold. The second largest overshoot was 231.2 feet recorded by LDA_D, with MAP 3,000 feet farther from the threshold than LDA_E. LDA_D had the most large overshoots with 5, LDA_E had 3 large overshoots, and LDA_A had only 2. All of the large overshoots occurred during a right-quartering headwind or tailwind. The CPAs associated with the overshoots are all quite large. The smallest CPA was 2,370 feet recorded by LDA_D with a right-quartering headwind.

RANK	SCENARIO	WIND	OVR_SHT	CPA
1	LDA_E	1	78.0	790
2	LDA_E	2	6.3	790
3	LDA_A	3	14.2	790
4	LDA_A	1	80.9	911
5	LDA_D	3	10.9	1276
6	LDA_A	2	1.1	1398
7	LDA_A	3	15.9	1398
8	LDA_E	2	17.4	1458
9	LDA_A	4	38.7	1580
10	LDA_D	1	21.1	1762

Table 7.13: TEN SMALLEST CPAs, WITH OVERSHOOT, SCENARIO, AND WIND

Table 7.13 indicates the smallest CPA was 790 feet, recorded three times. This number was recorded by LDA_E (twice) and LDA_A. The winds associated with the 790-foot CPA values were two quartering tailwinds, left and right, and a left-quartering headwind. Four of the smallest CPA values were associated with quartering headwinds. Although LDA_D recorded five of the ten largest overshoot values, LDA_D had only two of the ten smallest CPA values.

Tables 7.12 and 7.13 seem to indicate a correlation between overshoot and CPA may exist. In table 7.12, we see large values of overshoot with large values of CPA. In table 7.13, we see small values of CPA with small values of overshoot. Spearman's RHO statistic was computed to determine whether a correlation between CPA and overshoot exists. The result of Spearman's RHO test is shown in table 7.14. Several numbers are displayed in the table. In the row labeled "OVR_SHT" and in the column labeled "OVER_SHT", we see the number 1.000. This is the Spearman RHO statistic for OVR_SHT versus OVR_SHT. It indicates perfect correlation. In the row labeled "OVR_SHT" and in the column labeled "CPA", we see the number -0.053. This is the Spearman RHO statistic for OVR_SHT versus CPA. The significance of –0.053 is listed directly below it. The significance of –0.053 is 0.540. The null hypothesis is that there is no correlation. The alternate hypothesis is that there is a correlation. If the significance of RHO was less than 0.05 we would reject the null hypothesis and conclude there is a correlation. However, 0.540 is larger than 0.05 so we accept the null hypothesis; i.e., there is no correlation between the values of OVR_SHT and CPA. This is further illustrated by figure 7.1. From the figure we see that the CPA values corresponding to the large values of OVR_SHT are near the average for CPA.

Correlations

			OVR	CPA
Spearman's rho	OVR	Correlation Coefficient	1.000	-.053
		Sig. (2-tailed)	.	.540
		N	134	134
	CPA	Correlation Coefficient	-.053	1.000
		Sig. (2-tailed)	.540	.
		N	134	134

Table 7.14: SPEARMAN'S RHO OF OVERSHOOT AND CPA

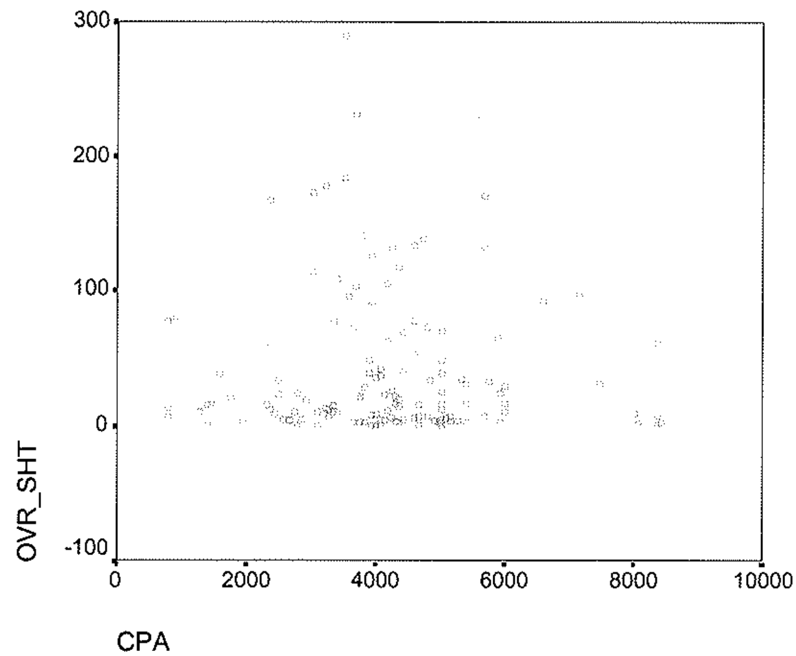


Figure 7.1: SCATTER PLOT OF CPA VERSUS OVR_SHT

8.0 ANALYSIS OF GLIDE SLOPE DATA

Another measure of the flyability of the approaches is the vertical deviation of the aircraft below the glide slope. The variable UNDER_GS measures the maximum deviation below the glide slope. A two-way ANOVA was performed on this variable. The two-way ANOVA indicated no significant differences at the 0.05 significance level. The two-way ANOVA also indicated no interaction between the two independent variables. A further analysis by wind case or scenario was not needed since the two-way ANOVA indicated no differences. Table 8.1 presents the results of the two-way ANOVA test. If the value of the significance of F, in the table, is less than 0.05 then a significant interaction is present. Note that none of the values of significance of F is less than 0.05.

Tests of Between-Subjects Effects

Dependent Variable: MIN_GS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SCENARIO	4312.168	2	2156.084	2.734	.069
WINDCASE	4828.586	3	1609.529	2.041	.111
SCENARIO * WINDCASE	3195.799	6	532.633	.676	.670

Table 8.1: TWO-WAY ANOVA WITH INTERACTION OF MIN_GS

9.0 ANALYSIS OF RATE OF DESCENT DATA

Another measure of the flyability of the three approaches is the rate of descent. The average rate of descent of the aircraft from the missed approach point to the stabilized approach point was recorded in the variable MAP2SAP. The average rate of descent of the aircraft from the stabilized approach point to a point 1,000 feet short of the threshold was recorded as the variable SAP2THR. The average was not computed to the threshold to avoid possible anomalies caused by the flaring action of the aircraft just prior to landing. A two-way ANOVA was performed on each of these two variables to determine whether significant differences existed. The ANOVA indicated there were no differences due to scenario, but there was a significant difference due to wind. The ANOVA also indicated no significant interaction. Therefore the analysis could be continued by scenario or wind case. Tables 9.1 and 9.2 present the results of the two-way ANOVA test. If the value of the significance of F, in the table, is less than 0.05 then a significant interaction is present. Note that the only value of significance of F less than 0.05 is the value corresponding to wind case. Therefore, wind direction does have an effect on rate of descent. Scenario or LDA does not have any effect on rate of descent.

Tests of Between-Subjects Effects

Dependent Variable: MAP2SAP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SCENARIO	178.344	2	89.172	.018	.982
WINDCASE	336184.423	3	112061.474	22.368	.000
SCENARIO * WINDCASE	22920.414	6	3820.069	.763	.601

Table 9.1: TWO-WAY ANOVA WITH INTERACTION OF MAP2SAP

Tests of Between-Subjects Effects

Dependent Variable: SAP2THR

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
SCENARIO	5194.974	2	2597.487	.400	.671
WINDCASE	321739.231	3	107246.410	16.502	.000
SCENARIO * WINDCASE	28491.943	6	4748.657	.731	.626

Table 9.2: TWO-WAY ANOVA WITH INTERACTION OF SAP2THR

9.1 ANOVA OF MAP2SAP AND SAP2THR BY WIND CASE

Since a significant difference due to scenario was not detected, it is not necessary to continue the analysis by scenario. Therefore, the analysis continued by considering each wind case separately. For example, a one-way ANOVA was performed on LDA_A data using wind case as the independent variable and MAP2SAP as the dependent variable. Significant differences were detected for each scenario. The results of the ANOVA analyses are presented in tables 9.3, 9.4, and 9.5.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
MAP2SAP	Between Groups	127513.8	3	42504.597	13.664	.000
	Within Groups	127536.5	41	3110.646		
	Total	255050.3	44			
SAP2THR	Between Groups	113377.2	3	37792.389	6.785	.001
	Within Groups	228360.8	41	5569.777		
	Total	341738.0	44			

Table 9.3: ANOVA, LDA_A, FARTHEST MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
MAP2SAP	Between Groups	101275.9	3	33758.617	5.918	.002
	Within Groups	228174.7	40	5704.367		
	Total	329450.5	43			
SAP2THR	Between Groups	124808.0	3	41602.659	5.199	.004
	Within Groups	320056.8	40	8001.420		
	Total	444864.8	43			

Table 9.4: ANOVA, LDA_D, CENTER MAP WITH WIND CASE INDEPENDENT

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
MAP2SAP	Between Groups	138709.2	3	46236.414	7.420	.000
	Within Groups	255494.6	41	6231.576		
	Total	394203.8	44			
SAP2THR	Between Groups	112318.0	3	37439.333	6.279	.001
	Within Groups	244476.9	41	5962.851		
	Total	356794.9	44			

Table 9.5: ANOVA, LDA_E, NEAREST MAP WITH WIND CASE INDEPENDENT

9.2 TUKEY'S B TEST OF RATE OF DESCENT DATA FOR LDA_A

Because of the significant differences found with the ANOVA of MAP2SAP and SAP2THR data, Tukey's B test was performed to find the causes of the differences. Tukey's B test indicated the rates of descent for wind cases 1 and 2 were significantly larger than wind cases 3 and 4. This was expected since wind cases 1 and 2 are both quartering tail winds. The average rate of descent for wind cases 1 and 2 were about 100 feet per minute larger than for wind cases 3 and 4. The results of Tukey's B test for LDA_A are presented in tables 9.6 and 9.7.

MAP2SAP

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
4	11	792.5273	
3	13	813.4462	
2	9		895.6000
1	12		917.9500

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.041.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 9.6: TUKEY'S B TEST, LDA_A, FARTHEST MAP, AND MAP2SAP DEPENDENT

SAP2THR

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05		
		1	2	3
3	13	748.1923		
4	11	794.1364	794.1364	
1	12		846.2833	846.2833
2	9			880.9889

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.041.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 9.7: TUKEY'S B TEST, LDA_A, FARTHEST MAP, AND SAP2THR DEPENDENT

9.3 TUKEY'S B TEST OF RATE OF DESCENT DATA FOR LDA_D

The results of Tukey's B test for LDA_D were very similar to those of LDA_A. Tukey's B test indicated the rates of descent for wind cases 1 and 2 were significantly larger than wind cases 3 and 4. This was expected since wind cases 1 and 2 are both quartering tail winds. The average rate of descent for wind cases 1 and 2 were about 100 feet per minute larger than for wind cases 3 and 4. The results of Tukey's B test for LDA_D are presented in tables 9.8 and 9.9.

MAP2SAP

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
3	10	803.0900	
4	12	814.9583	
1	10	880.6600	880.6600
2	12		918.5833

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.909.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 9.8: TUKEY'S B TEST, LDA_D, CENTER MAP, AND MAP2SAP DEPENDENT

SAP2THR

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05		
		1	2	3
4	12	772.9583		
3	10	786.2300	786.2300	
2	12		875.5500	875.5500
1	10			894.6700

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.909.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 9.9: TUKEY'S B TEST, LDA_D, CENTER MAP, AND SAP2THR DEPENDENT

9.4 TUKEY'S B TEST OF RATE OF DESCENT DATA FOR LDA_E

The results of Tukey's B test for LDA_E were very similar to those of LDA_A and LDA_D. Tukey's B test indicated the rates of descent for wind cases 1 and 2 were significantly larger than wind cases 3 and 4. This was expected since wind cases 1 and 2 are both quartering tail winds. The average rate of descent for wind cases 1 and 2 were about 100 feet per minute larger than for wind cases 3 and 4. The results of Tukey's B test for LDA_D are presented in tables 9.10 and 9.11.

MAP2SAP

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05	
		1	2
3	12	788.4500	
4	11	818.6455	
2	11		898.1091
1	11		922.8182

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.234.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 9.10: TUKEY'S B TEST, LDA_E, NEAREST MAP, AND MAP2SAP DEPENDENT

SAP2THR

Tukey B[a,b]

WINDCASE	N	Subset for alpha = .05		
		1	2	3
4	11	761.0364		
3	12	786.6833	786.6833	
1	11		852.1000	852.1000
2	11			887.0545

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 11.234.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 9.11: TUKEY'S B TEST, LDA_E, NEAREST MAP, AND SAP2THR DEPENDENT

9.5 DESCRIPTIVE STATISTICS OF RATE OF DESCENT DATA

One of the criteria for the success of the LDA approaches is sustained rates of descent should not be excessive; i.e., should not exceed 1,200 feet per minute. The variables, MAP2SAP and SAP2THR, represent the average rates of descent recorded from the MAP to the SAP and then from the SAP to 1,000 feet short of the threshold. Tables 9.12, 9.13, 9.14, and 9.15 are tables of descriptive statistics for MAP2SAP and SAP2THR by wind case. The tables indicate the maximum and minimum rates of descent for the wind case as well as the mean and standard deviation. In only one case, wind case 1 and SAP2THR, does the maximum rate of descent exceed 1,200 feet per minute.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
MAP2SAP	33	598.90	1008.00	908.2727	80.1830
SAP2THR	33	690.20	1212.90	862.8848	96.3560
Valid N (listwise)	33				

Table 9.12: RATE OF DESCENT STATISTICS FOR WIND CASE 1

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
MAP2SAP	32	689.70	1028.40	905.0813	73.8670
SAP2THR	32	741.70	1124.70	881.0344	85.2012
Valid N (listwise)	32				

Table 9.13: RATE OF DESCENT STATISTICS FOR WIND CASE 2

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
MAP2SAP	35	707.50	881.70	801.9171	37.8790
SAP2THR	35	659.90	922.90	772.2571	56.4015
Valid N (listwise)	35				

Table 9.14: RATE OF DESCENT STATISTICS FOR WIND CASE 3

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
MAP2SAP	34	618.00	1122.10	808.8941	79.8667
SAP2THR	34	595.60	953.20	775.9529	77.1099
Valid N (listwise)	34				

Table 9.15: RATE OF DESCENT STATISTICS FOR WIND CASE 4

9.6 MAXIMUM RATES OF DESCENT

ANOVA and Tukey's test are tests that determine whether the mean or average values of the data sets seem to be different. However, in regard to rate of descent data, and because one of the criteria for success is rates of descent should not exceed 1,200 feet per minute, it is advisable to also examine the extreme values of the distributions. Table 9.16 displays the ten largest rate of descent values along with the corresponding scenario and the wind case for MAP2SAP and SAP2THR.

MAP to SAP Maximum Values			SAP to THR Maximum Values		
LDA	Wind Case	MAP2SAP	LDA	Wind Case	SAP2THR
E	4	1122.10	D	1	1212.90
D	2	1028.40	E	2	1124.70
E	2	1014.20	D	1	1048.00
D	2	1010.80	A	2	1040.40
A	1	1008.00	E	2	1018.60
D	2	997.80	A	1	998.60
D	1	995.30	D	2	992.20
D	2	987.20	E	1	989.70
A	2	977.50	D	2	976.10
A	1	973.20	D	2	972.50

Table 9.16: MAXIMUM VALUES OF MAP2SAP AND SAP2THR

Table 9.16 indicates the criterion for success, the rate of descent should not exceed 1,200 feet per minute, was only violated one time. That value only exceeded 1,200 feet per minute by 12.9 feet per minute. In 19 of the 20 rate-of-climb values, the wind case was either 1 or 2. This result was expected since wind cases 1 and 2 are quartering tailwinds. However, even with tailwinds, the criterion for success was only exceeded one time.

10.0 SUMMARY OF THE FLYABILITY ANALYSIS

Several variables were extracted from the simulator flight track data to measure flyability and determine whether the stated criteria for success have been met. The variables THR500, THR300, THR100, and THR50 were designed to measure the distance from threshold the aircraft came within 500, 300, 100, or 50 feet laterally of the extended runway center line. The more stable approaches will have larger values of THR500, THR300, THR100, and THR50.

Statistical tests of THR500, THR300, THR100, and THR50 were performed by wind case and scenario. The results of the tests indicated:

a. Significant differences were present when the variables were grouped by either wind case or scenario.

b. When grouped by wind case, it was found LDA_E, the scenario with MAP nearest the threshold, had significantly smaller values of THR500, THR300, and THR100, and THR50 than LDA_A, the scenario with MAP farthest from the threshold. LDA_D had values between LDA_A and LDA_E. Therefore, as expected, the distance of the MAP from threshold is directly correlated to the distance the aircraft becomes stabilized on the extended runway center line.

c. When grouped by LDA, it was found the left-quartering winds, headwind or tailwind, had significantly smaller values of THR500, THR300, THR100, and THR50 than the right-quartering winds. Wind case 2, the left-quartering tailwind, always resulted in the smallest values of THR500, THR300, THR100, and THR50. Wind case 3, the left-quartering headwind was always the next smallest. Therefore, as expected, left-quartering winds cause the aircraft to align with the extended runway center line later in the approach than right-quartering winds.

The variables BANK_LEF and BANK_RT were designed to capture the maximum left and right bank angles recorded during the visual segment of the LDA approaches. Statistical tests of BANK_LEF and BANK_RT were performed by wind case and scenario. The results of the tests indicated:

a. When grouped by wind case, the smallest bank angles, left and right, were recorded for LDA_A. The largest bank angles were generally recorded for LDA_E, with the bank angles of LDA_D falling between LDA_A and LDA_E. In two cases, the largest values were recorded for LDA_D.

b. When grouped by scenario, the bank angles were generally not significantly different. Only two significant differences were detected. Tukey's B test indicated the largest angles were recorded for wind case 1, the right-quartering tailwind. Therefore, wind direction had little, if any, effect on maximum bank angle.

c. A criterion for success was the maximum bank angle should not exceed 25 degrees. The maximum bank angle recorded was 22.51 degrees. This bank angle was recorded during an LDA_E approach.

The variables LEFT_ALT and RT_ALT were designed to capture the altitudes corresponding to the maximum left and right bank angles. Statistical tests of LEFT_ALT and RT_ALT were performed by wind case and scenario. The results of the tests indicated:

a. The altitudes for the two turns were significantly higher for LDA_A, with MAP farthest from the threshold. The altitudes for the two turns were significantly lowest for LDA_E, with MAP nearest the threshold. The turn altitudes for LDA_D were always between the altitudes of the other two LDAs.

b. In two cases, for LDA_D and LDA_E, the altitude for the right turns was significantly lower for wind case 1 and 2. Otherwise, the wind direction had little effect on the turn altitude.

The variable OVR_SHT was designed to capture the amount of overshoot; i.e., the lateral distance the aircraft crossed the extended center line of runway 28R. The variable CPA was designed to capture the closest point of approach of the two aircraft. Statistical tests of OVR_SHT and CPA were performed by wind case and scenario. The results of the tests indicated:

a. Almost no differences due to LDA or wind case were recorded.

b. Wind direction did cause significant differences in OVR_SHT for LDA_D and LDA_E. It was found that the right-quartering winds tended to cause larger overshoots.

c. Only two overshoots in excess of 200 feet were recorded.

d. The smallest CPA was 790 feet, recorded three times.

e. Although it appeared small values of OVR_SHT were paired with small values of CPA and large values of OVR_SHT were paired with large values of CPA, Spearman's RHO test indicated there was no correlation of OVR_SHT with CPA.

The variable UNDER_GS recorded the maximum deviation of the aircraft below the glide slope. This variable is another measure of aircraft stability on the approach. The statistical tests performed indicated no significant differences due to LDA or wind case. Therefore, the location of the MAP or the wind direction had little, if any, effect on the maximum deviation of the aircraft below the glide slope.

The variable MAP2SAP recorded the average rate of descent of the aircraft from MAP to SAP. The variable SAP2THR recorded the average rate of descent of the aircraft from SAP to a point 1,000 feet from threshold. Statistical tests were performed on each of these two variables. The results of the tests indicated:

a. There were no significant differences due to LDA. Thus, the choice of LDA had no effect on the average rate of descent.

b. Significant differences were caused by the choice of wind direction. As expected, the quartering tailwinds resulted in higher rates of descent on the order of about 100 feet per minute.

c. Only one rate of descent in excess of 1,200 feet per minute was recorded.

The flyability analysis showed, in general, the two LDA approaches with MAP farthest from threshold aligned with the extended center line farther from the threshold. The largest bank angles were generally recorded by the LDA with MAP nearest the threshold. The lowest altitudes during the turns were recorded for the LDA nearest the threshold. Therefore, the two LDA approaches with MAP farthest from the threshold should be the easiest to fly and result in the smoothest ride for the passengers.

The location of the MAP did not have an effect on overshoot or CPA. Wind direction did have an effect on overshoot. Only two overshoots in excess of 200 feet were recorded. The minimum CPA was 790 feet recorded three times. There was no correlation between overshoot and CPA.

The rate of descent variables revealed the location of the MAP did not have an effect on the rate of descent. Wind direction did have a significant effect on rate of descent. The quartering tailwinds caused higher rates of descent. Only one rate of descent over 1,200 feet per minute was recorded.

11.0 ASAT SIMULATION AND COLLISION RISK ANALYSIS

The ASAT computer system was modified to conform to the conditions of LDA_D (DICKI), the MAP suggested by the proponents of the SOIA procedure. The runway spacing was set at 750 feet. The MAP for runway 28R was set 3,000 feet abeam of the extended runway center line of runway 28L and 3.3 NM from the threshold of runway 28R. The localizer course for runway 28R was offset 3° from the straight-in course to runway 28L. The decision altitude was set at 1,126 feet MSL.

The purpose of the simulation was to determine the forward boundary of an acceptable window of alignment of the two approaching aircraft. The rearmost boundary of the alignment window was determined by wake vortex considerations and will be discussed in the section pertaining to wake vortices.

Because of the necessity of visual acquisition of one aircraft by the other, it was accepted that aircraft approaching runway 28R should trail, at the MAP, aircraft approaching runway 28L. The question that must be answered is how far should the aircraft approaching runway 28R trail the aircraft approaching runway 28L in order to maintain an acceptably low level of collision risk. To answer this question, three scenarios were designed whose only difference was the trailing distance of aircraft approaching runway 28R when it crossed the MAP. Three trailing distances were simulated, 0.0 NM, 0.25 NM, and 0.50 NM. Computer graphics illustrating the starting positions of the two aircraft for 0.25 NM and 0.50 NM are presented in figures 11.1 and 11.2.

Each run of the simulation was performed as follows:

a. The trailing aircraft (28R) was placed at the MAP (DICKI)

b. The leading aircraft (28L) was placed at a pre-determined along track distance AHEAD of the trailing aircraft (0.0NM 0.25NM, or 0.5NM).

c. The aircraft were released at their associated operational approach airspeeds.

d. In the event the velocity of the trailing aircraft was higher than the leading aircraft and the trailing distance was equal or smaller than 0.1 NM, the trailing aircraft was slowed to its landing airspeed.

e. In the event the trailing aircraft reached its lowest possible speed, and passing did occur, the leading aircraft was sent around. This is an extremely conservative method of handling a passing situation. In an actual operational situation, the leading aircraft most likely will be sent around when a passing situation is eminent and not after it occurs.

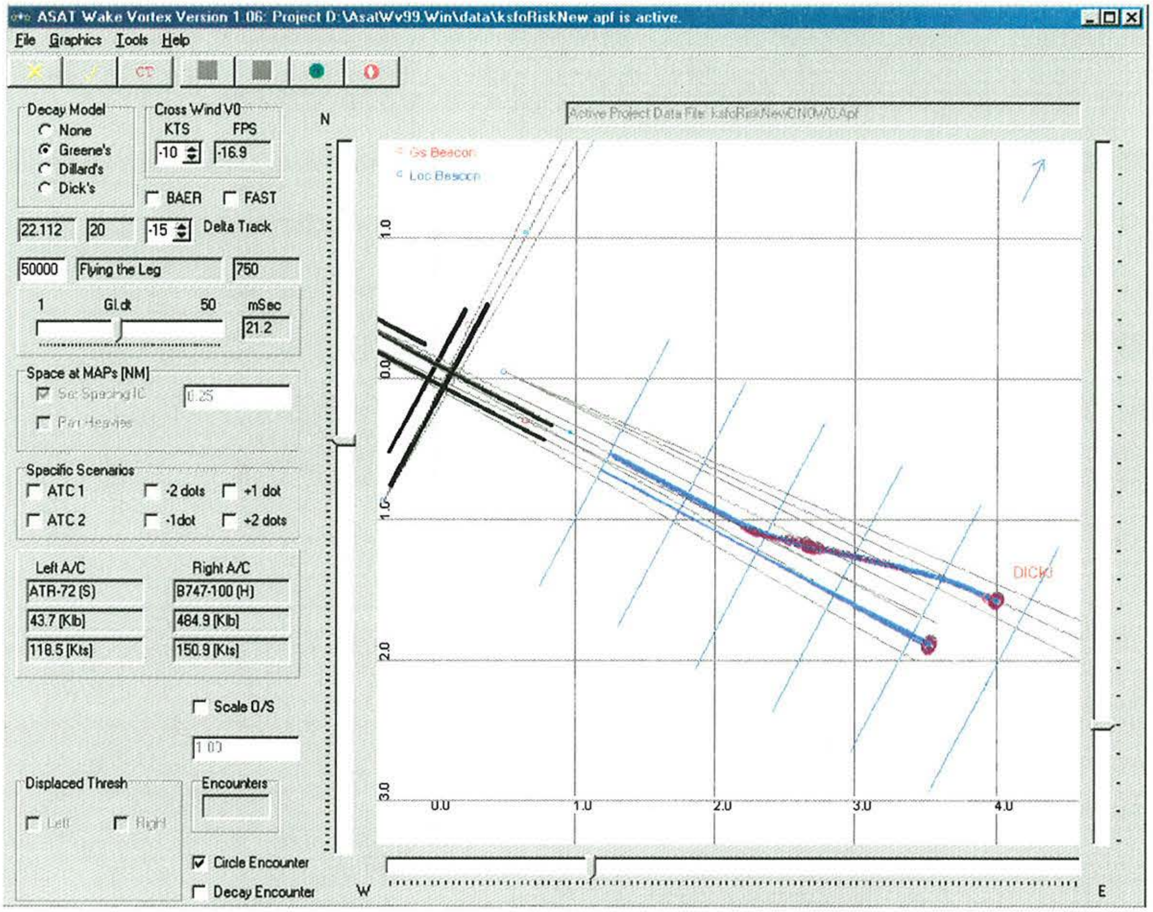


Figure 11.1: AIRCRAFT WITH 0.25 NM ALONG TRACK INITIAL SPACING AT THE MAP

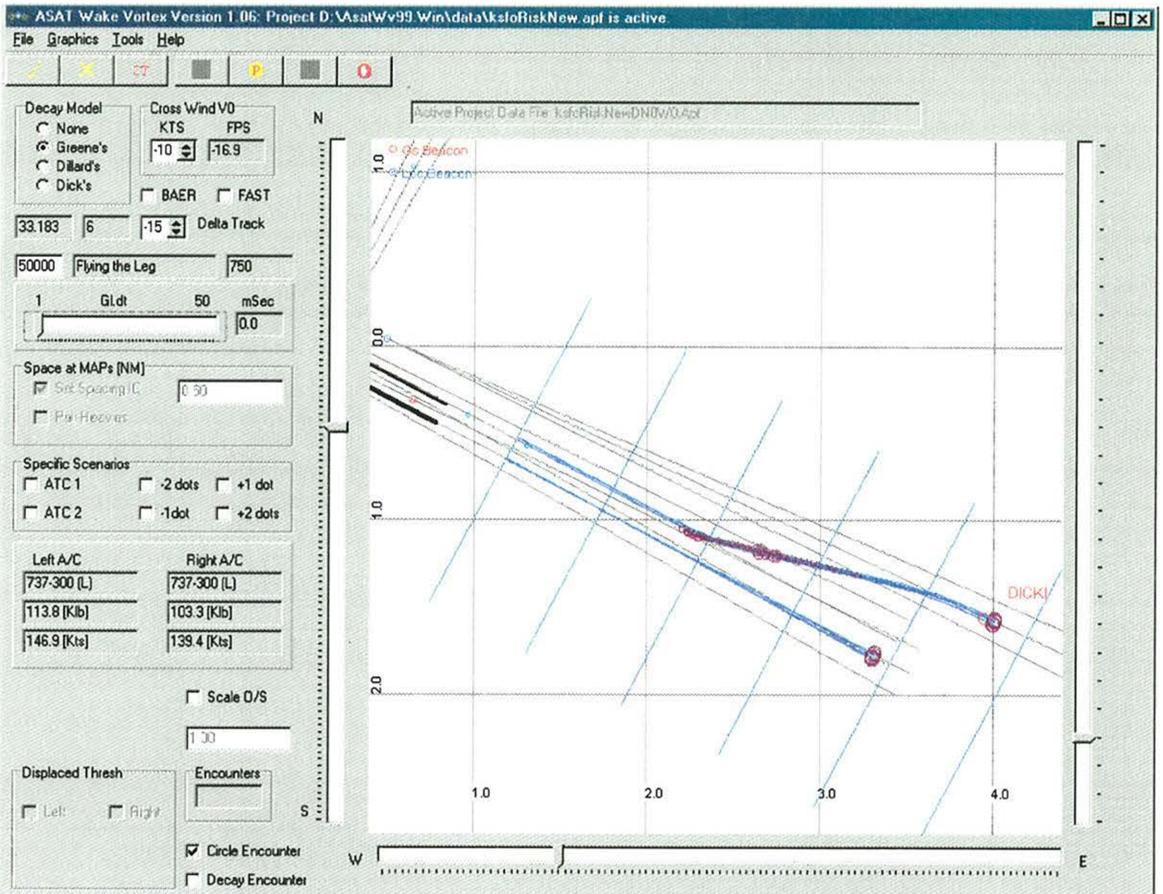


Figure 11.2: AIRCRAFT WITH 0.50 NM ALONG TRACK INITIAL SPACING AT THE MAP

Probability distributions of aircraft dynamics such as roll rates, maximum bank angles, and overshoots were derived from the real-time simulation. Continuous curves utilizing the Johnson family of probability density curves were fitted to the data. Since each aircraft would be following a localizer and glide slope, lateral and vertical probability distributions from the International Civil Aviation Organization (ICAO) Collision Risk Model (CRM) were used to establish the lateral and vertical position of the aircraft at the initiation of the simulation run.

Although the simulation is concerned with the visual segment of the LDA, the test criteria used in the analysis is the Test Criteria Violation (TCV) developed by the Multiple Parallel Approach Program (MPAP). A TCV, as used by the MPAP, results whenever the slant distance between the centers of gravity of two aircraft is less than or equal to 500 feet. It is assumed that a collision may result if a TCV occurs.

The probability or risk that a TCV will occur must be a very small number in order for the procedure to be considered acceptable. Generally a maximum allowable risk, called a Target Level of Safety (TLS), is determined for a given procedure. The risk of the procedure under study is compared to the TLS. If the risk is found to be less than or equal to the TLS, the risk is considered to be acceptable. The development of a TLS for a procedure requires a review of the accident data and the determination of the exposure level; i.e., the frequency the procedure is performed. In the case of the visual segment of simultaneous, offset instrument approach operations, a TLS has not been determined. However, it is expected the TLS for parallel missed approaches will not be smaller than that for multiple parallel approaches. The TLS for multiple parallel approaches is 4×10^{-8}. Therefore, the TLS used for this evaluation is 4×10^{-8}. If the risk is found to be less than or equal to 4×10^{-8}, the risk is considered to be acceptable.

Each of the three scenarios was performed 50,000 times. During the simulation of each scenario, no TCVs were observed. The smallest CPA observed was 650 feet during the simulation of the 0.0 NM scenario. Table 11.1 summarizes the basic statistics of each simulation.

Scenario	Mean [Feet]	Standard Deviation [Feet]	Minimum [Feet]	Maximum [Feet]
0.0 NM	1067.3	289.5	525	2460
0.25 NM	1868.0	586.4	535	3460
0.50 NM	3195.3	788.5	555	4550

Table 11.1: SIMULATION CPA STATISTICS

Because of the close spacing of the two runways, a collision could occur if the following conditions occur simultaneously:

a. The aircraft landing on 28R overshoots while trying to intercept the runway center line.

b. The aircraft landing on 28L will be abeam the overshooting aircraft.

The simulation is designed to measure the probability that these two conditions occur simultaneously and produce a TCV. In order to estimate the probability of a TCV from the simulation data, continuous curves were fit to the simulation output data. The probabilities are recorded in table 11.2. The probability of a TCV for the 0.0 NM scenario is larger than the TLS; however, the probability curve descends very steeply and the probability of a CPA within 490 feet is less than the TLS. For scenario 0.50 NM, the probability of a TCV was much less than the TLS.

Scenario	Probability 500 Feet	Probability 490 Feet
0.0 NM	1.4×10^{-7}	1.2×10^{-8}
0.25 NM	5.0×10^{-9}	$< 10^{-9}$
0.50 NM	$< 10^{-9}$	$< 10^{-9}$

Table 11.2: PROBABILITY OF A TCV

The ten feet required to reach the TLS is not considered significant. Therefore, the forward boundary of an acceptable window of alignment of the two approaching aircraft is 0.0 NM. This means that the two aircraft could be side-by-side when the aircraft approaching runway 28R reaches the MAP and still meet the TLS. However, the simulation results are site specific to SFO and must not be applied to other sites.

12.0 HUMAN FACTORS ANALYSIS

12.1 POST-TEST CREW QUESTIONNAIRE ANALYSIS

The participating pilots were separated into two groups determined by the airline affiliation. The groups are denoted as group 1 and group 2.

12.2 ANALYSIS OF GROUP 1 POST-TEST QUESTIONNAIRES

For convenience, each question of the questionnaire is presented along with the tabulated responses to the question. For pilot comments, see section 12.6.

Q1: Did this simulation present a realistic portrayal of an offset LDA operation?

Yes: 14
No: 2

Q2: How would you rate the flyability of the visual portion after departing the LDA?

	FREQUENCY OF SELECTION										
Approach	**Easy**				**Difficult**				**Not Safe**		
	1	2	3		4	5	6		7	8	9
LDA A (EICKI)	1	4	8		1						
LDA B (JOESS)	1	2	9				1				
LDA C (ADSBS)	1	2	7		1	1	1				
LDA D (DICKI)	2	2	9			1					
LDA E (CICKI)	1	2	2		4	2	1		1		
LDA F (HARVY)		1	2			2					

Q3: As a general observation, how would you characterize the new approach scenarios flown in this test?

	FREQUENCY OF SELECTION										
Approach	**Easy**				**Difficult**				**Not Safe**		
	1	2	3		4	5	6		7	8	9
LDA A (EICKI)	2	1	9		1						
LDA B (JOESS)	1	3	7		1						
LDA C (ADSBS)	1	1	9			1					
LDA D (DICKI)	1	3	8		1						
LDA E (CICKI)	1	1	3		3	3			1		
LDA F (HARVY)		1	2		1	1					

Q4: Under VMC there was sufficient distance given to be comfortably established at the 500 foot AFL point.

	FREQUENCY OF SELECTION									
Approach	**Strongly Agree**							**Strongly Disagree**		
	1	2	3	4	5	6	7	8	9	
LDA A (EICKI)	1	3	3	2	2				1	
LDA B (JOESS)	1	3	3	1	2	2				
LDA C (ADSBS)	1	3	1	2	1	3	1			
LDA D (DICKI)	1	3	1	1	5					
LDA E (CICKI)	1	1	2	1		4	1		2	
LDA F (HARVY)		2	1	1		1				

The group 1 answers to the post-test questionnaires generally indicated that the pilots considered the LDA approaches to be "easy". Most pilots selected 3 under "easy". Of the three LDAs under consideration, LDA_A, LDA_D, and LDA_E, LDA_E received the most "difficult" selections. LDA_E was the only LDA to receive "not safe" responses. Two pilots marked "disagree strongly" when asked if there was sufficient distance given to be comfortably established at the 500 foot AFL point during an LDA_E approach. Therefore, in the opinion of the group 1 pilots, LDA_E, with MAP nearest the MAP, is the least acceptable of the LDAs.

12.3 ANALYSIS OF GROUP 2 POST-TEST QUESTIONNAIRES

For convenience, each question of the questionnaire is presented along with the tabulated responses to the question.

Q1: Did this simulation present a realistic portrayal of an offset LDA operation?

Yes: 11
No: 2

Q2: How would you rate the flyability of the visual portion after departing the LDA?

	FREQUENCY OF SELECTION										
Approach	**Easy**				**Difficult**				**Not Safe**		
	1	2	3		4	5	6		7	8	9
LDA A (EICKI)		5	3		2	3					
LDA B (JOESS)			4		4	3					
LDA C (ADSBS)		2	4		2	3					
LDA D (DICKI)		2	3		5	2	1				
LDA E (CICKI)		2	2		2	4	2		1		
LDA F (HARVY)			2		1	1	1				

Q3: As a general observation, how would you characterize the new approach scenarios flown in this test?

	FREQUENCY OF SELECTION										
Approach	**Easy**				**Difficult**				**Not Safe**		
	1	2	3		4	5	6		7	8	9
LDA A (EICKI)		3	5		3	2					
LDA B (JOESS)			4		4	3					
LDA C (ADSBS)		2	4		2	3					
LDA D (DICKI)		1	5		3	3	1				
LDA E (CICKI)		1	3		2	4	2		1		
LDA F (HARVY)			3		1	1	1				

Q4: Under VMC there was sufficient distance given to be comfortably established at the 500 foot AFL point.

	FREQUENCY OF SELECTION									
Approach	**Strongly Agree**							**Strongly Disagree**		
	1	2	3	4	5	6	7	8	9	
LDA A (EICKI)	1	3	3	2	2		1			
LDA B (JOESS)	1	1	2	2	2	1	1			
LDA C (ADSBS)	1	1	2	4	2		1			
LDA D (DICKI)	1	2		5	3	1	1			
LDA E (CICKI)	1	1	1	1	2	1	6			
LDA F (HARVY)	1	1	1	1	2					

The group 2 responses are very similar to the group 1 responses. In general, the LDA_E approach was the least acceptable of the 6 LDAs.

12.4 CREW QUESTIONNAIRE

Since the analysis is only concerned with LDA_A, LDA_D, and LDA_E, only the crew responses to the questions about these LDAs are presented. There are four different wind conditions. The wind conditions are labeled 1, 2, 3, and 4, as before. Therefore, the notation "A1" refers to LDA_A with a right-quartering tailwind. There are seven questions per situation. For brevity, the questions were not grouped by pilot group.

12.4.1 SCENARIO A1

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		2	6	4	1			

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	2	5	6	1			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
		1	5	6	1			

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
	1	3	5	2	1	1		

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
	1	3	5	2	1	1		

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
2	2	7	2					

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	1	6	5	1				

SUMMARY OF A1 RESPONSES

The following table summarizes questions 1 through 7 for A1.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
2	6	24	32	21	5	2		

From the table, the most common response was MODERATE 4. Only 2 pilots responded SEVERE 7.

12.4.2 SCENARIO A2

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	2	5	5				

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		4	5	2	2			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
		1	5	6		1		

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
		1	4	6	2			

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
			3	7	3			

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	1	4	6	1	1			

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	1	3	6	2		1		

SUMMARY OF A2 RESPONSES

The following table summarizes questions 1 through 7 for A2.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
	3	15	34	29	8	2		

From the table, the most common response was MODERATE 4. Only 2 pilots responded SEVERE 7.

12.4.3 SCENARIO A3

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
1	1	2	5	3				

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
1	2	3	5		1			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
		1	6	5				

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
		1	4	6	1			

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
1	2		5	1	3			

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	5	2	5					

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
		6	4	1		1		

SUMMARY OF A3 RESPONSES

The following table summarizes questions 1 through 7 for A3.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
3	10	15	34	16	5	1		

From the table, the most common response was MODERATE 4. Only 1 pilot responded SEVERE 7.

12.4.4 SCENARIO A4

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	1	4	2	2			

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	2	4	3				

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			6	3	1			

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
		1	3	4	2			

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
	1	2	3	2	1	1		

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	1	4	4	1				

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	1	6		2	1			

SUMMARY OF A4 RESPONSES

The following table summarizes questions 1 through 7 for A4.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
	5	16	24	17	7	1		

From the table, the most common response was MODERATE 4. Only 1 pilot responded SEVERE 7.

12.4.5 SCENARIO D1

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		3	5	1	2			

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		3	6	2				

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			6	5				

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
		1	3	6	1			

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
		5	3	2	1			

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
1	4	2	4					

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	4	3	2				

SUMMARY OF D1 RESPONSES

The following table summarizes questions 1 through 7 for D1.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
1	6	18	30	18	4			

From the table, the most common response was MODERATE 4. No pilot responded SEVERE.

12.4.6 SCENARIO D2

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1		5	4				

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	2	4		3			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			1	7	2			

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
			1	6	2	1		

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
		1	2	1	4		1	1

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	4	2		2			

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
		2	4	2	2			

SUMMARY OF D2 RESPONSES

The following table summarizes questions 1 through 7 for D2.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
	4	9	19	20	15	1	1	1

From the table, the most common response was MODERATE 5. Three pilots responded SEVERE.

12.4.7 SCENARIO D3

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		2	6	3	2			

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		5	4	3	1			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			2	9	2			

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
			4	6	3			

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
		3	3	3	4			

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	4	3	3	3				

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	1	8		2			

SUMMARY OF D3 RESPONSES

The following table summarizes questions 1 through 7 for D3.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
	6	14	30	27	14			

From the table, the most common response was MODERATE 4. No pilots responded SEVERE.

12.4.8 SCENARIO D4

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	1	2	6	3			

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	2	5	4	1			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			5	8				

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
			3	6	4			

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
		3	2	2	6			

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	7	2	1	1			

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	6	2	1	1	1		

SUMMARY OF D4 RESPONSES

The following table summarizes questions 1 through 7 for D4.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
	6	19	21	28	16	1		

From the table, the most common response was MODERATE 5. Only one pilot responded SEVERE 7.

12.4.9 SCENARIO E1

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
			5	5	1	1		

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
			6	4	1	1		

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			4	4	3	1		

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
			3	1	4	4		

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
		1	3	4	3		1	

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
		8	2	1	1			

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
		5	2	3	1	1		

SUMMARY OF E1 RESPONSES

The following table summarizes questions 1 through 7 for E1.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
		14	25	21	14	6	1	

From the table, the most common response was MODERATE 4. Seven pilots responded SEVERE.

12.4.10 SCENARIO E2

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1		3	4	4			

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		2	4	2	4			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			2	5	4		1	

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
		1	2	2	4	2	1	

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
		1	2	2	7			

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	6		4				

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	3	3		4			

SUMMARY OF E2 RESPONSES

The following table summarizes questions 1 through 7 for E2.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
	5	13	16	19	27	2	2	

From the table, the most common response was MODERATE 6. Four pilots responded SEVERE.

12.4.11 SCENARIO E3

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		1	5	4	2			

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		1	5	1	6			

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			4	2	6			

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
			3	3	4	2		

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
			3	4	4	1		

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
1	3	4	1	1	2			

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	2	4	2	1	3			

SUMMARY OF E3 RESPONSES

The following table summarizes questions 1 through 7 for E3.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
1	5	10	23	16	27	3		

From the table, the most common response was MODERATE 6. Three pilots responded SEVERE 7.

12.4.12 SCENARIO E4

Q1: Rate the cockpit workload of this entire approach.

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
	1	3	2	2	3	1		

Q2: Rate the transition from the instrument portion to the visual portion (location, finding the runway, maneuvering).

VERY EASY			AVERAGE			VERY HARD		
1	2	3	4	5	6	7	8	9
		3	3	1	4	1		

Q3: Describe the bank angles required during the visual segment of the approach.

TOO SHALLOW			ABOUT RIGHT			TOO STEEP		
1	2	3	4	5	6	7	8	9
			4	2	4	2		

Q4: Was the distance allowed to execute the transition maneuver sufficient?

TOO LONG			ADEQUATE			TOO SHORT		
1	2	3	4	5	6	7	8	9
	1			4	5	2		

Q5: How safe is the procedure, considering the proximity to traffic, maneuvering speed, stabilized visual approach segment concept, etc?

VERY SAFE			AVERAGE			VERY UNSAFE		
1	2	3	4	5	6	7	8	9
		1	1	3	6	1		

Q6: At rollout for alignment with runway center line, were you in an acceptable position to complete a landing in keeping with your company's standards?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
		6	2	1	2	1		

Q7: What would be your assessment of the quality of accomplishment of this procedure flown by all pilots meeting your company's minimum B 747-400 first officer requirements?

NO PROBLEM			MODERATE PROBLEM			SEVERE PROBLEM		
1	2	3	4	5	6	7	8	9
	1	2	4	1	3	1		

SUMMARY OF E4 RESPONSES

The following table summarizes questions 1 through 7 for E4.

LOW			MODERATE			SEVERE		
1	2	3	4	5	6	7	8	9
	3	15	16	14	27	9		

From the table, the most common response was MODERATE 6. Nine pilots responded SEVERE 7.

12.5 SUMMARY OF POST FLIGHT QUESTIONNAIRES

The pilot responses to the post-flight questionnaires were generally in the low to moderate range for LDA_A and LDA_D. A slight shift toward higher values is apparent for LDA_D; although, the responses remain in the low to moderate range for LDA_D. The responses for LDA_E are higher than those of LDA_A and LDA_D. In the case of LDA_E, twenty three "severe" responses were recorded. Therefore, in the opinion of the pilots, LDA_E, with MAP nearest the threshold, is not acceptable.

12.6 PILOT COMMENTS

QUESTION 1:

The distraction of a parallel aircraft seemed real, caused a true distraction to the SOP.

I think visuals are tough in the 400 simulator.

The only variable was trying to get the A/Crew on the ground – No turbulence, no threat of breakout, etc.

The visual approach was quite good – the portrayal of the traffic on the parallel approach just didn't appear realistic. Would like to seen day VFR approaches.

Ability to distinguish distance from traffic. No visual cues. *<illegible>* lights.

QUESTION 2:

Never any problem correcting to runway centerline. Speed, in relation to other are a consideration. Biggest distraction is having traffic abeam.

It seems that strong winds blowing you towards traffic would increase the workload dramatically. The longer you have (of course) to align the A/C with the runway the better.

I found that the wind was more of a factor than the distance when maneuvering from the MDA.

Heading from fix not very useful. Approaches border on unsafe with any tailwind component.

Any tailwind component makes the transition much more difficult.

I'm sure these visuals would be easier to fly in the A/C.

SAP has no value. Traffic creates biggest problem both for profile, speed, stability at 500 feet.

Tailwinds definitely made it harder close traffic is more demanding. Crosswind on right made it easier to watch traffic.

Take a little more time for a std. Approach brf (ATIS, etc.) to make sure SOP is followed as much as practical. The recommended hdgs seem to work (no wind). The procedure for selecting hdg sel for PF needs to be briefed and well understood by both. Take A/P off prior to selecting anything on MCP.

A very complex approach without frequent ongoing training. It would be a big help if 28L would use a different tower frequency. After about 8 approaches, I felt more comfortable but I think approaches 28L/R should be staggered by at least 1.5 to 2 miles.

Need normal size approach plates! 8 ½ x 11 page is unwieldy if attached to the yoke.

Wind from the right and/or tailwind make the lower minimums altitude more challenging.

All of the approaches were very easy in my opinion. Awareness of the SAP helped stay on profile.

No problem / from MAP or SAP.

Wind direction none of *<illegible>* distance to runway. Easier to transition if wind is from right side.

Position of other traffic greatly affected the difficulty of the transition.

QUESTION 3:

Approach designation (LDA DME 28R) could be shortened to LDA 28R for voice reports SAP and course to it not used – picked point on extended center line and went to it.

Less time on LDA E for transition; wind recognize an important factor, especially tailwind.

Wind made a big difference – even more than proximity of traffic. LDA E is difficult to work without excessive bank. (Pax comfort level is stretched).

Every thing was very routine and easy to do. The differences were so subtle as to be almost unrecognizable. Not difficult with the wind at 15 KNOTS.

Winds played a big part, especially quartering tailwinds. With a quarterly tailwind on LDA E, you do not want to over or undershoot. Not much time to correct.

QUESTION 4:

All of these approaches seemed quite safe. Like any other approach, the more times you fly it, the more comfortable you are. After a long international non-stop and never having done it before, can see where you could have your hands full.

SAP never used. Should be established as soon as visual with parallel A/C. Flaps and speed adjusted to prevent any overtake. Recommend need to acquire climb out from tower beyond MAP. May differ from MA/procedures.

Course presented in SAP was of no use. SAP is of no use. Never used SAP info to operate visually. With tailwind it is important to have longer distance to line upon approach. (i.e. DICKI and CLICKI are too close when flying with a tailwind).

The one factor that mainly affected the ability to get lined up quickly was the wind direction, but under all conditions it was still quite simple. Not difficult to make that final turn onto the runway center line.

Winds greatly affected the difficulty of the transition.

500 feet point not a hard point – consider establishing at 250 feet-300 feet.

Again – X-wind component plays a big part in establishing self on runway center line especially on close in LDA E.

13.0 TCAS RESOLUTION ADVISORIES

This study was not intended to evaluate the operation of TCAS during the LDA approaches; however, the TCAS was set in the TA/RA mode during each approach. There were six RAs recorded during the real-time simulation. Four of the RAs were ignored by the pilots since the other aircraft approaching runway 28L was in sight, and a normal landing was the result each time. Two of the RAs resulted in breakouts since the aircraft had not yet reached visual conditions and the aircraft approaching runway 28L was not yet in sight.

14.0 WAKE TURBULENCE ASSESSMENT

14.1 INTRODUCTION

Since the extended runway center lines of runways 28L and 28R are only 750 feet apart, the possibility of encountering wake turbulence is a serious concern. Because of the close runway proximity, it is possible, under certain combinations of winds and aircraft longitudinal spacing, wake turbulence from one approach course could drift across to the other approach course and cause a wake encounter if proper wake turbulence spacing is not applied. When an aircraft is operating directly behind another aircraft; e.g., during in-trail procedures, instrument flight rules (IFR) separation standards are defined in the Air Traffic Control Manual, Order 7110.65. Practical guidance for avoiding wake turbulence is given in the Aeronautical Information Manual. Table 14.1 summarizes the IFR spacing requirements. Values greater than 3 NM are specifically for wake turbulence avoidance. In special cases, the 3 NM spacing can be reduced to 2.5 NM for some aircraft pairs. The table presents the required IFR separation, measured at the time the preceding aircraft is over the landing threshold. Parallel runways closer than 2,500 feet apart are considered a single runway for wake turbulence considerations.

Trailing Aircraft	**Lead-Aircraft (Wake Generating)**			
	Small	Large	B757	Heavy
Small	3	4	5	6
Large	3	3	4	5
Heavy	3	3	4	4

Table 14.1: STANDARD WAKE VORTEX SPACING CRITERIA (NM)

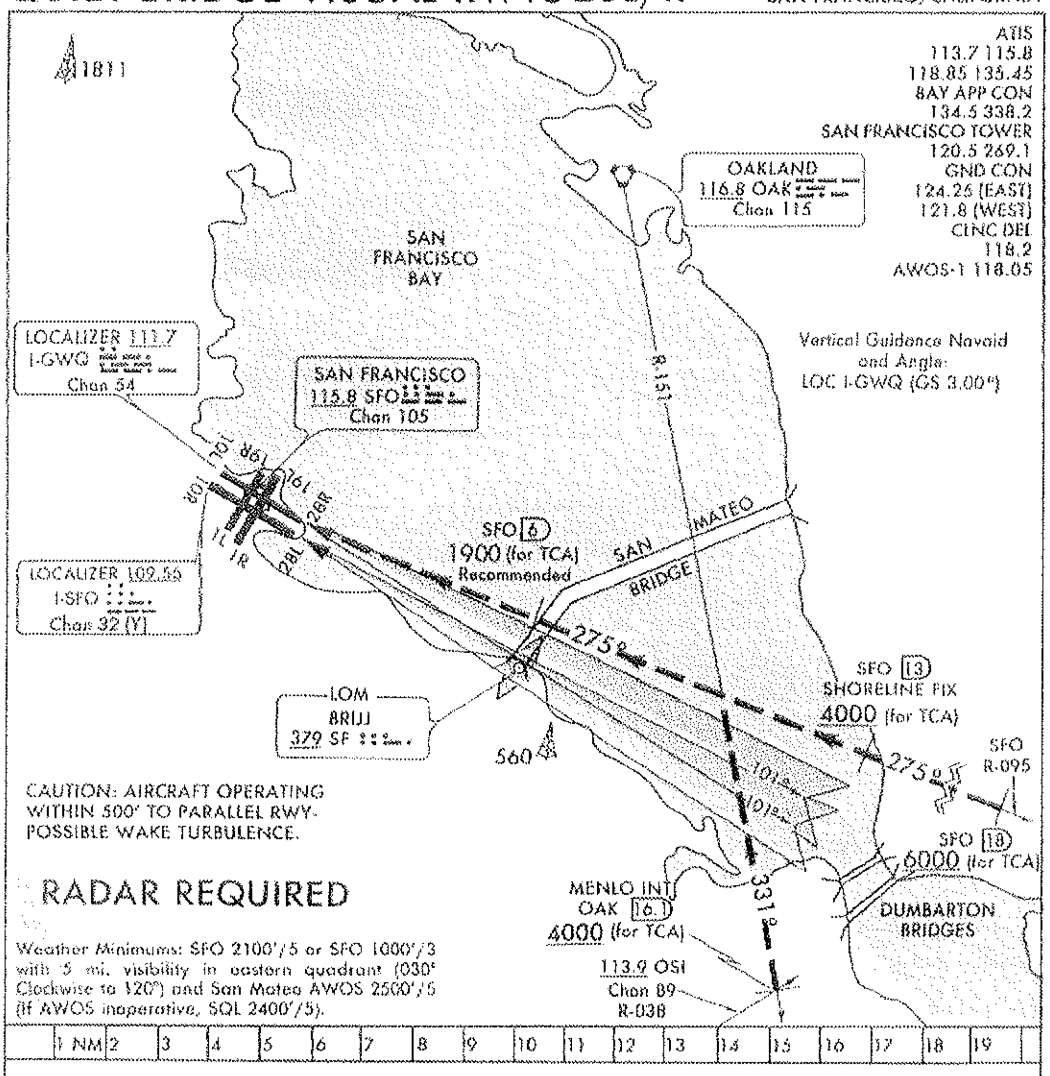
Although the possibility of wake turbulence encounters exists during visual operations at SFO, parallel visual approaches are routinely performed. A careful study of the current "QUIET BRIDGE VISUAL RNWY 28L/R" approach procedure reveals that this procedure differs by only 4 degrees from the proposed SOIA course and nearly matches the proposed glide slope (See figure 14.1). After the aircraft approaching runway 28R passes the San Mateo Bridge, the aircraft is free to align itself with the extended center line of runway 28R. In order to avoid any possibility of wake encounters, the trailing aircraft flies only a short distance behind the leading aircraft on the adjacent approach course. Thus, in a practical sense, wake encounters may be eliminated by flying close enough to the lead aircraft so that the wake does not have time to drift across to the path of the trailing aircraft. The purpose of this study is to provide guidance on the maximum distance between the lead and trailing aircraft that will preclude wake encounters. In the section dealing with collision risk, it was found that the target level of safety was met if the two approaching aircraft were abeam when the aircraft approaching runway 28R crossed the MAP of runway 28R. Intuitively, there should be a maximum longitudinal distance the aircraft approaching runway 28R can trail the aircraft approaching runway 28L when crossing the MAP and still avoid any possibility of wake encounters. Therefore, there is an "operational window"

SW-2, 30 DEC 1999

Amdt 7 99196 406 AL-375 (FAA)

QUIET BRIDGE VISUAL RWYS 28L/R

SAN FRANCISCO INTL (SFO)
SAN FRANCISCO, CALIFORNIA



QUIET BRIDGE VISUAL APPROACH RUNWAYS 28L/R

When visual approaches to Runways 28L/R are in progress, arriving aircraft may be vectored into a position for a straight-in visual approach to Runways 28L/R via the SFO VOR R-095.

SFO VOR and DME must be operating.

Aircraft should remain on the SFO R-095 until passing the San Mateo Bridge.

NOTE: Closely spaced parallel visual approaches may be in progress to Runway 28L utilizing I-SFO. In the event of a go-around on Runway 28L, turn left heading 265°, or on Runway 28R, turn right heading 310°, climb and maintain 3000, or as directed by Air Traffic Control.

QUIET BRIDGE VISUAL RWYS 28 L/R SAN FRANCISCO, CALIFORNIA SAN FRANCISCO INTL (SFO)

Amdt 7 99196 37°37'N-122°22'W

Figure 14.1: QUIET BRIDGE VISUAL APPROACH

for the two aircraft so that the risk of collision meets the target level of safety and the possibility of wake encounters is eliminated. The "operational window" is illustrated in figure 14.2. The front window boundary is determined by the collision risk analysis and the rear window boundary is determined by wake turbulence analysis. In addition there are other wake avoidance procedures which mitigate the risk of an encounter such as having the lead aircraft on the downwind runway if there is a crosswind or having smaller aircraft lead.

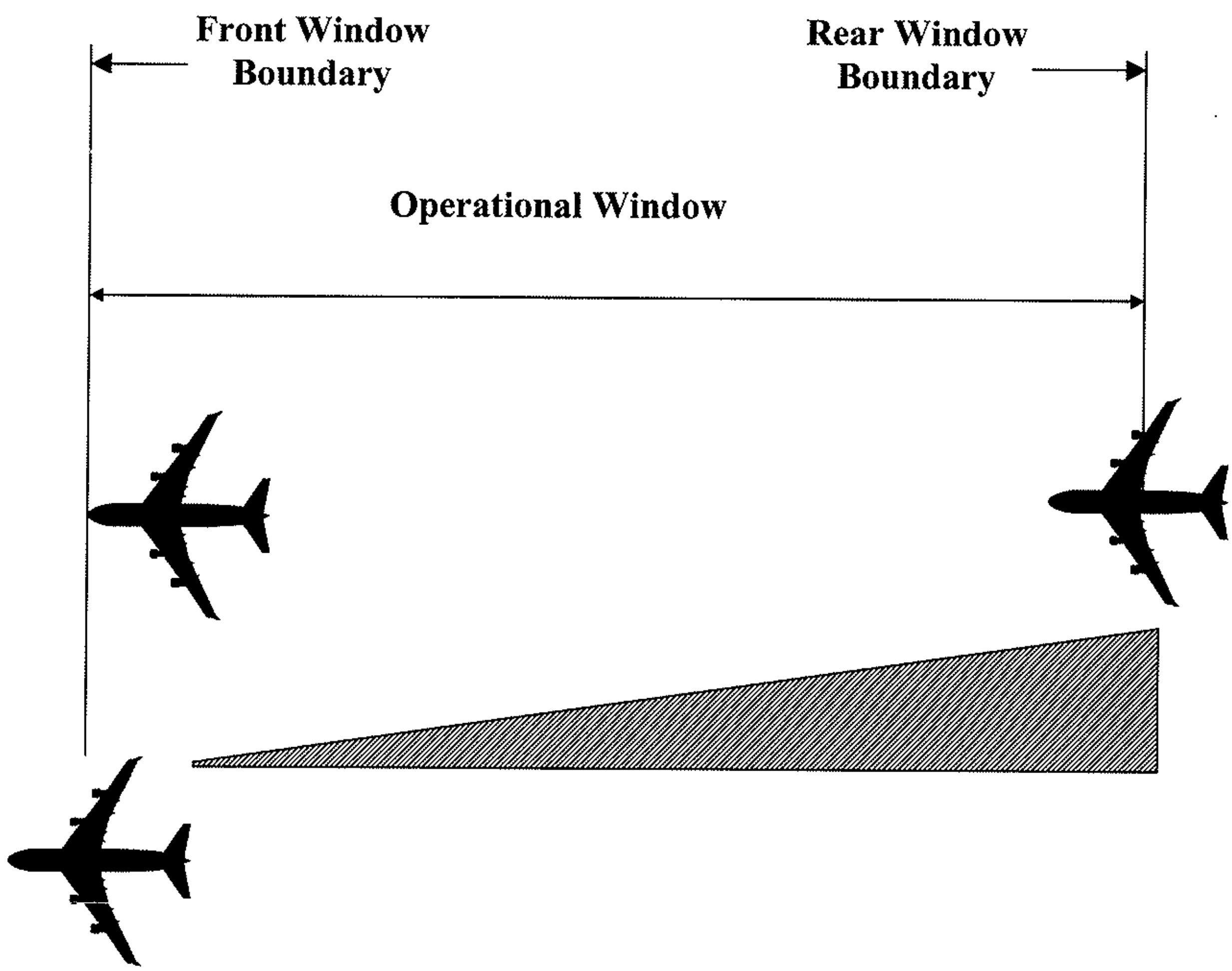


Figure 14.2: OPERATIONAL WINDOW BOUNDARIES

The wake turbulence analysis can be conducted in two ways: two-dimensional (2D) and three-dimensional (3D). The 2D method is strictly analytical in nature. In this method, the formulae that model the initial wake strength, decay, and sink rate are ignored. The calculation is only based on wind drift relative to aircraft speed. This is a very simplistic and inaccurate method for the following reasons:

a. It assumes that wakes do not sink,

b. It assumes that wakes do not decay,

c. Wake characteristics are not representative of aircraft types, and

d. It assumes constant wind speed at all altitudes.

The second method is a three-dimensional computer simulation performed by AFS-420's ASAT Wake Turbulence Risk Analysis module. This module was created by modifying the ASAT to include wake turbulence formulae provided by the Research Division, NASA Langley Field Office (AAR-210) to characterize the wake turbulence based on the aircraft type and approach speed. This method has the following advantages over the two-dimensional method:

a. It accounts for the sink rate of the wake,

b. It accounts for wake decay,

c. Wake characteristics are representative of aircraft types, and

d. It accounts for wind variation with altitude.

14.2 THREE-DIMENSIONAL WAKE VORTEX ANALYSIS

Research has shown that wake turbulence characteristics (including the strength and the descent rate of the wake) depend on parameters such as aircraft weight, wing span and speed (see Greene et al). Except near the ground, wake turbulence is transported by the prevailing wind. The initial strength, technically termed circulation or G_i, is described approximately by:

$$\Gamma_i = \frac{4W}{\pi \rho U b} \qquad (14.1)$$

where:

W = aircraft weight,
ρ = air density,
U = aircraft airspeed,
b = aircraft wing span.

The decay of the circulation Γ at time *t* can be modeled as follows:

$$\frac{\Gamma}{\Gamma_i} = 1 - \frac{T}{X} \qquad (14.2)$$

where:

$$T = \frac{8\Gamma_i t}{\pi^3 b^2} \qquad (14.3)$$

and

t = time in seconds
X = random decay factor between 3 and 5.

The wake sink rate, W_{vs}, is given by:

$$W_{vs} = \frac{2\Gamma}{\pi^2 b} \qquad (14.4)$$

The sink rate and horizontal velocity of the vortices can be corrected for ground effect by first computing the altitude ratio, A_r:

$$A_r = \frac{4H^2}{(4H^2 + S(t)^2)}, \qquad (14.5)$$

where:

H = height of the aircraft above the surface,
S(t) = spacing between wake centers at time *t*.

If we let Γ_r denote the decay ratio:

$$\Gamma_r = \frac{\Gamma}{\Gamma_i} \qquad (14.6)$$

and if S_r denotes the ratio of initial horizontal spacing, $S(0)$, of the wake vortices to their spacing at time t, $S(t)$, then S_r is given by:

$$S_r = \frac{S(0)}{S(t)}. \qquad (14.7)$$

The wake sink rate, corrected for ground effect, is given by:

$$W = W_i \Gamma_r S_r A_r. \qquad (14.8)$$

The rate of change of the horizontal spacing between the vortices is given by:

$$\frac{dS}{dt} = \frac{WS(t)^3}{4A^3} \qquad (14.9)$$

and the separation distance at time t can be found by integrating *dS/dt* as follows:

$$S(t) = \int_0^t \frac{dS}{dt} dt \qquad (14.10)$$

A classical boundary layer profile (wind increases with altitude) was used in this study. In this model wind speed doubles from 30 feet to 2,000 feet. The surface wind speed is assumed to be the wind speed, U_{30}, at 30 feet above the surface. The wind speed U at height H above the surface is given by:

$$U = U_{30}(0.238 \ln H + 0.19) \qquad (14.11)$$

The proposed SFO SOIA procedure to runway 28R has the potential for the occurrence of overshoots. The magnitude of the overshoot affects the relative position of the aircraft, which in turn affects, the possibility of a Wake Vortex Encounter (WVE). The database used for the simulation of overshoots is based on the data obtained during the B747 real-time simulation. These data represent actual pilots flying SOIA in a B747 certified flight simulator with the presence of another simulated aircraft approaching runway 28L.

For a realistic prediction of the wake turbulence in an operational situation all prediction models need to be verified and correlated with the local atmospheric conditions. Refinements to the wake vortex model, for the actual atmospheric conditions at SFO, will be incorporated in the ASAT system based on the results of ongoing wake monitoring field measurements at SFO.

14.3 THREE-DIMENSIONAL WAKE VORTEX SIMULATION

A wake vortex model based upon the mathematical model described in paragraph 14.2 was incorporated into ASAT. Then various scenarios were designed to determine the rear boundary of the operational window (see Figure 14.2). Aircraft of the same category were placed at a given in-trail distance at the MAP with a given crosswind. Continuous probability curves were developed for critical flight parameters such as airspeed, weight, and overshoot. The distribution of overshoot was developed from the database generated during the real-time flight simulator test.

14.3.1 FITTING CURVES TO DATA

In order to use the aircraft performance data, such as the overshoot distance that the aircraft crosses the extended center line of runway 28R, continuous probability curves must be fitted to the data. The Johnson family of curves, developed by N. L. Johnson in 1949, is used to fit probability curves to the data sets. The Johnson family includes three types of curves, the Johnson S_L family, the Johnson S_B family, and the Johnson S_U family (see Hahn et.al.). The curves of the S_L family are bounded at one end with an infinite tail at the other end. The curves of the S_B family are bounded at both ends. The curves of the S_U family are unbounded, i.e., have infinite tails at both ends. Each family of curves is based on a transformation of the observed data into a set of data that could be generated by a normal N(0,1) distribution. A test based on the statistics of the data determines which type of curve will best fit the data. It was found that the overshoot data set should be fitted with Johnson S_B curves. The transformation that determines the Johnson S_B family of curves is given by the following equation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda+\varepsilon-x}\right), \quad \varepsilon < x < \lambda + \varepsilon \qquad (14.12)$$

In equation 14.12, x represents a sample observation such as an overshoot distance, z represents the transformation of x into a number from a normal N(0,1) distribution, and γ, δ, λ, and ε represent parameters that "fit" the curve to the data. The parameters γ, δ, λ, and ε are determined from the data via an iterative numerical process.

14.3.2 RANDOM NUMBER GENERATION

Central to any computer simulation is the generation of random numbers. A random number generator is a computer program that computes numbers that lie within a specified range (typically 0 to 1) with any one number in the range just as likely as any other. Random numbers that are computed uniformly within a specified range are often called "uniform deviates". Most C language implementations have library routines for generating uniform deviates. However, many if not most of these implementations are flawed. Therefore, ASAT employs a random number generator developed by L'Ecuyer (see Flannery et al.). The sequence of uniform deviates produced by this generator passes all known tests of randomness.

14.3.3 GENERATION OF DEVIATES FROM A NORMAL DISTRIBUTION

Second only in importance to the generation of uniform random numbers described in 14.3.2 is the generation of random deviates from a normal distribution. The Box-Muller method is a simple, but effective, method for generating random deviates from a normal distribution with mean 0 and standard deviation 1. Two random deviates, x_1 and x_2, from a normal distribution with mean 0 and standard deviation 1 can be computed by first finding two uniform deviates, u_1 and u_2. Then compute x_1 and x_2 from the following formulae:

$$\begin{aligned} x_1 &= \sqrt{-2\ln u_1}\,\cos 2\pi u_2 \\ x_2 &= \sqrt{-2\ln u_1}\,\sin 2\pi u_2 \end{aligned} \qquad (14.13)$$

If random deviates from a normal distribution with a mean different from 0 and/or a standard deviation different from 1 are needed, then the deviates y_1 and y_2 can be computed from the following formulae:

$$\begin{aligned} y_1 &= \mu + \sigma x_1 \\ y_2 &= \mu + \sigma x_2 \end{aligned} \qquad (14.14)$$

where μ is the mean of the normal distribution being simulated and σ is its standard deviation.

If random deviates from a truncated normal distribution are required, then there are two numbers a and b, with $a < b$, such that every random deviate y must fall between a and b. The numbers a and b are determined from physical aspects of the data such as minimum and maximum indicated airspeeds or rates of climb. To sample from a truncated normal distribution, a random deviate y is selected from the entire normal distribution. The deviate is checked to see if it lies between a and b. If it lies between a and b, then it is used in the simulation. If it does not lie between a and b, then it is discarded and another random deviate is selected. The process is repeated until a random deviate lying between a and b is found.

14.3.4 GENERATION OF DEVIATES FROM A JOHNSON S_B DISTRIBUTION

The generation of deviates from a Johnson S_B distribution is a three step process. First two uniform deviates must be generated as described in paragraph 14.3.2. Then the uniform deviates are used to generate two deviates x_1 and x_2 from a normal distribution with mean 0 and standard deviation 1. Then two deviates y_1 and y_2 from a Johnson S_B distribution are computed from the equations:

$$y_i = \frac{(\varepsilon + \lambda)\exp\left(\frac{x_i - \gamma}{\delta}\right) + \varepsilon}{\left(1 + \exp\left(\frac{x_i - \gamma}{\delta}\right)\right)}, \quad i = 1,2. \qquad (14.15)$$

The equations of 14.15 are derived by solving equation 14.12 for x.

14.3.5 GENERATION OF DEVIATES FROM A COLLISION RISK MODEL DISTRIBUTION

The ICAO CRM includes cumulative probability distributions of lateral and vertical deviations from the glide slope of an ILS approach (see Manual on the Use of the Collision Risk Model (CRM) for ILS Operations). There are distributions for hand flown approaches, flight director approaches, and coupled approaches. These distributions have been incorporated into the ASAT in order to randomly position the simulated aircraft relative to a glide slope. The CRM distributions are not defined by equations like a normal distribution or a Johnson distribution. The CRM distributions are in tabular form with separate distributions for lateral deviation from the localizer course and vertical deviations from the glide slope. The table entries are of the form (x_i, y_i), where x_i represents a distance from the localizer course or the glide slope and y_i is the probability that a deviation will exceed that distance. Since the distributions are written as cumulative distributions, random variates can be derived using the method of inversion. A cumulative distribution has the general form $y = F(x)$, where y is the probability that the random variable X will be less than or equal to x. Since $0 \leq y \leq 1$, random deviates x can be generated by first finding the inverse function $x = F^{-1}(y)$. Then random deviates x are computed by computing a uniform random deviate y and substituting y into the equation $x = F^{-1}(y)$. Since the CRM distributions are in tabular form, when a uniform variate y is generated, a search of the table is performed to find two consecutive points (x_i, y_i) and (x_{i+1}, y_{i+1}), such that , $y_i \leq y < y_{i+1}$. Then linear interpolation is used to locate x between x_i and x_{i+1} corresponding to y.

14.3.6 SELECTION OF AIRCRAFT TYPE

The pairing of aircraft for the simulation is also performed in a random fashion. The interval of uniform deviates, $0 \leq y \leq 1$ is divided into subintervals, $y_i \leq y < y_{i+1}$ such that the length of each subinterval corresponds to the proportion of times that a particular aircraft is to be chosen. For example, if a B737 is to be chosen 33% of the time, a subinterval that is 0.33 long is assigned to B737. Then in the simulation, if a random deviate y is chosen that falls in the subinterval assigned to B737, the aircraft chosen for the simulation run is a B737. If a random deviate falls in the subinterval assigned to the B727, then a B727 is selected for the simulation run.

14.3.7 DETERMINATION OF A WAKE VORTEX ENCOUNTER

The test criterion used for this simulation is the WVE. A wake protection circle, with center on the longitudinal axis of the trailing aircraft is constructed in a geometric plane perpendicular to the longitudinal axis with radius equal to the semi-span of the aircraft. If a wake vortex circle of the wake producing aircraft intersects the protection circle about the trailing aircraft, then a WVE is said to have occurred.

14.3.8 SIMULATION ALGORITHM OUTLINE

Each simulation run consists of the following steps:

a. Randomly select an aircraft type for runway 28R.

b. Randomly select an aircraft type for runway 28L.

c. Operator selects a stagger distance at the MAP, deviation from the localizer course, and deviation from the glide slope for the aircraft approaching runway 28R.

d. Randomly select an overshoot distance for the aircraft approaching runway 28R.

e. Randomly select a deviation from the localizer course and deviation from the glide slope for the aircraft approaching runway 28L. Position the aircraft to have the selected stagger distance.

f. Randomly select aircraft performance parameters corresponding to the aircraft type for each aircraft.

g. Set the two aircraft in motion and monitor the distance between the two circles as the trailing aircraft passes through vertical planes, perpendicular to the localizer course of runway 28R and spaced 100 feet apart. The vertical planes are called tiles.

h. Write all the pertinent information, including a flag if a WVE occurs, of the simulation run in a file for analysis.

14.4 THREE-DIMENSIONAL (3D) SIMULATION RESULTS

Table 14.2 consists of 4 columns: In Trail @ MAP, S/S (for Small/Small), L/L (for Large/Large) and H/H for (Heavy/Heavy). The left column lists the in-trail initial separation values at MAP that were simulated. These values range from 0.5 to 1.25 NM. The other numeric values listed in the table represent the corresponding crosswind for a given in trail separation at MAP at which encounters might occur.

Table 14.2 indicates for two small aircraft approaching runways 28L and 28R (S/S), encounters will not occur for surface crosswinds not exceeding 10 knots for an initial stagger at the MAP ranging from 0.5 NM to 1.25 NM. For two large aircraft, encounters can occur if the initial stagger at the MAP exceeds 0.8 NM and the surface crosswind is in excess of 9 knots. For two heavy aircraft, encounters can occur if the initial stagger at the MAP exceeds 0.7 NM and the surface crosswind is in excess of 9 knots. Table 14.2 also indicates that if the initial stagger at the MAP exceeds 0.8 NM and the surface crosswind is in excess of 8 knots then encounters can occur.

	CROSSWIND SPEEDS RESULTING IN WAKE VORTEX ENCOUNTERS		
In Trail Distance at MAP	**Small Vs. Small**	**Large Vs. Large**	**Heavy Vs. Heavy**
0.50	10	10	10
0.60	10	10	10
0.70	10	10	9
0.80	10	9	8
1.00	10	9	7
1.25	10	8	6

Table 14.2: REAR WINDOW OPERATIONAL BOUNDARY VALUES

The results of table 14.2 are also depicted in graphical form in figure 14.3. In figure 14.3 the three lines depict the three aircraft types that were presented in table 14.2; i.e., S/S, L/L and H/H. All combinations of values *under* any given line are operationally safe; i.e., no wake vortex encounters.

Typical graphical output of the ASAT simulation is presented in figures 14.4 and 14.5. Figure 14.4 is a planar view of a B747 leading a B767 on a scenario that will result in the trailing aircraft crossing the runway threshold 15 seconds after the leading aircraft. The crosswind is 10 knots at the surface increasing to 20 knots at 2,000 feet. The blue lines perpendicular to the approach center lines represent the vertical tiles where the possibility of a WVE is determined.

Figure 14.5 is a composite view of the vertical tiles as the two aircraft pass through them. The right single circle defines a circle of diameter equal to the trailing aircraft wing span, with center on the aircraft center line. The left pair of circles depicts the time history of the leading aircraft wake vortices from the time was generated to the time the trailing aircraft intersects the tile. The horizontal brown line depicts the ground position.

14.5 CONCLUSIONS AND RECOMMENDATIONS

The rear boundary of the operational window was found to be 0.6 NM at the MAP, given a heavy following a heavy and a crosswind component of 10 knots at the surface increasing to 20 knots at 2,000 feet. For a large following the rear boundary is 0.7 NM and for a small following the rear boundary is unrestricted for the same crosswind conditions. The study indicated the implementation of LDA_D must include the following operational requirements:

a. Pilots of trailing aircraft will be instructed not to pass the leading aircraft inside the MAP.

b. The crosswind component of the total wind is 10 knots or less.

c. To ensure flyability and safety, aircraft on adjacent approach courses will be paired to mitigate potential wake vortex effects. The pairing of aircraft will be based on any one of the following mitigation strategies:

(1) The lead aircraft is downwind from the trailing aircraft; or

(2) The leading aircraft is a smaller category aircraft than the trailing aircraft; or

(3) A small aircraft is paired with another small aircraft; or

(4) A large aircraft is paired with another large aircraft and the paired aircraft are spaced within 0.7 NM longitudinally at the MAP; or

(5) A heavy aircraft or Boeing B757 aircraft is paired with another heavy aircraft (or B757) and the paired aircraft are spaced within 0.6 NM longitudinally at the MAP. When there is a size disparity, the smaller/slower aircraft should lead. For example, if a Boeing B757 is paired with a Boeing B747, the B757 should lead.

d. If none of the above wake mitigation strategies are employed, standard wake turbulence separation, as specified in Order 7110.65, shall be applied.

e. The FAA will continue its data collection at SFO to determine if the actual wind and wake conditions support an increase in the 0.6 NM longitudinal interval between heavy aircraft/B757.

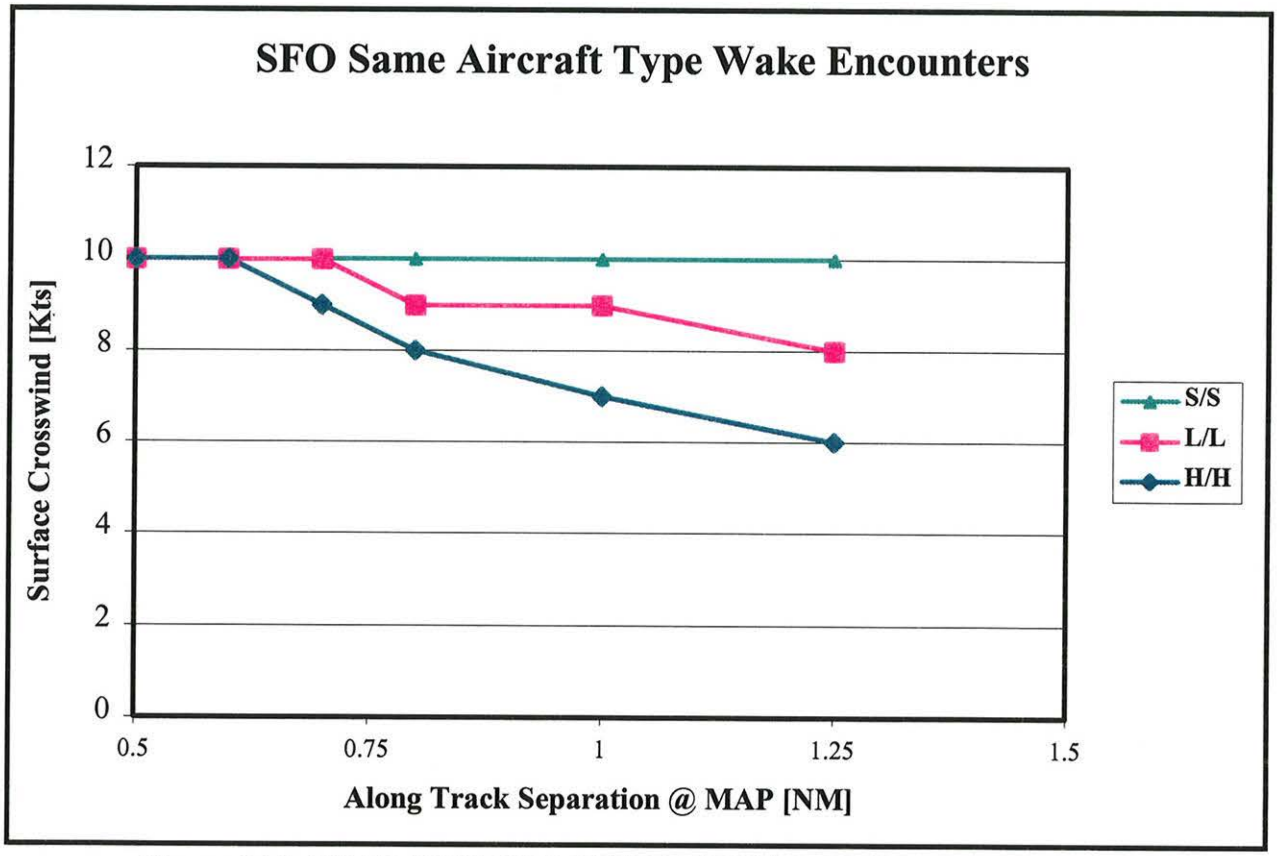


Figure 14.3 REAR WINDOW OPERATIONAL BOUNDARY VALUES

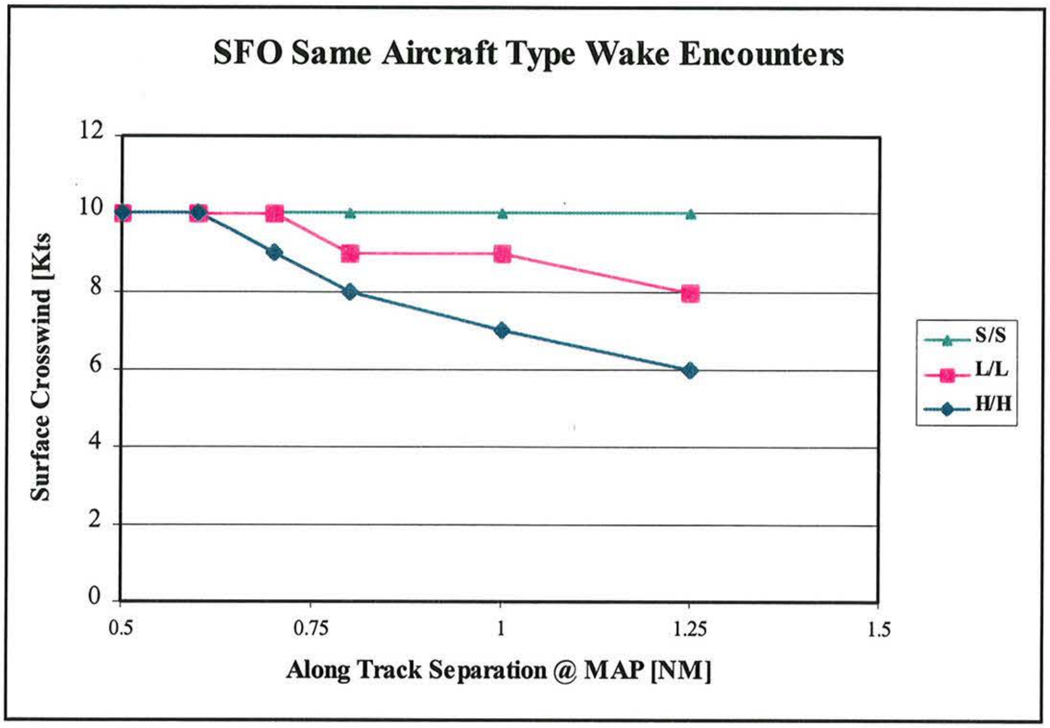


Figure 14.4: TEST CASE SCENARIO PLANAR VIEW

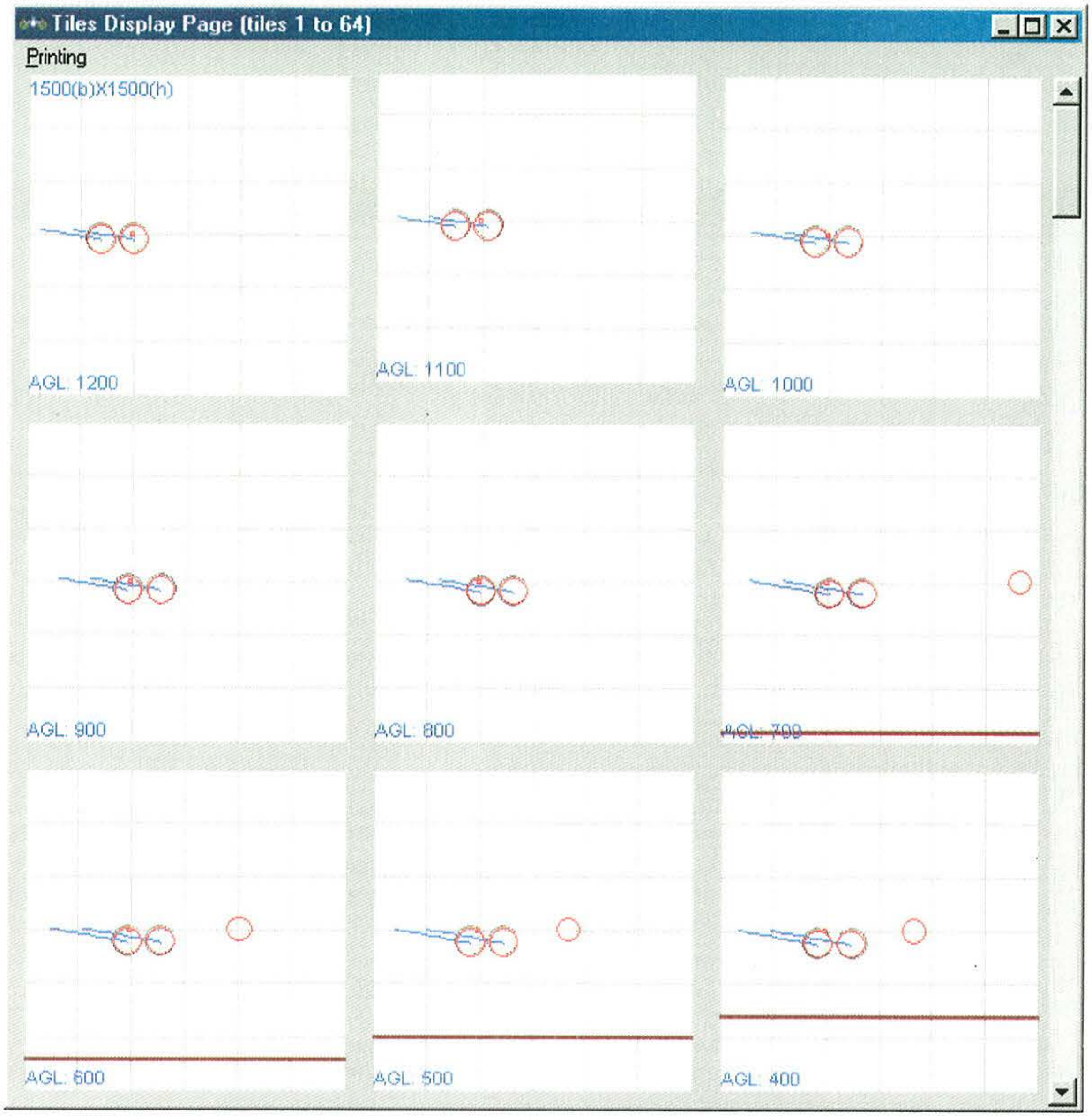


Figure 14.5: VORTICES SIMULATED ON INDIVIDUAL TILES

15.0 CONCLUSIONS AND RECOMMENDATIONS

This study was conducted and analyzed to determine flyability, collision risk, and wake turbulence factors associated with conducting PRM procedures to SFO runways 28L and 28R. This concept of operations introduces a SOIA procedure with an ILS straight-in to runway 28L and an LDA with glide slope and a sidestep to runway 28R. The purpose of the SOIA concept is to enhance and optimize safety of arrival procedures at SFO through the provision of more precise navigational guidance, PRM high update radar technology, higher definition visual displays, and predictive software. The implementation of parallel courses using an ILS for runway 28L and an offset LDA with glide slope for runway 28R will provide lateral and vertical electronic course guidance and defined missed approach procedures with obstacle protection as required by Orders 8260.3B and 8260.41. Additionally, the implementation of stabilized vertical paths to both runways will minimize the reliance on procedures in which aircraft are stepped down in altitude. By maximizing the use of the runway 28L ILS and runway 28R offset LDA with glide slope in most weather conditions, SFO arrival routings will be predictable, consistent, and characterized by stable and constant rates of descent. As ceiling and visibility decrease, the enhanced arrival procedures incorporate incremental increases in safety provisions through the use of monitor controllers, and procedural support for wake mitigation in low ceiling conditions.

Three LDA procedures were tested for flyability: LDA_A with MAP located 3.8 NM from threshold, LDA_D with MAP located 3.3 NM from threshold, and LDA_E with MAP located 2.9 NM from threshold. Statistical analysis confirmed that LDA_A and LDA_D, should be the preferred approaches among the three tested. The statistical analysis also indicated that the criteria for success, as stated in the test plan, were all met or exceeded by LDA_A and LDA_D. Additionally, the pilots indicated their preference for LDA_A and LDA_D. Because of the similarity in flyability qualities and the lower minimums provided by LDA_D, LDA_D is the preferred procedure. LDA_E is not recommended because of inferior flyability qualities and lack of pilot support.

The ASAT computer system was modified to conform to the conditions of LDA_D. The purpose of the simulation was to determine the forward boundary of an operational window of alignment of the two approaching aircraft at the MAP for runway 28R. Three scenarios were designed whose only difference was the trailing distance of aircraft approaching runway 28R when it crossed the MAP. Three trailing distances were simulated, 0.0 NM, 0.25 NM, and 0.50 NM. Each of the three scenarios was performed 50,000 times. During the simulation of each scenario, no TCVs were observed. The smallest CPA observed was 650 feet during the simulation of the 0.0 NM scenario. Each scenario met the TLS established for the simulation.

A three-dimensional computer simulation was performed by the ASAT Wake Turbulence Risk Analysis module to determine the rear boundary of the operational window. This module was created by modifying ASAT to include wake turbulence formulae provided by AAR-210 to characterize the wake turbulence based on the aircraft type and approach speed. The test criterion used for this simulation was the WVE. A wake protection circle, with center on the longitudinal axis of the trailing aircraft is constructed in a geometric plane perpendicular to the longitudinal axis with radius equal to the semi-span of the aircraft. If a wake vortex circle of the wake producing aircraft intersects the protection circle about the trailing aircraft, then a WVE is said to have occurred.

The rear boundary of the operational window was found to be 0.6 NM at the MAP, given a heavy following a heavy and a crosswind component of 10 knots at the surface increasing to 20 knots at 2,000 feet. For a large following the rear boundary is 0.7 NM and for a small following the rear boundary is unrestricted for the same crosswind conditions.

The study indicated that the implementation of LDA_D must include the following operational requirements:

a. Pilots of trailing aircraft will be instructed not to pass the leading aircraft inside the MAP.

b. The crosswind component of the total wind is 10 knots or less.

c. To ensure flyability and safety, aircraft on adjacent approach courses will be paired to mitigate potential wake vortex effects. The pairing of aircraft will be based on any one of the following mitigation strategies:

(1) The lead aircraft is downwind from the trailing aircraft; or

(2) The leading aircraft is a smaller category aircraft than the trailing aircraft; or

(3) A small aircraft is paired with another small aircraft; or

(4) A large aircraft is paired with another large aircraft and the paired aircraft are spaced within 0.7 NM longitudinally at the MAP; or

(5) A heavy aircraft or Boeing B757 aircraft is paired with another heavy aircraft (or B757) and the paired aircraft are spaced within 0.6 NM longitudinally at the MAP. When there is a size disparity, the smaller/slower aircraft should lead. For example, if a B757 is paired with a Boeing B747, the B757 should lead.

d. If none of the above wake mitigation strategies are employed, standard wake turbulence separation, as specified in Order 7110.65, shall be applied.

e. The FAA will continue its data collection at SFO to determine if the actual wind and wake conditions support an increase in the 0.6 NM longitudinal interval between heavy aircraft/B757.

f. During a defined period of time when conducting SOIA operations with ceilings above 2,400 feet and visibility greater than 4 statue miles, an evaluation will be performed prior to full SOIA approval.

g. The results and conclusions of the FAA's analysis of the SFO PRM-SOIA concept are based on the specific runway spacing and configuration, airspace, procedure design and design minima, aircraft mixes, and other criteria particular to SFO. Accordingly, there is no assurance that any part of the SFO PRM-SOIA analysis can be applied directly to any other location or situation, without additional study and analysis required.

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