Safety Study Report
DOT-FAA-AFS-440-30

Flight Operations Simulation and Analysis Branch
Flight Technologies and Procedures Division
Flight Standards Service

Safety Study Report for Minneapolis-St. Paul International Airport (MSP) Proposed Runway 22 Rejected Landing Procedure

Gerry McCartor
Carl Moore, Cherokee CRC

U.S. Department of Transportation
Federal Aviation Administration
Mike Monroney Aeronautical Center
Oklahoma City, OK 73125

March 2007

Flight Operations Simulation
and Analysis Branch, AFS-440
6500 S. MacArthur Blvd, STB Annex, RM 217
Oklahoma City, Oklahoma 73169
Phone: (405) 954-8191

Flight Systems Laboratory

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

DOT-FAA-AFS-440-30

Flight Operations Simulation and Analysis Branch
Flight Technologies and Procedures Division
Flight Standards Service

Safety Study Report for Minneapolis-St. Paul International Airport (MSP) Proposed Runway 22 Rejected Landing Procedure

Reviewed by:

Stephen W. Barnes March 13, 2007

Stephen W. Barnes **Date**
Manager, Flight Operations Simulation and Analysis Branch

Released by:

3/19/2007

John McGraw **Date**
Manager, Flight Technologies and Procedures Division

March 2007

Technical Report

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-FAA-AFS-440-30		

4. Title and Subtitle: Safety Study Report for Minneapolis-St. Paul International Airport (MSP) Proposed Runway 22 Rejected Landing Procedure	5. Report Date March 2007
6. Author(s) Gerry McCartor Carl Moore (Cherokee CRC)	7. Performing Organization Code
8. Performing Organization Name and Address Federal Aviation Administration Flight Operations Simulation and Analysis Branch, AFS-440 P.O. Box 25082, Oklahoma City, OK 73125	9. Type of Report and Period Covered Technical Report

10. Sponsoring Agency Name and Address

Federal Aviation Administration
Flight Operations Simulation and Analysis Branch,
P.O. Box 25082, Oklahoma City, OK 73125

11. Supplementary Notes

12. Abstract

Land and hold short operations (LAHSO) within the U.S. National Airspace System (NAS) are addressed in FAA Order 7110.118. The MSP Airport Traffic Control Tower (ATCT) plans LAHSO for aircraft arriving on runway 22 and aircraft departing on runway 17. Since the intersection of runways 22 and 17 is more than 2,000 ft from the threshold of the departure runway a safety study is required per paragraph 10.b(3) of FAA Order 7110.118. In 2006, the FAA Flight Operations Simulation and Analysis Branch (AFS-440) was asked to perform such a safety evaluation of the proposed Rejected Landing Procedure (RLP) for runway 22 at MSP. The runway 22 RLP is needed to support Land and Hold Short Operations (LAHSO) at MSP. This report presents the results of a safety study performed on the MSP RLP using the Airspace Simulation and Analysis Tool (ASAT).

13. Key Words	14. Distribution Statement
MSP LASHO RLP	Controlled by AFS-440
15. Security Classification of This Report	16. Security Classification of This Page
Unclassified	Unclassified

Executive Summary

Land And Hold Short Operations (LAHSO) within the U.S. National Airspace System (NAS) are addressed in FAA Order 7110.118. The Minneapolis-St.Paul International (MSP) Airport Traffic Control Tower (ATCT) plans LAHSO for aircraft arriving on runway 22 while aircraft depart on runway 17. Simultaneous independent operations to intersecting runways are allowed during LAHSO with the requirement that the aircraft landing on the designated LAHSO runway accepts responsibility for either stopping prior to the intersection or safely missing the aircraft on the other runway if a rejected landing becomes necessary. A Rejected Landing Procedure (RLP) is a set of specific instructions much like a missed approach procedure designed to safely transition the aircraft on the LAHSO runway from a rejected landing that commences at a very low-altitude, i.e. approximately 50 ft or even momentary touchdown, back into the terminal airspace.

Since the intersection of runways 22 and 17 is more than 2,000 ft from the threshold of the departure runway, a safety study is required by paragraph 10.b(3) of FAA Order 7110.118. In 2006, the FAA Flight Operations Simulation and Analysis Branch (AFS-440) was asked to perform such a safety evaluation of the proposed Rejected Landing Procedure (RLP) for runway 22 at MSP. The runway 22 RLP is required for LAHSO at MSP. This report presents the results of a safety study performed on the MSP RLP using the Airspace Simulation and Analysis Tool (ASAT). In FAA report DOT-FAA-AFS-420-86, "Risk Analysis of Rejected Landing Procedures for Land and Hold Short Operations at Chicago O'Hare International Airport, Runways 14R and 27L", the FAA developed the methodology for evaluating the risk associated with LAHSO rejected landings. This safety study draws heavily upon the methodology developed and described in that report.

Using simulator data collected from a number of representative aircraft types performing take-offs, landings, missed approaches, and RLPs, probability distributions were developed describing the critical performance parameters of aircraft involved in a LAHSO scenario. A Monte Carlo simulation was developed that randomly selected values from those distributions to examine all reasonable combinations of take-off and landing speeds, climb rates, bank angles, etc., for the different combinations of aircraft types. The aircraft types were selected based on fleet mix information provided by the MSP airport manager.

Table X-1 shows the various scenarios defined for this study. Scenario 1 is a straight ahead RLP along runway heading with a calm wind. MSP Airport Traffic Control Tower (ATCT) has proposed two turning RLP options. Option 1 is a climbing right turn to 3000 ft, then direct Flying Cloud (FCM) and hold. From MSP to FCM requires approximately a 25° course change. Option 2 is a climbing right turn to heading 260°, an approximately 40° course change. Scenarios 2 and 3 were designed to simulate RLP options 1 and 2, respectively, and were conducted with a calm wind. Scenarios 5 and 6 were also designed

to simulate RLP options 1 and 2, respectively, but were conducted with a 10 knot tailwind. Scenario 4 was designed to simulate an RLP executed at the end of the touchdown zone (3000 ft from threshold). Scenario 7 was designed to simulate a 10 knot headwind during RLP option 2. Scenario 8 was designed to simulate the effects of a 10 knot tailwind on the departing aircraft when the RLP is performed according to option 2.

Table X-1: LAHSO RLP Scenarios

Scenario	Wind	RLP	Number of ASAT Runs
1	Calm	Straight ahead from 400 ft AGL	1000000
2	Calm	25° right turn at 400 ft AGL	1000000
3	Calm	40° right turn at 400 ft AGL	1000000
4	Calm	40° right turn at 400 ft AGL from climb initiated 3000 ft down runway 22	1000000
5	10 knot tailwind on RLP a/c	25° right turn at 400 ft AGL	1000000
6	10 knot tailwind on RLP a/c	40° right turn at 400 ft AGL	1000000
7	10 knot headwind on RLP a/c	40° right turn at 400 ft AGL	1000000
8	10 knot tailwind on departing a/c	40° right turn at 400 ft AGL	1000000

Any three-dimensional Closest Point of Approach (CPA_{3D}) distance less than 500 ft between the centers of mass of the two aircraft was considered a Test Criterion Violation (TCV). While not technically a mid-air collision, separation distances of less than 500 ft during commercial operations are considered to be unacceptable. A TCV probability of less than 1×10^{-8} per LAHSO approach is referred to as the Target Level of Safety (TLS). If the probability of a TCV is less than or equal to the TLS, then the approach is considered safe and the approach is said to meet the TLS. If the probability of a TCV is greater than the TLS, then the approach is not considered safe and the approach does not meet the TLS.

A TCV caused by an RLP can only occur if an RLP occurs first. The probability of an RLP during an approach has been shown to be approximately 1×10^{-4}. Thus the probability of a TCV during an RLP must be less than 1×10^{-4} or less than 100 TCVs per 1,000,000 runs in each scenario to meet the TLS.

The results of the ASAT analysis are shown in Table X-2. The table indicates under all scenarios evaluated, significant numbers of TCVs, i.e. $CPA_{3D} < 500$ ft, were found and

none of the scenarios met the TLS. The table indicates the least numbers of TCVs were recorded during the simulation of the scenarios designed to emulate option 2. However, the numbers of TCVs all significantly exceed 100.

As with the earlier LAHSO studies, the principal cause of the TCVs were RLP aircraft with relatively low climb rates. Since the simulation did not allow the aircraft to begin the RLP turn until it reached some altitude Above Ground Level (AGL), nominally 400 ft, these aircraft were well down runway 22 before any turning could commence and thus obtain less separation benefit from the turning RLP maneuver.

Based on analysis of the TCV locations for all simulated aircraft evaluated, a "Departure Decision Area (DDA)" can be defined so that the departing aircraft is allowed to commence the take off roll only while the arriving aircraft is outside the DDA. Under these conditions, the TLS is met. If departing aircraft are allowed to begin their take off roll while the arriving aircraft is within the DDA, then the TLS is not met. For the particular runway geometry at MSP, the DDA begins a quarter mile from the runway 22 threshold on the approach side of the threshold and continues a mile from threshold on the runway side of the threshold. From an operational view, this could be implemented as holding departing aircraft once an arriving aircraft is within a quarter mile of the threshold until the arriving aircraft has touched down and is definitely landing. Clearly this limits the "independence" of arrivals and departures, but this or an equivalent level of safety mitigation strategy, is necessary to meet the TLS.

Table X-2: TCV Rates and Probability per Scenario

Scenario	Wind	RLP	# TCVs per 1,000,000 runs	TCV Probability
1	Calm	Straight ahead from 400 ft AGL	4251	4.25×10^{-7}
2	Calm	25° right turn at 400 ft AGL	3291	3.29×10^{-7}
3	Calm	40° right turn at 400 ft AGL	3175	3.17×10^{-7}
4	Calm	40° right turn at 400 ft AGL from climb initiated 3000 ft down runway 22	7760	7.76×10^{-7}
5	10 knot tailwind on RLP a/c	25° right turn at 400 ft AGL	5214	5.21×10^{-7}
6	10 knot tailwind on RLP a/c	40° right turn at 400 ft AGL	5112	5.11×10^{-7}
7	10 knot headwind on RLP a/c	40° right turn at 400 ft AGL	2254	2.25×10^{-7}
8	10 knot tailwind on departing a/c	40° right turn at 400 ft AGL	2019	2.01×10^{-7}

Table of Contents

1.0 Introduction 1
1.1 Background 1
2.0 Description of the Model 1
2.1 MSP Runway Configuration and RLP Guidelines 1
2.2 Airspace Simulation and Analysis Tool (ASAT) 3
2.3 ASAT MSP RLP Modifications 4
2.4 Scenario Definition and Fleet Mix 5
2.5 Test Criterion Violations and Target Level of Safety 7
3.0 Analysis of Results 8
4.0 Summary of Results and Conclusions 12
5.0 References 14

List of Tables

Table 1: MSP RLP Scenario Definition 5
Table 2: MSP RLP Fleet Mix 7
Table 3: TCV Rates per Scenario 13

List of Figures

Figure 1: MSP Airport Diagram 2
Figure 2: MSP RLP ASAT Screen Capture 4
Figure 3: TCV Occurrences for Scenario 2 9
Figure 4: TCV Occurrences for Scenario 6 10
Figure 5: TCV Occurrences for Scenario 8 11
Figure 6: Departure Decision Area on Runway 22 for Runway 17 Departures 12

Safety Study Report for Minneapolis-St. Paul International Airport (MSP)
Proposed Runway 22 Rejected Landing Procedure

DOT-FAA-AFS-440-30 March 2007

1.0 Introduction

Land And Hold Short Operations (LAHSO) within the U.S. National Airspace System (NAS) are addressed in FAA Order 7110.118 [1]. The MSP Airport Traffic Control Tower (ATCT) plans LAHSO for aircraft arriving on runway 22 and aircraft departing on runway 17. Since the intersection of runways 22 and 17 is more than 2,000 ft from the threshold of the departure runway, a safety study is required by paragraph 10.b (3) of [1]. In 2006, the FAA Flight Operations Simulation and Analysis Branch (AFS-440) was asked to perform such a safety evaluation of the proposed Rejected Landing Procedure (RLP) for runway 22 at MSP. The runway 22 RLP is required to support Land and Hold Short Operations (LAHSO) at MSP. This report presents the results of this safety study.

1.1 Background

LAHSO allows simultaneous independent operations to intersecting runways with the requirement of the aircraft landing on the designated LAHSO runway accepts responsibility for either stopping prior to the intersection or safely missing the aircraft on the other runway if a rejected landing becomes necessary. The RLP is a set of specific instructions, much like a missed approach procedure, designed to safely transition the aircraft on the LAHSO runway from a very low-altitude, i.e. approximately 50 ft or even momentary touchdown, on a rejected landing back into the terminal airspace. In [2], the FAA developed the methodology for evaluating the risk associated with LAHSO rejected landings. This safety study draws heavily upon the methodology developed and described in [2].

Using simulator data collected from a number of representative aircraft types performing take-offs, landings, missed approaches, and RLPs, probability distributions were developed describing the critical performance parameters of aircraft involved in a LAHSO scenario. A Monte Carlo simulation was developed that randomly selected values from those distributions to examine all reasonable combinations of take-off and landing speeds, climb rates, bank angles, etc., for the different combinations of aircraft types. The aircraft types were selected based on fleet mix information provided by the MSP airport manager.

2.0 Description of the Model

2.1 MSP Runway Configuration and RLP Guidelines

Shown in Figure 1 is the airport diagram of MSP. As Figure 1 indicates runway 22 is approximately 11,000 ft long and the departure end of runway 22 intersects runway 17 approximately 5700 ft from the runway 17 threshold. Since runway 22/17 intersection distance is greater than 2000 ft, an RLP must be developed and validated through modeling in accordance with guidelines found in [1], paragraph 10b(3).

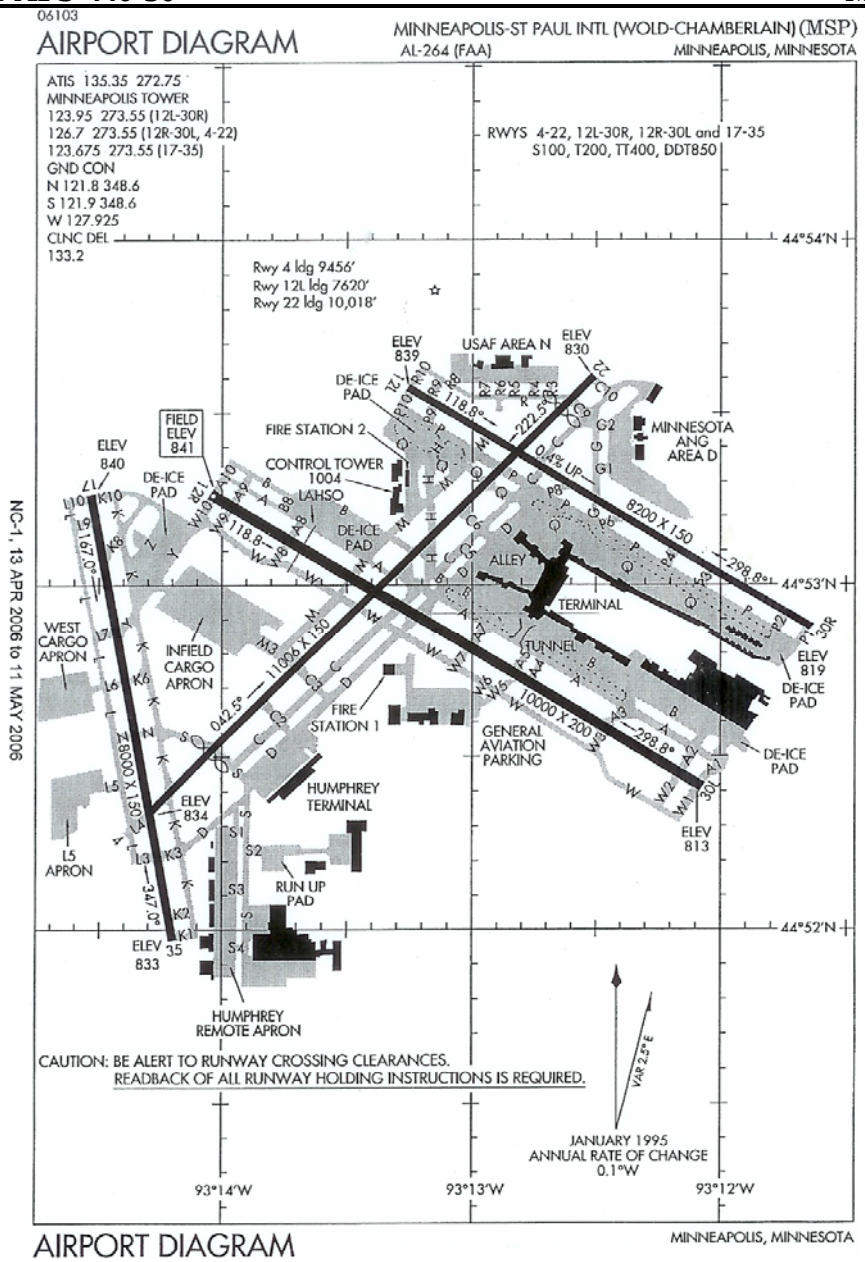

Figure 1: MSP Airport Diagram

RLPs should be developed with the following guidelines in mind:
1. A heading to fly should be given with instructions to remain clear of clouds.
2. The point from which the rejected landing is initiated is the first one-third of the runway or 3000 ft, whichever is less.
3. Potential conflict with terrain or obstacles along the rejected landing flight path should be considered.
4. Performance of the LAHSO aircraft and the full-length (departing) aircraft should be considered.

5. Different full-length traffic scenarios, e.g. arrival, departure, go-around, must be accounted for. (Note: For this evaluation, only departures from runway 17 were accounted for, as no arrivals are planned for this runway during LAHSO.)
6. Only one RLP can be developed for each runway configuration. Thus, this single RLP must be designed to accommodate all differing types of aircraft that could possibly be required to use it.
7. Through modeling, RLPs shall demonstrate an acceptable level of safety.

2.2 Airspace Simulation and Analysis Tool (ASAT)

The primary analysis tool for this safety evaluation was ASAT. ASAT is a multifaceted, highly adaptable computer-based modeling tool for aviation related simulations and safety evaluations. ASAT consists of high fidelity models and in some cases, empirical data representing the following major components of a typical real world operational aviation scenario:

a. At the heart of the system is high fidelity engineering flight dynamics models of actual aircraft obtained through various government/industry partnerships. Model definition and performance is also enhanced and tailored by empirical data collected in flight simulators and flight tests. Aircraft avionics are modeled based on requirements of the particular scenario. ASAT can model a broad range of advanced navigation systems such as Flight Management System (FMS), Global Positioning System (GPS) and Required Navigation Performance (RNP); as well as older navigation systems such as Instrument Landing System (ILS), Microwave Landing System (MLS) and Distance Measuring Equipment (DME). For the original AFS study of LAHSO at ORD, several airlines provided the FAA with unprecedented access to their simulators and pilots for the data collection required for the proposed evaluation. Details of these data collection efforts and the analysis of the resulting data can be found in [2].

b. ASAT has access to a wide range of environmental models including temperature, atmospheric pressure and wind profiles; both lateral and vertical. The aerodynamic flight models described above respond to the ASAT generated atmosphere around them in the same manner as actual aircraft do. In addition, ASAT contains an advanced aircraft wake vortex model which can generate and track wake vortices and identify encounters between wake vortices and scenario "aircraft". (Note: no wake encounter analysis was done for this study.)

c. The environment in which ASAT scenarios run is further defined by official FAA databases providing precise geographic locations of airports, runways, navaids, routes, fixes, waypoints and other facilities; such as radar site locations. In addition, ASAT incorporates the FAA's obstacle and terrain database for use in obstacle clearance studies.

d. Air traffic equipment scenarios are based on computer models of surveillance systems using manufacturer and government provided specifications. When and where necessary, the human factors contribution of air traffic controllers is measured during

simulations; from this data, statistical distributions of controller response times can be determined and made available to ASAT.

Once the scenario(s) of interest are defined and the components above statistically characterized, ASAT can perform many thousands of runs in a Monte Carlo type simulation. ASAT is also capable of statistically analyzing the results of the Monte Carlo simulation.

2.3 ASAT MSP RLP Modifications

For this study, ASAT was modified to allow control of the various parameters bearing on the MSP RLP study. Figure 2 shows an ASAT screen capture of a simulated MSP RLP run. The right center of the screen shows the runway configuration and the tracks of the two simulated aircraft. Along the left side are the various parameters used to define, control and document a single Monte Carlo run.

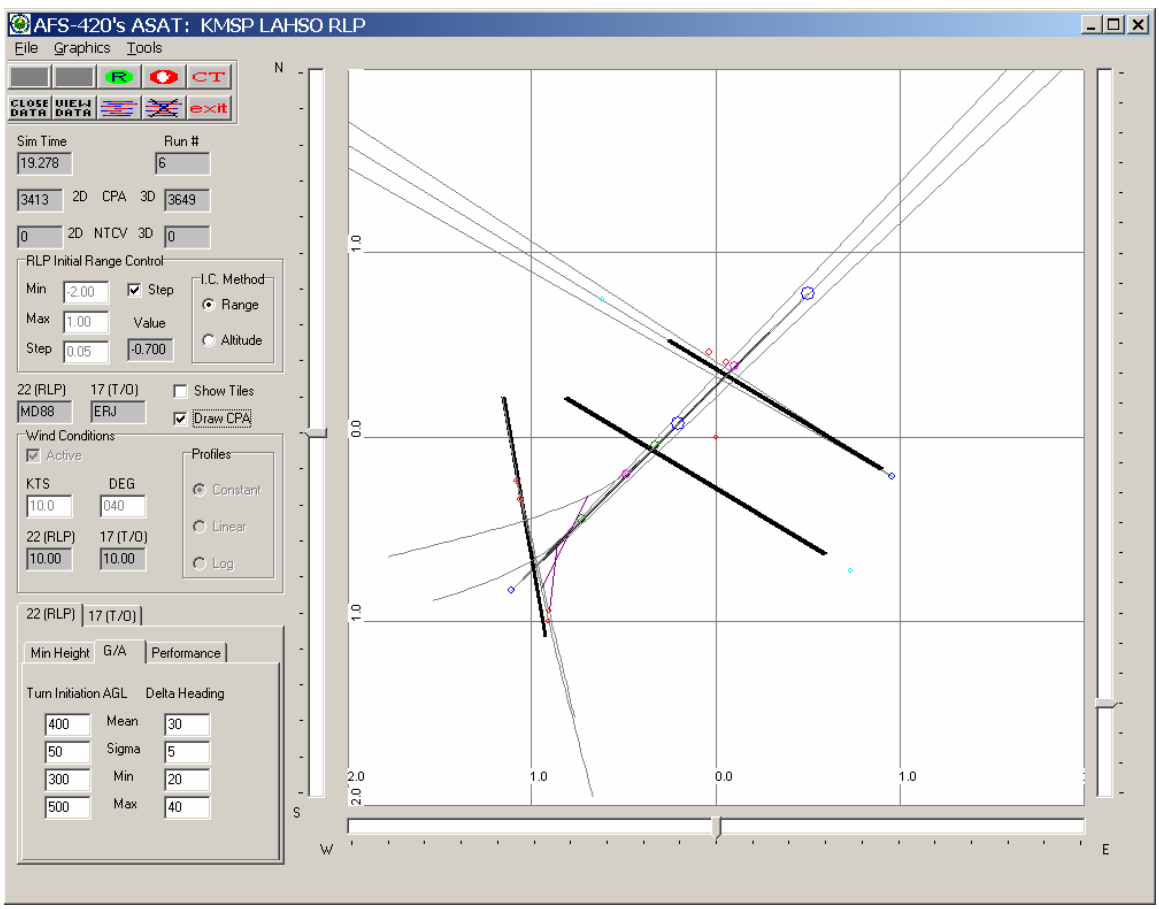

Figure 2: MSP RLP ASAT Screen Capture

Some of the more significant parameters are described below:

- CPA is closest point of approach between the two aircraft during the RLP. Both two dimensional and three dimensional CPAs are computed and displayed by ASAT.
- NTCV is the number of Test Criterion Violations (TCV). More will be said later about TCVs.
- RLP Initial Range Control is the method for determining where the RLP begins. The RLP may be set to begin based on range from the runway 22 threshold or altitude on the approach.
- 22 (RLP) denotes runway 22 is the RLP runway and during this run, a MD88 is performing the RLP.
- 17 (T/O) denotes runway 17 is the take off, i.e. departure, runway and during this run, an ERJ is performing the take off.
- Wind Conditions are active for this run and simulated winds are 040° at 10 knots, i.e. a tailwind for the LAHSO aircraft.
- G/A sets the statistical parameters for the RLP maneuver itself. In this case the turn initiation height parameters are as follows: mean 400 ft AGL, standard deviation 50 ft, minimum 300 ft AGL and maximum 500 ft AGL. The turn parameters themselves are mean heading change of 30°, standard deviation of 5°, minimum turn of 20° and a maximum turn of 40°. Tabs also exist for statistically characterizing RLP aircraft performance as well as the runway 17 take off maneuver.

2.4 Scenario Definition and Fleet Mix

Table 1 lists the various scenarios defined for this study.

Table 1: MSP RLP Scenario Definition

Scenario	Wind	RLP	Number of ASAT Runs
1	Calm	Straight ahead from 400 ft AGL	1000000
2	Calm	25° right turn at 400 ft AGL	1000000
3	Calm	40° right turn at 400 ft AGL	1000000
4	Calm	40° right turn at 400 ft AGL from climb initiated 3000 ft down runway 22	1000000
5	10 knot tailwind on the RLP a/c	25° right turn at 400 ft AGL	1000000
6	10 knot tailwind on the RLP a/c	40° right turn at 400 ft AGL	1000000
7	10 knot headwind on the RLP a/c	40° right turn at 400 ft AGL	1000000
8	10 knot tailwind on departing a/c	40° right turn at 400 ft AGL	1000000

Scenario 1 is a straight ahead RLP along runway heading with a calm wind. MSP Airport Traffic Control Tower (ATCT) has proposed two turning RLP options. Option 1 is a climbing right turn to 3000 ft, then direct Flying Cloud (FCM) and hold. From MSP to FCM requires approximately a 25° course change. Option 2 is a climbing right turn to heading 260°, an approximately 40° course change. Scenarios 2 and 3 were designed to simulate RLP options 1 and 2, respectively and were conducted with a calm wind. Scenarios 5 and 6 were also designed to simulate RLP options 1 and 2, respectively, but were conducted with a 10 knot tailwind. Scenario 4 was designed to simulate an RLP executed at the end of the touchdown zone (3000 ft from threshold). Scenario 7 was designed to simulate a 10 knot headwind during RLP option 2. Scenario 8 was designed to simulate the effects of a 10 knot tailwind on the departing aircraft when the RLP is performed according to option 2.

Note the ATC operational procedures do not allow for LAHSO operation when there is any tailwind component on the arriving aircraft. Scenarios 5 and 6 were considered in this study to address possible differences in surface winds measured at the airport and actual winds experienced by the aircraft for most of the approach.

An ASAT run consists of three phases:

Phase 1: Initialization. The aircraft types for arrival and departure were selected randomly according to the fleet mix (discussed below). Their performance data was loaded and approach and take-off airspeeds determined. The arriving aircraft was positioned some distance from the airport (uniformly distributed within the user selected range limits) with appropriate lateral and vertical errors. All parameters that were based on probability distribution functions (pdfs), such as rate of climb, roll rate, take-off distance, etc., were selected.

Phase 2: Performance. The LAHSO aircraft was “released” and the simulation advanced in simulated 50 millisecond steps with continuous updates of the aircraft state vectors based on their flight dynamics, wind conditions, and performance data. Thirty seconds of simulation time after the run started, the departing aircraft begins its take-off roll. This delay was necessary to compensate for the large threshold to intersection distance at MSP. When the arriving aircraft reached a pre-determined altitude or distance down the runway, it initiated a climb. If the scenario involved a turn (the RLP maneuver), the aircraft would not begin to turn until it reached a selected altitude (nominally 400 ft AGL). Slant range (3-dimensional) and system plane (2-dimensional) separation were continuously monitored and the simulation continued for approximately 20 seconds (simulation time) past the point where the slant range stopped decreasing and started increasing, i.e. the CPA. The simulation does not recognize collisions so even if the slant range separation reached 0.0, the model continues running.

Phase 3: Reporting. For each run, critical parameters were recorded and saved to output files. These included the aircraft types and runways involved, various performance

parameters, the minimum 2-dimensional and 3-dimensional separation, and a flag indicating a TCV had occurred.

Table 2 shows the aircraft types and percentage of overall traffic used for the Monte Carlo simulation. This mix is representative of MSP and contains relatively small turboprop aircraft such as the Saab 340 as well as large jet aircraft such as the B777. Each of the types shown is considered representative of a number of aircraft types; the Saab, for instance, is used as the closest available model for a variety of small turbo-prop aircraft. Where there was not an obvious type match, such as using the MD-88 model for DC-9 aircraft, thrust to weight ratios were determined and the closest match with a lower performance value was selected. Piston aircraft, primarily general aviation, were not considered in the evaluation.

Table 2: MSP RLP Fleet Mix

Representative Aircraft Type	Percentage of Fleet
B777	1.3
B737-200	2.3
B737-800	7.1
A320	20.3
Saab 340	13.7
B727	2.0
ERJ	31.3
B757-200	8.5
MD88	13.5

2.5 Test Criterion Violations and Target Level of Safety

Any three-dimensional Closest Point of Approach (CPA_{3D}) distance less than 500 ft between the centers of mass of the two aircraft was considered a Test Criterion Violation (TCV). While not technically a mid-air collision, separation distances of less than 500 ft during commercial operations are considered to be unacceptable. A TCV probability of less than 1×10^{-8} per LAHSO approach is referred to as the Target Level of Safety (TLS). If the probability of a TCV is less than or equal to the TLS, then the approach is considered safe and the approach is said to meet the TLS. If the probability of a TCV is greater than the TLS, then the approach is not considered safe and the approach does not meet the TLS.

A TCV caused by an RLP can only occur if an RLP occurs first. The probability of an RLP during an approach has been shown [3] to be approximately 1×10^{-4}. Thus the probability of a TCV during an RLP must be less than 1×10^{-4} or less than 100 TCVs per 1,000,000 runs in each scenario to meet the TLS.

3.0 Analysis of Results

In addition to the TCV count, the output from the model includes a file that provides a graphical depiction of where an arriving aircraft that was involved in a TCV was released. This provides a convenient way to define a hazardous window or "area" such that if the arriving aircraft is inside the area, there is an elevated risk of a TCV, i.e. probability of a TCV exceeds the TLS; but, if it is outside the area, then the probability of a TCV is less than the TLS. Figures 3 through 5 show the areas of conflict for all the possible combinations of aircraft types used in the model for three of the scenarios. The other scenario results were very similar.

In the figure, the first aircraft in each listed pair is the arrival aircraft, the second is the departure aircraft. The totals for 2 and 3 dimensional TCVs are shown at the top of the white area. The values for each combination are shown in parentheses following the paired aircraft type. The blue bars indicate the range of distances where the arriving 2D TCV aircraft were released. The red bars are the release ranges for the 3D TCV aircraft. The characteristics of the 3D TCV aircraft are the principal items of interest for this study. Once corrected for the 30 second delay in the departure aircraft, the specific item of interest is where the 3D LAHSO aircraft was when the departing aircraft began its take-off roll. Analysis of the arriving aircraft velocities shows that the window defined by the red bars in Figures 3-5 should be shifted approximately 1.15-1.2 miles to compensate for the delayed departures. Figure 3 is the most representative for the nominal case and the window defined by the red bars is from 1.5 NM to 0.25 NM from threshold. When the shift is applied, this translates to a risk window from about a quarter mile prior to the runway threshold to a mile down the runway. Since most aircraft will have landed in that distance, a possible operational mitigation strategy would be to hold the runway 17 departures when an arriving aircraft is less than a quarter mile from threshold until it touches down and is definitely landing.

Other operational considerations can be gleaned from Figures 3 through 5. These considerations would be limited by the level of complexity that can be utilized in the decision making process that must be implemented to safely mitigate the operation. Aircraft with climb performance equivalent to or better than a Boeing 777 should not experience any TCVs. Identifying these aircraft would require some research. Almost all of the TCVs involve lower performance aircraft such as the Saab turboprop or the ERJ (regional jet). If those types were excluded, the operation might approach the desired level of safety. However, these types represent 45% of the non-general aviation traffic at MSP (according to the data provided for this study).

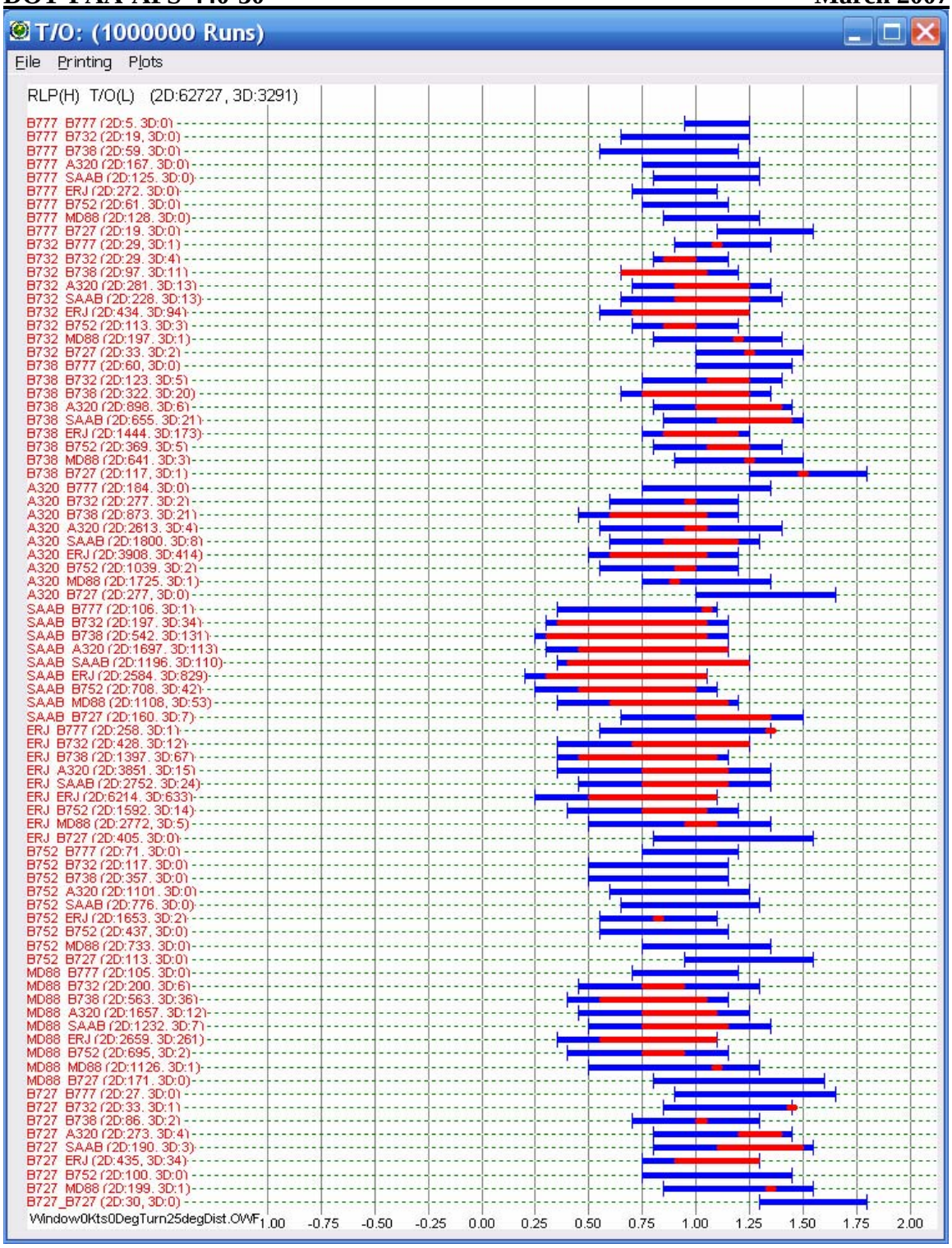

Figure 3: TCV Occurrences for Scenario 2

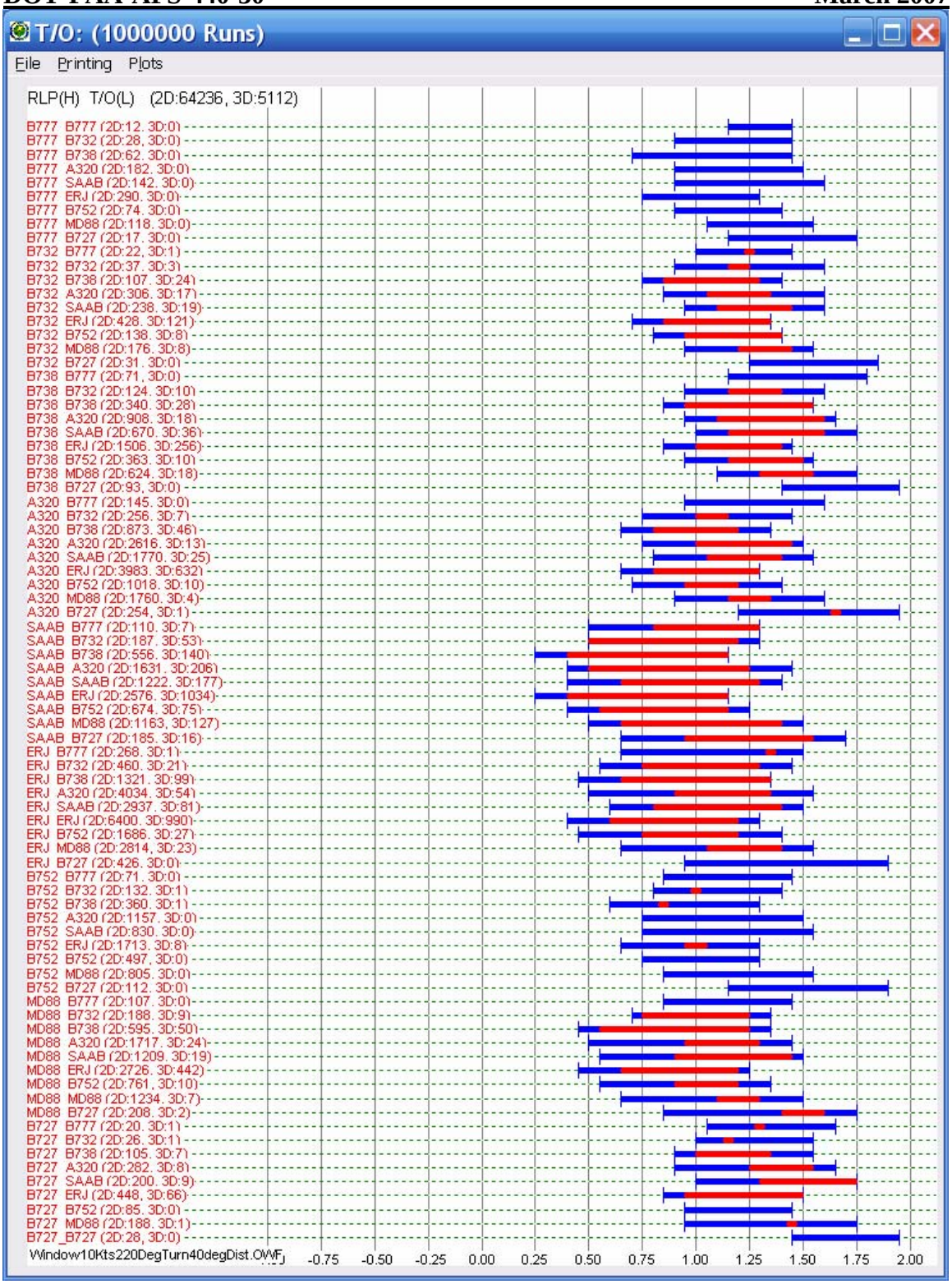

Figure 4: TCV Occurrences for Scenario 6

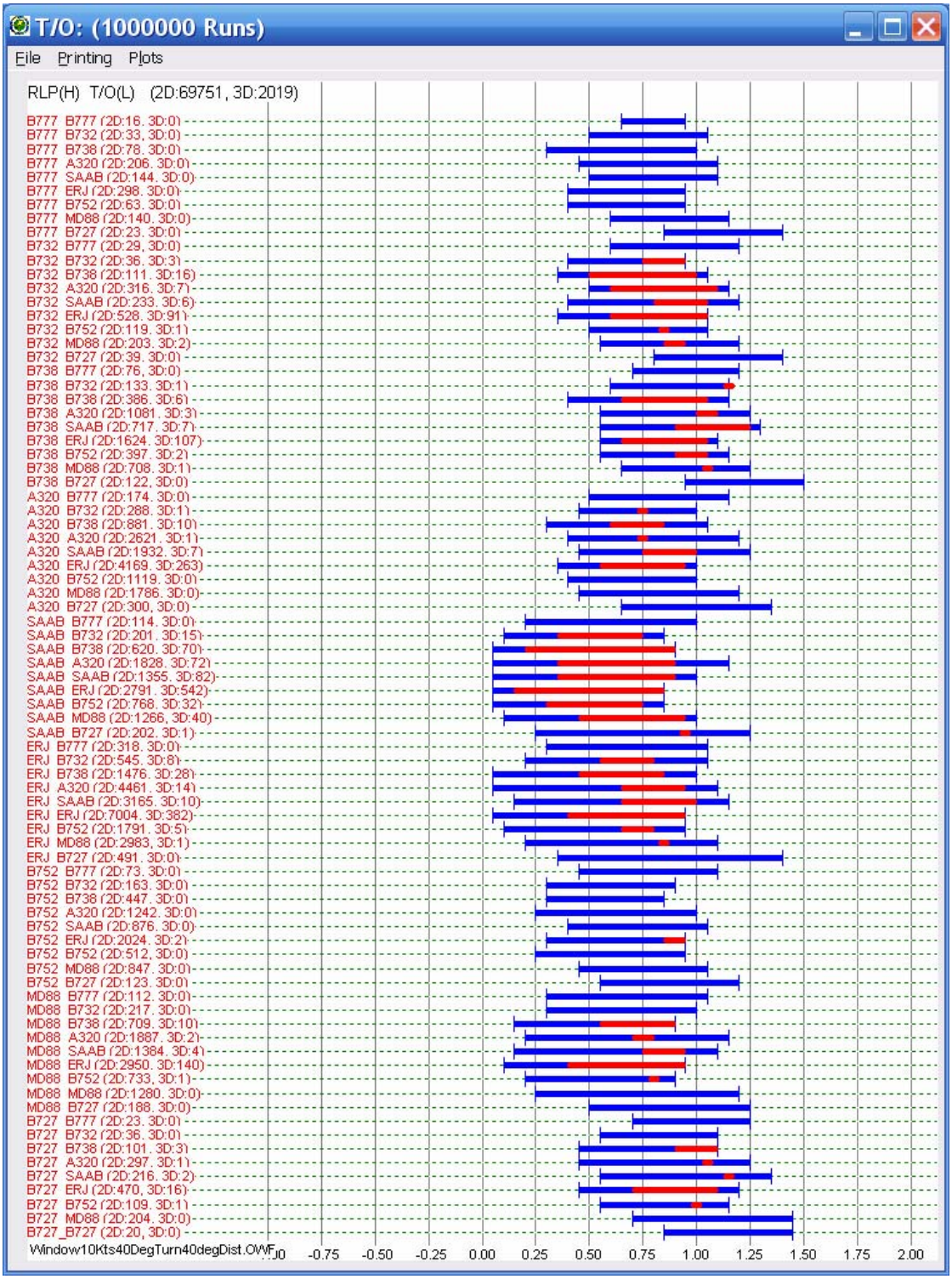

Figure 5: TCV Occurrences for Scenario 8

4.0 Summary of Results and Conclusions

The results of the ASAT analysis are shown in Table 3. The table indicates under all scenarios evaluated, significant numbers of TCVs, i.e. $CPA_{3D} < 500$ ft, were found and none of the scenarios met the TLS. The table indicates the least numbers of TCVs were recorded during the simulation of the scenarios designed to emulate option 2. However, the numbers of TCVs all significantly exceed 100, the TLS threshold discussed in section 2.5.

As with the earlier LAHSO studies, the principal cause of the TCVs were RLP aircraft with relatively low climb rates. Since the simulation did not allow the aircraft to begin the RLP turn until it reached some altitude AGL, nominally 400 ft, these aircraft were well down runway 22 before any turning could commence and thus obtain less separation benefit from the turning RLP maneuver.

Based on analysis of the TCV locations for all simulated aircraft evaluated, a "Departure Decision Area (DDA)" can be defined so that the departing aircraft is allowed to commence the take off roll only while the arriving aircraft is outside the DDA. Under these conditions, the TLS is met. If departing aircraft are allowed to begin their take off roll while the arriving aircraft is within the DDA, then the TLS is not met. For the particular runway geometry at MSP, the DDA begins a quarter mile from the runway 22 threshold on the approach side of the threshold and continues a mile from the threshold on the runway side of the threshold. From an operational view, this could be implemented as holding departing aircraft once an arriving aircraft is within a quarter mile of the threshold until the arriving aircraft has touched down and is definitely landing. Clearly this limits the "independence" of arrivals and departures, but this, or an equivalent level of safety mitigation strategy, is necessary to meet the TLS. Figure 6 illustrates a DDA on runway 22.

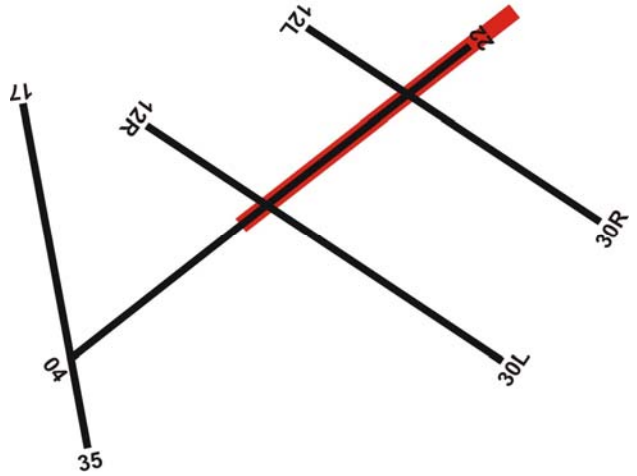

Figure 6. Departure Decision Area on Runway 22 for Runway 17 Departures

Table 3: TCV Rates per Scenario

Scenario	Wind	RLP	# TCVs per 1,000,000 runs	TCV Probability
1	Calm	Straight ahead from 400 ft AGL	4251	4.25×10^{-7}
2	Calm	25° right turn at 400 ft AGL	3291	3.29×10^{-7}
3	Calm	40° right turn at 400 ft AGL	3175	3.17×10^{-7}
4	Calm	40° right turn at 400 ft AGL from climb initiated 3000 ft down runway 22	7760	7.76×10^{-7}
5	10 knot tailwind on RLP a/c	25° right turn at 400 ft AGL	5214	5.21×10^{-7}
6	10 knot tailwind on RLP a/c	40° right turn at 400 ft AGL	5112	5.11×10^{-7}
7	10 knot headwind on RLP a/c	40° right turn at 400 ft AGL	2254	2.25×10^{-7}
8	10 knot tailwind on departing a/c	40° right turn at 400 ft AGL	2019	2.01×10^{-7}

5.0 References

[1] FAA Order 7110.118, Land and Hold Short Operations, 7/14/00.

[2] Lankford, David N., et al, "Risk Analysis of Rejected Landing Procedures for Land and Hold Short Operations at Chicago O'Hare International Airport, Runways 14R and 27L", DOT-FAA-AFS-420-86, October 2000.

[3] Lankford, David N. and Greenhaw, Richard, “Go Around Rates for Land and Hold Short Operations”, DOT-FAA-AFS-420-93, March 2003.