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Flight Operations Simulation and Analysis Branch, AFS-440
Flight Technologies and Procedures Division
Flight Standards Service

**Independent Instrument Approach
Procedures to Chicago O'Hare
Runways 14L and 14R and Chicago
Midway Runway 13C**



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Federal Aviation Administration
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Oklahoma City, OK 73125

December 2003

Technical Report



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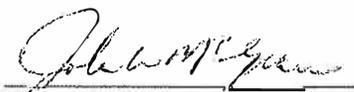
**Independent Instrument Approach Procedures to
Chicago O'Hare Runways 14L and 14R and
Chicago Midway Runway 13C**

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12. Abstract During certain weather conditions, Chicago O'Hare International (ORD) tower is forced to stagger approaches to runways 14R and 14L when approaches are being conducted to Chicago Midway (MDW) runway 13C. If the approaches are not staggered and simultaneous missed approaches occur from runways 14R and 14L, then the aircraft from runway 14R cannot be turned away from the approach to runway 13C thereby causing a potential loss of required separation. Staggering approaches to runways 14R and 14L at ORD results in a reduction in the Airport Acceptance Rate (AAR) at ORD from 72 to 60 per hour. The AAR at ORD could be improved to the normal rate of 72 per hour if the approaches to runways 14R and 14L could be conducted independently during periods when instrument approaches are required. A waiver to FAA Order 7110.65 can only be granted if the proposed procedure will provide an equivalent level of safety. An extensive computer simulation is required to determine whether independent approaches can provide an equivalent level of safety. The Flight Operations Simulation and Analysis Branch modified its Airspace Simulation and Analysis for TERPS (ASAT) computer modeling system in order to simulate four possible scenarios that could result from independent approach operations. The probability or risk associated with approach operations to ORD runways 14R and 14L and MDW 13C was found to be less than the target level of safety. Therefore, independent approach operations can be conducted safely at ORD to runways 14R and 14L and MDW runway 13C provided the approach controller at MDW is advised when a missed approach occurs at ORD.		
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EXECUTIVE SUMMARY

During certain weather conditions, Chicago O'Hare International (ORD) tower is forced to stagger approaches to runways 14R and 14L when approaches are being conducted to Chicago Midway (MDW) runway 13C. If the approaches are not staggered and simultaneous missed approaches occur from runways 14R and 14L, then the aircraft from runway 14R cannot be turned away from the approach to runway 13C thereby causing a potential loss of required separation. Staggering the approaches gives ORD the ability to provide separation between 14R and 14L missed approaches and the traffic landing on 13C at Midway. However, staggering approaches to runways 14R and 14L at ORD results in a reduction in the Airport Acceptance Rate (AAR) at ORD from 72 to 60 per hour. During these times, arrivals to MDW are virtually unrestricted. This apparent inequity may cause an undue economic hardship on the users of ORD.

It is anticipated that the AAR at ORD could be improved to the normal rate of 72 per hour if the approaches to runways 14R and 14L could be conducted independently during periods when instrument approaches are required. However, independent approaches would require a waiver to FAA Order 7110.65 separation standards. A waiver can only be granted if the proposed procedure will provide an equivalent level of safety.

An extensive computer simulation is required to determine whether independent approaches can provide an equivalent level of safety to Order 7110.65 separation standards. Therefore, the Operations Branch, AGL-530, Federal Aviation Administration (FAA) Great Lakes Regional Office requested that the FAA Flight Operations Simulation and Analysis Branch, AFS-440, develop and conduct a computer simulation.

The Flight Operations Simulation and Analysis Branch modified its Airspace Simulation and Analysis for TERPS (ASAT) computer modeling system to emulate geographical and aeronautical conditions peculiar to ORD and MDW. This included the precise relative location of runways, nav aids such as ILS, and surveillance radars. The electronic characteristics of the ILS and radars were also included in the model. AFS-440 worked closely with AGL-530 to determine scenarios for the simulation that would emulate anticipated air traffic procedures.

Since approaches to runways 14R and 14L must be staggered at ORD when MDW is conducting approaches to runway 13C, the primary situation of interest involves independent approaches to runways 14R and 14L with a missed approach from runway 14R while an aircraft is intercepting the localizer of the ILS of runway 13C at MDW. This situation can be resolved into four scenarios. In the first scenario, the aircraft approaching 14R performs a missed approach without a turn and with all engines operating. In the second scenario, the aircraft approaching 14R performs a missed approach without a turn and with one engine inoperative. In the third scenario, the aircraft approaching 14R performs a missed approach with a left turn after reaching 3,500 feet with all engines operating.

In the fourth scenario, the aircraft approaching 14R performs a missed approach with a left turn after reaching 3,500 feet with one engine inoperative. In all four scenarios, the aircraft approaching runway 13C at MDW is vectored to intercept the localizer for runway 13C.

In order to establish a probability density function of controller response time, a real time simulation test was carried out at the Elgin TRACON training facility near Chicago, IL on October 11, 2002. AFS-440 personnel supervised the simulation. AFS-440 personnel observed that the ORD departure controller verbally informed the MDW approach controller when a missed approach occurred at ORD. Additional testing was not performed where the ORD departure controller did not inform the MDW approach controller when a missed approach occurred at ORD.

For each of the simulation scenarios, one test realization consisted of an aircraft performing a missed approach from ORD runway 14R while a second aircraft turned to final for MDW runway 13C. The aircraft turning to final at MDW overshoots the turn with the amount of overshoot randomly selected. In each case, the smallest separation distance of the two aircraft as they flew simulated flight tracks, called the closest point of approach (CPA), was recorded. The CPA was the slant line distance between the centers of gravity of the two aircraft. If the CPA was less than 500 feet, a test criterion violation, TCV, was said to have occurred.

For each of the four scenarios, 100,000 simulated flights were conducted and their CPAs recorded. Probability density curves were developed for each set of CPA data. The probability of a TCV occurring during a scenario was estimated from the probability density curves.

The target level of safety is the maximum allowable probability of a collision. The target level of safety has been determined from historical data for various operations such as parallel independent instrument approaches. The most recent accident data was examined, along with departure rates, to determine the accident rate during ILS approaches. This rate was used to determine the rate that accidents could be allowed to occur and not increase the current overall ILS approach accident rate. The TLS was found to be 4×10^{-8} , or 1 accident per 25 million approaches.

The risk associated with scenario 1 was found to be 1.6×10^{-9} . The risk associated with scenario 2 was found to be 1.2×10^{-15} . The risk associated with scenario 3 was found to be 2.1×10^{-8} . The risk associated with scenario 4 was found to be 1.1×10^{-13} . However, during approach operations to ORD runways 14R and 14L and MDW runway 13C a TCV could be caused by the occurrence of any one of the four scenarios. Thus the total probability or risk associated with approach operations to ORD runways 14R and 14L and MDW 13C is the sum of the risks associated with each of the scenarios. The total risk was found to be 2.3×10^{-8} . This value is a conservative estimate of the total risk. The probability or risk associated with approach operations to ORD runways 14R and 14L and MDW 13C is less than the target level of safety.

Therefore, the approach operation represented by scenarios 1, 2, 3, and 4 can be considered to be a safe operation. However, since the ASAT simulation was conducted with the condition that the approach controller at MDW was informed when a missed approach occurred at ORD, it is recommended that this practice be an operational requirement.

TABLE OF CONTENTS

1.0. INTRODUCTION 1
2.0. SIMULATION SCENARIOS 1
3.0. ASAT REPRESENTATION OF THE FOUR SCENARIOS 3
4.0. TARGET LEVEL OF SAFETY AND TEST CRITERION VIOLATION 7
5.0. DESCRIPTION OF REAL-TIME SIMULATION 7
6.0. DESCRIPTION OF SIMULATION INPUT PARAMETERS 8
6.1. ORD RUNWAY 14R CONTROL PARAMETERS 8
6.2. MDW RUNWAY 13C CONTROL PARAMETERS 9
7.0. SIMULATION OUTPUT AND ANALYSIS 11
7.1. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 1 11
7.2. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 2 15
7.3. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 3 17
7.4. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 4 19
8.0. COMPILATION OF TOTAL RISK..... 21
9.0. CONCLUSIONS..... 22

LIST OF FIGURES

Figure 1. DESCRIPTION OF SIMULATION SCENARIOS 2
Figure 2: ASAT GRAPHIC DEPICTION OF SCENARIO 1 3
Figure 3: ASAT GRAPHIC DEPICTION OF SCENARIO 2 4
Figure 4: ASAT GRAPHIC DEPICTION OF SCENARIO 3 5
Figure 5: ASAT GRAPHIC DEPICTION OF SCENARIO 4 6
Figure 6: ASAT CONTROL PARAMETERS FORCHICAGO O’HARE RUNWAY
14R..... 10
Figure 7: ASAT CONTROL PARAMETERS FORCHICAGO MIDWAY RUNWAY
13C..... 12
Figure 8: ASAT CONTROL PARAMETERS FOR CHICAGO MIDWAY RUNWAY
13C TURN TO FINAL..... 13

LIST OF TABLES

Table 1. DESCRIPTION OF SIMULATION SCENARIOS..... 2

1.0. INTRODUCTION

During certain weather conditions, Chicago O'Hare International (ORD) tower is forced to stagger approaches to runways 14R and 14L when Instrument Landing System (ILS) approaches are being conducted to Chicago Midway (MDW) runway 13C. If the approaches are not staggered and simultaneous missed approaches occur from runways 14R and 14L, then the aircraft from runway 14R cannot be turned away from the approach to runway 13C thereby causing a potential loss of required separation. Staggering the approaches gives ORD the ability to provide separation between 14R and 14L missed approaches and the traffic landing on 13C at Midway. However, staggering approaches to runways 14R and 14L at ORD results in a reduction in the Airport Acceptance Rate (AAR) at ORD from 72 to 60 per hour. During these times, arrivals to MDW are virtually unrestricted. This apparent inequity may cause an undue economic hardship on the users of ORD.

It is anticipated that the AAR at ORD could be improved to the normal rate of 72 per hour if the approaches to runways 14R and 14L could be conducted independently during periods when instrument approaches are required. However, independent approaches would require a waiver to FAA Order 7110.65 separation standards. A waiver can only be granted if the proposed procedure will provide an equivalent level of safety.

An extensive computer simulation is required to determine whether independent approaches can provide an equivalent level of safety to Order 7110.65 separation standards. Therefore, the Operations Branch, AGL-530, Federal Aviation Administration (FAA) Great Lakes Regional Office, requested that the FAA Flight Operations Simulation and Analysis Branch, AFS-440, develop and conduct a computer simulation.

The Flight Operations Simulation and Analysis Branch modified its Airspace Simulation and Analysis for TERPS (ASAT) computer modeling system to emulate geographical and aeronautical conditions peculiar to ORD and MDW. This included the precise relative location of runways, nav aids such as ILS, and surveillance radars. The electronic characteristics of the ILS and radars were also included in the model. AFS-440 worked closely with AGL-530 to determine scenarios for the simulation that would emulate anticipated air traffic procedures.

2.0. SIMULATION SCENARIOS

Since approaches to runways 14R and 14L must be staggered at ORD when MDW is conducting approaches to runway 13C, the primary situation of interest involves independent approaches to runways 14R and 14L with a missed approach from runway 14R while an aircraft is intercepting the localizer of the ILS of runway 13C at MDW. This situation can be resolved into four scenarios. In the first scenario, the aircraft approaching 14R performs a missed approach without a turn and with all engines operating.

In the second scenario, the aircraft approaching 14R performs a missed approach without a turn and with one engine inoperative. In the third scenario, the aircraft approaching 14R performs a missed approach with a left turn after reaching 3,500 feet with all engines operating. In the fourth scenario, the aircraft approaching 14R performs a missed approach with a left turn after reaching 3,500 feet with one engine inoperative. In all four scenarios, the aircraft approaching runway 13C at MDW is vectored to intercept the localizer for runway 13C. The four scenarios are summarized in table 1. The properties of the four scenarios are also illustrated graphically in figure 1.

Scenario Number	O'Hare Runway 14R			Midway Runway 13C	
	Procedure	Mode	Engine Out	Procedure	Mode
1	Missed Approach	No Turn	NO	Land	Vectored
2			YES		
3		Turn @ 3,500Ft	NO		
4			YES		

Table 1. DESCRIPTION OF SIMULATION SCENARIOS

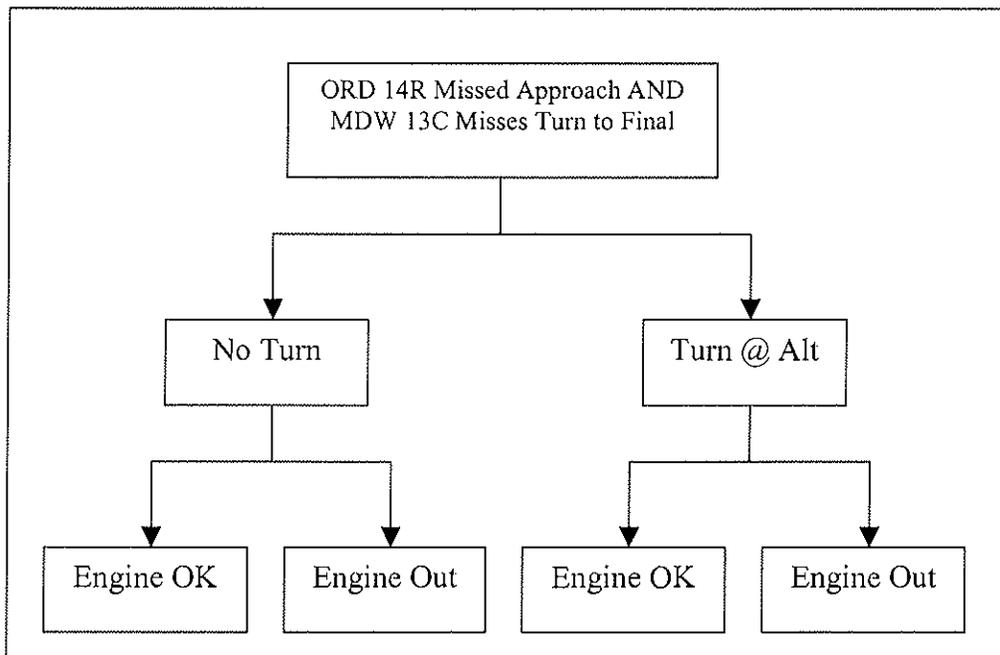


Figure 1. DESCRIPTION OF SIMULATION SCENARIOS

3.0. ASAT REPRESENTATION OF THE FOUR SCENARIOS

The ASAT computer system was adapted to represent the geographical and aeronautical features of the ORD and MDW complex. This included the precise relative location of runways, nav aids such as ILS, and surveillance radars. The electronic characteristics of the ILS and radars were also included in the model. The ASAT computer system was modified so that the computer operator could control the simulation from one comprehensive screen. The operator could select the scenario for the simulation along with the appropriate statistical parameters necessary for the simulation. The screen presented graphically the simulated tracks while the program stored data files for the statistical analysis. Figures 2 through 5 are screen captures of the ASAT that show the selection of some of the parameters necessary to conduct the simulation.

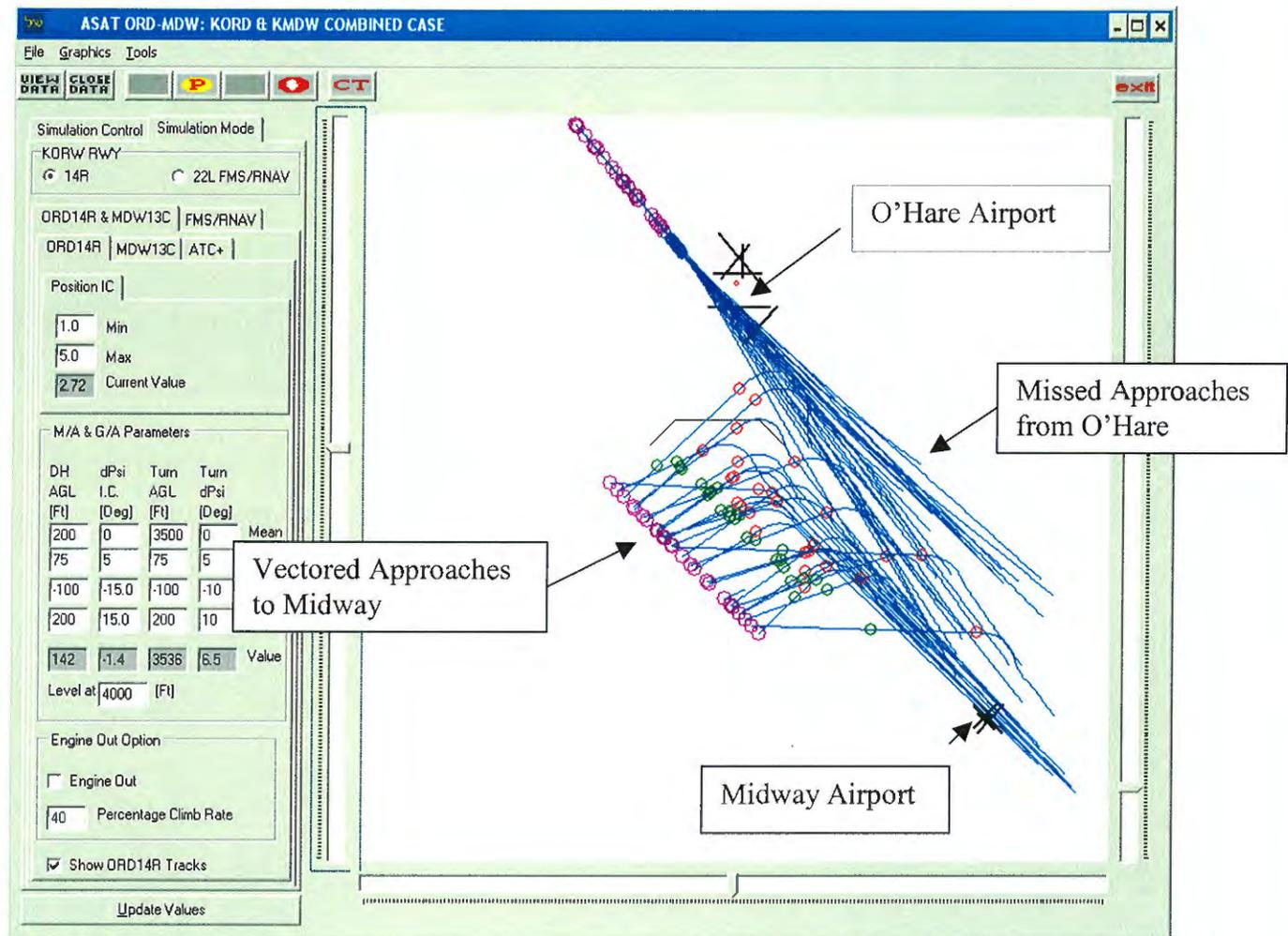


Figure 2: ASAT GRAPHIC DEPICTION OF SCENARIO 1

Figure 2 is a screen capture of the ASAT representation of scenario 1. In scenario 1, aircraft perform missed approaches from runway 14R at ORD.

The missed approach aircraft does not perform a turn and all engines are functioning. Aircraft are vectored to intercept the localizer for runway 13C at MDW and each simulated aircraft misses the ATC instruction to turn to final. The air traffic controller has to realize that the aircraft missed the turn to final and issue a second turn-to-final command.

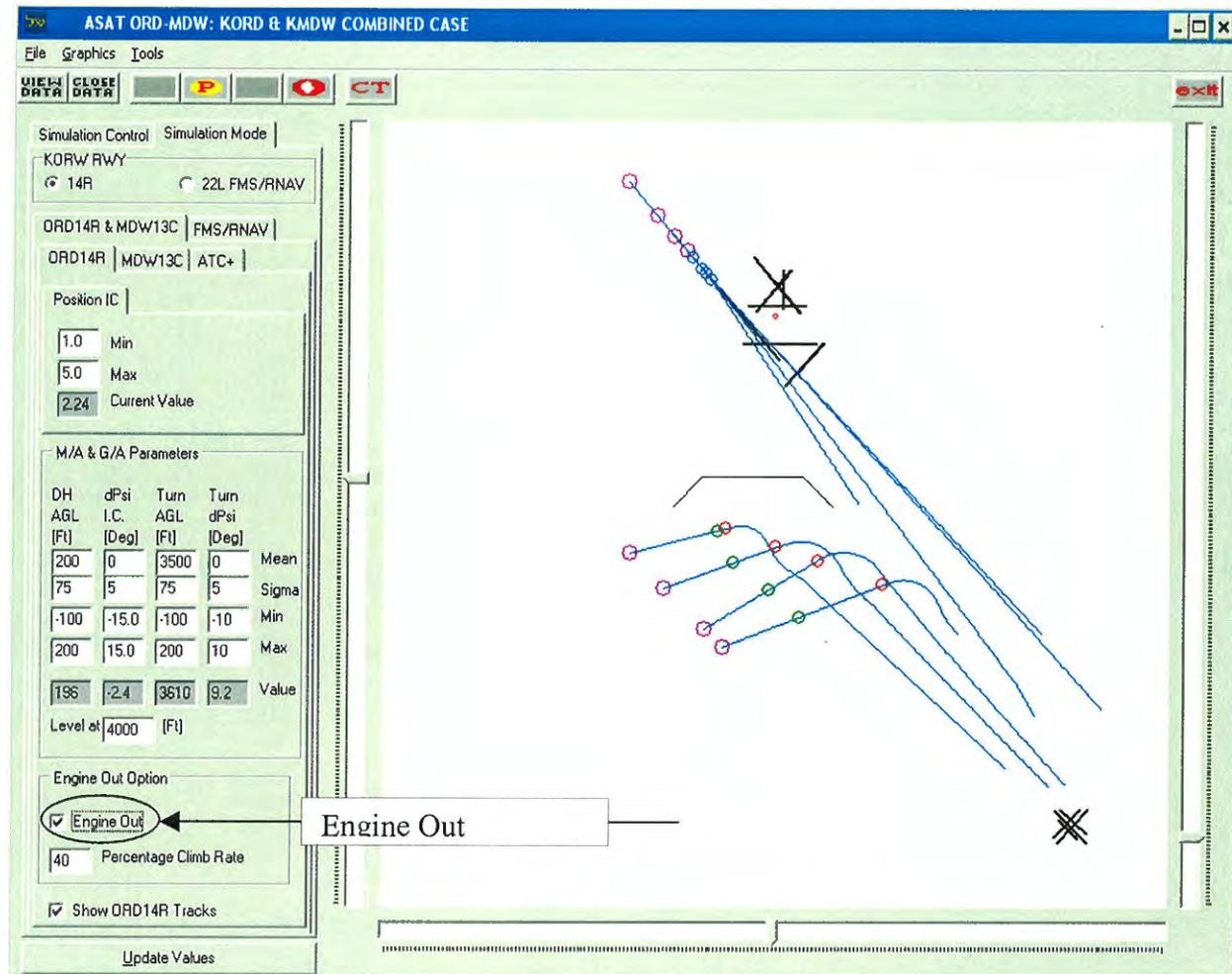


Figure 3: ASAT GRAPHIC DEPICTION OF SCENARIO 2

Scenario 2 is similar to scenario 1. The missed approaches from runway 14R at ORD do not turn. However, the missed approach is performed with one engine inoperative. Figure 3 shows the checkbox is selected for engine out. Aircraft are vectored to intercept the localizer for runway 13C at MDW and each simulated aircraft misses the ATC instruction to turn to final. The air traffic controller has to realize that the aircraft missed the turn to final and issue a second turn-to-final command.

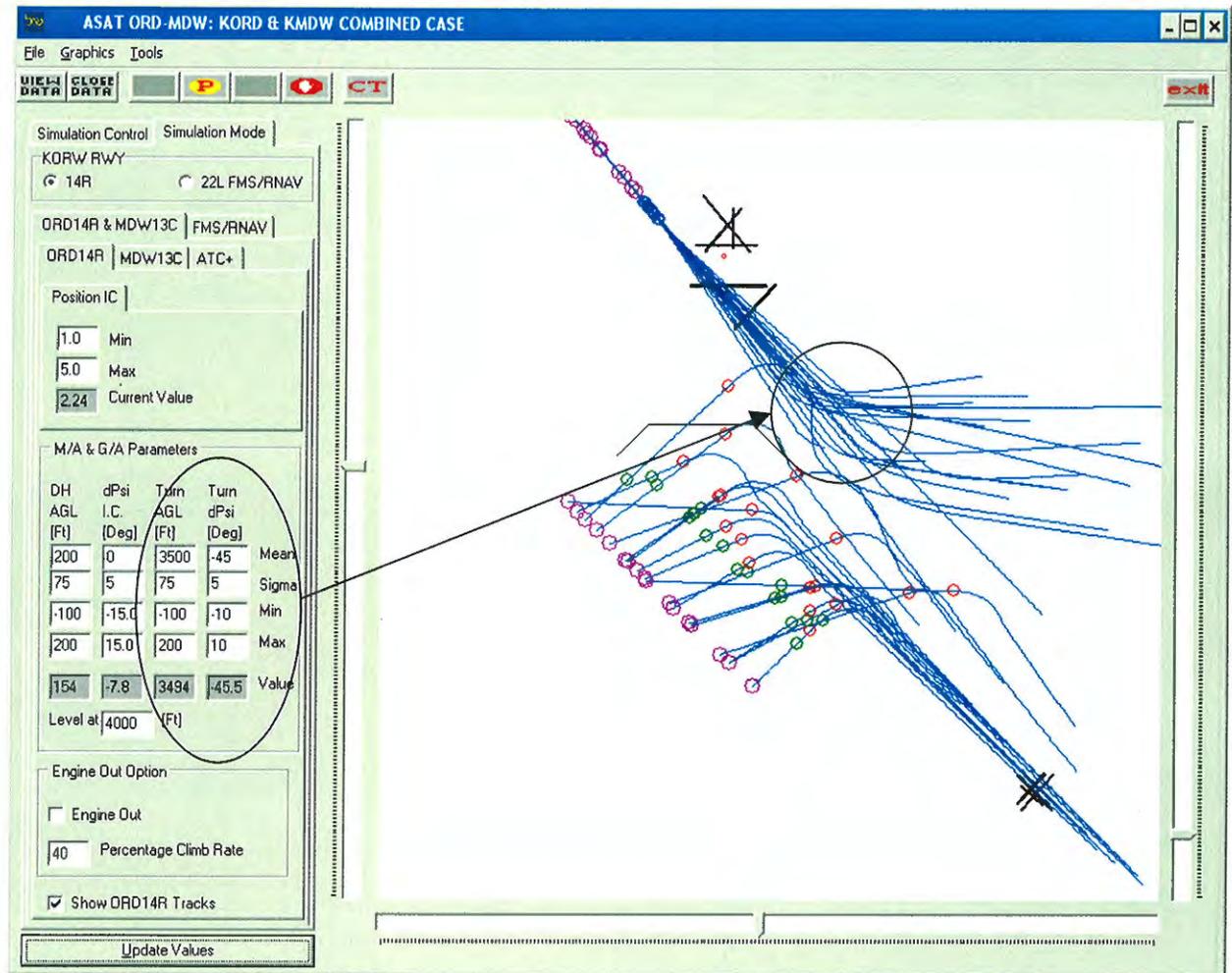


Figure 4: ASAT GRAPHIC DEPICTION OF SCENARIO 3

Figure 4 is a screen capture of the ASAT representation of scenario 3. In scenario 3, aircraft perform missed approaches from runway 14R at ORD. The missed approach aircraft performs a left turn and all engines are functioning. The left oval in figure 4 highlights the parameters used to determine the point and the amount of each turn. The right oval in figure 4 highlights the area in which the turns occur. Aircraft are vectored to intercept the localizer for runway 13C at MDW and each simulated aircraft misses the ATC instruction to turn to final. The air traffic controller has to realize that the aircraft missed the turn to final and issue a second turn-to-final command.

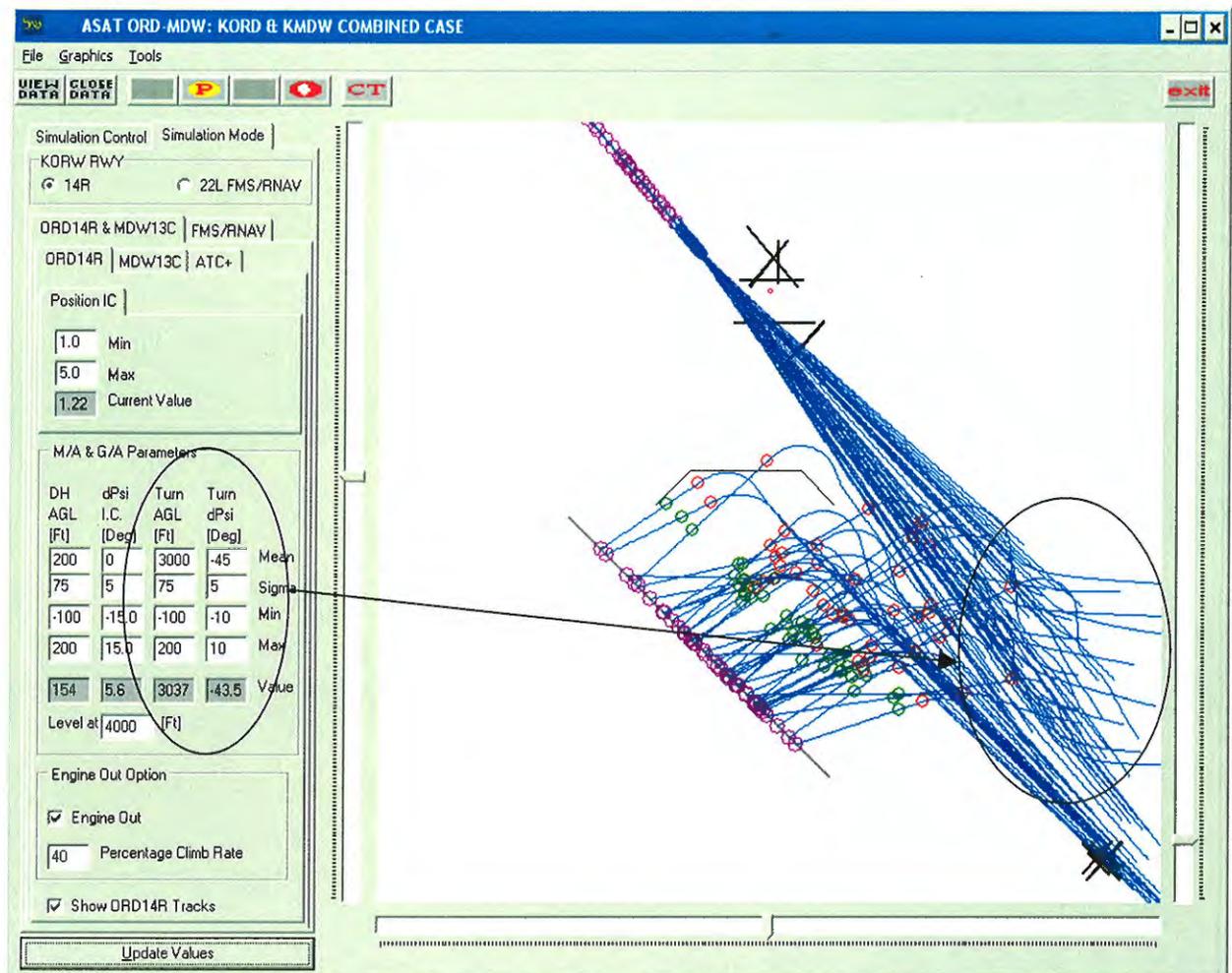


Figure 5: ASAT GRAPHIC DEPICTION OF SCENARIO 4

Scenario 4 is similar to scenario 3. Each missed approach from runway 14R at ORD performs a turn. However, the missed approach is performed with one engine inoperative. Figure 5 shows the checkbox is selected for engine out. The left oval in figure 5 highlights the parameters used to determine the point and the amount of each turn. The right oval in figure 5 highlights the area in which the turns occur. Aircraft are vectored to intercept the localizer for runway 13C at MDW and each simulated aircraft misses the ATC instruction to turn to final. The air traffic controller has to realize that the aircraft missed the turn to final and issue a second turn-to-final command.

4.0. TARGET LEVEL OF SAFETY AND TEST CRITERION VIOLATION

The target level of safety is the maximum allowable probability of a collision. The target level of safety has been determined from historical data for various operations such as parallel independent instrument approaches. The most recent accident data were examined, along with departure rates, to determine the accident rate during ILS approaches. This rate was used to determine the rate that accidents could be allowed to occur and not increase the current overall ILS approach accident rate. The TLS was found to be 4×10^{-8} , or 1 accident per 25 million approaches.

For each of the simulation scenarios, one test realization consisted of an aircraft performing a missed approach from ORD runway 14R while a second aircraft turned to final for MDW runway 13C. The aircraft turning to final at MDW overshoots the turn with the amount of overshoot randomly selected. In each case, the smallest separation distance of the two aircraft as they flew simulated flight tracks, called the closest point of approach (CPA), was recorded. The CPA was the slant line distance between the centers of gravity of the two aircraft. If the CPA was less than 500 feet, a test criterion violation, TCV, was said to have occurred. Although in reality, the occurrence of a TCV does not guarantee that a collision will occur; a TCV was treated as a collision. The TCV is a standard test criterion that was developed during the Multiple Parallel Approach Program and has been used in numerous studies and simulations.

5.0. DESCRIPTION OF REAL-TIME SIMULATION

A critical component of each scenario is the time required for ATC to realize that the aircraft vectored to MDW runway 13C missed the instruction to turn to final. The resulting distribution of controller recognition and reaction times directly determines the overshoot distance. Obviously, the number of large overshoot distances will affect the number of TCVs and the collision risk of the operation. In order to establish a probability density function of controller response time, a real time simulation test was carried out at the Elgin TRACON training facility near Chicago, Illinois on October 11, 2002.

The controllers that participated in the test were selected by the facility managers in coordination with NATCA representatives. At least one NATCA representative was present during the entire duration of the tests. The controllers were given a familiar ORD/MDW traffic scenario. During the tests, the "pilots" were asked to perform two tasks without controller awareness. The tasks were the following:

1. Upon the test manager's request, cause the aircraft approaching to runway 14R at Chicago O'Hare (ORD RWY14R) to execute a missed approach.

2. Upon the test manager's request, ignore the controller instruction given to the aircraft on base leg to runway 13C at Chicago Midway (MDW RWY13C) to turn and intercept the localizer.

Using silent stopwatches, the test manager and two assistants measured the elapsed time from when the instruction was given to a non-responding pilot to execute a turn (to heading 090 or to intercept MDW RWY13C localizer) until the controller realized that the pilot did not follow the original instruction and issued a new one. The digital data were recorded during the real-time simulation and all of the visual and audio data were also recorded using RAPTOR files.

AFS-440 personnel supervised the simulation and observed that the ORD departure controller verbally informed the MDW approach controller when a missed approach occurred at ORD. Additional testing was not performed where the ORD departure controller did not inform the MDW approach controller when a missed approach occurred at ORD.

6.0. DESCRIPTION OF SIMULATION INPUT PARAMETERS

Prior to the execution of a simulation run consisting of a missed approach from ORD and an approach to MDW, several variables were selected in a random manner to control the generation of both flight tracks. Because the two aircraft were not executing the same procedure, different statistical parameters were needed to control each one of the flight tracks. ASAT allows the operator to control the parameters that determine the way a given procedure is executed. If the parameter is determined from a probability density function, the operator has the ability to adjust values such as the mean and standard deviation of the distribution. The following section describes the way that the procedures are controlled for both aircraft. The operator enters control values using ASAT's Interactive Graphic User Interface (GUI).

6.1. ORD RUNWAY 14R CONTROL PARAMETERS

The following parameters (see figure 6) were either randomly determined by ASAT or set by the operator to control the tracks simulating the missed approach at ORD runway 14R:

a. "Position IC:" This variable determines how far from the threshold of runway 14R the aircraft is positioned at the beginning of the simulation run. This variable is selected from a uniform probability distribution with minimum value 1.0 NM and maximum value 5.0 NM from the threshold of runway 14R. The operator can change the values by highlighting the appropriate box and typing the desired value.

b. "DH AGL:" This variable determines the altitude at which the missed approach starts. This variable is selected from a truncated normal probability distribution with mean 200 FT and standard deviation 75 FT.

c. The minimum value is 100 FT and the maximum value is 400 FT. The operator can change the values by highlighting the appropriate box and typing the desired value.

d. “dPsi I.C.:

” This variable determines the ground track deviation during the initial climb phase of the go around prior to the first turn. This variable is selected from a truncated normal probability distribution with mean 0 degree and standard deviation 5 degrees. The minimum value is -15 degrees and the maximum value is 15 degrees. The operator can change the values by highlighting the appropriate box and typing the desired value.

e. “Turn AGL:” This variable determines the altitude at which the first turn is initiated during the go around. This variable is selected from a truncated normal probability distribution with mean 3500 FT and standard deviation 75 FT. The minimum value is 3400 FT and the maximum value is 3700 FT. The operator can change the values by highlighting the appropriate box and typing the desired value.

f. “Turn dPsi:” This variable determines the amount of turn performed during the first turn of the go around. This variable is selected from a truncated normal probability distribution with mean 0 degree and standard deviation 5 degrees. The minimum value is -10 degrees and the maximum value is 10 degrees. The operator can change the values by highlighting the appropriate box and typing the desired value.

g. “Engine Out:” This switch determines if the tracks will be generated under “Engine Out” conditions. This switch is not a random variable and must be set by the operator. If this switch is set, the climb performance of the aircraft executing a go-around is degraded and will be set to the product of the nominal climb performance (non engine out) and the value entered at the “Percentage Climb Rate” field (default=40%).

6.2. MDW RUNWAY 13C CONTROL PARAMETERS

The following parameters (see figure 7) were either randomly determined by ASAT or set by the operator to control the tracks simulating the vectored approach to Chicago Midway runway 13C:

a. “IC Tile Definition:” This set of variables defines the location and orientation of the imaginary tile from where tracks of flights into Chicago Midway runway 13DC will be initiated. These variables are constant during the simulation, but can be changed prior to the simulation by the operator.

b. “Position IC Distribution:” This section contains four controls that allow the operator the flexibility to select the following initial conditions related parameters associated with the tile defined in “a:”

1. “Position I.C.:

” Determines the distribution across the tile defined in “a” of the position of the aircraft at simulation initialization.

2. This is a normal distribution with mean 4.45 NM and standard deviation 2.03 NM. The minimum value is 3.79 NM and the maximum value is 11.17 NM.

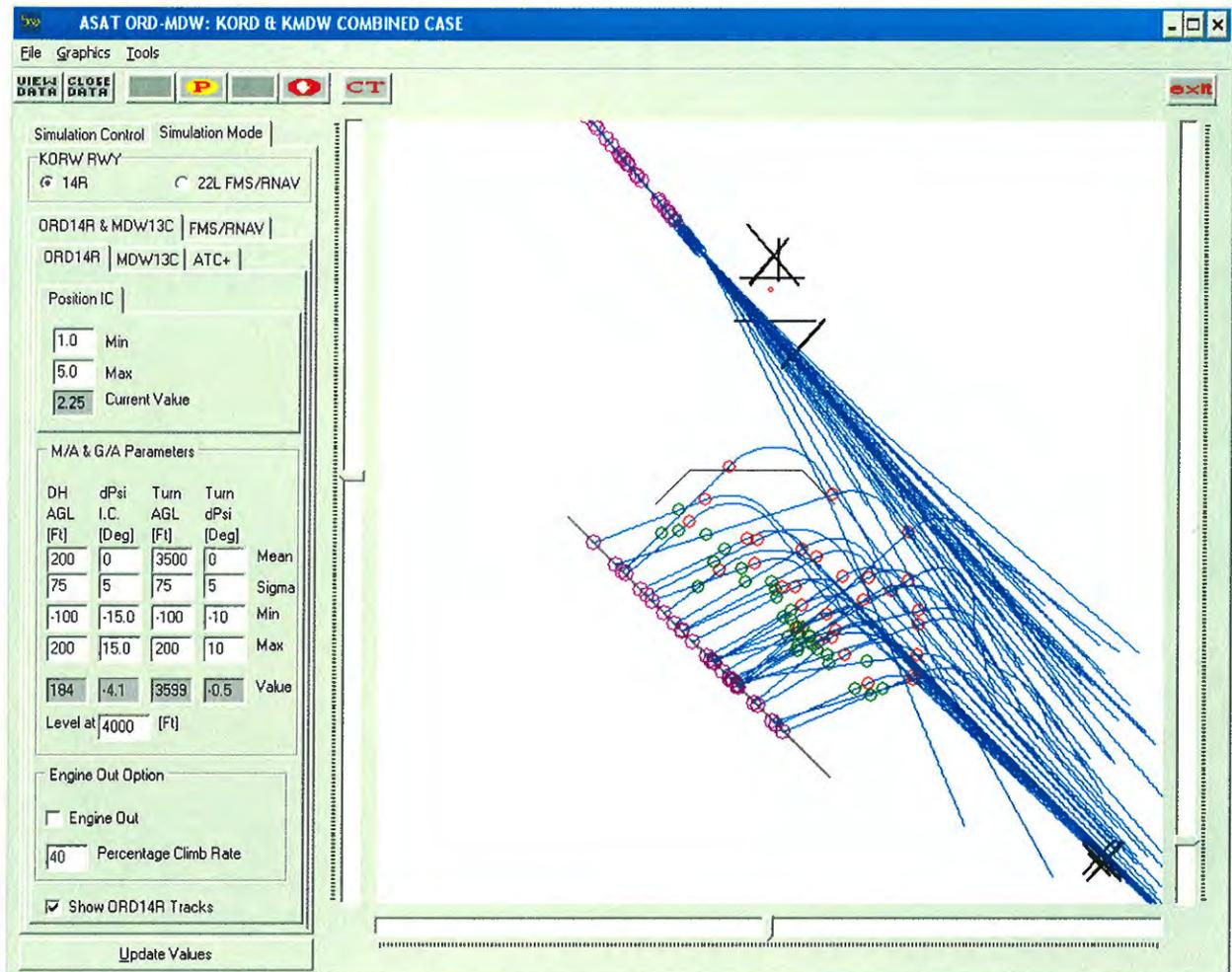


Figure 6: ASAT CONTROL PARAMETERS FOR CHICAGO O'HARE RUNWAY 14R

3. "Track I.C.:" Determines the distribution across the tile defined in "a" of the ground track of the aircraft at simulation initialization. This is a normal distribution with mean 55.7 degrees and standard deviation 22.2 degrees. The minimum value is 10.7 degrees and the maximum value is 150.7 degrees.

4. "Altitude I.C.:" Determines the distribution across the tile defined in "a" of the altitude of the aircraft at simulation initialization. This is a normal distribution with mean 1,528 FT and standard deviation 229.3 FT. The minimum value is 1,097 FT and the maximum value is 2,443 FT.

5. "Start After:" Determines the time differential between the simulation start of the track approaching to Chicago O'Hare runway 14R and the simulation start of the track approaching to Chicago Midway runway 13C.

6. This is a uniform distribution with minimum value 30 seconds and maximum value 90 seconds.

c. "Turn to Final" tab (see figure 8) contains variables that determine the overshoot or undershoot value during the turn to intercept the localizer. The size of the variation is controlled by the following parameters taken from a uniform distribution:

1. "Miss Min [NM]:" the lower end (or undershoot) in nautical miles. This value determines how early the turn will be initiated (undershoot) relative to the localizer centerline.

2. "Miss Max [NM]:" the upper end (or overshoot) in nautical miles. This value determines how late the turn will be initiated (overshoot) relative to the theoretical localizer centerline.

7.0. SIMULATION OUTPUT AND ANALYSIS

For each of the four scenarios, 100,000 simulated flights were conducted and their CPAs recorded. Probability density curves were developed for each set of CPA data. The probability of a TCV occurring during a scenario was estimated from the probability density curves. The probability of a CPA being less than or equal to 500 FT is found by mathematically determining the area under the curve for CPAs less than or equal to 500 FT. By letting X represent the value of a CPA, the probability is found from the equation:

$$P(X \leq 500) = \int_{-\infty}^{500} f(x) dx \quad (1)$$

The function $f(x)$ represents the probability density function.

7.1. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 1

The probabilities found from equation 1 do not completely describe the probability or risk associated with each of the four scenarios. The probabilities found using equation 1 are conditional probabilities. Each scenario assumes that a missed approach is performed from ORD runway 14R and almost simultaneously an aircraft overshoots the turn to final. Probabilities computed from equation 1 assume that at least two independent events have occurred: i.e., a missed approach from ORD runway 14R and an overshoot of the turn to final to MDW runway 14R. In scenario 1, three events have to occur, a missed approach from ORD runway 14R, a missed approach from ORD runway 14L, and an overshoot of the turn to final to MDW runway 14R. In scenario 1, the missed approach from ORD runway 14R is unable to turn because of the missed approach from ORD runway 14L.

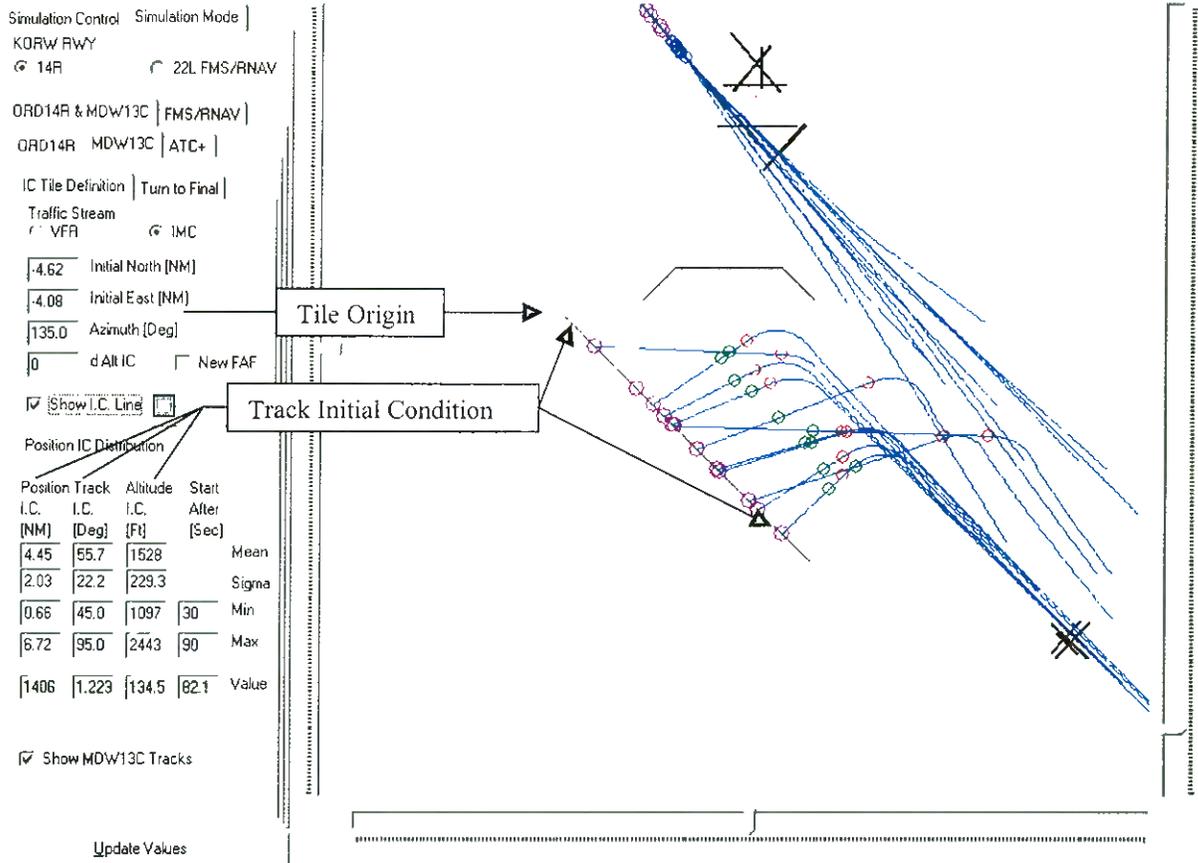


Figure 7: ASAT CONTROL PARAMETERS FOR CHICAGO MIDWAY RUNWAY 13C

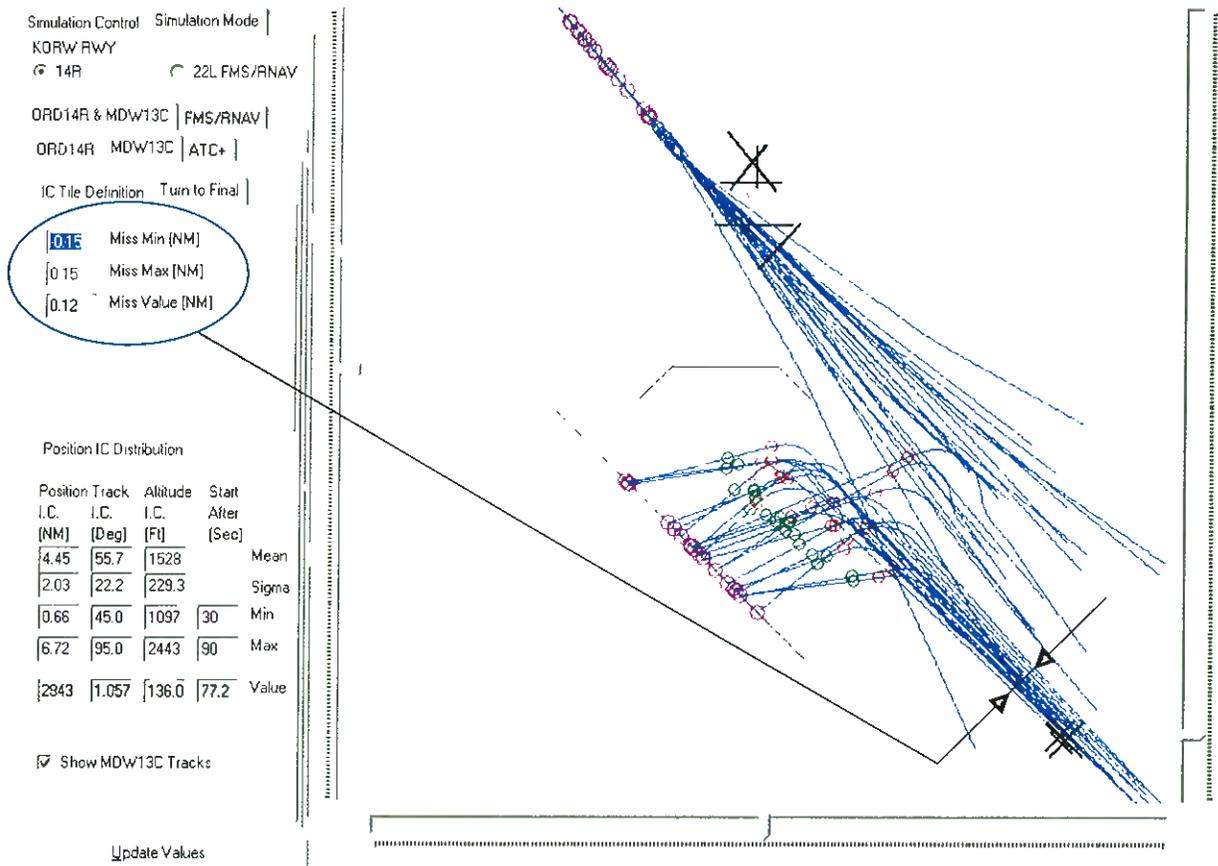


Figure 8: ASAT CONTROL PARAMETERS FOR CHICAGO MIDWAY RUNWAY 13C TURN TO FINAL

Suppose that the event “missed approach from ORD runway 14R” is denoted M14R, the event “missed approach from ORD runway 14L” is denoted by M14L, and the event “overshoot the approach to MDW runway 13C” is denoted by O13C, then the probability of a TCV caused by the conditions related to scenario 1 is given by the following probability equation.

$$\begin{aligned}
 P(TCV) &= P(TCV \cap M14R \cap M14L \cap O13C) \\
 &= P(TCV | M14R \cap M14L \cap O13C) \times P(M14R \cap M14L \cap O13C) \\
 &= P(TCV | M14R \cap M14L \cap O13C) \times P(O13C | M14R \cap M14L) \times P(M14R \cap M14L) \\
 &= P(TCV | M14R \cap M14L \cap O13C) \times P(O13C | M14R \cap M14L) \times P(M14R | M14L) \times P(M14L)
 \end{aligned}
 \tag{2}$$

The symbol “ \cap ” stands for “and.” The symbol “ $|$ ” stands for “given.”

The first factor in equation 2:

$$P(\text{TCV} | M14R \cap M14L \cap O13C)$$

is the probability of a TCV given that a missed approach from ORD runway 14R, a missed approach from ORD runway 14L and an overshoot to MDW runway 13C have all occurred. This is the probability that is estimated from the simulation of scenario 1. The application of equation 1 to the curve fitted to the CPA data determines that

$$P(\text{TCV} | M14R \cap M14L \cap O13C) = 3.8 \times 10^{-5}.$$

The second factor in equation 2:

$$P(O13R | M14R \cap M14L)$$

is the probability that an overshoot to MDW runway 13C occurs given that missed approaches occur on both ORD runways 14R and 14L. Since the occurrence of an overshoot to MDW runway 13C is independent of the missed approaches from ORD runways 14R and 14L, this probability can be written as:

$$P(O13R | M14R \cap M14L) = P(O13R).$$

Recent radar data indicates that 2 overshoots occurred out of 221 vectored turns to final to MDW runway 13C. Thus, $2/221$ is an estimate of the overshoot probability. If we assume that the probability of an overshoot remains constant over time and that one overshoot incident is independent of any other, then overshoots can be modeled as Bernoulli events.

In a Bernoulli experiment, two possible events can occur. The two events are usually called "success" and "failure." In this case, the two events are "overshoot" and "non-overshoot." When a Bernoulli experiment is repeated a number of times N and S successes are observed, then S/N is an estimate of the actual probability P of a success. But the number of successes S will vary with different samples of size N leading to different estimates of P . Therefore, a confidence interval is computed to determine the possible range of the actual probability P . The 99% confidence interval for P given the observed rate $2/221$ is $4.7 \times 10^{-4} \leq P \leq 4.1 \times 10^{-2}$. Therefore there is only a one percent chance that the actual rate is more than 4.1×10^{-2} . The result is a conservative (large) estimate of $P(O13R)$.

The third factor in equation 2:

$$P(M14R|M14L)$$

is the probability of a missed approach from ORD runway 14R given that a missed approach from ORD runway 14L occurs. These events may not be independent because weather conditions that force a missed approach may also tend to cause a missed approach from the other. The probability of a single missed approach is internationally estimated to be 1×10^{-2} . If the two events are independent, then the probability of a missed approach from ORD runway 14R given a missed approach from ORD runway 14L occurred would also be 1×10^{-2} . If the two events are dependent, then the conditional probability could be as high as 1×10^{-1} . Therefore the value of $P(M14R|M14L)$ will be assumed to be 1×10^{-1} . This results in a conservative estimate.

The fourth factor in equation 2:

$$P(M14L)$$

is the probability of a missed approach from ORD runway 14L. This probability is internationally assumed to be 1×10^{-2} and is considered a conservative estimate.

The risk associated with scenario 1 can now be computed from equation 2 as:

$$P(TCV) = 3.8 \times 10^{-5} \times 4.1 \times 10^{-2} \times 1 \times 10^{-1} \times 1 \times 10^{-2} = 1.6 \times 10^{-9}$$

7.2. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 2

Scenario 2 is similar to scenario 1. The difference is that a fourth event, one engine inoperative, must also occur. Therefore, four events have to occur, a missed approach from ORD runway 14R, a missed approach from ORD runway 14L, an overshoot of the turn to final to MDW runway 14R, and the failure of one engine in the missed approach aircraft from ORD runway 14R. In scenario 2, the missed approach from ORD runway 14R is unable to turn because of the missed approach from ORD runway 14L.

Suppose that the event “missed approach from ORD runway 14R” is denoted M14R, the event “missed approach from ORD runway 14L” is denoted by M14L, the event “overshoot the approach to MDW runway 13C” is denoted by O13C, and the event “failed engine” is denoted by FE, then the probability of a TCV caused by the conditions related to scenario 2 is given by the following probability equation.

$$\begin{aligned}
 P(TCV) &= P(TCV \cap M14R \cap M14L \cap O13C \cap FE) \\
 &= P(TCV|M14R \cap M14L \cap O13C \cap FE) \times P(O13C|M14R \cap M14L \cap FE) \\
 &\quad \times P(FE|M14R \cap M14L) \times P(M14L|M14R) \times P(M14R)
 \end{aligned}
 \tag{3}$$

The first factor in equation 3:

$$P(TCV|M14R \cap M14L \cap O13C \cap FE)$$

is the probability of a TCV given that a missed approach from ORD runway 14R, a missed approach from ORD runway 14L, an overshoot to MDW runway 13C, and a failed engine in the missed approach aircraft from ORD runway 14R have all occurred. This is the probability that is estimated from the simulation of scenario 2. The application of equation 1 to the curve fitted to the CPA data determines that

$$P(TCV|M14R \cap M14L \cap O13C \cap FE) = 6.3 \times 10^{-4}.$$

The second factor in equation 3:

$$P(O13R|M14R \cap M14L \cap FE)$$

is the probability that an overshoot to MDW runway 13C occurs given that missed approaches occur on both ORD runways 14R and 14L and a failed engine occurs on the missed approach aircraft from ORD runway 14R. Since the occurrence of an overshoot to MDW runway 13C is independent of the missed approaches from ORD runways 14R and 14L and a failed engine occurs on the missed approach aircraft from ORD runway 14R, this probability can be written as:

$$P(O13R|M14R \cap M14L \cap FE) = P(O13R).$$

This probability is the same as the second factor of equation 2 for scenario 1. Therefore:

$$P(O13R|M14R \cap M14L \cap FE) = P(O13R) = 4.1 \times 10^{-2}.$$

The third factor in equation 3:

$$P(FE|M14R \cap M14L)$$

is the probability of a failed engine on the missed approach aircraft from ORD runway 14R given that a missed approach from ORD runways 14R and 14L have occurred.

Since the probability of a failed engine is independent of the occurrence of missed approaches from ORD runways 14R and 14L, the third factor becomes:

$$P(FE|M14R \cap M14L) = P(FE).$$

Historical data indicates that between January 1, 1997 and January 1, 2003, twenty engine failures of air carrier aircraft occurred. During the same time period about 43,004,000 departures of air carrier aircraft occurred. Thus the probability of a failed engine during an air carrier flight is on the order of 4.7×10^{-7} . The probability of an engine failure during a missed approach or aborted landing will be much lower since the elapsed time during a missed approach or aborted landing is only a small fraction of the total time of a complete flight. Therefore,

$$P(FE|M14R \cap M14L) = P(FE) = 4.7 \times 10^{-7}.$$

is a conservative estimate of the probability of an engine failure during a missed approach or aborted landing.

The fourth and fifth factors of equation 3,

$$P(M14L|M14R) \text{ and } P(M14R)$$

have the same values as in scenario 1. Therefore,

$$P(M14L|M14R) = 1 \times 10^{-1}$$

and

$$P(M14R) = 1 \times 10^{-2}.$$

The risk associated with scenario 2 can now be computed from equation 3 as:

$$P(TCV) = 6.3 \times 10^{-5} \times 4.1 \times 10^{-2} \times 4.7 \times 10^{-7} \times 1 \times 10^{-1} \times 1 \times 10^{-2} = 1.2 \times 10^{-15}$$

7.3. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 3

Scenario 3 is similar to scenario 1. The difference is that a missed approach from ORD runway 14L does not occur and the missed approach from ORD 14R can be turned away from the ILS approach to MDW runway 13C. Therefore, three events have to occur, a missed approach from ORD runway 14R, a landing on ORD runway 14L, and an overshoot of the turn to final to MDW runway 14R.

As in scenarios 1 and 2, the event “missed approach from ORD runway 14R” is denoted M14R, the event “missed approach from ORD runway 14L” is denoted by M14L, and the event “overshoot the approach to MDW runway 13C” is denoted by O13C. The event “aircraft approaching ORD runway 14L lands and does not perform a missed approach,” is the negative of M14L and is denoted by $\overline{M14L}$. The probability of a TCV caused by the conditions related to scenario 3 is given by the following probability equation.

$$\begin{aligned} P(TCV) &= P(TCV \cap M14R \cap \overline{M14L} \cap O13C) \\ &= P(TCV|M14R \cap \overline{M14L} \cap O13C) \times P(O13C|M14R \cap \overline{M14L}) \quad (4) \\ &\quad \times P(\overline{M14L}|M14R) \times P(M14R) \end{aligned}$$

The first factor in equation 4:

$$P(TCV|M14R \cap \overline{M14L} \cap O13C)$$

is the probability of a TCV given that a missed approach from ORD runway 14R, a landing on ORD runway 14L, and an overshoot to MDW runway 13C have all occurred. This is the probability that is estimated from the simulation of scenario 3. The application of equation 1 to the curve fitted to the CPA data determines that

$$P(TCV|M14R \cap \overline{M14L} \cap O13C) = 5.6 \times 10^{-5}.$$

The second factor in equation 4:

$$P(O13R|M14R \cap \overline{M14L})$$

is the probability that an overshoot to MDW runway 13C occurs given that missed approach occurs on ORD runway 14R and a landing on ORD runway 14L. Since the occurrence of an overshoot to MDW runway 13C is independent of the missed approach from ORD runway 14R and the landing on ORD runway 14L, this probability can be written as:

$$P(O13R|M14R \cap \overline{M14L}) = P(O13R).$$

This probability is the same as the second factor of equation 2 for scenario 1. Therefore:

$$P(O13R|M14R \cap \overline{M14L}) = P(O13R) = 4.1 \times 10^{-2}$$

The third factor in equation 4 is the probability that a missed approach from ORD 14L does not occur given that a missed approach from ORD 14R does occur. This probability can be found from the probability that a missed approach from ORD 14L occurs given that missed approach from ORD 14R does occur.

The value of the third factor is given by:

$$P(\overline{M14L}|M14R) = 1 - P(M14L|M14R) = 9 \times 10^{-1}$$

The fourth factor of equation ,

$$P(M14R)$$

has the same values as in scenario 1. Therefore,

$$P(M14R) = 1 \times 10^{-2}.$$

The risk associated with scenario 3 can now be computed from equation 3 as:

$$P(TCV) = 5.6 \times 10^{-5} \times 4.1 \times 10^{-2} \times 9 \times 10^{-1} \times 1 \times 10^{-2} = 2.1 \times 10^{-8}$$

7.4. ANALYSIS OF RISK ASSOCIATED WITH SCENARIO 4

Scenario 4 is similar to scenario 2. The difference is that a landing occurs on ORD runway 14L. Therefore, four events have to occur, a missed approach from ORD runway 14R, a landing on ORD runway 14L, an overshoot of the turn to final to MDW runway 14R, and the failure of one engine in the missed approach aircraft from ORD runway 14R.

As in scenarios 1, 2, and 3, the event “missed approach from ORD runway 14R” is denoted M14R, the event “missed approach from ORD runway 14L” is denoted by M14L, the event “overshoot the approach to MDW runway 13C” is denoted by O13C, and the event “failed engine” is denoted by FE. The event “aircraft approaching ORD runway 14L lands and does not perform a missed approach,” is the negative of M14L and is denoted by $\overline{M14L}$. The probability of a TCV caused by the conditions related to scenario 4 is given by the following probability equation.

$$\begin{aligned} P(TCV) &= P(TCV \cap M14R \cap \overline{M14L} \cap O13C \cap FE) \\ &= P(TCV|M14R \cap \overline{M14L} \cap O13C \cap FE) \times P(O13C|M14R \cap \overline{M14L} \cap FE) \\ &\quad \times P(FE|M14R \cap \overline{M14L}) \times P(\overline{M14L}|M14R) \times P(M14R) \end{aligned} \tag{5}$$

The first factor in equation 5:

$$P(TCV|M14R \cap \overline{M14L} \cap O13C \cap FE)$$

is the probability of a TCV given that a missed approach from ORD runway 14R, a landing on ORD runway 14L, an overshoot to MDW runway 13C, and a failed engine in the missed approach aircraft from ORD runway 14R have all occurred. This is the probability that is estimated from the simulation of scenario 4. The application of equation 1 to the curve fitted to the CPA data determines that

$$P(\text{TCV}|M14R \cap \overline{M14L} \cap O13C \cap FE) = 6.5 \times 10^{-4}.$$

The second factor in equation 5:

$$P(O13R|M14R \cap \overline{M14L} \cap FE)$$

is the probability that an overshoot to MDW runway 13C occurs given that a missed approach occurs from ORD runway 14R, a landing occurs on ORD runway 14L, and a failed engine occurs on the missed approach aircraft from ORD runway 14R. Since the occurrence of an overshoot to MDW runway 13C is independent of the missed approach from ORD runway 14R, the landing on ORD runway 14L, and a failed engine occurrence on the missed approach aircraft from ORD runway 14R, this probability can be written as:

$$P(O13R|M14R \cap \overline{M14L} \cap FE) = P(O13R).$$

This probability is the same as the second factor of equation 2 for scenario 1. Therefore:

$$P(O13R|M14R \cap \overline{M14L} \cap FE) = P(O13R) = 4.1 \times 10^{-2}.$$

The third factor in equation 5:

$$P(FE|M14R \cap \overline{M14L})$$

is the probability of a failed engine on the missed approach aircraft from ORD runway 14R given that a missed approach from ORD runway 14R and a landing on ORD runway 14L have occurred. Since the probability of a failed engine is independent of the occurrence of a missed approach from ORD runway 14R and a landing on ORD 14L, the third factor becomes:

$$P(FE|M14R \cap \overline{M14L}) = P(FE).$$

This probability is the same as the probability of an engine failure found in scenario 2. Therefore,

$$P(FE|M14R \cap \overline{M14L}) = P(FE) = 4.7 \times 10^{-7}.$$

The fourth and fifth factors of equation 3,

$$P(\overline{M14L}|M14R) \text{ and } P(M14R)$$

have the same values as in scenario 1 and 3. Therefore,

$$P(\overline{M14L}|M14R) = 9 \times 10^{-1}$$

and

$$P(M14R) = 1 \times 10^{-2}.$$

The risk associated with scenario 4 can now be computed from equation 5 as:

$$P(TCV) = 6.5 \times 10^{-4} \times 4.1 \times 10^{-2} \times 4.7 \times 10^{-7} \times 9 \times 10^{-1} \times 1 \times 10^{-2} = 1.1 \times 10^{-13}$$

8.0. COMPILATION OF TOTAL RISK

Paragraphs 7.1, 7.2, 7.3, and 7.4 presented the risk associated with each of the four scenarios. In each of the paragraphs conservative estimates of the probability of an overshoot during the turn to final to MDW runway 13C, of a missed approach, and an engine failure were used. This results in conservative estimates of the risk associated with each scenario, i.e., the computed risks can be considered to be upper bounds of the actual risk. However, during approach operations to ORD runways 14R and 14L and MDW runway 13C a TCV could be caused by the occurrence of any one of the four scenarios. If we denote the occurrence of a TCV during scenario 1 by SC1, during scenario 2 by SC2, during scenario 3 by SC3, and during scenario 4 by SC4, then the probability of a TCV can be written as follows:

$$P(TCV) = P(SC1 \cup SC2 \cup SC3 \cup SC4) \tag{6}$$

where the symbol “ \cup ” stands for the word “or.”

The four scenarios are mutually exclusive events, i.e., they cannot occur simultaneously. This means that equation 6 can be written as follows:

$$P(TCV) = P(SC1 \cup SC2 \cup SC3 \cup SC4) = P(SC1) + P(SC2) + P(SC3) + P(SC4)$$

Thus the total probability or risk associated with approach operations to ORD runways 14R and 14L and MDW 13C can be determined as follows:

$$P(TCV) = 1.6 \times 10^{-9} + 1.2 \times 10^{-15} + 2.1 \times 10^{-8} + 1.1 \times 10^{-13} = 2.3 \times 10^{-8}$$

This probability or risk is based upon conservative assumptions and is therefore also a conservative estimate of the risk. Since this estimate is less than the target level of safety, the actual probability or risk associated with approach operations to ORD runways 14R and 14L and MDW 13C is less than the target level of safety. Therefore, the approach operations represented by scenarios 1, 2, 3, and 4 can be considered to be a safe operation.

9.0. CONCLUSIONS

Four scenarios were designed, simulated, and analyzed to assess the risk associated with missed or aborted approaches from Chicago O'Hare International, runways 14L and 14R, while ILS approaches are being conducted at Chicago Midway runway 13C. In the first scenario, the aircraft approaching ORD 14R and 14L perform missed approaches without a turn and with all engines operating. In the second scenario, the aircraft approaching ORD 14R and 14L perform missed approaches without a turn and with one engine inoperative on the aircraft approaching 14R. In the third scenario, the aircraft approaching ORD 14R performs a missed approach with a left turn after reaching 3,500 feet with all engines operating. In the fourth scenario, the aircraft approaching 14R performs a missed approach with a left turn after reaching 3,500 feet with one engine inoperative. In all four scenarios, the aircraft approaching runway 13C at MDW is vectored to intercept the localizer for runway 13C and overshoots the localizer.

In order to establish a probability density function of controller response time, a real time simulation test was carried out at the Elgin TRACON training facility near Chicago Illinois on October 11, 2002. During the test, the ORD departure controller verbally informed the MDW approach controller when a missed approach occurred at ORD. Additional testing was not performed where the ORD departure controller did not inform the MDW approach controller when a missed approach occurred at ORD.

In each of the simulations, pairs of aircraft were simulated. One aircraft performed a missed approach from runway 14R at ORD and the other aircraft performed the vector-to-final phase of the ILS approach to MDW runway 13C. Critical parameters that determined the aerodynamic behavior of the two aircraft were randomly selected from probability distributions developed from actual flight data. The types of aircraft were randomly selected based on the traffic mix at ORD and MDW. The probability distributions of controller and pilot reaction times during the vector-to-final phase of the ILS approach at MDW were based on actual pilot and controller data. Each simulation was performed 100,000 times.

The test criterion used in the simulation was the Test Criterion Violation (TCV). A TCV is said to have occurred when the slant distance between the centers of gravity of the two aircraft becomes less than 500 feet. The target level of safety for the scenarios was based on the target level of safety established for ILS approaches. The target level of safety is the maximum risk of collision that will be permitted. The target level of safety was set at 4×10^{-8} .

