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TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) AND PRECISION RUNWAY MONITOR (PRM) COLLISION RISK DIFFERENCES IN THE CLOSELY SPACED APPROACH ENVIRONMENT

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12. Abstract

When the precision runway monitor (PRM) was certified to monitor closely spaced approaches it was recommended that the TCAS be placed in the traffic alert (TA) mode that provides warning but not resolution of conflicts. Since TCAS was not designed for use during parallel approaches, it was assumed that TCAS in the resolution alert (RA) mode might issue an excessive number of false alerts. The Airline Pilots Association (ALPA) has asked the Federal Aviation Administration (FAA) to determine the feasibility of leaving the TCAS in the resolution alert (RA) mode throughout a closely spaced approach. The Flight Procedure Standards Branch (AFS-420) was asked to conduct a data collection and analysis to compare the risk associated with using TCAS with RA as the only traffic alert system using PRM with TCAS set in the RA mode and to evaluate the potential for false alerts. For risk evaluation, if the aircraft centers of gravity passed within 500 feet of each other a test criterion violation (TCV) was said to have occurred. The target level of safety adopted for the occurrence of a TCV was 4×10^{-8}. The risk analysis covered a wide range of operational scenarios with parallel runways spaced at 3,400 feet (parallel localizer beams), parallel runways spaced at 3,000 feet with one localizer offset 3 degrees, and simultaneous offset instrument approaches (SOIA). The false alert scenarios differed from the scenarios used for risk evaluation since they consisted of normal aircraft operations without the occurrence of blunders and evasive maneuvers. The simulation indicated that the target level of safety was not met when TCAS was used alone without PRM. The target level of safety was met when using TCAS in conjunction with PRM. The simulation indicated that the false alert rate was not excessive during any of the three general conditions that were simulated. Therefore, the TCAS may be set to the RA mode without excessive false alerts, but if a pilot responds to a TCAS RA alert, then the pilot must also follow the PRM controller turn instruction to meet the target level of safety using the standard 500-foot TCV.

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EXECUTIVE SUMMARY

When the precision runway monitor (PRM) system was certified to monitor closely spaced approaches (runways as close as 3,000 feet apart) it was recommended that the TCAS be placed in the traffic alert (TA) mode that provides warning but not resolution of conflicts. Since TCAS was not designed for use during parallel approaches, it was assumed that TCAS in the resolution alert (RA) mode might issue an excessive number of false alerts. Since the PRM provides 1-second update rate, sophisticated alert algorithms, and future position predictive software, the Airline Pilots Association (ALPA) initially accepted this TA-only procedure. However, ALPA recently has asked the Federal Aviation Administration (FAA) to determine the feasibility of leaving the TCAS in the resolution alert (RA) mode throughout a closely spaced approach. The Flight Procedure Standards Branch (AFS-420) was asked to conduct a data collection and analysis to compare the risk associated with using TCAS set in the RA mode as the only traffic alert system using PRM with TCAS set in the RA mode and to evaluate the potential for false alerts.

Collision risk based on the PRM monitor controller's instructions assumed a 500-foot protective sphere surrounding the endangered aircraft. Penetration of this sphere was considered a Test Criterion Violation (TCV). Using the sphere as the measure of protection, the collision risk for PRM collision avoidance was determined to be at most 4×10^{-8}.

A Monte Carlo study was performed using AFS-420's Airspace Simulation and Analysis for TERPS (ASAT) system to determine the level of safety that TCAS can provide under a closely spaced parallel approach (CSPA) blunder environment.

The risk analysis covered a wide range of operational scenarios with parallel runways spaced at 3,400 feet (parallel localizer beams), parallel runways spaced at 3,000 feet with one localizer offset 3 degrees, and simultaneous offset instrument approaches (SOIA). Both cases were analyzed for TCAS Sensitivity Levels (SL) of 3 and 4 and for blunder angles of 20 degrees and 30 degrees.

The simulation indicated that the target level of safety was not met when TCAS was set in the RA mode and used alone without PRM. That is, when the pilot followed only a TCAS climb or descend instruction without a turn instruction, the target level of safety was not met. The target level of safety was met when using TCAS in conjunction with PRM. That is, when the TCAS climb or descend instruction was coupled with a turn instruction from the air traffic controller using PRM the target level of safety was met. Therefore, if a pilot responds to a TCAS RA alert, then the pilot must also follow the PRM controller turn instruction to meet the target level of safety using the standard 500-foot TCV.

The investigation also considered five scenarios consisting of normal aircraft operations without the occurrence of blunders and evasive maneuvers for the evaluation of the false alert rate while using PRM with TCAS in the RA mode. The five scenarios can be grouped into three distinct categories; those with parallel localizers and runways spaced 3,400 feet apart, those with one localizer offset 3 degrees with runways spaced 3,000 feet apart, and a SOIA approach to runways

spaced 750 feet apart. The simulation indicated that the false alert rate was not excessive during any of the three general conditions that were simulated. Therefore, the TCAS may be set to the RA mode during dual parallel approaches with PRM without excessive false alerts.

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1.0 INTRODUCTION

When the PRM was certified to monitor closely spaced approaches (runways as close as 3,000 feet apart), it was recommended that the TCAS be placed in the traffic alert (TA) mode that provides warning but not resolution of conflicts. Since TCAS was not designed for use during parallel approaches, it was assumed TCAS in the resolution alert (RA) mode might issue an excessive number of false alerts. Since the PRM provides 1-second update rate, sophisticated alert algorithms, and future position predictive software, the Airline Pilots Association (ALPA) initially accepted this TA-only procedure. However, ALPA recently has asked the Federal Aviation Administration (FAA) to determine the feasibility of keeping the TCAS in the resolution alert (RA) mode throughout a closely spaced approach.

The Flight Procedure Standards Branch (AFS-420) was asked to conduct a data collection and analysis to compare the risk associated with using TCAS with RA as the only traffic alert system using PRM with TCAS set in the RA mode and to evaluate the potential for false alerts. Data were collected at United Airlines Training Center in Denver, Colorado using certified flight simulators flown by current and qualified airline pilots.

Collision risk based on the PRM monitor controller's instructions assumed a 500-foot protective sphere surrounding the endangered aircraft. Penetration of this sphere was considered a Test Criterion Violation (TCV). Using the 500-foot sphere as the measure of protection, the target level of safety (TLS) for PRM collision avoidance was determined to be at most 4×10^{-8}. The purpose of this final report is to determine whether TCAS in RA mode alone or PRM with TCAS in RA mode meet the target level of safety when using the standard 500-foot test criterion. An additional purpose is the evaluation of the false alert rate.

Preliminary data developed for this report indicated that TCAS in RA mode without PRM did not meet the target level of safety for the standard 500-foot sphere. The TCAS RA is considered to be the protection of last resort by ALPA, providing a measure of collision avoidance in the extremely unlikely event that a blunder occurs and PRM fails or all communications are lost. ALPA asked the FAA to conduct an analysis assuming that an endangered aircraft in a closely spaced approach scenario was required to rely only on the TCAS RA for collision avoidance. Based on that assumption, the FAA was asked to determine the radius of the protective sphere surrounding the endangered aircraft that would yield a collision risk of 4×10^{-8}. The results of that study can be found in appendix A.

2.0 SIMULATION SCENARIOS DESCRIPTION

A Monte Carlo study was performed using AFS-420's Airspace Simulation and Analysis for TERPS (ASAT) system to determine the level of safety that TCAS can provide under a closely spaced parallel approach (CSPA) blunder environment.

The analysis covered a wide range of operational scenarios with parallel runways spaced at 3,400 feet (parallel localizer beams) and parallel runways spaced at 3,000 feet with one localizer offset 3 degrees. Since the missed approach point (MAP) of the simultaneous offset instrument approach (SOIA) at San Francisco is located 3,000 feet from the adjacent extended centerline, the risk analysis for runways spaced 3,000 feet apart applies to SOIA. Both cases were analyzed for TCAS Sensitivity Levels (SL) of 3 and 4 and for blunder angles of 20 degrees and 30 degrees. The standard blunder angle used in the risk analysis of multiple parallel approaches is 30 degrees. However, in this simulation, 20-degree blunders were included to test the sensitivity of TCAS to less severe blunder angles and to evaluate the TCAS false alert rate. Table 1 lists the different runway configurations and operational scenarios that were tested.

Scenario Number	Purpose	Runways Spacing	Blunder Angle	TCAS SL	Evasive Maneuver	
					Vertical	Vertical + Turn
1	Risk	3,400	30	3	√	
2						√
3				4	√	
4						√
5			20	3	√	
6						√
7				4	√	
8						√
9		3,000	30	3	√	
10						√
11				4	√	
12						√
13			20	3	√	
14						√
15				4	√	
16						√
17	False Alerts	3,400	N/A	3	N/A	
18				4		
19		3,000		3		
20				4		
21		750 (SFO)		3		

Table 1: DESCRIPTION OF ASAT RUNWAY CONFIGURATIONS AND OPERATIONAL SCENARIOS

In all scenarios a pair of aircraft approach to a pair of closely spaced parallel runways. The "Own Ship" (OS) approaches the left runway while the "Adjacent Ship" (AS) approaches the right runway.

In all of the scenarios, scenarios 1 through 16, the AS blunders towards the OS, causing the OS to take evasive action. The OS can perform one of two evasive maneuvers:

a. Follow the TCAS instruction only. This will result in an evasive maneuver based solely on climb or descend.

b. Follow the TCAS instruction and the PRM controller instructions to turn. This will result in an evasive maneuver composed of climb or descend in conjunction with a turn.

In all of the false alert evaluation scenarios (scenarios 17 through 21) both aircraft execute simultaneous approaches without any blunder occurring. Scenario 21 models a procedure to San Francisco International Airport (SFO) that addresses the flight path in the visual segment between the Localizer-Type Directional Aid (LDA) Missed Approach Point (MAP) and runway threshold. When the aircraft descends below 900 feet radar altitude no RAs are issued.

Figures 1 and 2 depict the ASAT graphic on-line output for scenarios number 1 and 2, respectively. In both figures, critical relevant information is shown to assist the reader in understanding the definition of each one of the scenarios.

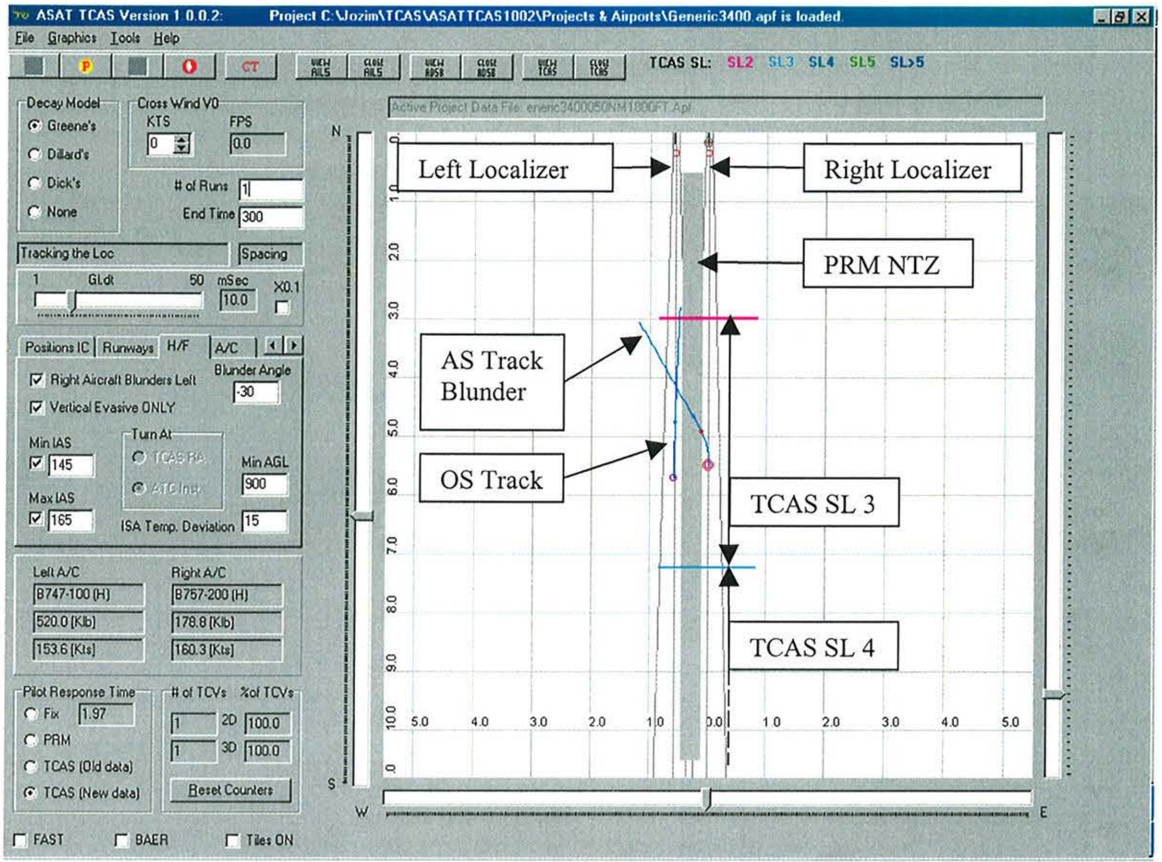


Figure 1: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 1

SCENARIO 1 DESCRIPTION: RISK ANALYSIS

a.	**Runway Spacing:**	3,400 feet
b.	**Blunder Angle:**	30 degrees
c.	**TCAS Sensitivity Level:**	3
d.	**Evasive Action:**	TCAS command only

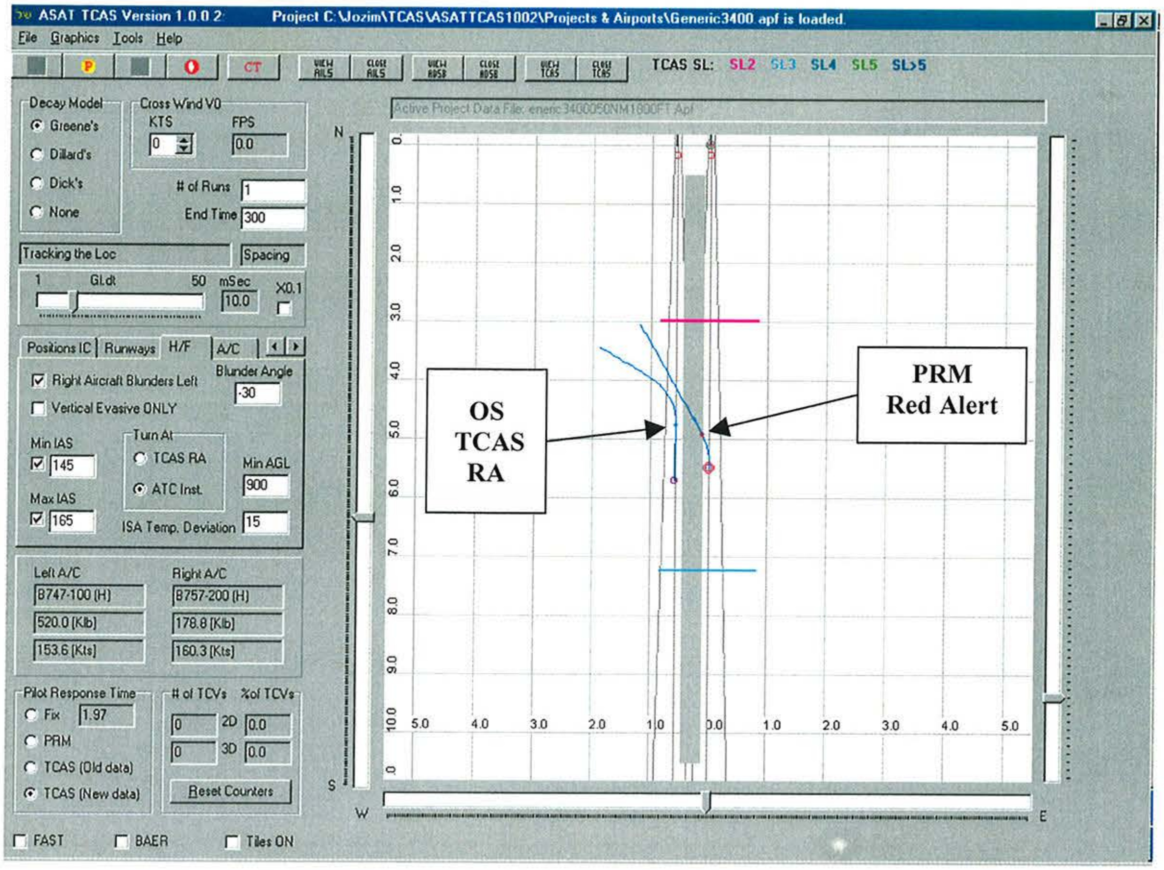


Figure 2: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 2

SCENARIO 2 DESCRIPTION: RISK ANALYSIS

a. **Runway Spacing:** 3,400 feet

b. **Blunder Angle:** 30 degrees

c. **TCAS Sensitivity Level:** 3

d. **Evasive Action:** TCAS command + Turn

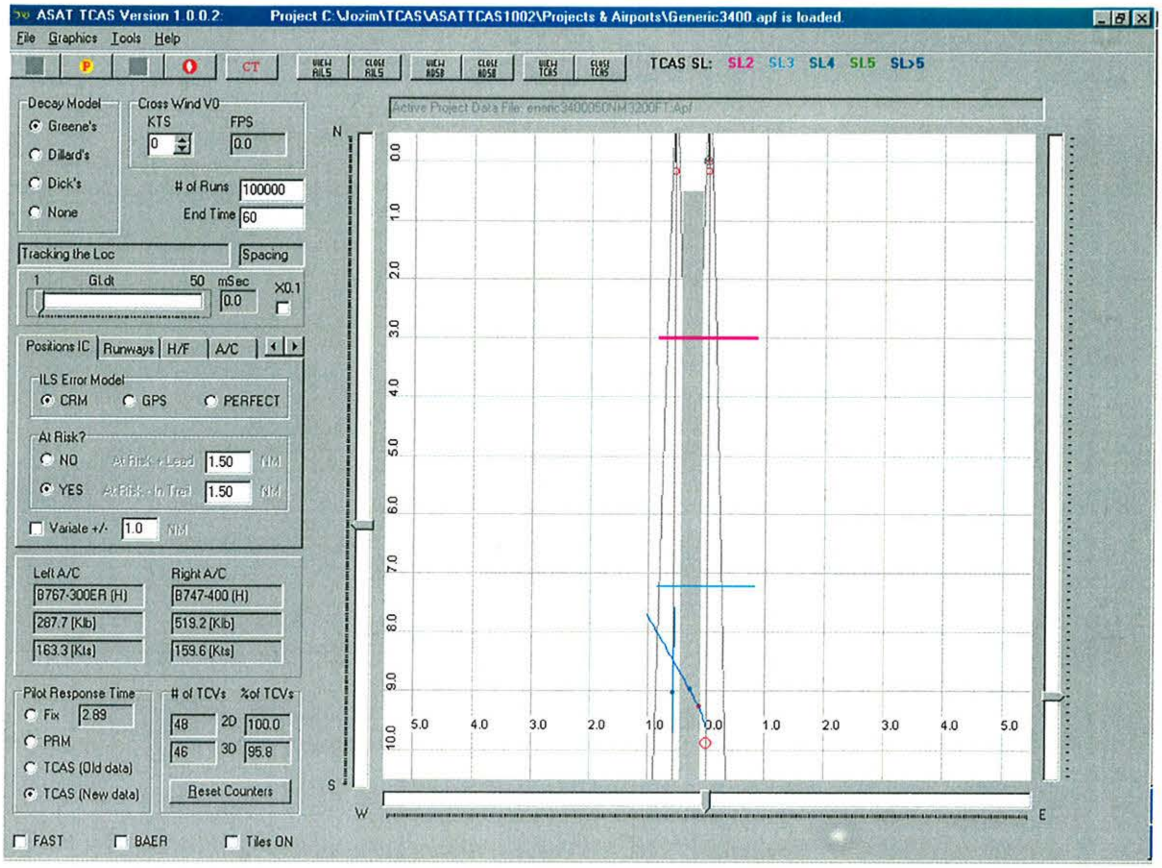


Figure 3: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 3

SCENARIO 3 DESCRIPTION: RISK ANALYSIS

a.	**Runway Spacing:**	3,400 feet
b.	**Blunder Angle:**	30 degrees
c.	**TCAS Sensitivity Level:**	4
d.	**Evasive Action:**	TCAS command only

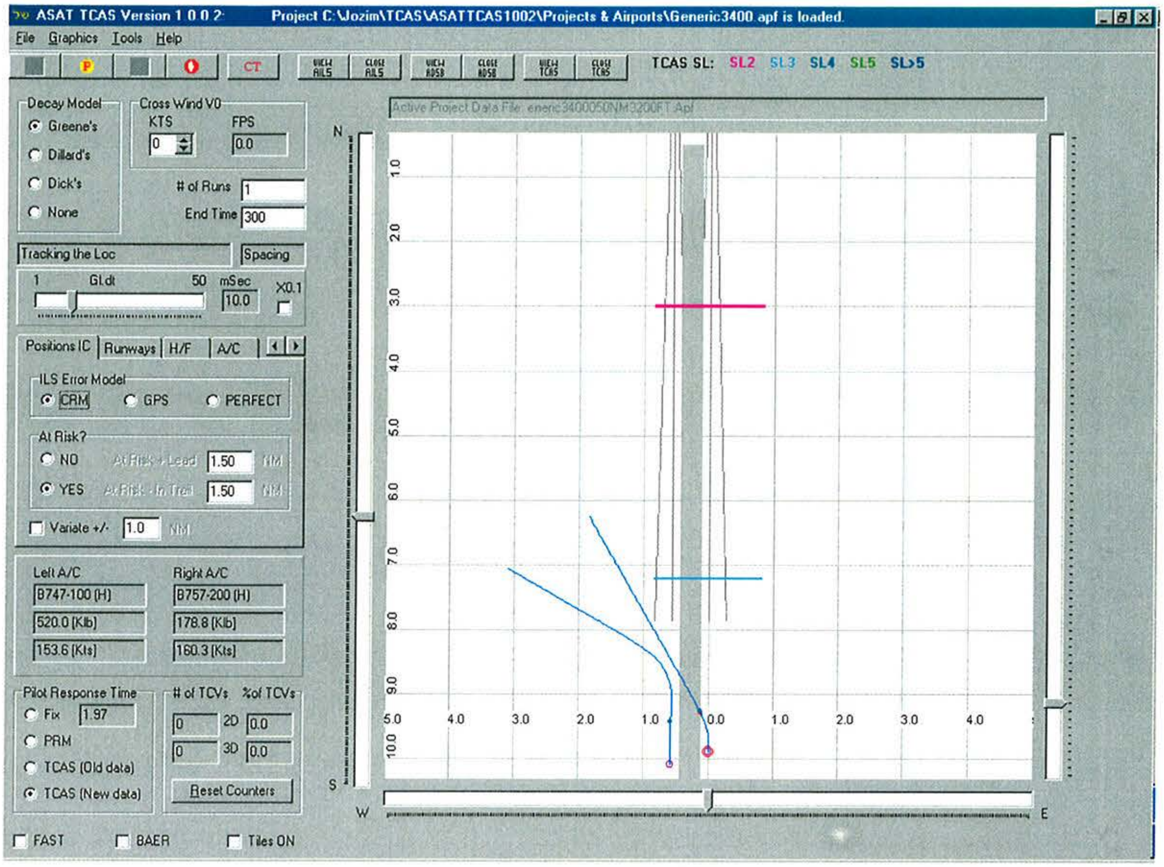


Figure 4: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 4

SCENARIO 4 DESCRIPTION: RISK ANALYSIS

a.	**Runway Spacing:**	3,400 feet
b.	**Blunder Angle:**	30 degrees
c.	**TCAS Sensitivity Level:**	4
d.	**Evasive Action:**	TCAS command + Turn

> **NOTE: Scenarios number 5 through number 8 are similar to scenarios number 1 through number 4 except that in scenarios number 5 through number 8 the blunder angle is 20 degrees instead of 30°.**

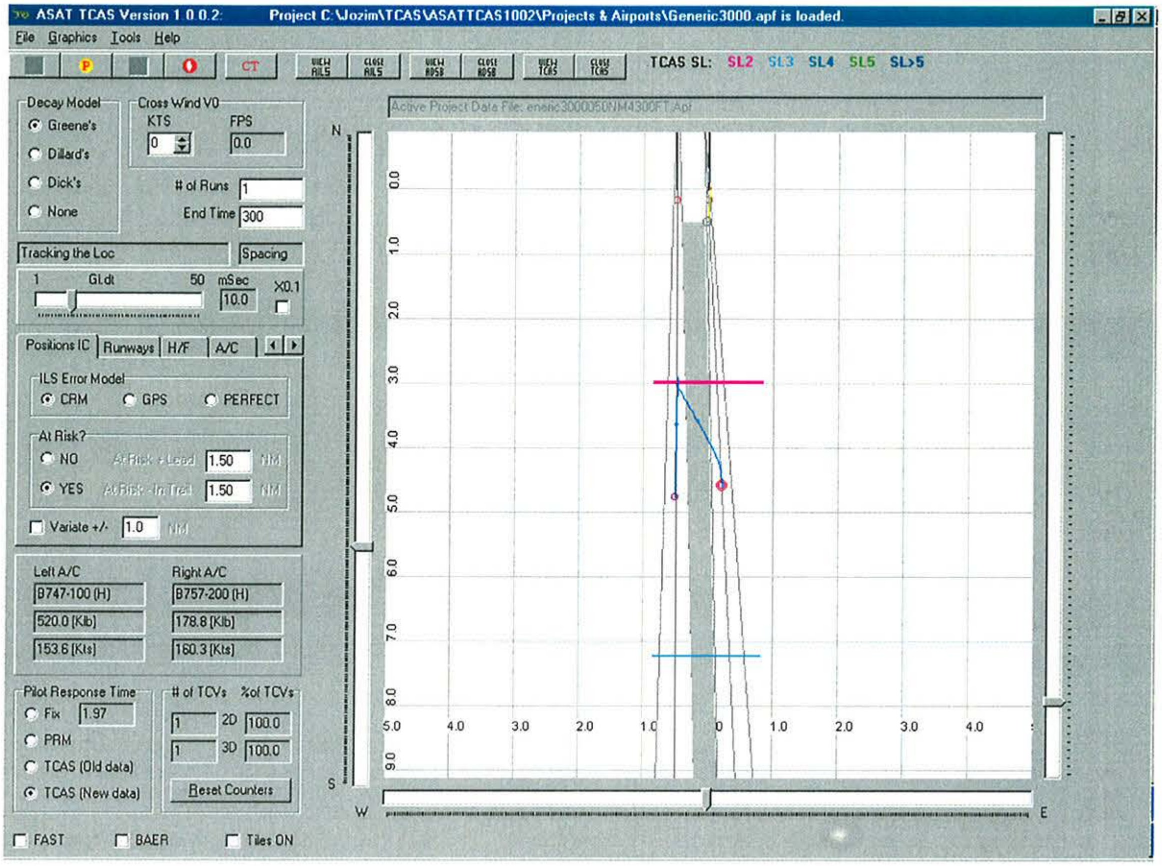


Figure 5: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 9

SCENARIO 9 DESCRIPTION: RISK ANALYSIS

a.	**Runway Spacing:**	3,000 feet
b.	**Localizer Offset:**	3 degrees
c.	**Blunder Angle:**	30 degrees
d.	**TCAS Sensitivity Level:**	3
e.	**Evasive Action:**	TCAS command only

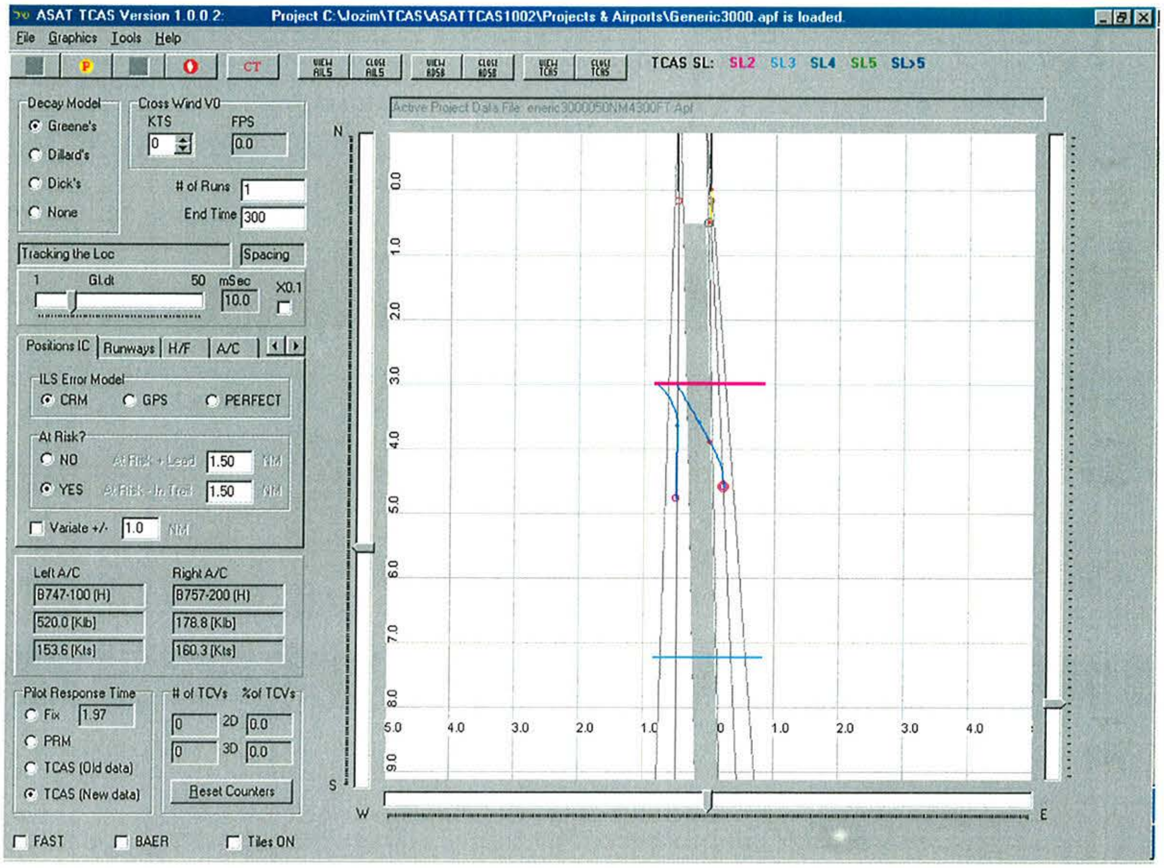


Figure 6: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 10

SCENARIO 9 DESCRIPTION: RISK ANALYSIS

a.	**Runways Spacing:**	3,000 feet
b.	**Localizer Offset:**	3 degrees divergent
c.	**Blunder Angle:**	30 degrees
d.	**TCAS Sensitivity Level:**	3
e.	**Evasive Action:**	TCAS command only + Turn

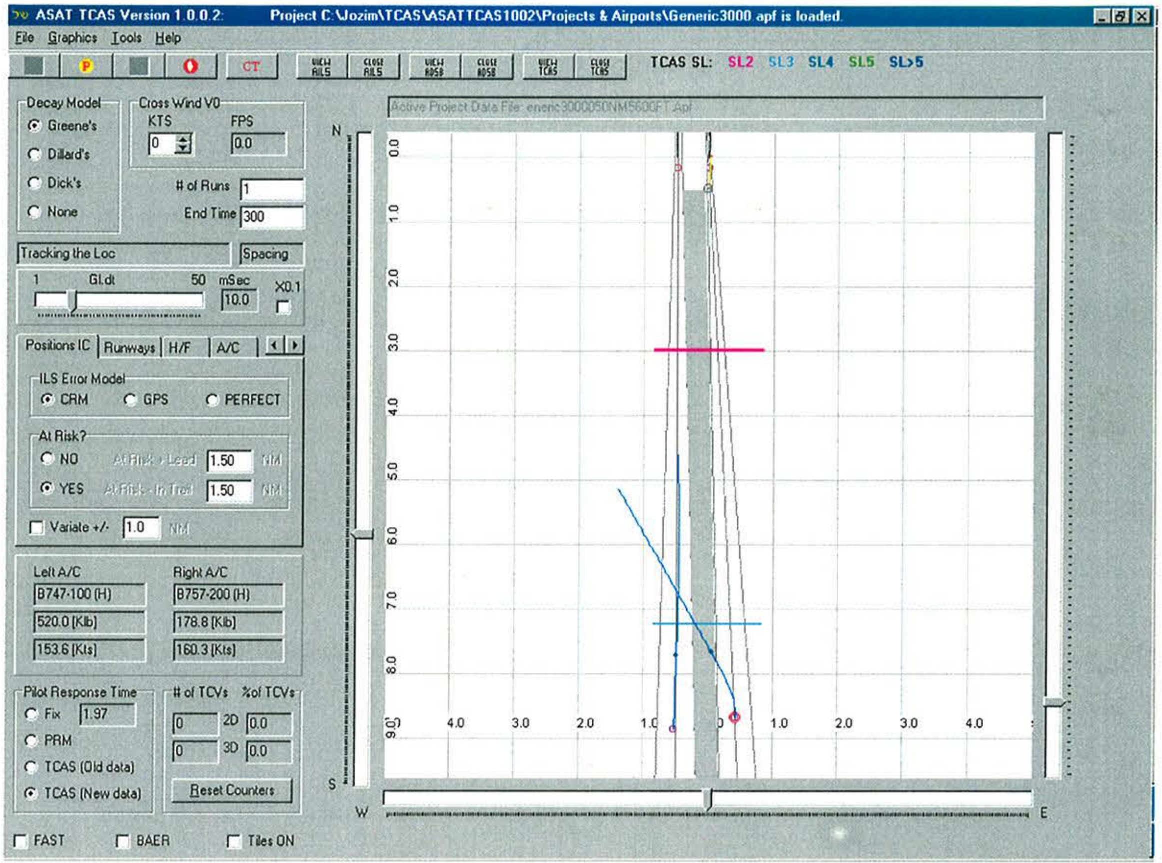


Figure 7: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 11

SCENARIO 11 DESCRIPTION: RISK ANALYSIS

a.	**Runway Spacing:**	3,000 feet
b.	**Localizer Offset:**	3 degrees
c.	**Blunder Angle:**	30 degrees
d.	**TCAS Sensitivity Level:**	4
e.	**Evasive Action:**	TCAS command only

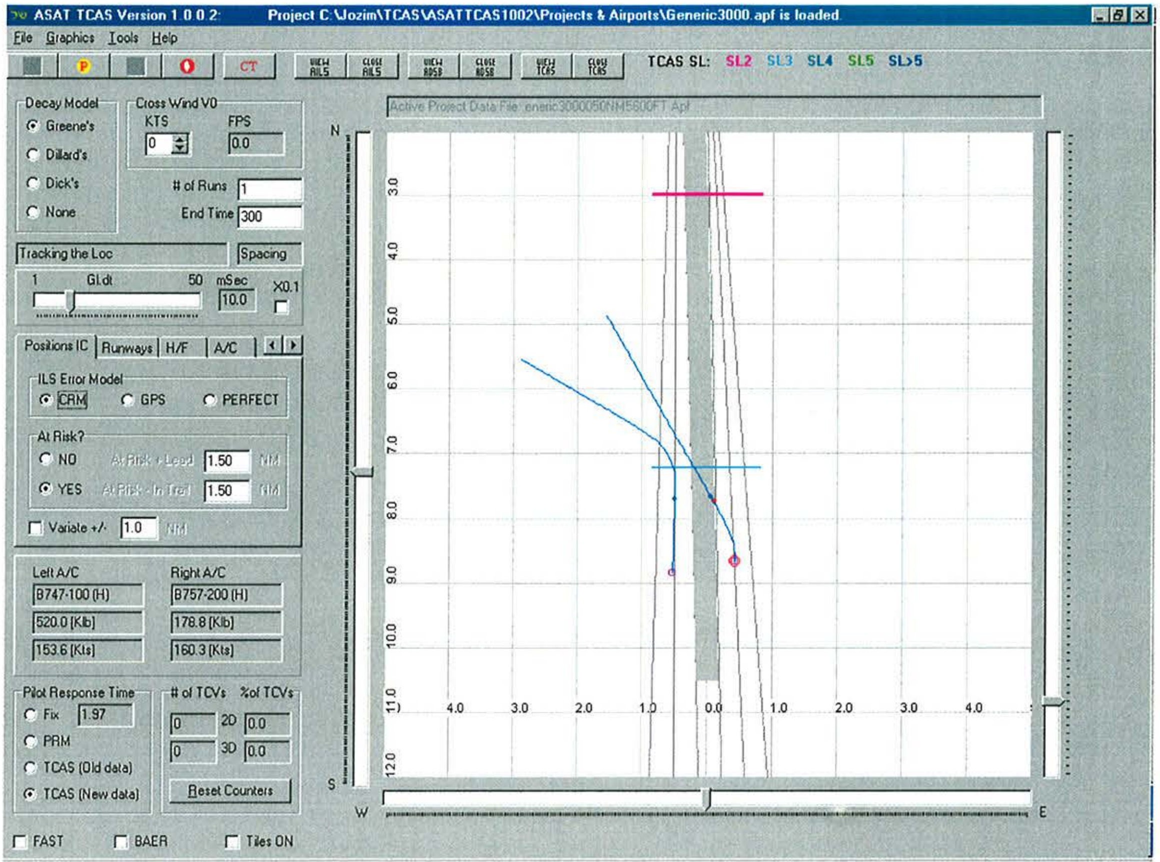


Figure 8: EXAMPLE OF A PAIR OF TRACKS FOR SCENARIO 12

SCENARIO 12 DESCRIPTION: RISK ANALYSIS

a. **Runways Spacing:** 3,000 feet

b. **Localizer Offset:** 3 degrees divergent

c. **Blunder Angle:** 30 degrees

d. **TCAS Sensitivity Level:** 4

e. **Evasive Action:** TCAS command only + Turn

NOTE: Scenarios number 13 through number 16 are similar to scenarios number 9 through number 12 except that in scenarios number 13 through number 16 the blunder angle is 20 degrees

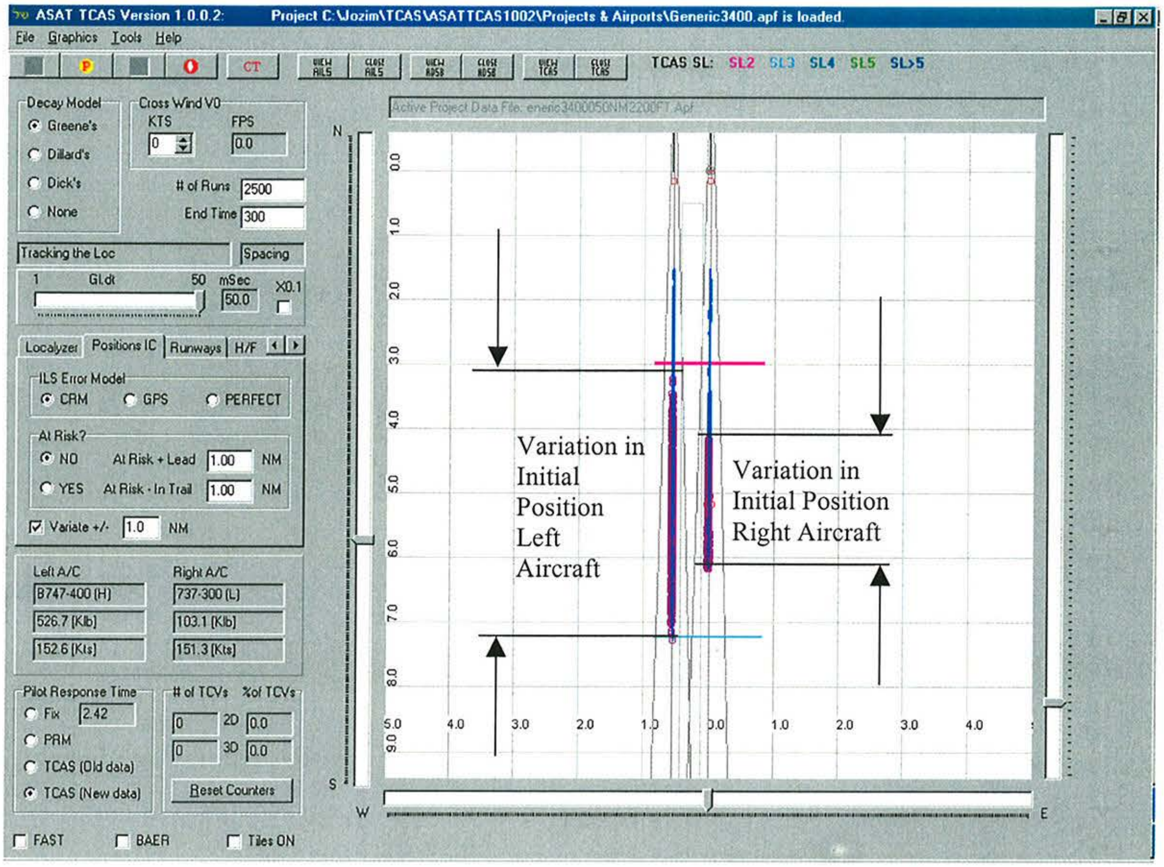


Figure 9: EXAMPLE OF A NUMBER OF PAIRS OF TRACKS FOR SCENARIO 17 (FALSE ALERTS)

SCENARIO 17 DESCRIPTION: FALSE ALERTS ANALYSIS

a.	**Runway Spacing:**	3,400 feet
b.	**Blunder Angle:**	No Blunder
c.	**TCAS Sensitivity Level:**	3

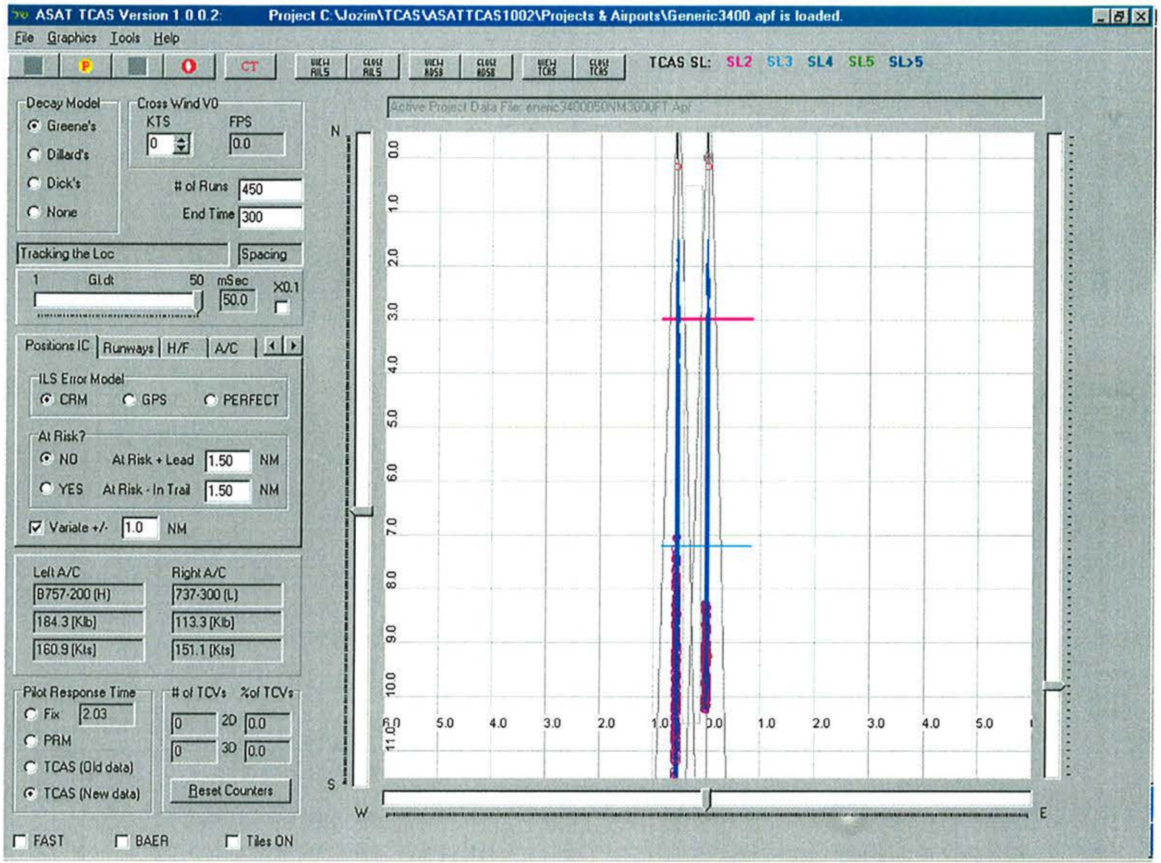


Figure 10: EXAMPLE OF A NUMBER OF PAIRS OF TRACKS FOR SCENARIO 18 (FALSE ALERTS)

SCENARIO 18 DESCRIPTION: FALSE ALERTS ANALYSIS

a.	**Runways Spacing:**	3,400 feet
b.	**Blunder Angle:**	No Blunder
c.	**TCAS Sensitivity Level:**	4

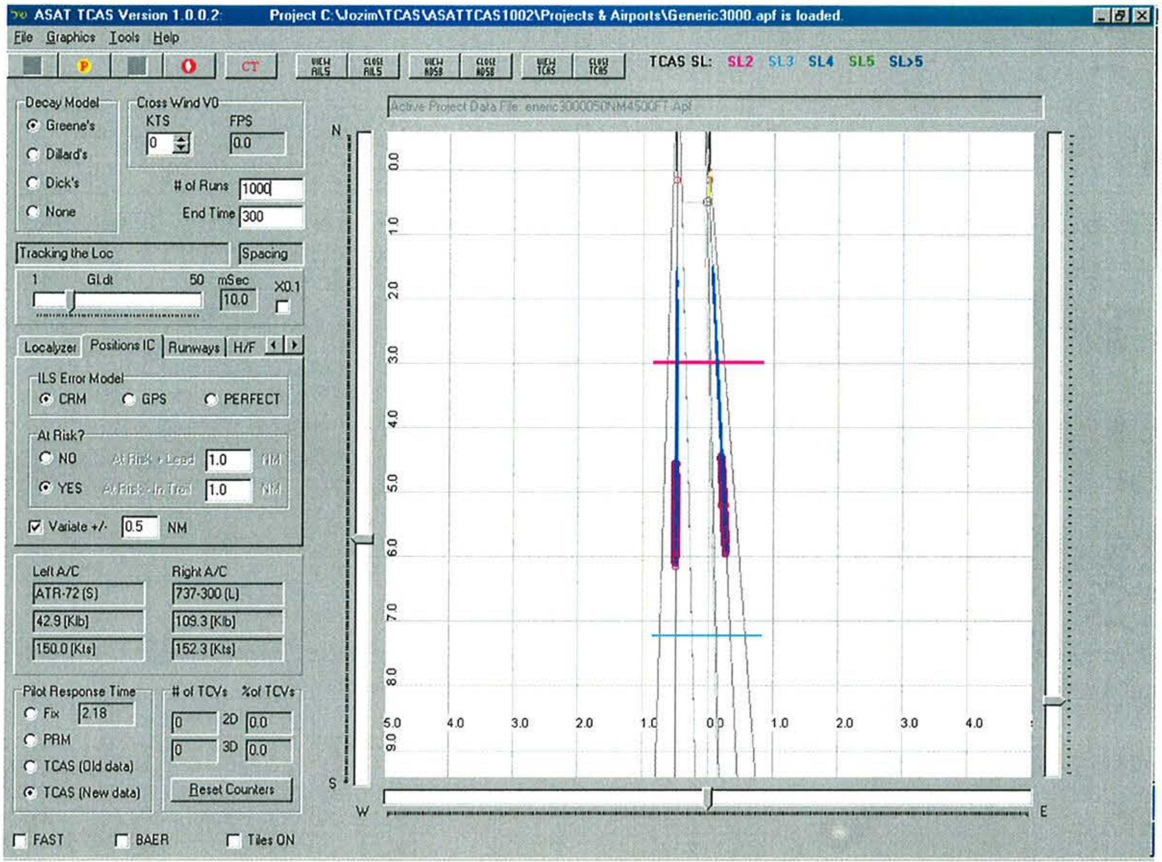


Figure 11: EXAMPLE OF A NUMBER OF PAIRS OF TRACKS FOR SCENARIO 19 (FALSE ALERTS)

SCENARIO 19 DESCRIPTION: FALSE ALERTS ANALYSIS

- a. **Runway Spacing:** 3,400 feet
- b. **Localizer Offset:** 3 degrees divergent
- c. **Blunder Angle:** No Blunder
- d. **TCAS Sensitivity Level:** 3

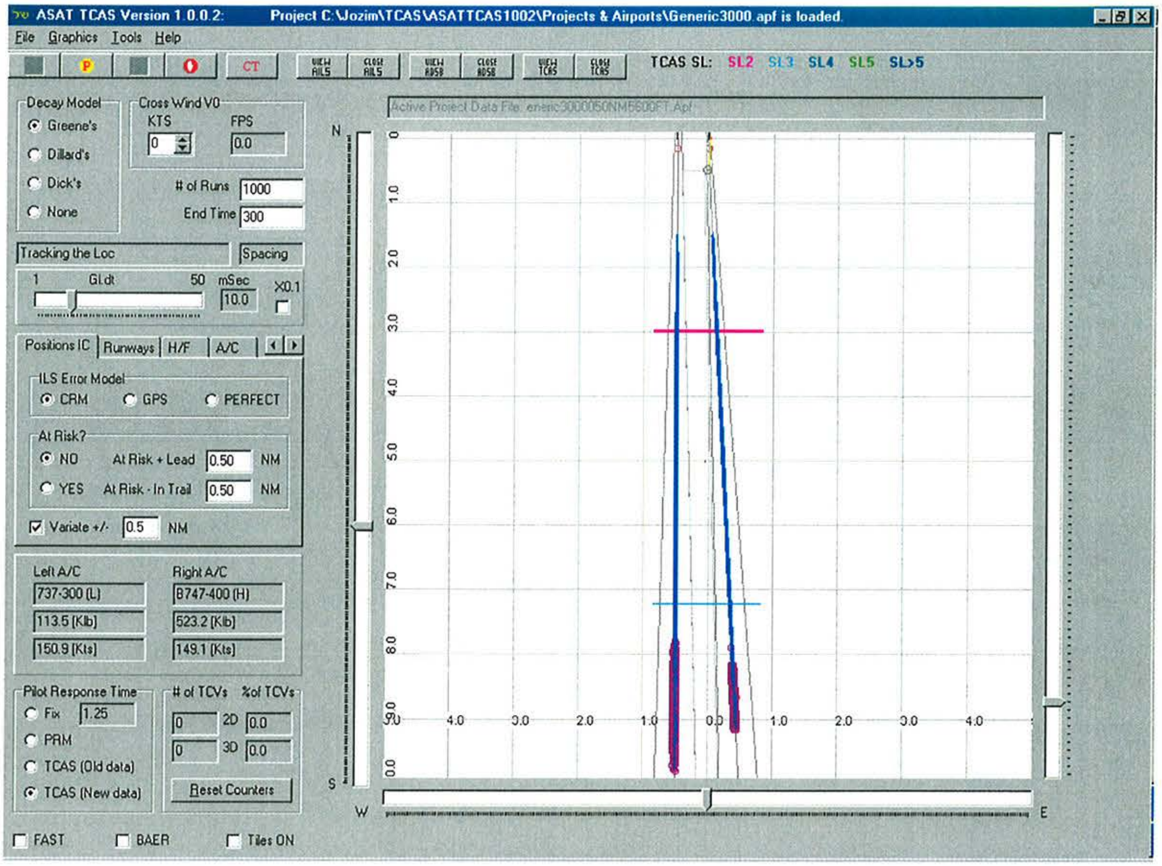


Figure 12: EXAMPLE OF A NUMBER OF PAIRS OF TRACKS FOR SCENARIO 20 (FALSE ALERTS)

SCENARIO 20 DESCRIPTION: FALSE ALERTS ANALYSIS

a.	**Runway Spacing:**	3,400 feet
b.	**Localizer Offset:**	3 degrees divergent
c.	**Blunder Angle:**	No Blunder
d.	**TCAS Sensitivity Level:**	4

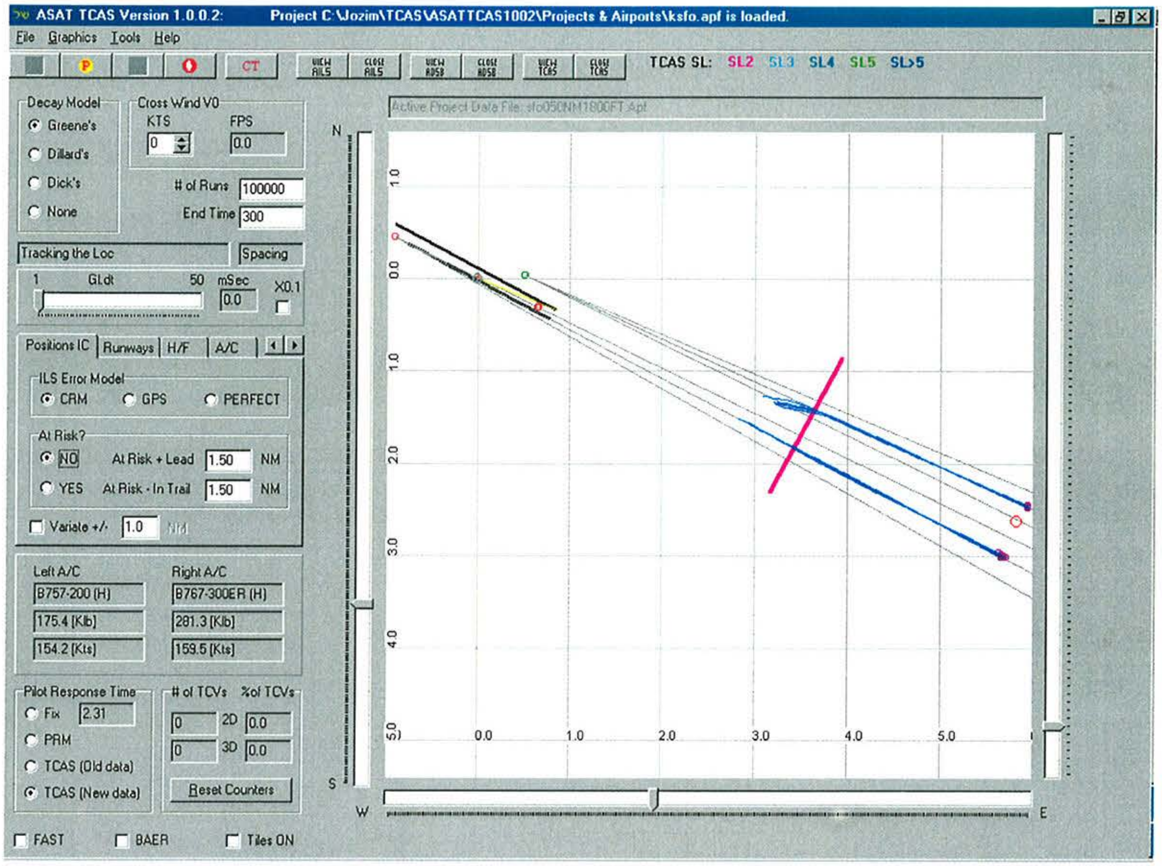


Figure 13: EXAMPLE OF A NUMBER OF PAIRS OF TRACKS FOR SCENARIO 21 (FALSE ALERTS)

SCENARIO 21 DESCRIPTION: SOIA AT SAN FRANCISCO INTERNATIONAL AIRPORT (SFO). FALSE ALERTS ANALYSIS

a.	**Runway Spacing:**	750 feet
b.	**Localizer Offset:**	3 degrees divergent
c.	**Blunder Angle:**	No Blunder
d.	**TCAS Sensitivity Level:**	3

3.0 MONTE CARLO RUNS

The Monte Carlo study was based on output generated by a customized version of ASAT, ASATTCAS1002.

Each one of the test scenarios was run 100,000 times in a Monte Carlo fashion. The following critical parameters were randomly varied from run to run:

a. Aircraft types,

b. Initial aircraft location around the theoretical ILS glidepaths,

c. Initial IAS,

d. Climb rate during evasive maneuver,

e. Rate of change of rate of climb during evasive maneuver,

f. Bank angle during the performance of an evasive maneuver (where applicable)[1],

g. Bank angle rate during the performance of an evasive maneuver (where applicable)[1],

h. Pilot response time to TCAS RA,

i. Pilot response time to ATC turn instruction (where applicable), and

j. Appendix B describes the random variation of the critical parameters in detail.

4.0 RISK ANALYSIS RESULTS

In order to achieve the target level of safety, 4×10^{-8}, when 100 percent of the simulated aircraft are placed at risk, the TCV rate must not exceed 6.8 percent for dual approaches. ASAT results are shown for all of the 16 risk evaluation cases presented in table 1, i. e., (2 runway configurations) × (2 TCAS sensitivity levels) × (2 blunder angles) × (2 types of evasive maneuvers). The last three columns of table 2 presents the results of the risk analysis and contains the TCV rates as follows:

a. "Vertical Only": displays the TCV rate for the scenarios for which the evasive maneuver only followed the TCAS RA command, i. e., climb or descend.

[1] For scenarios involving a turn as a part of the evasive action taken by the pilot

b. "Vertical + Turn @ ATC": displays the TCV rate for the scenarios for which the evasive maneuver followed the TCAS RA climb or descend command and also followed the ATC turn command.

In table 2 the TCV rate for aircraft following only the TCAS alert, i. e., a climb or descent, exceeds 6.8 percent and does not meet the target level of safety. However, the TCV rate for those aircraft that follow the TCAS alert and also follow the PRM controller's turn instruction is always less than 6.8 percent. Therefore, the target level of safety is only met when the pilot follows the controller's command as well as the TCAS alert.

Scenario Number	Runway Spacing	Blunder Angle	TCAS SL	Evasive Maneuver	
				Vertical Only (No Turn)	Vertical + Turn @ ATC Instruction
1	3400	30	3	56.0%	
2					<6.8%
3			4	53.9%	
4					< 6.8%
5		20	3	47.5%	
6					< 6.8%
7			4	24.9%	
8					< 6.8%
9	3000	30	3	67.2%	
10					< 6.8%
11			4	51.5%	
12					< 6.8%
13		20	3	44.1%	
14					< 6.8%
15			4	31.8%	
16					< 6.8%

Table 2: RISK FIGURES FOR VARIOUS SCENARIOS TESTED

5.0 FALSE ALERT ANALYSIS RESULTS

The false alert scenarios differed from the scenarios used for risk evaluation since they consisted of normal aircraft operations without the occurrence of blunders and evasive maneuvers. Five scenarios were evaluated to determine the probability of a false alert occurring during a simultaneous approach to closely spaced parallel runways. The scenarios used were scenarios 17 through 21 as listed in table 1. These scenarios can be grouped into three distinct categories as follows:

a. **Parallel Localizers** (scenarios 17 and 18): Runways spaced at 3400 feet apart with localizers parallel to each other.

b. **Offset Localizers** (scenarios 19 and 20): Runways spaced at 3000 feet apart with one localizer offset 3°.

c. **SOIA Approach** (scenario 21): Runways spaced at 750 feet apart (San Francisco International Airport, SFO) using an offset localizer and performing a SOIA approach procedure.

In scenarios 18 through 20 the initial positions of the two aircraft along the approach path were selected so the widest possible range of combinations of two aircraft approaching parallel runways simultaneously and independently could be covered. This was achieved by placing the first aircraft anywhere within the range that will initialize the TCAS at the required sensitivity level while the second aircraft was placed randomly at a range from 1.5 NM ahead of the first aircraft to a range of 1.5 NM in-trail of the first aircraft. (see figure 14). From the selected initial positions, each aircraft executes an approach to its designated runway. The aircraft will "wander" around the glide slope and localizer in a manner compatible with the ICAO Collision Risk Model (CRM) total system error probability distributions. Since the aircraft are executing independent approaches, one aircraft may pass the other.

Because of the nature of the SOIA procedure, scenario 21 was run under more strict conditions as follows:

a. The aircraft following the offset LDA while approaching runway 28R is placed at a randomly selected distance prior to the 28R LDA MAP.

b. The aircraft, approaching runway 28L is placed ahead of the aircraft approaching runway 28R. The lead distance varies from 0.25 to 0.75 NM

c. The speed differential (KIAS) is limited to no more than 20 KIAS.

d. The aircraft, approaching runway 28R executes the runway alignment maneuver after passing the LDA MAP.

The simulation is terminated when both aircraft are below 900 feet AGL since the nominal altitude where the TCAS RA is inhibited is 1000 feet.

This results in a more conservative test for false alerts than would nominally be the case in a real life operation. For all of the above false alert related scenarios, ASAT keeps a record of the TCAS alerts that were triggered.

Table 3 summarizes the false alert rate encountered during the evaluation runs.

Scenario Number	Runways Spacing	TCAS SL	False Alerts Rate (Out of 10,000)	False Alert Rate (in %)
17	3400	3	2	0.02%
18		4	0	0.00%
19	3000	3	0	0.00%
20		4	0	0.00%
21	750 (SOIA)	3	6	0.06%

Table 3: SUMMARY OF FALSE ALERTS ANALYSIS RESULTS

From table 3, the false alert rate of each scenario is less that one percent and can be considered acceptably small.

6.0 SUMMARY AND CONCLUSIONS

AFS-420 was asked to investigate the feasibility of allowing TCAS to be set in the resolution alert (RA) mode during simultaneous independent dual approaches when a Precision Runway Monitor (PRM) system is in use. The purpose of the study would be the comparison of collision risk using TCAS alone to the risk of collision using TCAS in conjunction with PRM. In addition, the study would determine whether the TCAS false alert rate in the RA mode would be excessive.

The investigation considered two general circumstances should a blunder occur. The pilot could respond to a TCAS alert only and climb or descend without a turn. The pilot could respond to a TCAS alert and a turn instruction from an air traffic controller using PRM. Since in either case it was necessary to compare the risk using TCAS to PRM without TCAS, the standard Test Criterion Violation (TCV) was adopted. A TCV is said to have occurred when the aircraft centers of gravity pass within 500 feet of each other. The target level of safety, 4 x 1 o·8 that was adopted for PRM without TCAS, was adopted as the target level of safety of this study.

The simulation indicated the target level of safely was not met when TCAS was set in the RA mode and used alone without PRM. Thal is, when the pilot followed only a TCAS climb or descend instruction without a turn instruction, the target level of safety was not met. The target level of safety was met when using TCAS in conjunction with PRM. That is, when the TCAS climb or descend instruction was coupled with a turn instruction from the air traffic controller using PRM the target level of safety was met. Therefore, if a pilot responds to a TCAS RA alert, then the pilot must also follow the PRM controller turn instruction to meet the target level of safety using the standard 500-foot TCV.

The investigation also considered five scenarios consisting of normal aircraft operations without the occurrence of blunders and evasive maneuvers for the evaluation of the false alert rate while using PRM with TCAS in the RA mode. The five scenarios can be grouped into three distinct categories; those with parallel localizers and runways spaced 3,400 feet apart, those with one localizer offset 3 degrees with runways spaced 3,000 feet apart, and a SOIA approach to runways spaced 750 feet apart. The simulation indicated that the false alert rate was not excessive during any of the three general conditions that were simulated. Therefore, the TCAS may be set to the RA mode during dual parallel approaches with PRM without excessive false alerts.

APPENDIX A

INTERMEDIATE REPORT: DETERMINATION OF THE PROTECTED AREA SIZE USING TCAS ONLY TO ACHIEVE THE SAME TLS AS PRM

TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS) AND PRECISION RUNWAY MONITOR (PRM) COLLISION RISK DIFFERENCES IN THE CLOSELY SPACED APPROACH ENVIRONMENT

A1 INTRODUCTION

When the PRM was certified to monitor closely spaced approaches (runways as close as 3,000 feet apart) it was assumed that the TCAS would be placed in the traffic alert (TA) position that provides warning but not resolution of conflicts. The PRM provides 1-second update rate, sophisticated alert algorithms, and future position predictive software. The Airline Pilots Association (ALPA) initially accepted this TA-only procedure, but more recently has asked the Federal Aviation Administration (FAA) to determine the feasibility of keeping the TCAS in the resolution alert (RA) mode throughout a closely spaced approach.

The FAA was asked to conduct a data collection and analysis to compare the risk associated with PRM with TA-only to PRM with RA. Data were collected at United Airlines Training Center in Denver, Colorado using certified flight simulators flown by current and qualified airline pilots. The Flight Procedures Standards Branch (AFS-420) is in the process of completing the final study report.

Prior to the issuance of the final report, AFS-420 was asked to specifically analyze the collision risk difference between sole reliance on the PRM controller's breakout instructions as compared to sole reliance on the TCAS RA. The TCAS RA is considered to be the protection of last resort by ALPA, providing a measure of collision avoidance in the extremely unlikely event that a blunder occurs and PRM fails or all communications are lost.

Collision risk based on the PRM monitor controller's instructions assumed a 500-feet protective sphere surrounding the endangered aircraft. Penetration of this sphere was considered a Test Criteria Violation (TCV). Using the sphere as the measure of protection, the collision risk for PRM collision avoidance was determined to be 4×10^{-8}. ALPA asked the FAA to conduct an analysis assuming that an endangered aircraft in a closely spaced approach scenario was required to rely only on the TCAS RA for collision avoidance. Based on that assumption, the FAA was asked to determine the size of the protected airspace surrounding the endangered aircraft that would yield the same collision risk as that achieved by the monitor controller using the PRM and issuing breakout instructions.

A2 SIMULATION DESCRIPTION

A Monte Carlo (statistical) study was performed using AFS-420's Airspace Simulation and Analysis for TERPS (ASAT) system in order to determine the level of safety that TCAS can provide under a closely spaced parallel approach (CSPA) blunder environment, providing it is the only means available to the pilot to resolve a conflict.
The analysis covered a wide range of operational scenarios namely, parallel runways spaced at 3,400 feet (parallel localizer beams) and parallel runways spaced at 3,000 feet with one localizer beam shifted outbound 3 degrees. Both cases were analyzed for TCAS Sensitivity Levels (SL) of 3 and 4 and for blunder angles of 20 degrees and 30 degrees.

The results show that for all cases, performing an evasive maneuver based upon TCAS command only (vertical maneuver without any turn) will not satisfy the current Target Level of Safety (TLS). However the results also indicate that following only the TCAS command will still guarantee a ***vertical*** separation of between 150 feet to 250 feet depending on the specific geometry of the scenario and current TCAS SL.

It must be emphasized that the results of this study reflect the level of safety providing that ALL other means of surveillance and/or communication have failed and the TCAS is used as the "last line of defense" in order to avoid a mid-air collision. To illustrate the meaning of this statement: the results predict the level of safety expected from TCAS as a sole source of collision avoidance in a CSPA environment providing (see figure 1):

a. A blunder occurs, **AND**

b. PRM **AND** all other surveillance is not functioning, **AND**

c. **OR** ALL Communications fail for **both** aircraft

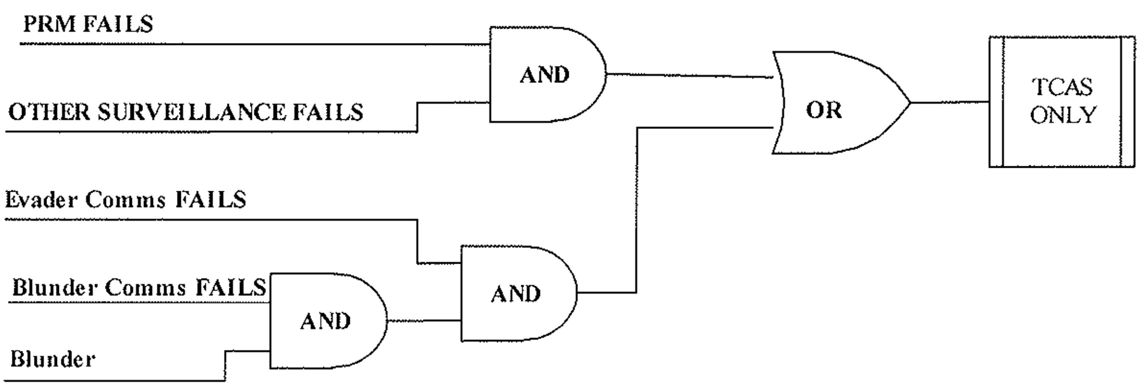


Figure A1: CONDITIONAL DESCRIPTION THAT WILL LEAD TO A "TCAS ONLY" STATE

A3 MONTE CARLO RUNS

The Monte-Carlo study was based on output generated by ASAT TCAS Version (ASATTCAS1002, see Deliverables 1 and 2, contract DTFA02-01-F-14616).

A3.1 PURPOSE

Runs were performed in order to evaluate the level of safety that TCAS can provide under a closely spaced parallel approach (CSPA) blunder environment, providing that it is the only means available to the pilot to resolve a conflict[1].

A3.1.1 CONFIGURATIONS

In both cases, two runway configurations were used as follows:

a. Non-staggered parallel runways at 3,400 feet separation,

b. Non-staggered parallel runways at 3,000 feet separation and one localizer shifted outbound 3.0 degrees.

A3.1.2 OPERATIONAL SCENARIOS

The following operational scenarios were evaluated:

A3.1.3 RISK RELATED RUNS

a. Blunders at 20 degrees and 30 degrees.

b. Evaders performing evasive maneuver consisting of:

(1) Vertical only,

(2) Vertical and lateral (turn) combined.

Table A1 lists the different runway configurations and operational scenarios tested.

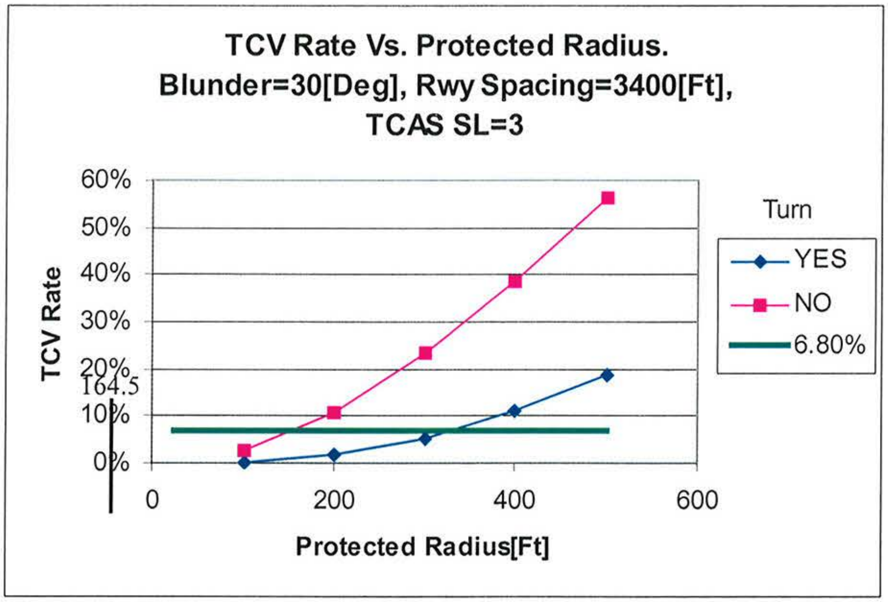
[1] For comparison only, graphic data depicting safety levels for a combined vertical and lateral (turn) maneuver are shown.

Run #	Purpose	Runways Spacing	Blunder Angle	TCAS SL	Evasive Maneuver	
					Vertical	Vertical + Turn
1	Risk	3,400	30	3	√	
2						√
3				4	√	
4						√
5			20	3	√	
6						√
7				4	√	
8						√
9		3,000	30	3	√	
10						√
11				4	√	
12						√
13			20	3	√	
14						√
15				4	√	
16						√

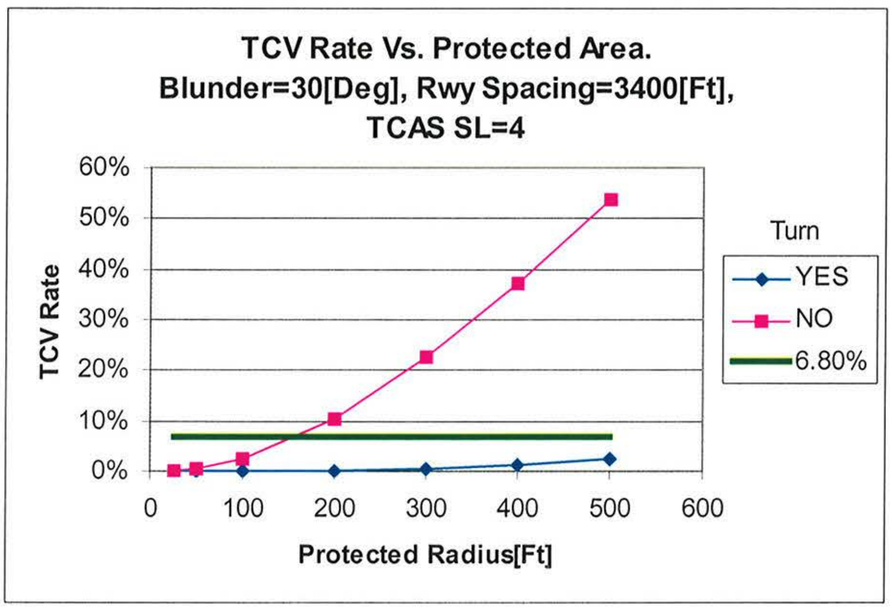
Table A1: ASAT RUNWAY CONFIGURATIONS AND OPERATIONAL SCENARIOS TESTED

A4 STATISTICAL RISK ANALYSIS

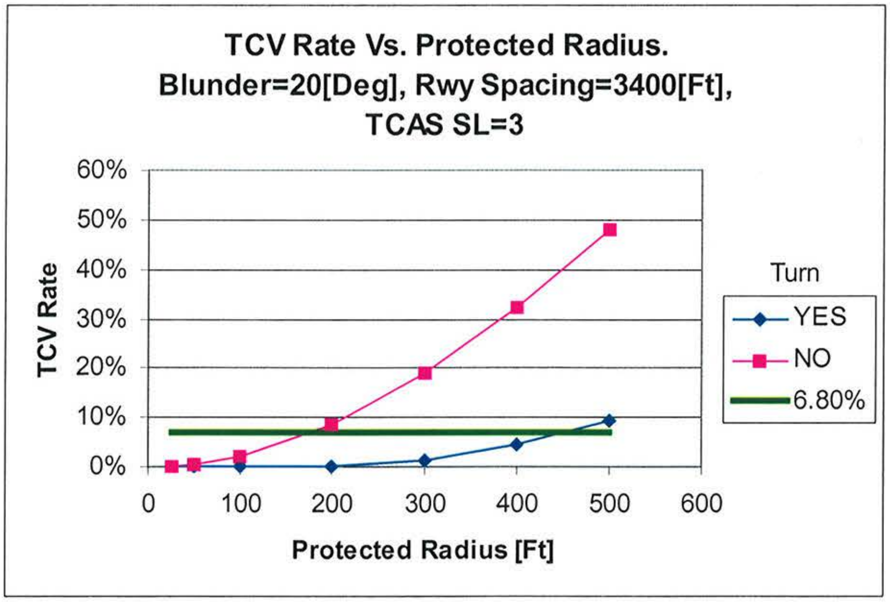
In order to achieve the target level of safety, 4×10^{-8}, when 100 percent of the simulated aircraft are placed at risk, the TCV rate must not exceed 6.8 percent. ASAT results are shown for all 16 cases presented in table 1, i. e., (2 runway configurations) × (2 TCAS sensitivity levels) × (2 blunder angles) × (2 types of evasive maneuvers). The results are presented in 8 charts where each chart consists of three lines. The pink line is a plot of probabilities versus smallest separation distance associated with a vertical (climb) evasive maneuver. The blue line is a plot of probabilities versus smallest separation distance associated with a combined vertical and lateral (turn) evasion maneuver. **Under this scenario, it is assumed that the pilot initiates the turn only after the TCAS RA is issued.** The green line represents the 6.8 percent level. The point where the green line intersects the pink line determines the radius of the sphere that meets the target level of safety for a vertical-only evasion maneuver. The point where the green line intersects the blue line determines the radius of the sphere that meets the target level of safety for a vertical and lateral evasion maneuver. For example, in plot 1 the green line intersects the pink line at the point where the radius of the protected sphere is 164.5 feet.



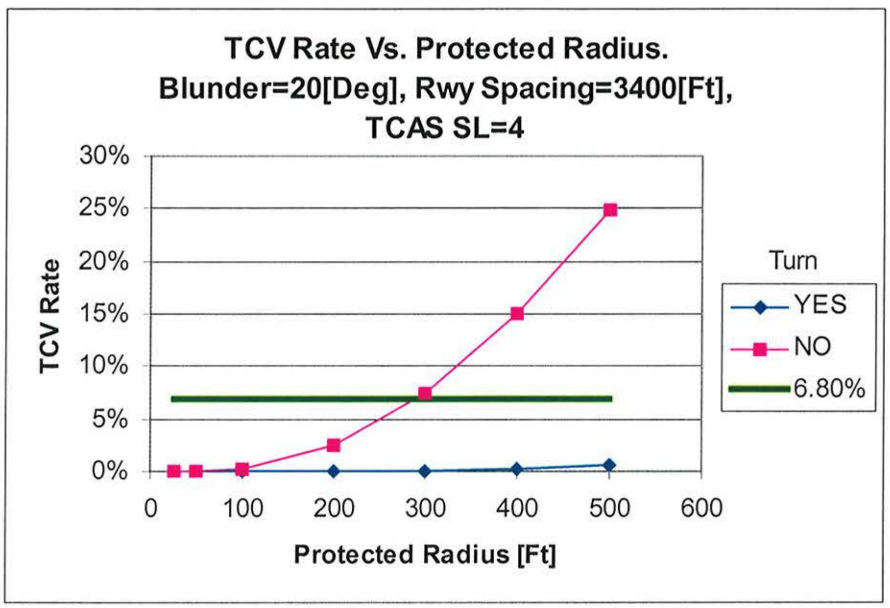
Plot 1: Cases 1 and 2 (R=164.5 FEET FOR 6.8% TCV RATE)



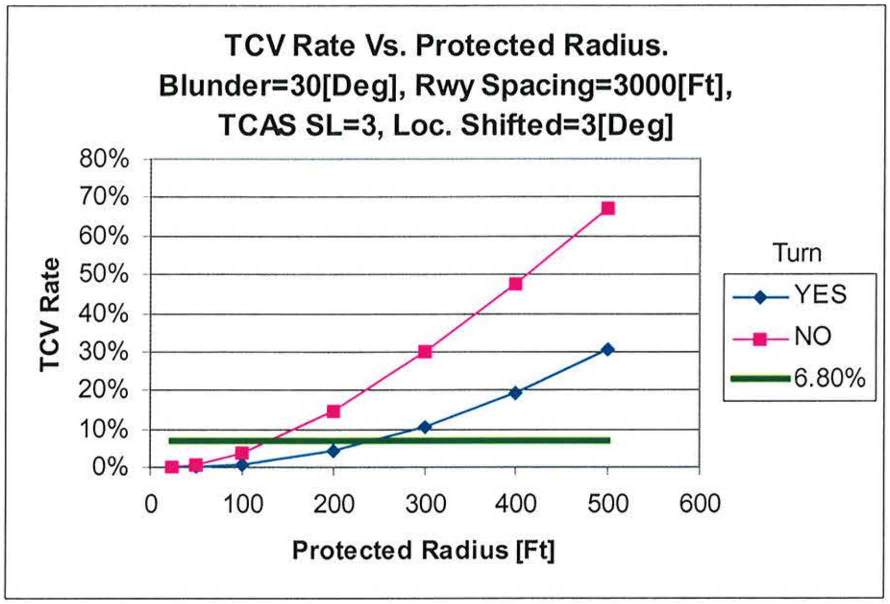
Plot 2: Cases 3 and 4 (R=164.5 FEET FOR 6.8% TCV RATE)



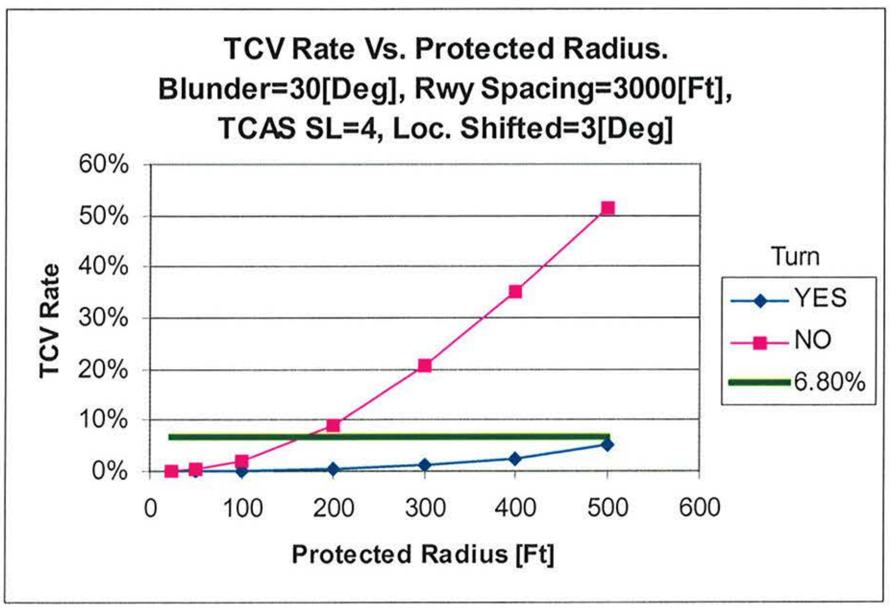
Plot 3: Cases 5 and 6 (R=170.8 FEET FOR 6.8% TCV RATE)



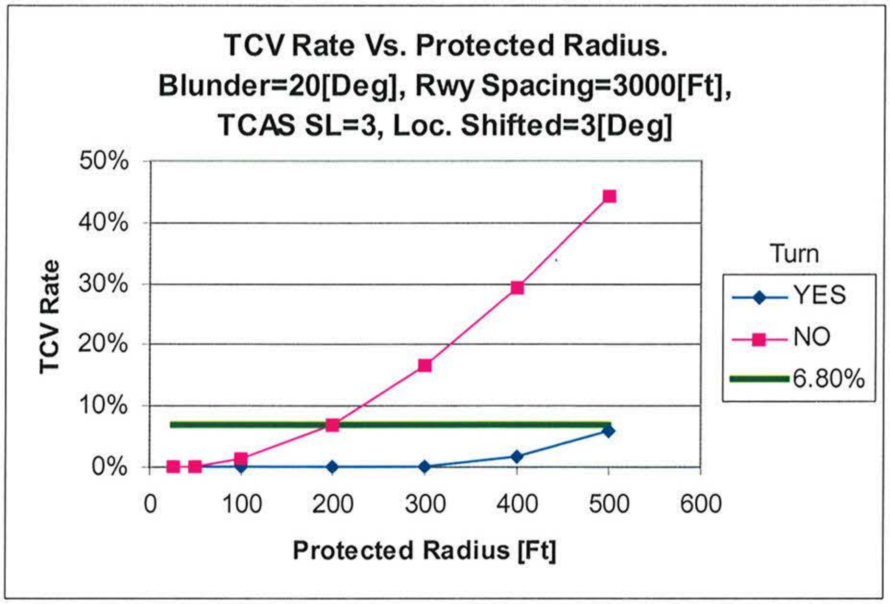
Plot 4: Cases 7 And 8 (R=290.2 FEET FOR 6.8% TCV RATE)



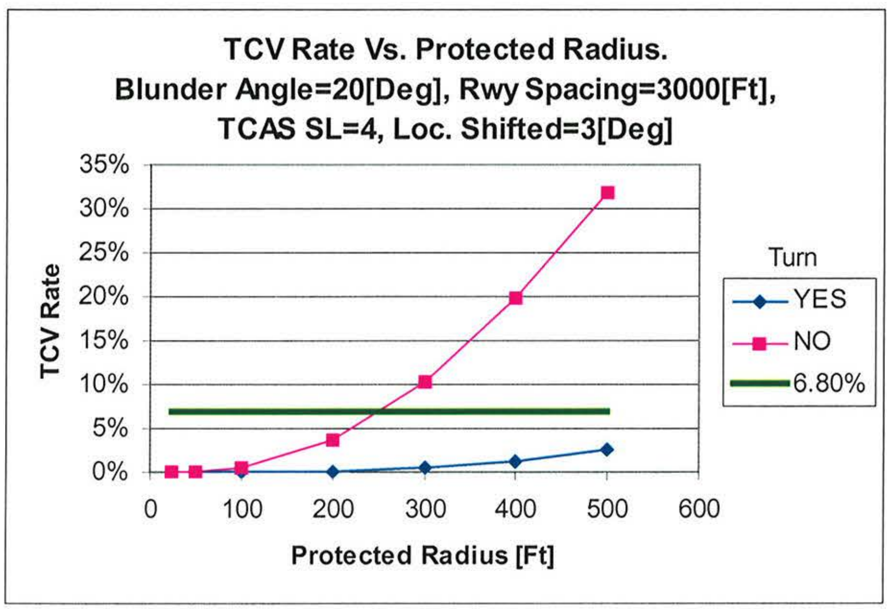
Plot 5: Cases 9 and 10 (R=148.3 FEET FOR 6.8% TCV RATE)



Plot 6: Cases 11 and 12 (R=173.6 FEET FOR 6.8% TCV RATE)



Plot 7: Cases 13 and 14 (R=199.9 FEET FOR 6.8% TCV RATE)



Plot 8: Cases 15 and 16 (R=248.0 FEET FOR 6.8% TCV RATE)

APPENDIX B

STATISTICAL PARAMETERS VARIED DURING THE MONTE CARLO SIMULATION RUNS

B1 AIRCRAFT TYPES

The following aircraft types mix was used:

Aircraft Type	Data File Source	Percentage Mix
B737-300	DATA\B737-300.TXT	30%
B757-200	DATA\B75-200.TXT	30%
B767-300ER	DATA\B767-300ER.TXT	10%
B747-100	DATA\B747-100.TXT	10%
B747-400	DATA\B747-400.TXT	10%
ATR-72	DATA\ATR-72.TXT	10%

Table B1: AIRCRAFT TYPES

B2 AIRCRAFT INITIAL POSITION

B2.1 DISTANCE FROM THRESHOLD

Aircraft were placed at a distance from threshold that will result in the required altitude above ground level (Altitude AGL) to initialize the TCAS model to the desired sensitivity level (TCAS SL: please refer to Figure 1 at the main section of this report).

B2.2 LOCALIZER AND GLIDESLOPE INITIAL DEVIATIONS

CRM distributions were used in order to determine the initial localizer and glide-slope deviations. The normalized CRM data used is contained in the DATA\CAT1030.TXT data file.

B3 INITIAL IAS

Initial IAS was selected from a nominal operational indicated air speeds range associated with each individual aircraft type. The data is contained in each one of the aircraft type data files listed in Table B1.

B4 CLIMB RATE

B5 RATE OF CHANGE OF CLIMB RATE

B6 BANK ANGLE

B7 BANK ANGLE RATE

All of the above data were collected using certified flight simulators and current airline pilots. Data is aircraft specific and is contained in each one of the aircraft type data files listed in table B1.

B8 PILOT RESPONSE TIME

B8.1 RESPONSE TO ATC UNDER PRM

Data were collected during the PRM studies using certified flight simulators and current airline pilots. The data gathered during these tests were analyzed. The Johnson SB type function described by the following Johnson curve coefficients statistically fits the data collected and it applies to all aircraft types:

a. Gamma (γ) = 0.2899054066e+02

b. Delta (δ) = 0.1753367537E+01

c. Lambda (λ) = 0.6224611455E+08

d. Xi (χ) = 0.9772152784E+00

The data are bounded by the following values:

a. Minimum = 0.1900000000E+01

b. Maximum = 0.1330000000E+02

B8.2 RESPONSE TO TCAS RA

Data was collected for the current study using the United Airlines (UAL) flight simulators facility in Denver, Colorado. Certified, flight simulators were flown by current airline pilots. The tests took place on the following dates:

a. A320: June 25 through June 30, 2001

b. B757: June 19, June 21, and June 25, 2001

The data gathered during these tests were analyzed. The Johnson SB type function described by the following Johnson curve coefficients statistically fits the data collected and it applies to all aircraft types:

a. Gamma (γ) = 0.2097496100E+01

b. Delta (δ) = 0.2510126097E+01

c.	Lambda (λ)	=	0.7380000000E+01
d.	Xi (χ)	=	-0.7000000000E -01

The data are bounded by the following values:

a.	Minimum	=	0.9300000000E+00
b.	Maximum	=	0.5310000000E+01