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Flight Technologies and Procedures Division
Flight Standards Service

ANALYSIS OF MISSED APPROACHES TO RUNWAY 26 WITH DEPARTURES FROM RUNWAY 27R AT PHILADELPHIA INTERNATIONAL AIRPORT

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12. Abstract

With the completion of runway 8/26, the Philadelphia International Airport (PHL) has three parallel runways, runway 8/26, runway 9L/27R, and runway 9R/27L. The parallel runways, 8/26 and 9L/27R are separated by 1,600 feet. The threshold of runway 26 is staggered 3,360 feet east of the threshold of runway 27R. It is intended that during Instrument Meteorological Conditions (IMC), simultaneous instrument approaches approaches will be conducted to runways 26 and 27L and departures will be conducted from 27R, the center runway. Because of the runway spacing and stagger between runways 26 and 27R the runways do not meet the meet the conditions of FAA Order 7110.65, paragraph 5-8-5, Departures and Arrivals on Parallel or Nonintersecting Diverging Runways. Therefore, a request for waiver to FAA order 7110.65 paragraph 5-8-5 was submitted by the Operations Branch, AEA-530. The Flight Procedure Standards Branch, Airspace Simulation and Analysis for TERPS (ASAT) computer system was modified so that a comparative study could be made of three operational scenarios. Two of the scenarios met the conditions of Order 7110.65 and the third met the conditions of runways 26 and 27R at PHL. A Target Level of Safety (TLS) of $4x10^{-8}$ established for the simulation. The test criteria used in the analysis was the Test Criteria Violation (TCV). The probability or risk of a TCV was estimated for each of the three scenarios. The risk of a TCV for each of the three scenarios was found to be less than the TLS. Therefore, the risk of collision is acceptably low for each of three scenarios and the runway spacing and stagger conditions at PHL result in a level of safety equivalent to that of the two scenarios which complied with FAA Order 7110.65, paragraph 5-8-5.

13. Key Words	14. Distribution Statement
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EXECUTIVE SUMMARY

The Philadelphia International Airport (PHL) has completed construction of runway 8/26, a 5,000-foot runway with a 2.5 degree offset localizer and a 250 foot decision height, at the northeast boundary of the airport. With the completion of runway 8/26, the airport has three parallel runways, runway 8/26, runway 9L/27R, and runway 9R/27L. Parallel runways 8/26 and 9L/27R are separated by 1,600 feet. The threshold of runway 26 is staggered 3,360 feet east of the threshold of runway 27R. Since the length of runway 8/26 is 5,000 feet, the runway will be used for commuter and general aviation departures on runway 8 and arrivals on runway 26. It is intended that during Instrument Meteorological Conditions (IMC), simultaneous instrument approaches will be conducted to runways 26 and 27L, which are separated by 3,000 feet.

According to FAA Order 7110.65, paragraph 5-8-5, Departures and Arrivals on Parallel or Nonintersecting Diverging Runways, simultaneous operations between an aircraft departing on a runway and an aircraft on final approach to another parallel or nonintersecting diverging runway are authorized if the departure course diverges immediately by at least 30 degrees from the missed approach course until separation is applied and provided one of the following conditions are met:

a. When parallel runway thresholds are even, the runway centerlines are at least 2,500 feet apart.

b. When parallel runway thresholds are staggered, and

(1) The arriving aircraft is approaching the nearer runway: the centerlines are at least 1,000 feet apart and the landing thresholds are staggered at least 500 feet for each 100 feet less than 2,500 feet the centerlines are separated.

(2) The arriving aircraft is approaching the farther runway: the runway centerlines separation exceeds 2,500 feet by at least 100 feet for each 500 feet the landing thresholds are staggered.

Runway 26 is to be used for arrivals and runway 27R is to be used for departures when traffic lands and departs west bound. Since the centerlines of runways 8/26 and 9L/27R are separated by 1,600 feet and the thresholds are staggered, the threshold of runway 26 must be staggered east of the threshold of runway 27R by a distance of 4,500 feet to meet condition b(1). Since the threshold of runway 26 is only staggered east of the threshold of runway 27R by a distance of 3,360 feet, condition b(1) is not met at PHL. Condition b(2) is not applicable to PHL since the arriving aircraft approaches the nearer runway.

A proponent believes that because of certain unique features at PHL an equivalent level of safety to that provided by the conditions of paragraph 5-8-5 can be achieved for independent landing operations on runway 26 and departure operations on runway 27R using 3,360 feet as the stagger distance. Therefore, a request for a waiver to Order 7110.65, paragraph 5-8-5, was submitted by the Air Traffic Control Operations Branch.

The Flight Procedure Standards Branch Airspace Simulation and Analysis for TERPS (ASAT) computer system was used so that a comparative study could be made of three operational scenarios. For all three scenarios, the ASAT approach module was set to reflect the localizer alignment and decision height used at PHL. For scenario one, runway thresholds were not staggered and the runway separation was set at 2,500 feet so that the configuration complied with paragraph 5-8-5. For the second scenario, the thresholds were staggered 4,500 feet and the separation was set at 1,600 feet to comply with paragraph 5-8-5. For the third scenario, the thresholds were staggered 3,360 feet and the separation was set at 1,600 feet to comply with the waiver request. In each of the three scenarios, missed approaches and balked landings to runway 26 and departures from runway 27R were simulated.

A Target Level of Safety (TLS) of 4×10^{-8} was established for the simulation. Test criteria used in the analysis was the Test Criteria Violation (TCV). A TCV results whenever the slant distance between the centers of gravity of two aircraft is less than or equal to 500 feet. It was assumed that a collision might result if a TCV occurs. Each scenario was simulated the equivalent of 20,000 times. The probability or risk of a TCV was estimated for each of the three scenarios.

The probability or risk of a TCV for each of the three scenarios was found to be less than the TLS. Therefore, the risk of collision is acceptably low for each of the three scenarios. The runway spacing and stagger conditions at PHL resulted in a level of safety equivalent to that of the two scenarios which complied with Order 7110.65, paragraph 5-8-5, Departures and Arrivals on Parallel or Nonintersecting Diverging Runways. The simulation results are site specific to the Philadelphia International Airport and must not be extended to other sites.

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1.0 INTRODUCTION

The Philadelphia International Airport (PHL) has completed construction of runway 8/26, a 5,000-foot runway with a 2.5 degree offset localizer and a 250-foot decision height, at the northeast boundary of the airport. With the completion of this runway, the airport has three parallel runways, runway 8/26, runway 9L/27R, and runway 9R/27L. The parallel runways 8/26 and 9L/27R, are separated 1,600 feet while 9L/27R and 9R/27L are separated 1,400 feet. The threshold of runway 26 is staggered 3,360 feet east of the threshold of runway 27R. See figure 1 for a graphical depiction of the parallel runway configuration at PHL.

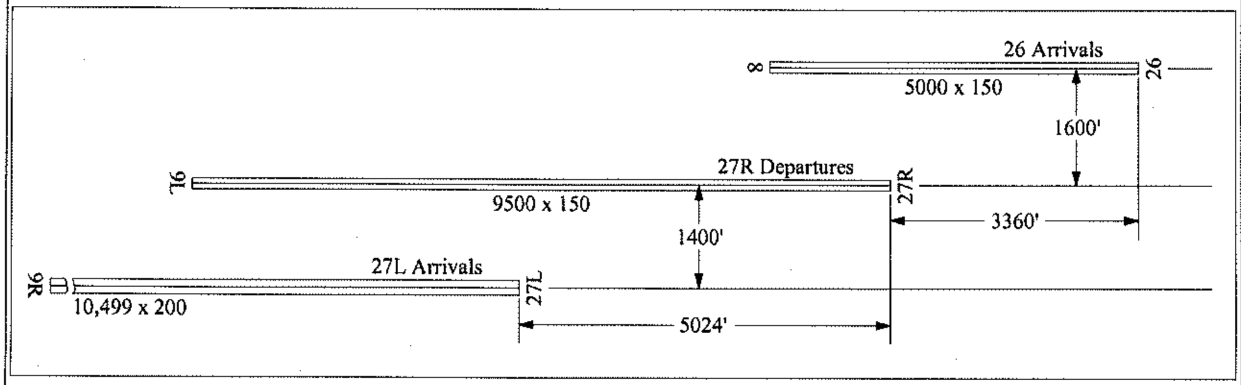

Figure 1. PHL PARALLEL RUNWAY CONFIGURATION

Since the length of runway 8/26 is 5,000 feet, the runway will be used for commuter and general aviation departures on runway 8 and arrivals on runway 26. It is intended that during Instrument Meteorological Conditions (IMC) simultaneous instrument approaches will be conducted to runways 26 and 27L. Since runways 26 and 27L are separated by 3,000 feet and in accordance with FAA Order 8260.39A, a Precision Runway Monitor (PRM) will be installed to enable simultaneous, independent approaches to be performed to the two runways. Departures would be conducted from runway 27R. Runway 8/26 will improve the capacity of PHL if independent arrival and departure operations can be conducted on runway 26 and 27R.

According to FAA Order 7110.65, paragraph 5-8-5, Departures and Arrivals on Parallel or Nonintersecting Diverging Runways, simultaneous operations between an aircraft departing on a runway and an aircraft on final approach to another parallel or nonintersecting diverging runway are authorized if the departure course diverges immediately by at least 30 degrees from the missed approach course until separation is applied and provided one of the following conditions is met:

a. When parallel runway thresholds are even, the runway centerlines are at least 2,500 feet apart.

b. When parallel runway thresholds are staggered, and

(1) The arriving aircraft is approaching the nearer runway: the centerlines are at least 1,000 feet apart and the landing thresholds are staggered at least 500 feet for each 100 feet less than 2,500 the centerlines are separated.

(2) The arriving aircraft is approaching the farther runway: the runway centerlines separation exceeds 2,500 feet by at least 100 feet for each 500 feet the landing thresholds are staggered.

Runway 26 is to be used for arrivals and runway 27R is to be used for departures when traffic lands and departs west bound. Since the centerlines of runways 8/26 and 9L/27 are separated by 1,600 feet and the thresholds are staggered, the threshold of runway 26 must be staggered east of the threshold of runway 27R by a distance of 4,500 feet to meet condition b(1). Since the threshold of runway 26 is only staggered east of the threshold of runway 27R by a distance of 3,360 feet, condition b(1) is not met at PHL. Condition b. (2) is not applicable to PHL since the arriving aircraft approaches the nearer runway.

The requirements of paragraph 5-8-5 could be met by displacing the threshold of runway 27R 1,140 feet west of the current threshold; however, the effective runway length for departures from runway 27R would be reduced from approximately 9,500 feet to 8,360 feet. This reduction in runway length is undesirable from an operational viewpoint, both in terms of reduced payloads and pilot reluctance to depart from a displaced threshold. Furthermore, because of the unique geometry and the type of aircraft using runway 26 (only Category A, B, and some C) there appears to be little safety gain by requiring aircraft to depart 1,140 feet down field on runway 27R. Therefore, a request for waiver to Order 7110.65, paragraph 5-8-5, was submitted by the Air Traffic Control Operations Branch.

The author of the request for waiver believes that an equivalent level of safety to that provided by the conditions of paragraph 5-8-5 can be achieved for independent landing operations on runway 26 with a 2.5 degree localizer offset and departure operations on runway 27R. It is the purpose of this paper to determine whether the conditions unique to PHL will allow independent landing and departure operations on runways 26 and 27R, respectively, while maintaining the level of safety intrinsic to the conditions of paragraph 5-8-5.

2.0 ANALYSIS PROCEDURE

The author of the request for waiver believes that an equivalent level of safety to that provided by the conditions of paragraph 5-8-5 can be achieved at PHL for independent landing operations on runway 26 and departure operations on runway 27R. The Flight Procedure Standards Branch (AFS-420), Airspace Simulation and Analysis for TERPS (ASAT) computer system was used to simulate three different scenarios. The first scenario complied with paragraph 5-8-5 since the runway spacing was 2,500 feet with zero feet stagger. Arrivals utilized the right hand runway and departures the left. The second scenario also complied with paragraph 5-8-5 since the runway spacing was 1,600 feet with a threshold stagger of 4,500 feet. Arrivals utilized the right hand runway, which had the nearer threshold during the approach, and departures utilized the left. The third scenario simulated the waiver request with runway spacing set at 1,600 feet with a threshold stagger of 3,360 feet. Arrivals utilized the right hand runway, which had the nearer threshold during the approach, and departures utilized the left. Table 1 summarizes the three scenarios.

Scenario Number	Spacing Feet	Stagger Feet	Comments
1	2,500	0	Complies with paragraph 5-8-5
2	1,600	4,500	Complies with paragraph 5-8-5
3	1,600	3,360	Stagger 1140 feet short of standard

Table 1: ASAT TEST SCENARIOS

The ASAT approach module was set up to conform to the conditions of each of the three scenarios. For scenario one, ASAT was set up to the localizer alignment and decision height used at PHL. Although the runway thresholds were not staggered, the configuration for scenario one complied with paragraph 5-8-5 since the runway separation was 2,500 feet. For scenarios two and three, ASAT was set up to the runway spacing, runway stagger, localizer alignment and siting, and decision height used at PHL. The configuration for scenario two complied with paragraph 5-8-5 by having a threshold stagger of 4,500 feet. The configuration for scenario three did not comply with paragraph 5-8-5 since the threshold stagger was 3,360 feet. In each of the three scenarios, simultaneous missed approaches or balked landings were simulated to the right-hand runway and departures from the left-hand runway. In each of the three scenarios, the right-hand runway was identified as runway 26 and the left-hand runway was identified as runway 27R. It was assumed that there would be no air traffic control (ATC) intervention when an aircraft performing a missed approach deviated toward runway 27L. The only difference between the three scenarios was the geographic layout of the runways. The conditions on three scenarios were as follows:

a. For runway 26, only aircraft from categories A, B, and C were selected for missed approaches or balked landings. For runway 27R, aircraft from categories A, B, C, and D were selected for departures.

b. The wind for each scenario was set at 15 KT crosswind from 350 degrees.

c. Aircraft approaching runway 26 performs either a missed approach or a balked landing.

d. A second aircraft departs runway 27R as the aircraft approaching 26 begins a missed approach or a balked landing.

A plan view of the ASAT simulation of each of the three scenarios is shown in figures 2, 3, and 4. In each of the figures, the red circle on the approach path of runway 26 denotes the point at which the missed approach or balked landing was initiated. The altitude for the initiation of the missed approach or balked landing was chosen randomly. This resulted in a large number of initiation points near the threshold that represent balked landings. The magenta line joining each pair of tracks shows the position of each aircraft at their Closest Point of Approach (CPA) and the magnitude of the CPA.

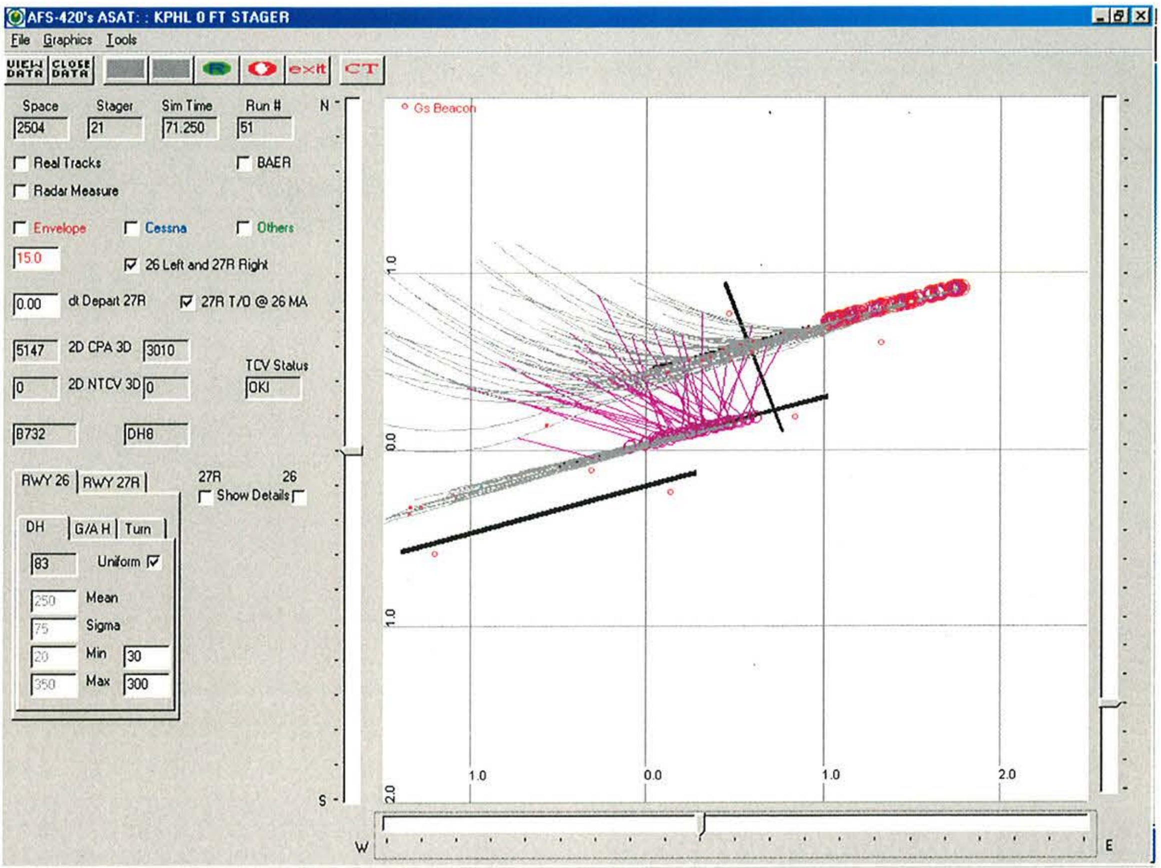

Figure 2: **2,500 FEET SPACING, 0 FEET STAGGER (SCENARIO #1 IN TABLE 1)**

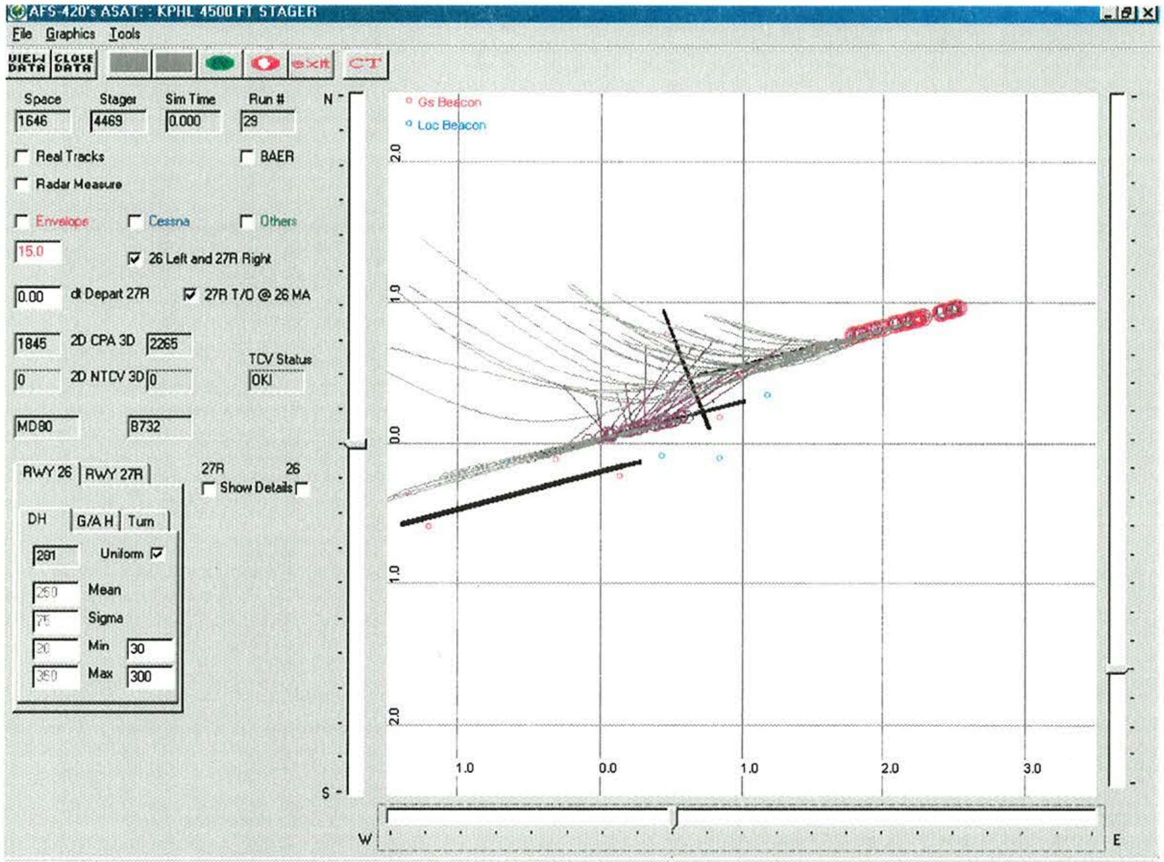

Figure 3. 1,600 FEET SPACING, 4,500 FEET STAGGER (SCENARIO #2 IN TABLE 1)

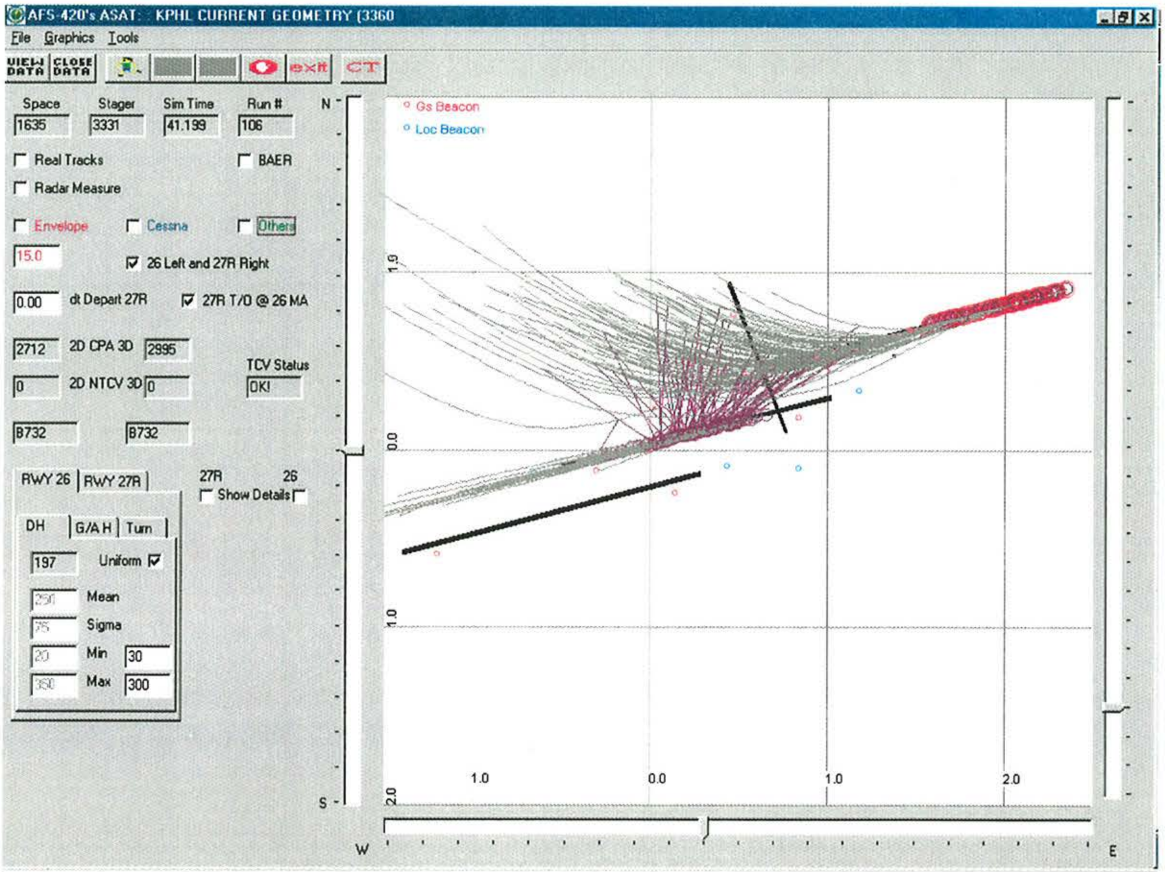

Figure 4: 1,600 FEET SPACING, 3,360 FEET STAGGER (SCENARIO #3 IN TABLE 1)

2.1 RANDOM VARIATION OF CRITICAL PARAMETERS

Radar track data of operations at PHL were used to develop probability distributions of take off distances, aircraft lateral dispersion during take off, and aircraft mix for principal aircraft types. For a discussion of radar accuracy see Shank. Certain aircraft performance data were obtained from previous real time simulations. Other performance parameters such as approach indicated airspeeds (IAS), go-around IAS, and climb rate were determined by consultation with major airlines operating at PHL (see appendix B). In every case probability distributions were developed to describe the variation of aircraft performance parameters. Table 2 describes the statistical parameters that were varied. Parameters depending on aircraft type are denoted "A/C" in the "Comments" column. Parameters associated with human factors are marked with "H.F." in the "Comments" column. Appendix A provides a more detailed mathematical description of the various statistical parameters, including probability density functions and ranges of variation.

Parameter	Description	Comments
Parameters Associated with Runway 26		
26 AC TYPE	Aircraft type for aircraft approaching runway 26	See Table 3
26 DH	Altitude at which the A/C on runway 26 initiates the missed approach or balked landing	H.F.
26 IAS APP	Approach indicated airspeed	A/C
26 DELTA PSI	Heading deviation during go around relative to final approach heading	H.F.
26 ROC	Rate of climb during the missed approach or balked landing	A/C
26 IAS GA	Indicated air speed during the missed approach or balked landing	A/C
26 ACCEL	Acceleration rate used in the transition from IAS APP to IAS GA	A/C
26 H TURN	Altitude at which the right turn is initiated during the missed approach or balked landing	H.F.
26 BANK	The bank angle used to turn at 26 H TURN	A/C
26 BANK RATE	The bank rate used to achieve the 26 BANK bank angle	A/C
Parameters Associated with Runway 27R		
27R AC TYPE	Aircraft type for aircraft departing from runway 27R	See Table 3
27R IAS TO	Take off IAS	A/C
27R ROC	Rate of climb after take off	A/C
27R TO LENGTH	Runway length required for take off	100 Ft AGL
27R ACCEL TO	Acceleration used from holding point to take off	A/C
27R H TURN	Altitude at which the aircraft taking off initiates a left turn	H.F.
27R BANK	The bank angle used to turn at 27R H TURN	A/C
27R BANK RATE	The bank rate used to achieve the 27R BANK bank angle	A/C
27R DELTA PSI	Heading deviation during take off relative to runway bearing	H.F

Table 2: STATISTICAL CRITICAL PARAMETERS USED IN ASAT

Each of the three scenarios that were simulated involved simultaneous missed approaches or balked landings to runway 26 and departures from runway 27R, i.e., the departure was released simultaneously with the initiation of the missed approach. This is an extremely conservative method of initializing the simulation. The altitudes for the initiation of the missed approach or balked landing were selected uniformly from 30 feet to 300 feet. This range of altitudes resulted in 70% balked landings, which is also considered extremely conservative. Probability distributions of lateral dispersion from the International Civil Aviation Organization (ICAO), Collision Risk Model (CRM), were used to position the aircraft about the localizer course prior to the missed approach or balked landing. The CRM is a computer system used internationally to evaluate the risk of collision with an obstacle during an instrument approach using the Instrument Landing System or Microwave Landing System for approach guidance. Aircraft headings for the missed approaches or balked landings were selected from a truncated normal distribution with mean zero and standard deviation of 5 degrees in the range -15 to +15 degrees. Only runs in which the missed approach aircraft deviated left of course; i.e., toward runway 27R were simulated since those that deviated away from runway 27R were not at risk of collision. After climbing to a nominal 800 feet, the aircraft performing the missed approach or balked landing turned right about 45 degrees. A normal probability distribution was used to determine the turn angle. All category A, B, and C aircraft models available were used in the simulation of the missed approaches and balked landing. The wind was set at a constant 15 knots from 350 degrees.

Missed approach data collected during an FAA flight test of the Microwave Landing System (MLS) conducted in 1986 was used to validate the probability distribution of angular dispersion about the missed approach point. Since the dispersion about the glide path at the missed approach point of aircraft using MLS is statistically the same as for aircraft using ILS, and since electronic guidance is not used during the missed approach segment, the missed approach dispersions of MLS and ILS are equivalent. Figure 5 depicts three boundaries about the nominal Missed Approach Point for runway 26. The inner most green lines form the boundaries of the dispersion of category A, B, C, and D aircraft used in the MLS study. The blue lines form the boundaries of the dispersion of a Cessna 172 used in the MLS study. The red lines bound a range of ±15 degrees used in the ASAT simulation. Since the red lines encompass the blue and green lines, the angular dispersion used in the simulation is considered to be conservative; i.e., too wide.

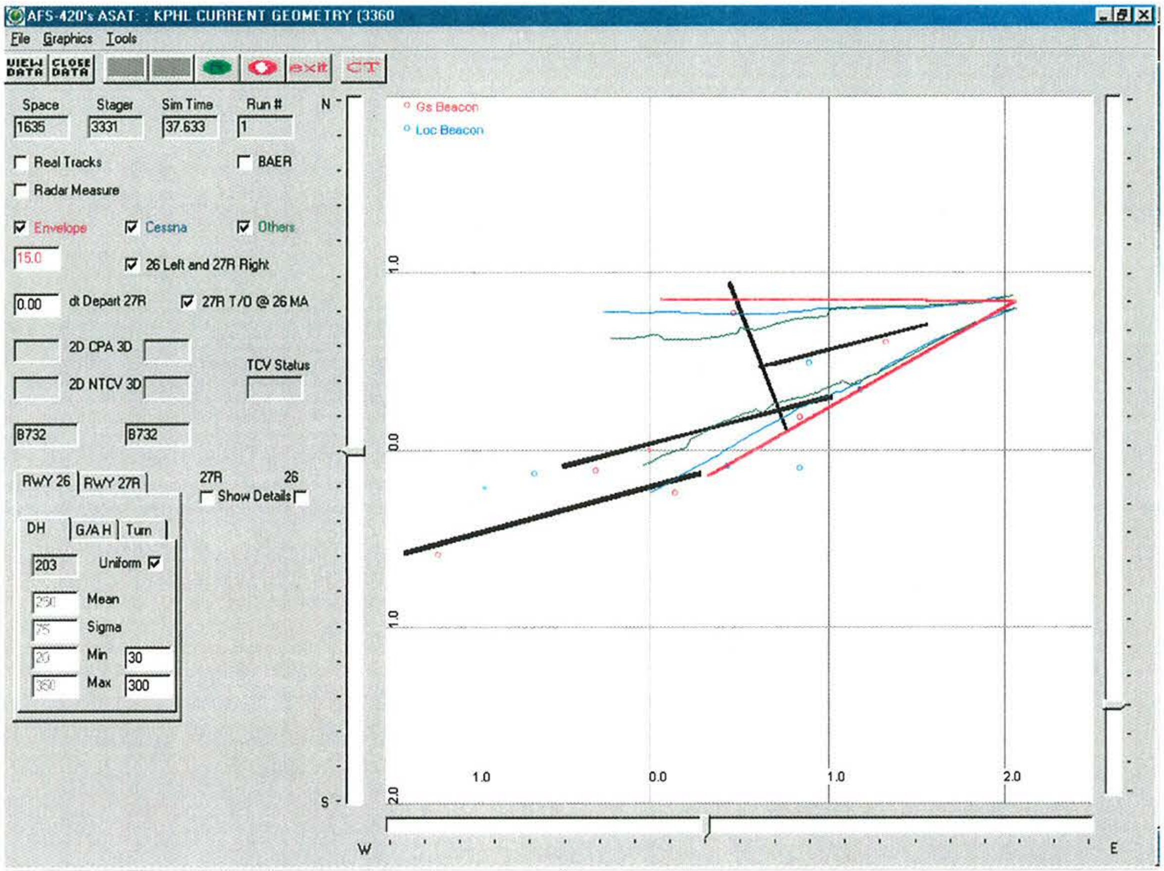

Figure 5: AIRCRAFT DEVIATIONS DURING A MISSED APPROACH

The aircraft types, aircraft categories, and aircraft mix used in the simulation were as follows:

a. Category A: DH8, 6%.

b. Category B: F100, 5.2%

c. Category C:

(1) B737, 38.8%

(2) B727, 14.2%

(3) MD80, 19%

(4) DC9, 4.7%

(5) A320, 9.5%

d. Category D: (Departing runway 27R only)

(1) DC8, 1.4%

(2)GLF2/4/5, 1.2%

Aircraft indicated airspeeds and climb rates used in the simulation are depicted in table 3.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)	
	Min	Max	Min	Max	Min	Max
Dash8	110	120	125	145	1000	2000
B737	137	147	170	180	1500	3000
B727	132	142	160	190	1000	3000
A320	132	142	155	170	2000	3000
DC8	130	145	145	165	1500	2500
F100	130	135	135	150	1500	2500
GLF2	130	144	140	160	2000	3000
MD80	135	140	155	170	2000	3000

Table 3: SPEED RANGES OF AIRCRAFT SIMULATED AT PHL

In order to increase the level of confidence in the risk analysis results, the statistical variation of the parameters was designed to be conservative, i.e., worst case. To illustrate this, consider a worst case defined by the following combination of critical parameters:

The aircraft while approaching runway 26 will:

a. execute a late missed approach,
b. climb at a low rate,
c. climb at a high air speed,
d. deviate left during the missed approach, and
e. initiate right turn at a high altitude.

The aircraft while departing from runway 27R will:

a. start its take off run after the aircraft on 26 descends below its DH,
b. climb at a moderate to high rate of climb,
c. climb at a low air speed,
d. deviate right during its take off, and
e. initiate left turn at a high altitude.

In actual operations, the situation described above would seldom happen. However, in the ASAT simulation runs, critical parameters were selected in a way that those combinations occurred more often than would be expected during actual operations. This results in an increased probability of selecting a high-risk case and makes the analysis results conservative; i.e., the probabilities derived by ASAT are larger than the actual probabilities.

2.2 PROCESSING PHL RADAR TRACKS.

In order to establish a reliable data base of take off distances and deviation from runway centerline following take off of the various aircraft operating at PHL, the ASAT system was enhanced to include a module system that displays radar tracks, sorted by runway and category. Radar tracks of aircraft operating from PHL for nine days during seven months of 1999 were obtained on magnetic media. The ASAT system was used to display radar tracks so that personnel of the PHL Air Traffic Control Tower could select those tracks that were most representative of anticipated aircraft departures from runway 27R. The dates and times the tracks were recorded is shown in table 3. The resulting data was used by AFS-420 to develop statistics for the take off characteristics of the most common types of aircraft operating from PHL. Although several different types of aircraft operate from PHL, the number of tracks pertaining to certain types of aircraft was too small for statistical analysis. The most important parameters that were derived from the radar tracks were:

a. Take off distances of the most common types of aircraft, and

b. Cross track deviations during take off and initial climb of the most common types of aircraft.

The radar track data processed by AFS-420 using ASAT consisted of:

a. 17 data files listed in table 4, containing more than 1 million records,
b. 3,868 departure tracks, out of them 2,289 departures from runway 27L,
c. 3,966 arrival tracks, and
d. 169 aircraft names grouped into 5 categories A, B, C, D, and X (used for "unknown" aircraft types).

Date	File Name	AM/PM
January 15, 1999	Jan 15A DT.TXT	AM
January 15, 1999	Jan 15B DT.TXT	PM
February 1, 1999	Feb 1A DT.TXT	AM
February 1, 1999	Feb 1B DT.TXT	PM
March 12, 1999	March 12A DT.TXT	AM
March 12, 1999	March 12B DT.TXT	PM
April 1, 1999	April 1A DT.TXT	AM
April 1, 1999	April 1B DT.TXT	PM
April 22, 1999	April 22A DT.TXT	AM
April 22, 1999	April 22B DT.TXT	PM
May 23, 1999	May 23B DT.TXT	PM
June 8, 1999	June 8A DT.TXT	AM
June 8, 1999	June 8B DT.TXT	PM
June 29, 1999	June 29A DT.TXT	AM
June 29, 1999	June 29B DT.TXT	PM
July 2, 1999	July 2A DT.TXT	AM
July 2, 1999	July 2B DT.TXT	PM

Table 4: RADAR TRACK DATA

The ASAT system provides graphic output of the tracks as well as numerical output suitable for statistical analysis. Figures 6 and 7 depict the graphic output of the radar track analysis section of ASAT. The color of each track indicates the category of the aircraft as follows: Red is Category A, Green is Category B, Blue is Category C, and Light Green is Category D.

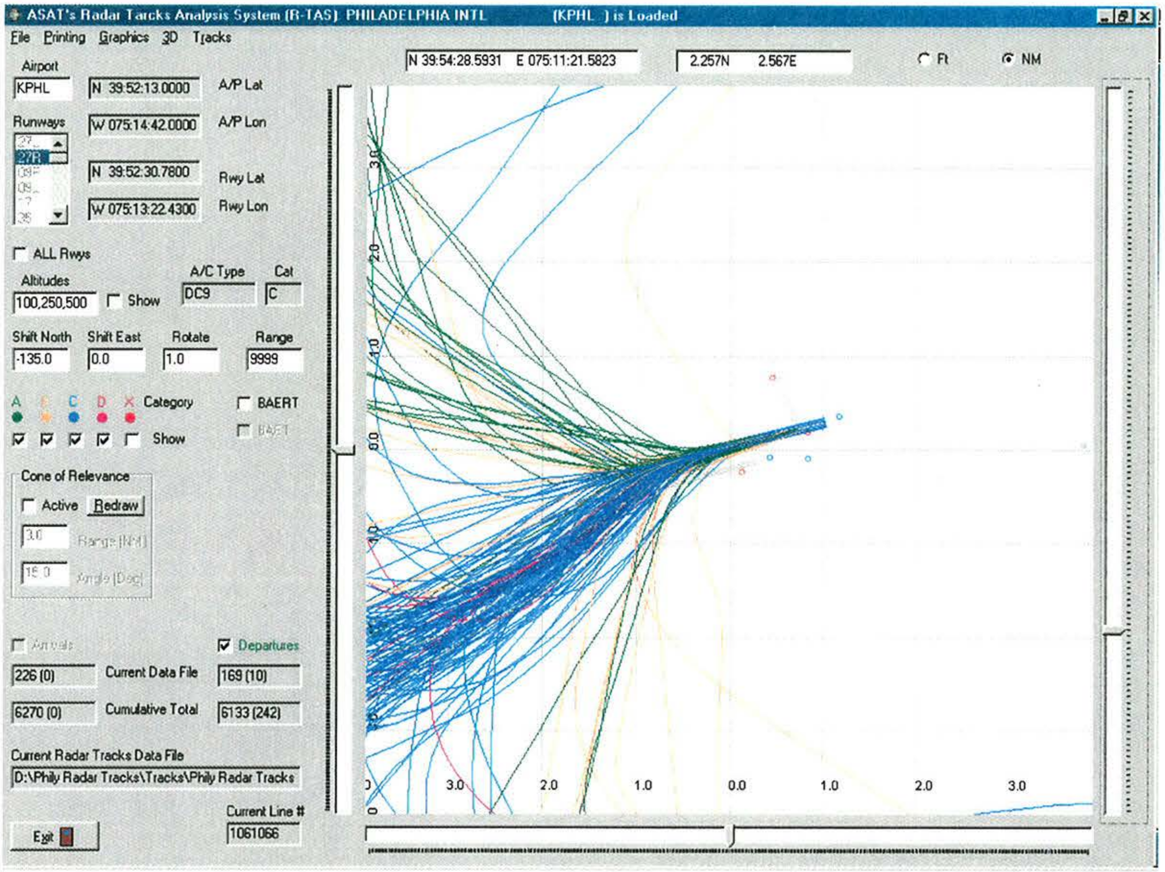

Figure 6: ASAT RADAR TRACKS ANALYSIS TOOL GRAPHIC OUTPUT (ALL TRACKS)

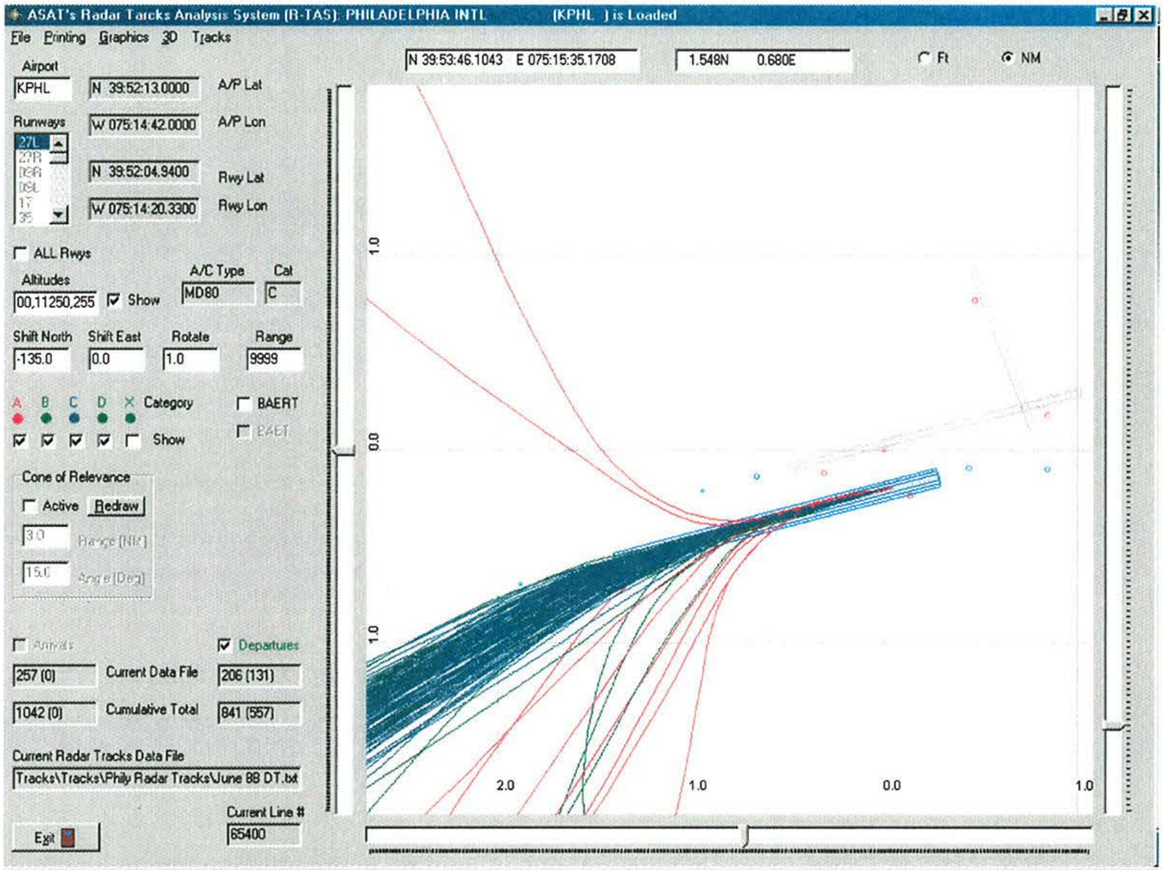

Figure 7: ASAT RADAR TRACKS ANALYSIS TOOL GRAPHIC OUTPUT (ATC SELECTED TRACKS)

3.0 SIMULATION CRITERIA

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

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

4.0 SIMULATION RESULTS AND CONCLUSIONS

Each of the three scenarios was performed 10,000 times. During actual flight operations, half of the missed approaches/balked landings would deviate to the right and away from runway 27R. The missed approaches/balked landings that deviate away from runway 27R pose no risk to the aircraft departing on runway 27R. Therefore, it is only necessary to simulate deviations from runway 26 toward runway 27R, but the number of runs simulated is equivalent to twice that number of actual flight operations. In this simulation, the number of runs actually simulated was equivalent to 20,000 runs for each scenario.

During the simulation of each scenario, no TCVs were observed. The smallest CPA observed was 650 feet during the simulation of scenario 3 (1,600 feet runway separation, 3,360 feet stagger). Table 5 summarizes the basic statistics of each simulation.

Scenario	Mean [Feet]	Standard Deviation [Feet]	Minimum [Feet]	Maximum [Feet]
1	4238.4	1321.7	900	9960
2	4492.1	1119.1	840	9150
3	4928.0	1358.3	650	9330

Table 5: SIMULATION CPA STATISTICS

In order for a TCV to occur during simultaneous operations on runway 26 and runway 27R, three events must occur. A missed approach or balked landing to runway 26 must occur. The aircraft performing the missed approach/balked landing must deviate toward runway 27R, and the CPA must be less than or equal to 500 feet. Let M stand for the event "missed approach/balked landing". Let D stand for the event "deviates toward runway 27R", let C stand for the event "CPA less than or equal to 500 feet". Then the probability of a TCV is the probability that event M and event D and event C occur simultaneously. Letting P(event) stand for "probability of event" and letting $\cap$ stand for "and", the probability of a TCV may be written in a formula as follows:

$$P(TCV) = P(M \cap D \cap C). \qquad (1)$$

Using conditional probabilities, formula (1) can be written as follows:

$$P(TCV) = P(C \mid M \cap D) \times P(D \mid M) \times P(M), \qquad (2)$$

where the symbol "|" is read "given". Formula (2) states that the probability of a TCV is equal to the probability of the CPA being less than 500 feet given that a missed approach and deviation toward runway 27R have occurred, times the probability that a deviation toward runway 27 R will occur given a missed approach occurred, times the probability of a missed approach. Since the aircraft performing the missed approach/balked landing has an equal chance of deviating right or left (toward runway 27R), we can write:

$$P(D \mid M) = 0.5 \qquad (3)$$

The probability of a missed approach used in the ICAO Collision Risk Model is 0.01. This number is considered to be conservative, i.e., too large. Therefore, the probability of the event M can be written as:

$$P(M) = 0.01 \qquad (4)$$

The only remaining factor in equation (2) is $P(C \mid M \cap D)$. This number is the probability of a CPA given that a missed approach/balked landing and a left deviation of the aircraft have occurred. This number is the number that is estimated for each scenario from the output of the simulation. Probability curves were fitted to the output data from ASAT in order to estimate $P(C \mid M \cap D)$ for each scenario. Table 6 summarizes the estimates of $P(C \mid M \cap D)$ for each of the scenarios as well as the probability of a TCV, P(TCV). P(TCV) is found using equations (2), (3), and (4).

Scenario	**$P(C \mid M \cap D)$**	**P(TCV)**
1	$.5 \times 10^{-10}$	2.5×10^{-13}
2	$.5 \times 10^{-8}$	2.5×10^{-11}
3	$.3 \times 10^{-6}$	1.5×10^{-9}

Table 6: ESTIMATED TCV PROBABILITIES

Despite the fact that care was taken to ensure that worst-case scenarios were more likely to occur than would be expected during actual operations, all of the entries in the third column of table 6 are significantly less than the TLS, 4×10^{-8}. In fact, the TLS is almost 27 times larger than P(TCV) for scenario 3.

Two of the most conservative conditions were changed to realistic conditions, i.e., departures were released independent of missed approaches and the number of balked landings was reduced to realistic levels, and another 20,000 runs of each scenario were run. The result was that P(TCV) for each of the three scenarios became insignificantly small. The planned addition of a Precision Runway Monitor (PRM) will allow ATC intervention and further enhance the safety of the operation. Therefore, the level of safety is not adversely affected by using a stagger of 3,360 feet at PHL instead of the required 4,500 feet and the requested waiver can be safely granted. However, the simulation results are site specific to the Philadelphia International Airport and must not be applied to other sites.

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APPENDIX A

APPENDIX A

TABLES

FIGURES

APPENDIX A

A-1. STATISTICAL ANALYSIS OF FLIGHT TRACK DATA

Radar tracks of aircraft operating from PHL for nine days during seven months of 1999 were obtained on magnetic media. The resulting data were used by ASF-420 to develop statistics of the take off characteristics of the most common types of aircraft operating from PHL. The most important parameters that were derived from the radar tracks were:

a. Take off distances of the most common types of aircraft, and

b. Cross track deviations during take off and initial climb of the most common types of aircraft.

The radar track data could not be used to determine the exact point of takeoff; however, the track data could be used to determine the distance from the departure end of the runway where the aircraft attained a given altitude such as 100 feet. At the point where the aircraft attained a given altitude the deviation of the aircraft from the extended runway centerline could also be determined.

Although several different types of aircraft operate from PHL, the number of tracks pertaining to most types of aircraft was too small for statistical analysis. Table A-1 summarizes the types of aircraft used in the simulation. Also included are the category of aircraft, the number of departures, and standard statistics for the distance from the departure end of the runway where the aircraft attained 100 feet altitude. The category of the aircraft refers to the approach speed category of the aircraft as defined in Part 97 of Title 14 of the Code of Federal Regulations (14 CFR). Category D aircraft were used only for departures from runway 27R.

A/C Type	Category	Mean	Standard Deviation	Count
1. A320	C	4868.021	1108.863	145
2. B727	C	5248.854	1477.822	151
3. B737	C	5016.195	1153.08	307
4. B757	C	4519.928	1319.424	139
5. DC8	D	4523.255	774.7598	47
6. DH8A	A	3455.26	951.8551	100
7. F100	B	4873.868	1194.186	129
8. GLF	D	4553.364	1521.887	22
9. MD80	C	4999.68	1174.278	169

Table A-1: TAKEOFF DISTANCES TO 100 FEET ALTITUDE

In a similar fashion, table A-2 summarizes the types of aircraft, category of aircraft, the number of departures, and standard statistics for the lateral deviation of the aircraft from the extended runway centerline where the aircraft attained 100 feet altitude.

A/C Type	Category	Mean	Standard Deviation	Count
1. A320	C	-49.4828	60.26079	145
2. B727	C	-34.3841	75.89579	151
3. B737	C	-14.8469	87.68906	307
4. B757	C	-46.9424	62.12491	139
5. DC8	D	21.82979	78.38293	47
6. DH8A	A	-29.48	99.16433	100
7. F100	B	-30.4186	78.88349	129
8. GLF	D	-66.8182	47.59515	22
9. MD80	C	-39.3195	69.91716	169

Table A-2: LATERAL DEVIATION AT 100 FEET ALTITUDE

Figure A-1 presents the takeoff distances of the four categories of aircraft. All data, including the data from those aircraft not used in the simulation are represented in the figure. The minimum values shown are in some cases unrealistically small and are caused by radar tracking anomalies. However, the use of these minimum values enhances the conservative nature of the simulation, since the aircraft performing a missed approach or aborted landing to runway 26 and aircraft departing runway 27R are at greatest risk when the departing aircraft's takeoff run is shortest.

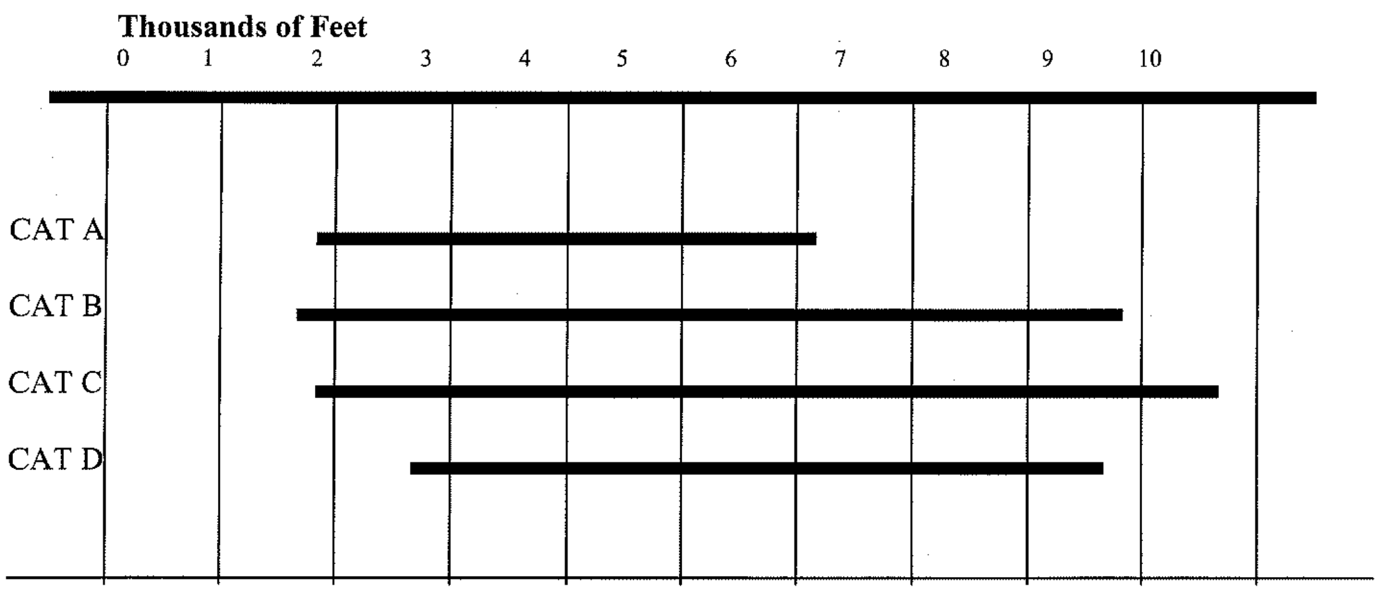

Figure A-1: MINIMUM AND MAXIMUM TAKEOFF DISTANCES BY CATEGORY

A-2. GROUPING OF AIRCRAFT

Several different types of aircraft were represented in each category. In many cases, there were not enough observations of particular types of aircraft for analysis. In other cases, there were several different models of the same type aircraft. For example, the Boeing 737 was produced in several different models. There were eight models of Boeing 737 in operation at PHL. Table A-3 summarizes the types of aircraft and the number of flights of each type.

Category A		Category B		Category C		Category D	
Plane	Count	Plane	Count	Plane	Count	Plane	Count
BE35	1	AC6T	2	A306	1	B741	15
BE36	1	AEST	12	A310	4	B742	1
C182	1	B190	148	A319	55	B747	1
C712	1	B350	2	A320	100	DC8	1
D328	8	BE10	1	A321	3	DC86	22
DH8A	311	BE20	14	B721	9	DC87	14
P28A	2	BE30	2	B722	111	DC8Q	10
P28T	1	BE40	9	B727	3	GLF2	6
PA23	1	BE58	17	B72Q	61	GLF4	14
PA46	2	BE60	1	B732	67	GLF5	2
PAY2	3	BE90	2	B733	317		
PC12	3	BE9L	2	B734	192		
		C210	1	B735	63		
		C310	11	B737	13		
		C402	1	B738	7		
		C414	1	B73A	3		
		C421	2	B73Q	61		
		C441	2	B752	160		
		C525	1	B762	14		
		C550	2	B763	21		
		C560	9	CARJ	118		
		DA50	2	CL60	11		
		F100	135	CL64	2		
		F2TH	4	DC9	102		
		F50	1	DC9Q	205		
		F900	4	H25A	6		
		FA10	1	H25B	11		
		FA20	4	H25C	4		
		FA50	2	LJ24	1		
		JS31	1	LJ25	2		
		JS32	26	LJ31	3		
		JS41	26	LJ35	43		
		MU2	39	LJ45	1		
		MU30	2	LJ55	5		
		PA31	11	LJ60	6		
		PA34	1	LR25	3		
		PA42	1	LR35	17		
		PAY3	1	MD80	179		
		PAYE	1	MD90	1		
		SBR1	3				
		SF34	64				
		SW3	1				

Table A-3: AIRCRAFT OPERATIONS AT PHL FROM RADAR TRACKS

The Kruskal-Wallis one-way analysis of variance (see Siegel) was used to determine whether the data produced by the various models of a particular aircraft type could be combined into one data set. This was found to be possible for the various models of a particular type of aircraft. For example, the data from the eight models of Boeing 737 were combined into one data set to represent the Boeing 737. The Kruskal-Wallis one-way analysis of variance test is a non-parametric test used to test whether several independent samples could have been drawn from the same continuous population.

After the data had been grouped by aircraft type, the Kruskal-Wallis one-way analysis of variance was used to determine whether the different aircraft types could be grouped together. For example, could the category C aircraft be grouped together to form one set of data for category C. The Kruskal-Wallis test indicated that significant differences exist between the types of aircraft. The Kruskal-Wallis test ranks the sample values from the several data sets; i.e., all of the scores from all of the several samples combined are ranked in a single series. After ranking, the test sums the ranks in each sample. The test then determines whether these sums of ranks are so disparate that they are not likely to have come from samples which were all drawn from the same population.

The results of the Kruskal-Wallis test for the distance from the departure end of the runway that the aircraft attained 100 feet altitude are shown in tables A-4 and A-5. Table A-4 presents the ranking of each aircraft type. The numbers under the heading "THRESH CASE" correspond to the numbers under the heading "A/C Type" in the first column of table A-1. Table A-5 presents the results of the Kruskal-Wallis test. The third row of the table presents the probability that the nine aircraft types would have the rankings found in table A-4 if they all were from the same population. The probability given is .000. That is, if the aircraft samples were all from the same population, the probability of obtaining the rankings of table A-5 is .000. Therefore, we conclude that the aircraft samples are from different populations. In a similar fashion, the sets of lateral deviations were tested using the Kruskal-Wallis test and found to be significantly different. The results of the test are found in tables A-6 and A-7.

Ranks

	CASE	N	Mean Rank
THRESH	1	145	636.27
	2	151	717.35
	3	307	664.90
	4	139	522.79
	5	47	544.34
	6	100	242.55
	7	129	623.03
	8	22	497.45
	9	169	668.16
	Total	1209	

Table A-4: RANKINGS OF DISTANCES TO 100 FEET ALTITUDE

Test Statistics[a,b]

	THRESH
Chi-Square	150.697
df	8
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: CASE

Table A-5: SIGNIFICANCE LEVEL FOR RANKINGS OF DISTANCES TO 100 FEET ALTITUDE

Ranks

	CASE	N	Mean Rank
LATERAL	1	145	523.54
	2	151	592.53
	3	307	695.52
	4	139	515.16
	5	47	863.16
	6	100	555.01
	7	129	614.86
	8	22	417.68
	9	169	570.13
	Total	1209	

Table A-6: RANKINGS OF LATERAL DEVIATIONS AT 100 FEET ALTITUDE

Test Statistics[a,b]

	LATERAL
Chi-Square	73.801
df	8
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: CASE

Table A-7: SIGNIFICANCE LEVEL FOR RANKINGS OF LATERAL DEVIATIONS AT 100 FEET ALTITUDE

A-3. FITTING CURVES TO DATA

In order for the ASAT Monte Carlo routines to use the aircraft performance data, such as the distance from the departure end of the runway that the aircraft attains 100 feet altitude, continuous probability curves must be fitted to the data. The Johnson family of curves, developed by N. L. Johnson in 1949, is used to fit probability curves to the data sets. The Johnson family includes three types of curves, the Johnson S_L family, the Johnson S_B family, and the Johnson S_U family (see Hahn et.al.). The curves of the S_L family are bounded at one end with an infinite tail at the other end. The curves of the S_B family are bounded at both ends. The curves of the S_U family are unbounded, i.e., have infinite tails at both ends. Each family of curves is based on a transformation of the observed data into a set of data that could be generated by a normal N(0,1) distribution. A test based on the statistics of the data determines which type of curve will best fit the data. It was found that for each data set, lateral deviation and distance from the departure end where 100 feet altitude is attained, and for each aircraft type, the data sets should be fitted with Johnson S_B curves. The transformation that determines the Johnson S_B family of curves is given by the following equation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda+\varepsilon-x}\right), \ \varepsilon < x < \lambda + \varepsilon \qquad \text{A(1)}$$

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

A-4. RANDOM NUMBER GENERATION

Central to any computer simulation is the generation of random numbers. A random number generator is an algorithm that produces numbers that lie within a specified range (typically 0 to 1) with any one number in the range just as likely as any other. Random numbers that are computed uniformly within a specified range are often called "uniform deviates". Most programming language implementations have library routines for generating uniform deviates. However, most of these were designed for less complex applications than high order Monte Carlo simulations and were unsuitable for our purposes, primarily due to repeatability; i. e., the same set of values kept coming out. Therefore, ASAT employs a random number generator developed by L'Ecuyer (see Flannery et.al.). The sequence of uniform deviates produced by this generator is more than sufficient for ASAT requirements.

A-5. GENERATION OF DEVIATES FROM A NORMAL DISTRIBUTION

Second only in importance to the generation of uniform random numbers described in A-4 is the generation of random deviates from a normal distribution. The Box-Muller method is a simple, but effective, method for generating random deviates from a normal distribution with mean 0 and standard deviation 1. Two random deviates, x_1 and x_2, from a normal distribution with mean 0 and standard deviation 1 can be computed by first finding two uniform deviates, u_1 and u_2. Then compute x_1 and x_2 from the following formulae:

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

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

$$y_1 = \mu + \sigma x_1$$
$$y_2 = \mu + \sigma x_2 \qquad \text{A(3)}$$

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

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

A-6. GENERATION OF DEVIATES FROM A JOHNSON S_B DISTRIBUTION

The generation of deviates from a Johnson S_B distribution is a three step process. First two uniform deviates must be generated as described in paragraph A-4. Then the uniform deviates are used to generate two deviates x_1 and x_2 from a normal distribution with mean 0 and standard deviation 1. Then two deviates y_1 and y_2 from a Johnson S_B distribution are computed from the equations:

$$y_i = \frac{(\varepsilon + \lambda)\exp\left(\frac{x_i - \gamma}{\delta}\right) + \varepsilon}{\left(1 + \exp\left(\frac{x_i - \gamma}{\delta}\right)\right)}, \quad i = 1,2. \qquad \text{A(4)}$$

The equations of A(4) are derived by solving equation A(1) for *x*.

A-7. GENERATION OF DEVIATES FROM A COLLISION RISK MODEL DISTRIBUTION

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

A-8. SELECTION OF AIRCRAFT TYPE

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

A-9. SIMULATION ALGORITHM OUTLINE

Each simulation run consists of the following steps:

1. Select an aircraft type for runway 26.

2. Select an aircraft type for runway 27R.

3. Select an altitude, distance from threshold, and deviation from the localizer course for the approaching aircraft.

4. Select aircraft performance parameters corresponding to the aircraft type for each aircraft. These would include rate of climb, indicated airspeed, and turn rate. For the departing aircraft, a takeoff distance to 100 feet altitude and a lateral deviation at 100 feet altitude are selected.

5. Select a course deviation angle for the approaching aircraft.

6. Set the two aircraft in motion and continuously monitor the distance between the two centers of gravity.

7. Record the closest point of approach (CPA), i.e., the smallest distance between the two centers of gravity.

8. Write all the pertinent information, including the CPA, of the simulation run in a file for analysis.

Whenever the word select is used, the selection is made in a random fashion as described in the previous paragraphs.

A-10. DETERMINATION OF THE PROBABILITY OF A TCV

The test criterion used in this simulation is the Test Criterion Violation (TCV). A TCV occurs whenever the CPA of a simulation run is less than or equal to 500 feet. In order for a TCV to occur during simultaneous operations on runway 26 and runway 27R, three events must occur.

1. A missed approach or balked landing to runway 26 must occur.

2. The aircraft performing the missed approach/balked landing must deviate toward runway 27R.

3. The CPA must be less than or equal to 500 feet.

Let M stand for the event "missed approach/balked landing". Let D stand for the event "deviates toward runway 27R",and let C stand for the event "CPA less than or equal to 500 feet". Then the probability of a TCV is the probability that event M and event D and event C occur simultaneously. Letting P(event) stand for "probability of event" and letting $\cap$ stand for "and", the probability of a TCV may be written in a formula as follows:

$$P(TCV) = P(M \cap D \cap C). \qquad A(5)$$

Using conditional probabilities, formula (1) can be written as follows:

$$P(TCV) = P(C \mid M \cap D) \times P(D \mid M) \times P(M), \qquad A(6)$$

where the symbol "|" is read "given". Formula A(6) states that the probability of a TCV is equal to the probability of the CPA being less than 500 feet given that a missed approach and deviation toward runway 27R have occurred, times the probability that a deviation toward runway 27 R will occur given a missed approach occurred, times the probability of a missed approach.

Since the aircraft performing the missed approach/balked landing has an equal chance of deviating right or left (toward runway 27R), we can write:

$$P(D \mid M) = 0.5 \qquad A(7)$$

The probability of a missed approach used in the ICAO Collision Risk Model is 0.01. This number is considered to be conservative. Therefore, the probability of the event M can be written as:

$$P(M) = 0.01 \qquad A(8)$$

The only remaining factor in equation A(6) is $P(C \mid M \cap D)$. This number is the probability of a CPA less than 500 feet given that a missed approach/balked landing and a left deviation of the aircraft-approaching runway 26 have occurred. This number is the number that is estimated for each scenario from the output of the simulation. Probability curves were fitted to the output data from ASAT in order to estimate $P(C \mid M \cap D)$ for each scenario. It was found that each of the three curves, corresponding to the three scenarios, should be fitted with a Johnson S_B curve. After the curves have been fitted, i.e., the appropriate parameters γ, δ, λ, and ε have been determined, the probability that the CPA distance is less than or equal to 500 feet can be computed from equation A(1). By substituting 500 for x in equation A(1) a value z corresponding to x is found. Since z is from a normal N(0,1) distribution, the probability that $Z \leq z$ can be found either from a table or by computation. This probability is the probability that the CPA distance is less than or equal to 500 feet and is represented by $P(C \mid M \cap D)$ in equation A(6). The probability of a TCV is then found by substitution of $P(C \mid M \cap D)$, $P(D \mid M)$, and $P(M)$ into equation A(6).

APPENDIX B

APPENDIX B

TABLES

Airlines Requested

To Supply Operational Data List As of 1/26/00

	Received
Airborne Express	
Air Canada	X
Allegheny Airlines	X
America West	
American Airlines	X
American TransAir	
Continental	X
Delta Air Lines	X
DHL	X
Emery Worldwide	X
Federal Express	X
Mesa Airlines	
Midwest Express	X
Northwest	X
Piedmont Airlines	X
PSA	
Trans World Airlines	X
United Airlines	X
UPS	X
US Airways	X

Table B-1. AIRLINES REQUESTED

Airline Speed Requirements
Data Collection For PHL Operations Evaluation

Please fax back To

CE Boschen 215-937-7873 (fax)

AirCanada

Alex Bretzel 1-514-422-6963

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727									
B737									
B747-100									
B747-400									
B757									
B767									
B777									
A310									
A320									
A340									
DC8									
DC9	118	123	123	162	1500	2500	128	171	Maneuvering 200kts 80000 lbs.
DC10-30									
DC10-40									
CRJ									
F100									
GLF2									
MD80									
C170									
CRJ	130	150	140	160	1500	3000	120	155	

Table B-2. AIR CANADA

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
<u>Allegheny Airlines</u>

Bob Schmidt 717-948-5490

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8	103	120	105	110	1000	1500	84	96	
B727									
B737									
B747-100									
B747-400									
B757									
B767									
B777									
A310									
A320									
A340									
DC8									
DC9									
DC10-30									
DC10-40									
CRJ									
F100									
GLF2									
MD80									
C170									
CRJ									

Table B-3. ALLEGHENY AIRLINES

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
American Airlines
Jeff Parks

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727-200	134	143	149	158	2500	2500	119	145	Climb rate is an average of PHL departures
B737									
B747-100									
B747-400									
B757-200	123	135	123	135	2500	2500	120	142	Climb rate is an average of PHL departures
B767									
B777									
CRJ									
F100	131	143	136	148	2200	2200	123	157	Climb rate is an average of PHL departures
GLF2									
MD80									
MD80-200	128	136	128	136	2200	2200	123	157	Climb rate is an average of PHL departures
MD80-300	128	136	128	136	2200	2200	123	157	Climb rate is an average of PHL departures
C170									
CRJ									

Table B-4. AMERICAN AIRLINES

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
<u>Continental Airlines</u>

Dan Ginty 713-324-5184

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727									
B737	110	140	125	155	2000	-	113	174	Data for 737-300,-500,-700
B747-100									and -800
B747-400									
B757									
B767									
B777									
A310									
A320									
A340									
DC8									
DC9									
DC10-30									
DC10-40									
CRJ									
F100									
GLF2									
MD80									
C170									
CRJ									

Table B-5. CONTINENTAL AIRLINES

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
Delta Air Lines

Roland Schmid 404-715-1698

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727	129	140	139	150	1250	800	119	143	Min and Max values are based
B737	132	139	142	149	750	600	127	145	on Minimum and Maximum
B737-300	134	141	144	151	500	400	125	145	operational weights.
B737-800	142	153	152	163	900	600	127	150	
B747-100									The Climb rate @G/A (FPM) data
B747-400									are based on 100 deg.F with one
B757	122	137	127	142	850	500	124	161	engine inoperative.
B767-200	126	142	131	153	1150	600	113	137	
B767-300-GE	134	153	139	158	1100	550	128	163	The Min Climb Rate corresponds
B777	126	144	131	149	1500	900	136	168	to the MIN speed from the previous
A310									column; The same holds true
A320									for the MAX.
A340									
DC8									
DC9									
DC10-30									
DC10-40									
CRJ									
F100									
GLF2									
MD88	132	141	135	145	800	600	125	139	
C170									
CRJ									

Table B-6. DELTA AIRLINES

Airline Speed Requirements
Data Collection For PHL Operations Evaluation

DHL Airways

Rob Dorsey 606-283-2200

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727	117	145	128	159	1100	5000+	137	174	
B737									
B747-100									
B747-400									
B757									
B767									
B777									
A310									
A320									
A340									
DC8	128	158	140	160	1500	5000+	136	161	
F100									
GLF2									
MD80									
C170									
A300	122	138	122	148	1500	5000+	150	180	

Table B-7. DHL AIRWAYS

Airline Speed Requirements
Data Collection For PHL Operations Evaluation

Emery Worldwide

Rob Barrow 937-264-6081

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727									
B737									
B747-100									
B747-400									
B757									
B767									
B777									
A310									
A320									
A340									
DC8-62/63	125	162	162	213	1000	3000	124	161	
DC8-71	126	163	168	220	1000	3000	119	160	
DC8-73	121	156	161	210	1000	3000	114	164	
F100									
GLF2									
MD80									
C170									

Table B-8. EMERY WORLDWIDE

Airline Speed Requirements
Data Collection For PHL Operations Evaluation

Federal Express

David Sorrell 901-224-4557

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727-100		139		146		1940		151	MLW=142.5 MTOW=169.5
B727-200/-17		150		155		2000		162	MLW=166 MTOW=199.5
B727-200/-217		149		154		2575		163	MLW=164 MTOW=197
B727-200/-15		149		154		1900		161	MLW=164 MTOW=203.2
A310 GE		140		150		1620		154	MLW=245 MTOW=313.1
A310 PW		140		150		2500		155	MLW=267.5 MTOW=313.1
A300		140		150		2665		169	MLW=310 MTOW=375.9
A310									
A320		145		164		2070		171	MLW=375 MTOW=423
A340		157		178		2370		185	MLW=436 MTOW=562
DC8		161		189		2740		185	MLW=481.5 MTOW=621.5
DC9									
DC10-10									
DC10-30									
MD11									
F100									
GLF2									
MD80									
C170									
CRJ									

Table B-9. FEDERAL EXPRESS

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
Midwest Express

Stan Cooper 414-294-6249

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
C170									
DC9	116	138	134	149	1500	2300	125	142	We do not have actual climb performance data. These fpm rates are estimated using actual takeoff and goaround experience and reference to climb gradient data throughout transition and final segment climb segments.

Table B-10. MIDWEST EXPRESS

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
Northwest Airlines

Chris Schul 612-727-6794

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727	117	138	123	145	2405	3206	117	149	
B737									
B747-100	136	164	164	196	2490	3430	147	198	
B747-400	139	166	164	191	2690	3650	149	213	
B757	117	137	147	168	2000	2000	132	165	Automatic G/A
B767									
B777									
A310									
A320	107	137	118	146			118	157	
A340									
DC8									
DC9	116	137	121	142	2258	2670	110	136	
DC10-30	128	154	134	161	2600	3300	122	174	
DC10-40	130	152	143	169	2500	3350	126	176	
F100									
GLF2									
MD80									
C170									

Table B-11. NORTHWEST AIRLINES

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
Piedmont Airlines

Steve Farrows 410-742-4399

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8	101	147	102	122	1000	1500	103	117	
B727									
B737									
B747-100									
B747-400									
B757									
B767									
B777									
A310									
A320									
A340									
DC8									
DC9									
DC10-30									
DC10-40									
CRJ									
F100									
GLF2									
MD80									
C170									
CRJ									

Table B-12. PIEDMONT AIRLINES

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
TWA

Bob Clack 314-895-6806

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727									
B737									
B747-100									
B747-400									
B757									
B767									
B777									
A310									
A320									
A340									
DC8									
F100									
GLF2									
MD80	108	147	128	150	2000	3500	150	176	
C170									

Table B-13. TWA

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
<u>United Airlines</u>
Chester Gong 650-634-5137

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727	112	135	123	148	300	-	107	146	
B737	109	138	117	148	249	-	103	146	
B747-100									
B747-400	127	155	137	165	375	-	124	177	
B757	117	132	128	143	272	-	109	152	
B767	125	146	134	154	285	-	116	160	
B777	120	138	140	158	298	-	124	167	
A310									
A320	112	134	128	152	272	-	116	153	
A340									
DC8									
DC9									
DC10-30									
DC10-40									
CRJ									
F100									
GLF2									
MD80									
C170									
CRJ									

Table B-14. UNITED AIRLINES

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
UPS

David Baker 502-359-7318

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
B-727-100QF	106	128	116	139	500	3,800	112	147	Rolls-Royce Tay 651-54 Engines
B-727-200	117	140	127	150	400	4,200	119	158	PW JT8D-15/-17 Engines
B-757-200	109	136	119	148	400	11,000	123	166	PW 2040 & RR RB.211-535E4
DC-8-71	117	147	127	157	600	4,800	120	160	CFM56-2-C1 Engines
DC-8-73	115	146	125	156	500	4,800	124	158	CFM56-2-C1 Engines
A300F4-622R	115	138	120	125	300	8,500	142	167	PW 4158 Engines
B-767-300ERF	119	148	128	156	400	11,500	144	160	GE CF6-80C2B6F Engines
B-747-100	123	152	128	157	400	3,700	114	169	JT9D-7A Engines
B-747-200	123	160	128	162	400	4,200	134	178	JT9D-7Q Engines

Table B-15. UPS

Airline Speed Requirements
Data Collection For PHL Operations Evaluation
US Airways

Mark Jones 412-747-3698

PLEASE FEEL FREE TO ADD AIRCRAFT THAT ARE NOT LISTED IN THE TABLE

1. **Approach IAS:** The IAS (KTS) at the MAP.
2. **Go Around IAS:** The IAS (KTS) the aircraft is most likely to achieve during the Go Around climb.
3. **Climb Tate G/A:** The stabilized or maximum rate of climb during the Go Around phase.
4. **Take Off IAS:** The IAS at which the aircraft takes off, if available. Otherwise the rotation IAS.

A/C Type	Approach IAS (KTS)		Go Around IAS (KTS)		Climb Rate @ G/A (FPM)		Take Off IAS (KTS)		Comments
	Min	Max	Min	Max	Min	Max	Min	Max	
Dash 8									
B727									
B737-300	120	136	FL15 119	134	1000	2000	125	162	Step 2: V2 @ Min = OEW + 15000 lbs Max = MLW
B747-100									Step4: V2 @ Min = OEW + 15000 lbs Max = MTOW
B747-400									
B757	110	132	FL20 119	132	2000		120	159	
B767	117	136	FL20 118	123	2000		136	168	
B777									
A310									
A320	123	138	123	138	NA	NA	125	168	
A340									
DC8									
F100	113	130	FL15 119	131		2000	119	150	
GLF2									
MD80	122	135	FL11 132	144	NA		132	150	
C170									
DC9-30-9	115	129	FL15 121	133	NA		121	154	
A319	119	133	119	132	550	950	121	172	

Table B-16. US AIRWAYS