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**Analysis Of Risk Associated With
Elimination Of 250-KT Speed
Restriction At Houston George
Bush International Airport**

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Technical Report



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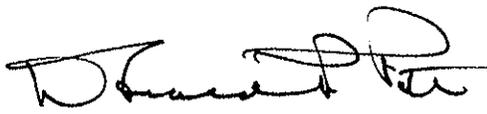
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Of 250 Kt Speed Restriction At Houston
George Bush Intercontinental Airport**

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12. Abstract Elimination of the 250-KT speed restriction below 10,000 feet MSL in class B airspace will provide an additional tool for Air Traffic Control (ATC) to achieve in-trail spacing of aircraft resulting in increased terminal airspace efficiency. In 1995 an RTCA Task Force recommended to the Federal Aviation Administration (FAA) that a study of the 250-KT speed restriction for aircraft operating below 10,000 feet within class B airspace be conducted to determine whether the speed restriction can be increased or eliminated. In response, the FAA initiated a field test of the proposed change conducted by Houston Intercontinental Terminal Radar Approach Control (TRACON) beginning June 26, 1997. Two reports were issued, one by MITRE and one by the FAA Flight Procedure Standards Branch, AFS-420, but neither addressed the possibility that the risk of collision may be increased because of the increase in departure speeds. The Flight Procedure Standards Branch was tasked to develop a simulation to evaluate the risk of collision between transient aircraft just outside class B airspace with aircraft departing class B airspace at speeds greater than 250-KT. This report is concerned with the analysis of risk associated with allowing departing aircraft to exceed 250-KT within class B airspace at the Houston George Bush Intercontinental Airport (KIAH). It was found that the risk of an encounter between an aircraft departing at a speed exceeding 250-KT and a transient aircraft, is acceptable and statistically equivalent to the risk of an encounter between an aircraft departing at a speed less than or equal to 250-KT and a transient aircraft.		
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EXECUTIVE SUMMARY

Elimination of the 250-KT speed restriction below 10,000 feet MSL in class B airspace will provide an additional tool for Air Traffic Control (ATC) to achieve in-trail spacing of aircraft resulting in increased terminal airspace efficiency. This procedure, conducted in a radar-controlled environment, will ensure that only specific identified aircraft that have received an ATC instruction are allowed to exceed 250-KT below 10,000 feet.

In 1995 an RTCA Task Force recommended to the Federal Aviation Administration (FAA) that a study of the 250-KT speed restriction for aircraft operating below 10,000 feet within class B airspace be conducted to determine whether the speed restriction can be increased or eliminated. In response, the FAA initiated a field test of the proposed change conducted by Houston Intercontinental Terminal Radar Approach Control (TRACON) beginning June 26, 1997. In December 1997, the MITRE Center for Advanced Aviation System Development (CAASD) published a preliminary evaluation of that study.

The most significant effect of the increase in the speed limit reported by MITRE, was the apparent increase in the number of aircraft that appeared to exit the side of the class B airspace below 10,000 feet at speeds greater than 250-KT. The MITRE study did not include an in-depth analysis of the underlying causes of the increased exit rate, but this conclusion fostered the perception that the level of collision risk with uncontrolled traffic passing just outside the class B airspace may be increased with the increase in the speed limit. As a consequence, the FAA Flight Procedure Standards Branch, AFS-420, was tasked to determine the conditions or performance limitations that might cause an unintentional exit of the class B airspace below 10,000 feet at speeds greater than 250-KT.

The FAA Flight Procedure Standards Branch issued a report of the study in June 2000. The report concluded that the Boeing B727 is capable of successfully reaching 10,000 feet prior to exiting class B airspace at speeds up to 300-KT with an air temperature of 95° and a gross takeoff weight of 183,000 pounds, if appropriate piloting techniques are employed. The Boeing 727 was one of the aircraft most likely to exit class B airspace below 10,000 feet in the Houston data, and its performance was considered representative of the class of aircraft that was an apparent problem. The report also included five recommendations that would increase the probability that aircraft exit the side of class B airspace above 10,000 feet. However, the report did not address the possibility that the risk of collision may be increased because of the increase in departure speeds.

As a consequence, the Flight Procedure Standards Branch was tasked to develop a simulation of the interaction of transient aircraft just outside class B airspace with aircraft departing class B airspace at speeds greater than 250-KT. The purpose of the simulation was to evaluate the risk of collision between transient aircraft just outside class B airspace with aircraft departing class B airspace at speeds greater than 250-KT.

This report is concerned with the analysis of the risk of collision of an aircraft exiting class B airspace with a transient aircraft outside class B airspace by allowing departing aircraft to exceed 250-KT within class B airspace at the Houston George Bush Intercontinental Airport (KIAH). This report focuses on traffic that exits the class B airspace below the class B airspace ceiling (10,000 FT at KIAH). This report does not consider any other hazards, such as wildlife strikes, that may be affected by allowing aircraft to exceed 250-KT within class B airspace. A report addressing wildlife strike risk (see Herricks, et. al) has been completed.

Since the departure of aircraft from class B airspace at speeds less than or equal to 250-KT is considered a safe operation, a simulation was designed to compare the distribution of closest points of approach (CPA) at departure speeds less than 250-KT to the distribution of CPAs at departure speeds more than 250-KT. If it can be established that the two distributions are essentially the same, then it can be inferred that the risk of collision is the same.

The Airspace Simulation and Analysis for TERPS (ASAT) computer system for the Flight Procedure Standards Branch, AFS-420, was modified to conform to conditions at the KIAH class B airspace. ASAT was also modified to accept actual radar tracks of departing aircraft as well as transient aircraft in the vicinity of KIAH. ASAT was used to conduct two simulation studies. The first study was conducted to determine the distribution of closest points of approach (CPA) of departing aircraft with aircraft flying near the boundary of class B airspace with the 250-KT departure speed limit imposed. The second study was conducted to determine the distribution of CPAs of departing aircraft with aircraft flying near the boundary of class B airspace without the 250-KT departure speed limit. Both samples were statistically analyzed to determine whether differences in the location of the means or shape of the underlying distributions were present.

Statistical tests performed on the two data sets indicate that no differences in mean or standard deviation could be detected. Additionally, the simulation was performed in a random manner without Air Traffic Control participation. In actual departure operations, only specific identified aircraft that have received an ATC instruction will be allowed to exceed 250-KT below 10,000 feet. Air traffic controllers providing ATC instructions to the aircraft will be fully aware of individual aircraft allowed to exceed 250-KT below 10,000 feet. Therefore, the risk of an encounter between an aircraft departing at a speed exceeding 250-KT and a transient aircraft is acceptable and equal to the risk of an encounter between an aircraft departing at a speed less than or equal to 250-KT and a transient aircraft.

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1.0. INTRODUCTION

Elimination of the 250-KT speed restriction below 10,000 feet MSL in class B airspace will provide an additional tool for Air Traffic Control (ATC) to achieve in-trail spacing of aircraft resulting in increased terminal airspace efficiency. Procedures for elimination of the speed restriction require that a specific ATC instruction assigned to an individual radar controlled aircraft in class B airspace is necessary to authorize an airspeed exceeding 250-KT below 10,000 feet MSL. This procedure, conducted in a radar-controlled environment, will ensure that only specific identified aircraft that have received an ATC instruction are allowed to exceed 250-KT below 10,000 feet. The ATC environment in areas where class B airspace exists is extremely complex. Letters of agreement between ATC facilities require specific in-trail spacing and coordination of aircraft assigned speeds. This rigorous coordination requirement will assure that air traffic controllers providing ATC instructions to the aircraft are aware of individual aircraft allowed to exceed 250-KT below 10,000 feet.

In 1995, an RTCA Task Force recommended to the Federal Aviation Administration (FAA) that a study of the 250-KT speed restriction for aircraft operating below 10,000 feet within class B airspace, be conducted to determine whether the speed restriction can be increased or eliminated. In response, the FAA initiated a field test of the proposed change conducted by Houston Intercontinental Terminal Radar Approach Control (TRACON) beginning June 26, 1997. In December 1997, the MITRE Center for Advanced Aviation System Development (CAASD) published a preliminary evaluation (see Spelman, et al) of that study. Although the primary purpose of the study was to assess the impact on air traffic controllers, flight crew, and the surrounding population, the study also included a comparison of flight tracks before initiation of the field test and during the field test, based on Automated Radar Terminal System (ARTS) data.

The most significant effect of the increase in the speed limit, reported by MITRE, was the apparent increase in the number of aircraft that appeared to exit the side of the class B airspace below 10,000 feet at speeds greater than 250-KT. The MITRE report states "...there is a noticeable shift outward of the point at which aircraft reach 10,000 feet. That in itself is unremarkable, as it was expected that most aircraft would climb somewhat slower when allowed to accelerate to higher forward speeds. However, the results also indicate that there was an apparent increase in the number of aircraft exiting the side of class B, below 10,000 feet, at speeds in excess of 250-KT, during the field test."

The MITRE study did not include an in-depth analysis of the underlying causes of the increased exit rate, but this conclusion fostered the perception that the level of collision risk with uncontrolled traffic passing just outside the class B airspace may be increased with the increase in the speed limit.

As a consequence, the FAA Flight Procedure Standards Branch, AFS-420, was tasked to determine the conditions or performance limitations that might cause an unintentional exit of the class B airspace below 10,000 feet at speeds greater than 250-KT.

The evaluation was divided into two principal efforts. The first activity was an in-depth analysis of the data that initiated the report by MITRE that the rate of unintentional exit of aircraft exceeding 250-KT from class B airspace below 10,000 feet had increased. The second effort involved the design and performance of a flight test utilizing the Boeing B727-200 level C simulator, located at the Mike Monroney Aeronautical Center (MMAC) in Oklahoma City. The objective was to design and perform departure routings in order to collect flight tracks for comparison to the radar track data collected at Houston. The Boeing B727 simulator was chosen because it represents an older generation aircraft with a below average rate of climb.

The FAA Flight Procedure Standards Branch issued a report of the study in June 2000. The report concluded that the Boeing B727 is capable of successfully reaching 10,000 feet prior to exiting class B airspace at speeds up to 300 KT with an air temperature of 95° and a gross takeoff weight of 183,000 pounds, if appropriate piloting techniques are employed. The report also included five recommendations that would increase the probability that aircraft not exit the side of class B airspace below 10,000 feet.

The report did not address the possibility that the risk of collision may be increased because of the increase in departure speeds. Since the pattern of transient traffic and departure traffic at a given airport having class B airspace is complex, an analytical solution would be intractable. As a consequence, the Flight Procedure Standards Branch was tasked to develop a simulation of the interaction of transient aircraft just outside class B airspace with aircraft departing class B airspace at speeds greater than 250-KT. The purpose of the simulation was to evaluate the risk of collision between transient aircraft just outside class B airspace with aircraft departing class B airspace at speeds greater than 250-KT.

The Flight Procedure Standards Branch computer simulation system, Airspace Simulation and Analysis for Terminal Instrument Procedures (ASAT), was used to conduct the evaluation. Although ASAT was originally developed for TERPS applications, the system was designed for flexibility and can be used in a wide variety of situations. The ASAT system was used to generate a database that could be used in the evaluation. Because of the differences in geometry and location of outlying airports, the simulation was designed to be site specific, but easily converted from one site to another.

This report is concerned with the analysis of the risk of collision of an aircraft exiting class B airspace with a transient aircraft outside class B airspace by allowing departing aircraft to exceed 250 KT within class B airspace at the Houston George Bush Intercontinental Airport (KIAH). This report focuses on traffic that exits the class B airspace below the class B airspace ceiling (10,000 FT at KIAH). This report does not consider any other hazards, such as wildlife strikes, that may be affected by allowing

aircraft to exceed 250 KT within class B airspace. A report addressing wildlife strike risk (see Herricks, et. al) has been completed.

2.0. EVALUATION DESCRIPTION

Often in a risk analysis, a target level of safety is established and the analysis determines an estimate of the risk associated with the operation. If the risk associated with the operation is less than or equal to the target level of safety, the operation is considered to be a safe operation. If the risk associated with the operation is more than the target level of safety, the operation is considered to be unsafe.

If lack of data or experience does not permit the establishment a target level of safety, a different strategy must be employed. In the case of aircraft departing class B airspace and interacting with transient aircraft just outside class B airspace, little is known about the number of encounters or the magnitude of the closest point of approach (CPA). Although data pertaining to collisions does exist, the absence of the number of encounters precludes the establishment of a rate. However, since the departure of aircraft from class B airspace at speeds less than or equal to 250-KT is considered a safe operation, a simulation can be designed to compare the distribution of CPAs at departure speeds less than 250-KT, to the distribution of CPAs at departure speeds more than 250-KT. If it can be established that the two distributions are essentially the same, it can be inferred that the risk of collision is the same. If it can be established that the mean of one distribution is larger than the mean of the other, it can be inferred that the distribution having the smaller mean represents the higher risk. If it can be established that the variance of one distribution is larger than the variance of the other, it can be inferred that the distribution having the larger variance represents the higher risk.

The Airspace Simulation and Analysis for TERPS (ASAT) computer system for Flight Procedure Standards Branch, AFS-420, was modified to conform to conditions of the KIAH class B airspace. ASAT was also modified to accept actual radar tracks of departing aircraft as well as transient aircraft in the vicinity of KIAH. ASAT was used to conduct two simulation studies. The first study was conducted to determine the distribution of CPAs of departing aircraft with aircraft flying near the boundary of class B airspace with the 250-KT departure speed limit imposed. The second study was conducted to determine the distribution of CPAs of departing aircraft with aircraft flying near the boundary of class B airspace without the 250-KT departure speed limit. Both samples were statistically analyzed to determine whether differences in the location of the means or shape of the underlying distributions were present.

The evaluation consists of two phases. The first phase involves an additional statistical analysis of the field test data recorded in June 1997 by the Houston Intercontinental Terminal Radar Approach Control in order to develop performance ratios. The second phase involves the development of a Monte Carlo simulation based on the data from the Houston field trial.

2.1. DEVELOPMENT OF PERFORMANCE RATIOS

Radar data representing departures during the field test were obtained from the Houston TRACON. The radar data pertaining to aircraft departing with the 250-KT speed restriction imposed does not contain tracks of transient aircraft flying outside the class B airspace. However, the radar data pertaining to aircraft departing without the 250-KT speed restriction does contain tracks of transient aircraft flying outside the class B airspace.

Therefore, in order to develop a simulation so that the risk associated with the 250-KT speed restriction can be compared to the risk without the 250-KT speed restriction, a method must be found to simulate departures with the 250-KT speed restriction.

The climb gradient of an aircraft is a measure of the slope of the angle that the aircraft's flight path makes with the ground. The climb gradient is usually given in feet per nautical mile. A jet aircraft climbing with a given power setting, with a given load and atmospheric conditions, will attain a certain climb gradient R_1 while flying at a given airspeed. If the same jet aircraft climbs with the same power setting, the same load, with the same atmospheric conditions but with a higher airspeed, then the climb gradient will be reduced. This leads to the development of performance ratios.

A performance ratio is a measure of the increased distance required to reach a given altitude when the aircraft is flown at a speed greater than 250-KT. To develop performance ratios for various aircraft models, data from the Houston field test were analyzed for the association of climb performance versus departure speed. The data from five different aircraft types were analyzed because it is representative of a wide range of aircraft.

Figures 1, 2, and 3 present climb performance data recorded during the Houston field trial pertaining to the Boeing B737 aircraft type. Each figure consists of two charts. The upper chart presents aircraft speed versus distance from the center of the class B airspace. The lower chart presents aircraft altitude versus distance from the center of the class B airspace. The red lines on the lower chart denote the boundary of class B airspace. Figure 1 presents climb performance data recorded at Houston with the 250-KT speed restriction imposed. Figure 2 presents climb performance data recorded at Houston with the 250-KT speed restriction lifted. Figure 3 is a composite of figures 1 and 2, with the tracks from figure 1 presented in green and the tracks from figure 2 presented in red.

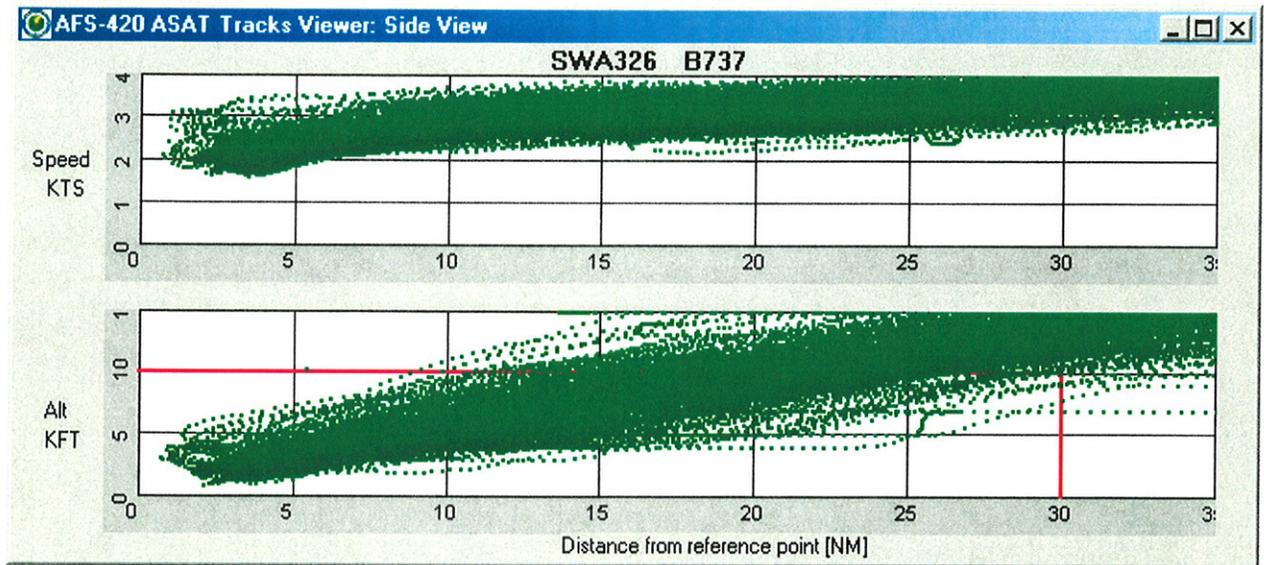


Figure 1: B737 Tracks With 250-KT Departure Speed Restriction

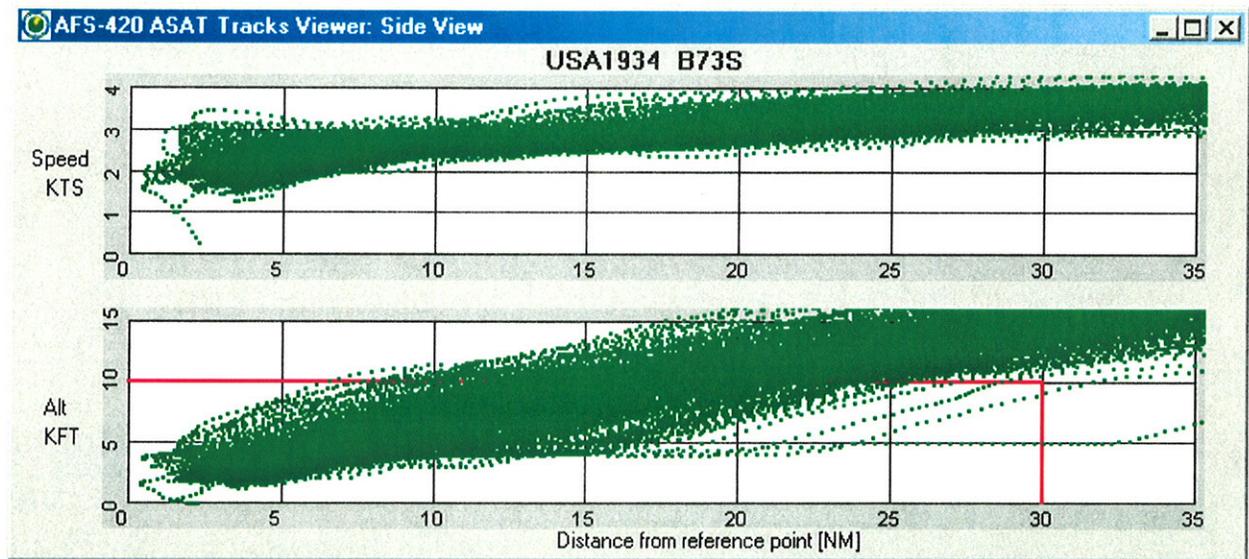


Figure 2: B737 Tracks Without 250-KT Departure Speed Restriction

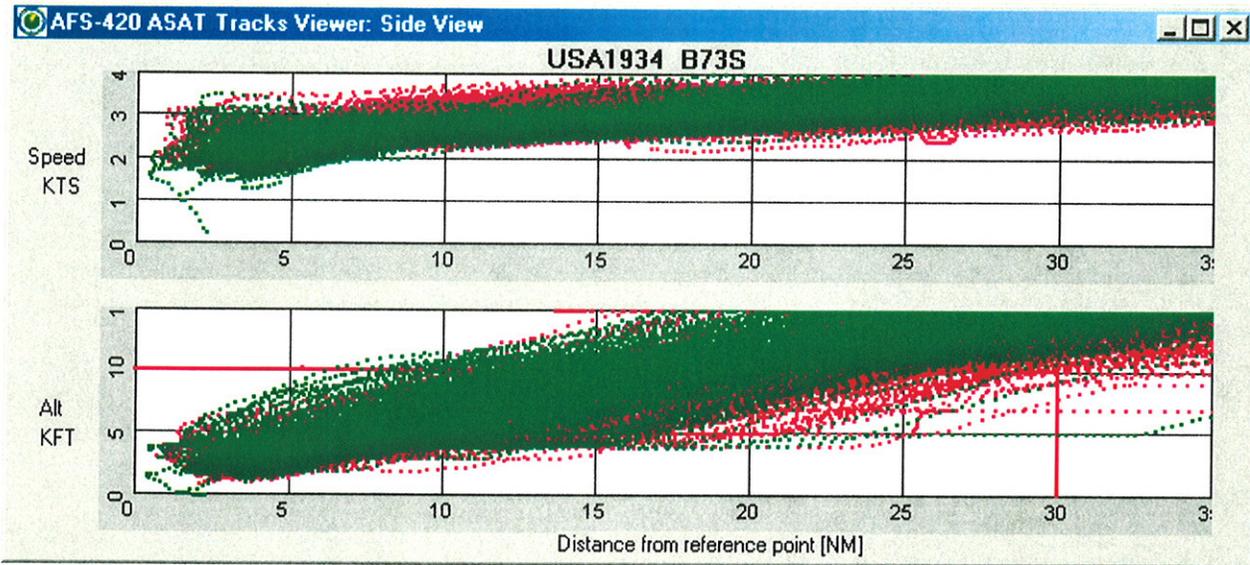


Figure 3: B737 Tracks **With (Green)** and **Without (Red)** 250-KT Departure Speed Restriction

Figure 4 is a planar view of the points where the B737 aircraft first attained 10,000 feet prior to and during the Houston field trial. The outline of the class B airspace is depicted in green. Small green circles depict the points where the aircraft reached 10,000 feet with the 250-KT speed restriction. Even with the 250-KT speed restriction, some aircraft reached 10,000 feet after passing through the lateral boundary of the class B airspace. Red circles depict these points. The points where the aircraft reached 10,000 feet without the 250-KT speed restriction are depicted by red plus signs. The figure indicates that aircraft without the 250-KT speed restriction tend to reach 10,000 feet farther from the center of class B airspace than aircraft with the imposition of the 250-KT speed restriction.

Figure 5 is similar to figure 4. Figure 5 is a planar view of the points where McDonnell-Douglas MD80 series aircraft first reached 10,000 feet prior to and during the Houston field trial. As in figure 4, the points where the aircraft reached 10,000 feet with the 250-KT speed restriction are depicted by small green circles. Red circles depict those points where the aircraft reached 10,000 feet after passing through the lateral boundary of the class B airspace. The points where the aircraft reached 10,000 feet without the 250-KT speed restriction are depicted by red plus signs. The figure indicates that the MD80 series aircraft operating without the 250-KT speed restriction also tend to reach 10,000 feet farther from the center of class B airspace than aircraft with the imposition of the 250-KT speed restriction.

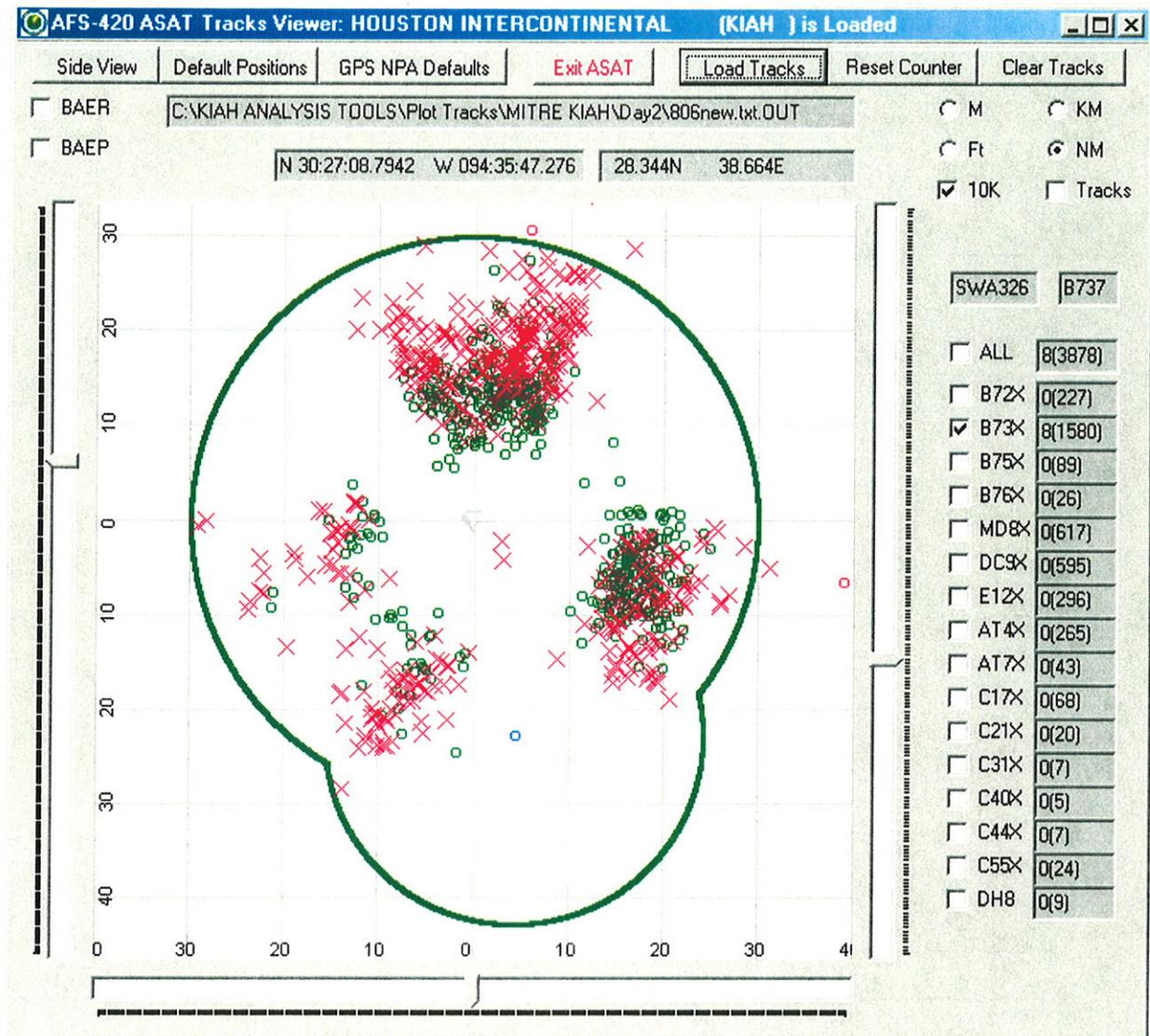


Figure 4: B737 Tracks 10K ft Altitude Crossing Points **With (o)** and **Without (x)** 250-KT Departure Speed Restriction

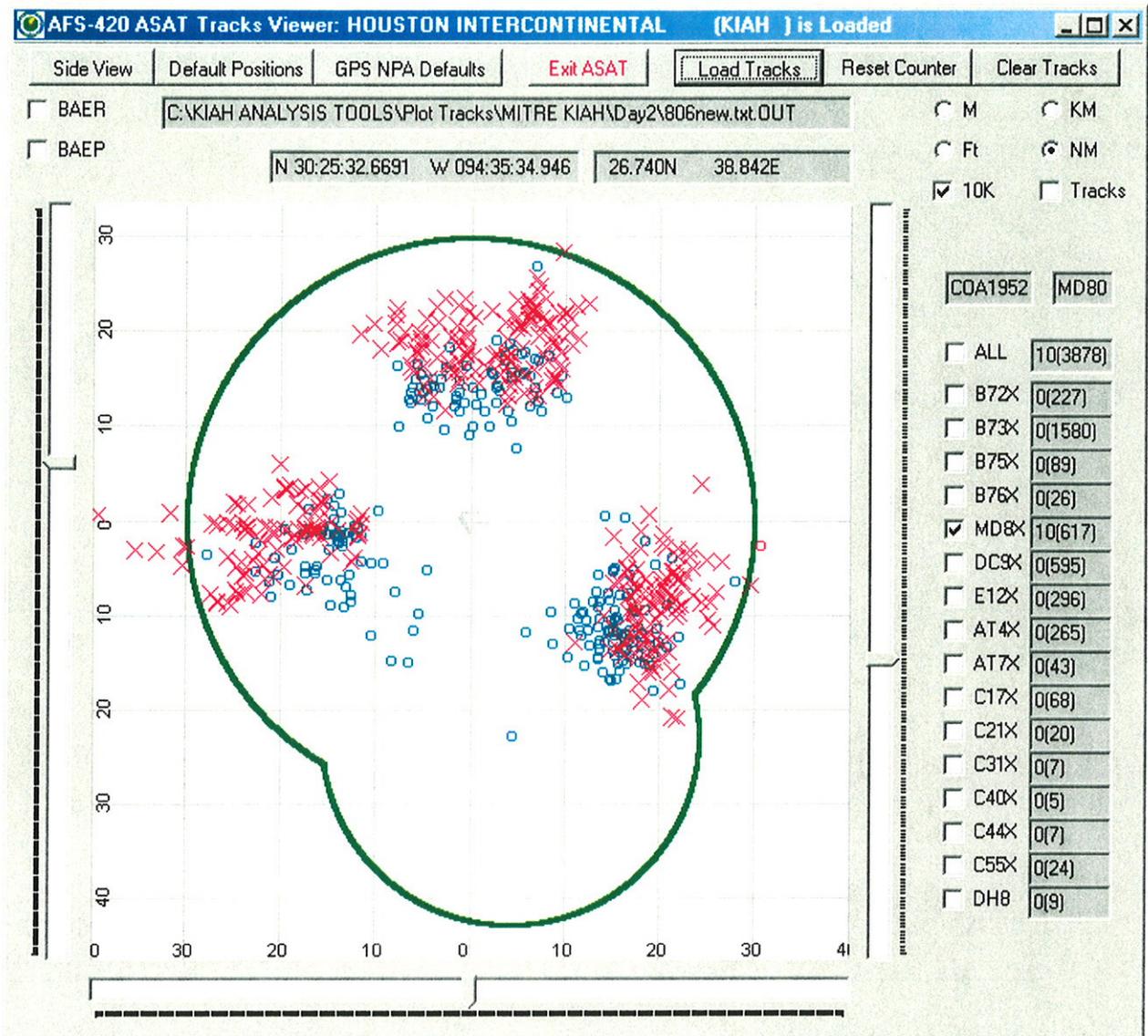


Figure 5: MD80 Tracks 10K ft Altitude Crossing Points With (o) and Without (x) 250-KT Departure Speed Restriction

Table 1 presents standard statistics of climb performance data taken from the Houston field trial. Five aircraft are represented, the Boeing B727, B737, B757, the McDonnell-Douglas MD80, and the DC9. The data were collected during 24-hour periods prior to the field trial, i.e., with the 250-KT speed restriction and during 24-hour periods without the 250-KT speed restriction. The data are distances from the center of class B airspace where the aircraft first reached 10,000 feet. The table indicates that the mean distance from the center of class B airspace without the 250-KT speed restriction appears to be larger than the mean distance with the 250-KT speed restriction.

Aircraft	B727		B737		B757		MD80		DC9	
	≤250	>250	≤250	>250	≤250	>250	≤250	>250	≤250	>250
Speed KT										
Mean NM	18.6	22.9	16.5	18.9	12.5	16.6	17.4	20.9	18.1	21.7
Standard Deviation NM	3.4	3.8	4.4	5.1	3.5	3.0	3.8	3.7	3.5	4.8
Kurtosis	2.7	2.9	0.1	-0.1	3.1	-0.1	0.3	-0.5	0.0	2.7
Skewness	-0.3	-1.0	0.3	-0.4	1.1	0.6	0.5	-0.2	0.3	-1.1
Count	97	94	689	688	54	32	234	327	231	283

Table 1: Summary Statistics of Climb Distances for Five Aircraft

Although table 1 indicates that the means of data recorded during the field test are larger than those recorded before the field test, the data must be statistically tested. Since the skewness and kurtosis values are generally not near zero, the data cannot be considered to have come from normal distributions. Therefore, a non-parametric test of means, the Mann-Whitney test, was used to determine whether the means are significantly different.

The Mann-Whitney test is a non-parametric test (distribution-free) used to compare two independent groups of sampled data. Unlike the parametric t-test, this non-parametric makes no assumptions about the distribution of the data (e.g., normality). This test is an alternative to the independent group t-test, when the assumption of normality or equality of variance is not met. The Mann-Whitney test uses the ranks of the data rather than their raw values to calculate the test statistic. The hypotheses for the comparison of two independent groups are:

H_0 : The two samples have identical means

H_a : The two samples have different means

The null hypothesis, H_0 is rejected if the probability of the Mann-Whitney U statistic is less than 0.05.

Table 2 presents results of the Mann-Whitney test applied to the Boeing B727 data. The upper box presents the sum of ranks and the mean rank of each data subset used to compute the Mann-Whitney U statistic. The variable B727CASE refers to the two data subsets. Subset number 1.00 contains the climb performance data collected prior to the field trial, i.e., the 250-KT speed restriction is in effect. Subset number 2.00 contains the climb performance data collected during the field trial, i.e., the 250-KT speed restriction is not in effect. The lower box presents the Mann-Whitney U statistic and the Wilcoxon W statistic. The Wilcoxon test is equivalent to the Mann-Whitney test. For sample sizes greater than 10, the probability associated with the U statistic can be found from a standard normal Z value. The output shows the Z value. The probability is the last entry in the lower box. Since the probability is less than 0.05 the null hypothesis is rejected and the alternate hypothesis is accepted.

Since the value of Z is negative, we conclude that the mean of the climb performance data with the 250-KT speed restriction in effect is less than the mean of the climb performance data without the 250-KT speed restriction in effect.

Ranks			
B727CASE	N	Mean Rank	Sum of Ranks
B727 1.00	97	64.16	6224.00
2.00	94	128.85	12112.00
Total	191		

Test Statistics ^a	
	B727
Mann-Whitney U	1471.000
Wilcoxon W	6224.000
Z	-8.085
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: B727CASE

Table 2: Mann-Whitney Test of B727 Data

Tables 3, 4, 5, and 6 present the results of the Mann-Whitney test applied to the Boeing B737, the Boeing B757, the McDonnell Douglas MD80, and the Douglas DC9. In each case the probability of the U statistic is less than 0.05 and the null hypothesis is rejected.

Ranks			
B737CASE	N	Mean Rank	Sum of Ranks
B737 1.00	689	584.81	402935.00
2.00	688	793.34	545818.00
Total	1377		

Test Statistics ^a	
	B737
Mann-Whitney U	165230.0
Wilcoxon W	402935.0
Z	-9.730
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: B737CASE

Table 3: Mann-Whitney Test of B737 Data

Ranks				
	B757CASE	N	Mean Rank	Sum of Ranks
B757	1.00	54	32.65	1763.00
	2.00	32	61.81	1978.00
	Total	86		

Test Statistics ^a	
	B757
Mann-Whitney U	278.000
Wilcoxon W	1763.000
Z	-5.236
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: B757CASE

Table 4: Mann-Whitney Test of B757 Data

Ranks				
	MD80CASE	N	Mean Rank	Sum of Ranks
MD80	1.00	234	199.18	46607.50
	2.00	327	339.55	111033.51
	Total	561		

Test Statistics ^a	
	MD80
Mann-Whitney U	19112.500
Wilcoxon W	46607.500
Z	-10.114
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: MD80CASE

Table 5: Mann-Whitney Test of MD80 Data

Ranks				
	DC9CASE	N	Mean Rank	Sum of Ranks
DC9	1.00	231	183.81	42459.00
	2.00	283	317.65	89896.00
Total		514		

Test Statistics ^a	
	DC9
Mann-Whitney U	15663.00
Wilcoxon W	42459.00
Z	-10.163
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: DC9CASE

Table 6: Mann-Whitney Test of DC9 Data

After establishing that the means of the distributions with the 250-KT speed restriction imposed are less than the means of the distributions without the 250-KT speed restriction, the performance ratios can be computed. The performance ratio for a given aircraft is defined to be the mean of the distribution without the 250-KT speed restriction divided by the mean of the distribution with the 250-KT speed restriction. Table 7 summarizes the performance ratios of the five aircraft.

Aircraft	B727		B737		B757		MD80		DC9	
	≤250	>250	≤250	>250	≤250	>250	≤250	>250	≤250	>250
Speed KT										
Mean NM	18.6	22.9	16.5	18.9	12.5	16.6	17.4	20.9	18.1	21.7
Performance Ratio	1.23		1.15		1.33		1.20		1.20	

Table 7: Performance Ratios of Five Aircraft

2.2. USING PERFORMANCE RATIOS TO SIMULATE SPEEDS UNDER 250-KT

The performance ratios provide a means to convert radar data acquired with the 250-KT restriction removed into simulated data with the 250-KT speed restriction imposed. There are three basic assumptions used to develop the algorithm. The first is that the ground track of an aircraft flying at a speed less than or equal to 250-KT would have the same ground track if it were flying at a speed greater than 250-KT.

The second is that the climb gradient of an aircraft flying at a speed greater than 250-KT will be smaller than its climb gradient while flying at a speed less than 250-KT. The third assumption is that even without the 250-KT speed restriction, the aircraft speed will be below 250-KT until reaching 2,000 feet above ground level (AGL). Therefore, if an aircraft were to fly a given departure route with the 250-KT speed restriction and return and fly the same route with a departure speed above 250-KT, the path of the aircraft would be the same ground track and altitude up to 2,000 feet AGL. Above 2,000 feet AGL, the path flown with the faster speed would have the same ground track as the path flown with the slower speed, but the altitude of the path with the faster speed will be less than the altitude of the path with the slower speed.

The key to the algorithm is to be able to find the speed that will be required of aircraft departing Houston to obtain the measured performance ratio of that aircraft type. The idea of a speed factor is used to increase the average climb gradients of the aircraft so that the performance ratios of the simulated data will match those at Houston. If an aircraft travels at a speed S_1 less than 250-KT and then travels at a speed S_2 more than 250-KT, then the speed factor is defined to be $R_s = S_2/S_1$.

Each radar track recorded at a speed greater than 250-KT is converted to a simulated track with a speed less than or equal to 250-KT. The radar data are not adjusted until the altitude of the aircraft reaches 2,000 feet. The ground track points of the radar data are not adjusted, but the altitude of the aircraft is adjusted at each recorded point. The original altitude data is used, but the time stamp is adjusted as a function of the speed factor so that the new altitude of each ground track point is actually the altitude of a succeeding point in time. The effect is that the aircraft will climb faster and will have a greater climb gradient.

For a given current ground track point, the time stamp of the succeeding point in the flight track used to provide the altitude for the current ground track point is computed according to the following equation:

$$T_{\text{Succ}} = T_{2000\text{Ft}} + (T_{\text{Current}} - T_{2000\text{Ft}}) * R_s$$

Where

$T_{2000\text{Ft}}$ is the time in seconds, at which the altitude of the original data was at a value equal or greater than 2,000 Feet AGL,

T_{Current} is the current radar simulated data time in seconds,

T_{Succ} is the time in seconds used to access the altitude data of a succeeding point of the original track data set,

R_s is the speed factor.

The application of the time stamp function is illustrated in figure 6. In the figure, the speed factor is 2.0. The altitudes of points along the ground track are not adjusted prior to reaching 2,000 feet, since it is assumed that aircraft speed will not exceed 250-KT until 2,000 feet altitude is attained. For ground track points after 2,000 feet has been attained, the time stamp of the succeeding point whose altitude will be used is computed according to the formula. For example, at the current time $T_{Current} = 60$ seconds, the time T_{Succ} of the succeeding point that provides the altitude for the current point is found to be:

$$T_{Succ} = 40 + (60 - 40) \times (2.0) = 80 \text{ seconds.}$$

The original altitude corresponding to the current ground track point at $T_{Current} = 60$, as shown on figure 6, is 2,500 feet. The simulated data uses the same ground track point, but the altitude assigned to it is taken from the original data point corresponding to 80 seconds. Therefore, the altitude assigned to the ground track point at $T_{Current} = 60$ is 3,000 feet.

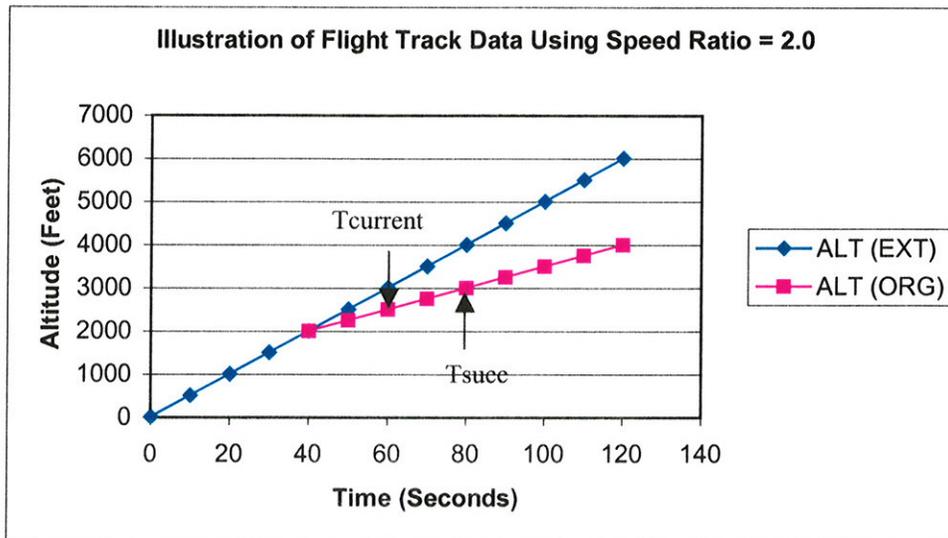


Figure 6: Illustration of Simulated Flight Track Data

Figure 7 shows a set of B737 departure tracks at KIAH. The graphing program generates an output file for each type of aircraft containing the flight number and the distance from the center of the class B airspace where 10,000 feet altitude was achieved. Figure 8 shows the same set of departure tracks after the application of a speed factor equal to 1.14.

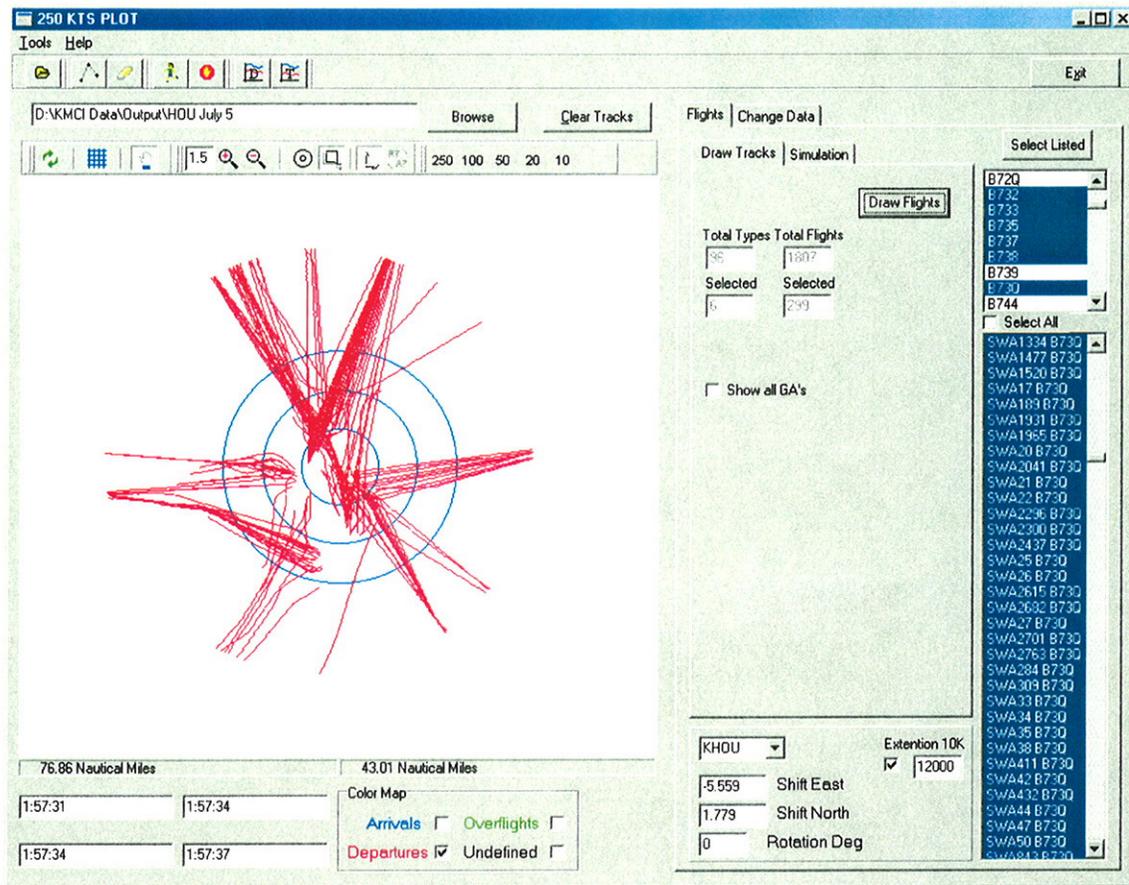


Figure 7: B737 Tracks Departing KIAH With the 250-KT Speed Restriction

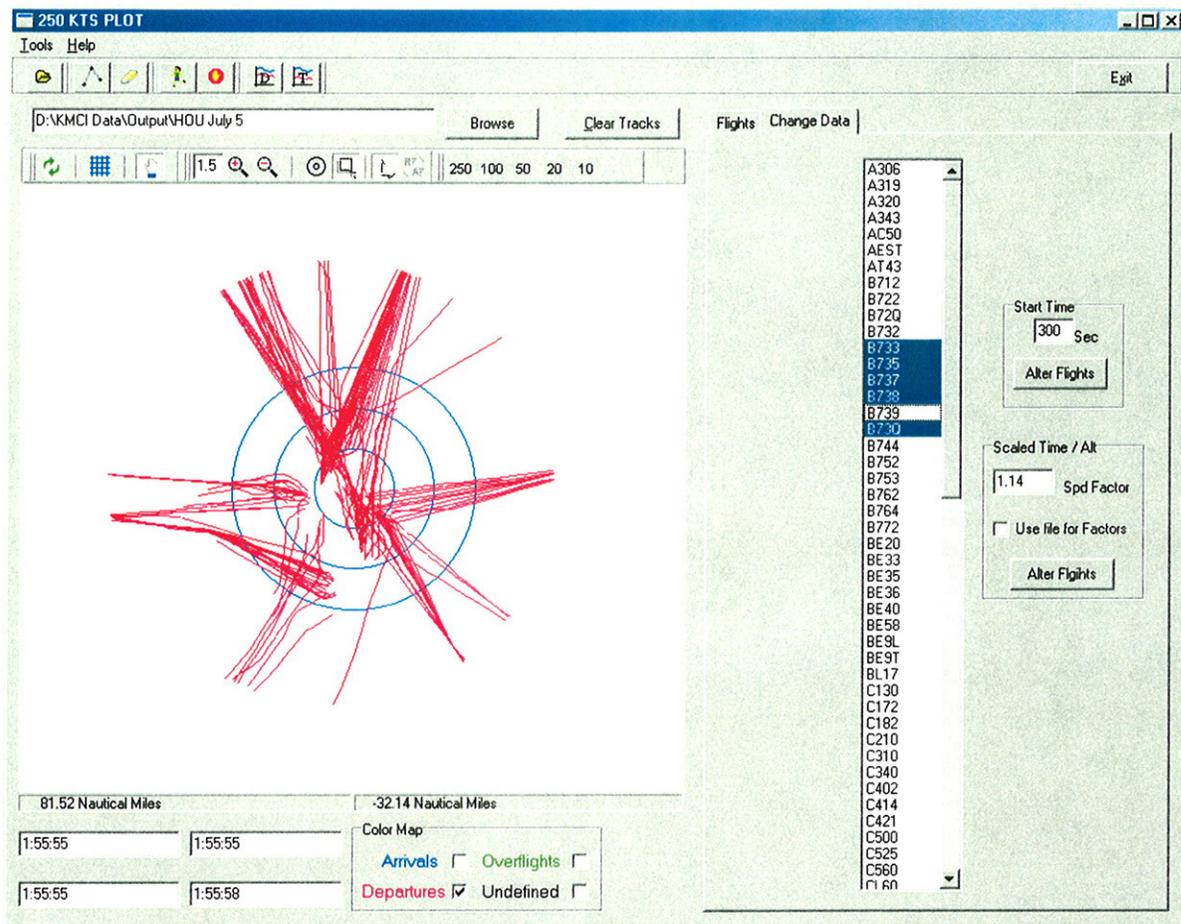


Figure 8: B737 Tracks Departing KIAH Adjusted With A 1.14 Speed Factor

2.3. DETERMINATION OF AN APPROPRIATE SPEED FACTOR

The speed factor for a particular type of aircraft is chosen so that the resulting performance ratio closely matches the performance ratio found from the Houston field-test data. An iterative process was used to determine the appropriate speed factor. First the speed factor for a particular type of aircraft was set equal to $300/250 = 1.2$ and a set of simulated data was produced using the speed factor. Then the mean of the distribution of the simulated distances from KIAH where the aircraft first reached 10,000 feet without the 250-KT speed restriction, was divided by the mean of the distribution of distances from KIAH where the aircraft first reached 10,000 feet with the 250-KT speed restriction. If the ratio was equal to the performance ratio from the Houston data, the search was stopped. If the ratio was different from the performance ratio of the Houston data, the speed factor was adjusted and a new set of simulated data was produced. The comparative process continued until an appropriate speed factor was found. A flow chart of the speed factor selection process is shown in figure 9.

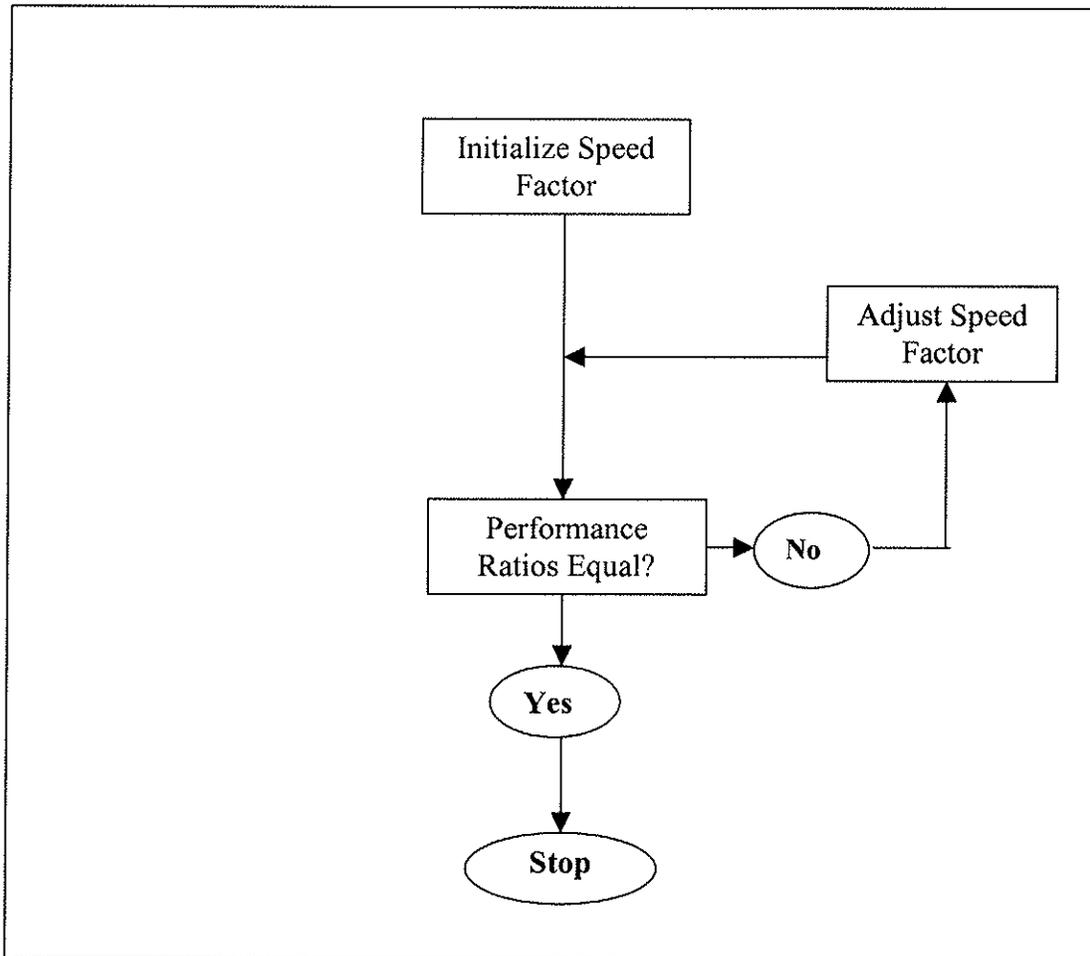


Figure 9: Flow Chart of Speed Factor Selection Process

Table 8 summarizes the results of the speed factor selection process for the aircraft shown in table 7. The table presents the speed factors and the resulting performance ratios. For convenience, the Houston field-test performance ratios are also presented. The performance ratios for the KIAH data were found to be nearly equal to those of the Houston data.

Aircraft	B727		B737		B757		MD80		DC9	
	≤250	>250	≤250	>250	≤250	>250	≤250	>250	≤250	>250
Speed KT										
Mean NM	18.6	22.7	16.5	18.8	12.5	16.7	17.4	20.7	18.1	21.8
Performance Ratio KIAH	1.23		1.14		1.32		1.20		1.20	
Speed Factor KIAH	1.20		1.12		1.31		1.16		1.17	

Table 8: Performance Ratios for KIAH

For aircraft that were not included in the KIAH data, the performance ratio was set equal to 1.3.

3.0. DATA EXTRACTION

The data extraction consisted of the following phases:

a. **Data Collection:** A large number of radar tracks from KIAH were collected and stored on electronic media. The data consists of tens of thousands of tracks detailing all air traffic within at least 50 NM around the airport.

b. **Processing of Radar Data:** Using the ARTS editor, a special software application designed to extract data from the raw ARTS radar data, and additional dedicated software tools specifically developed for this application, the radar raw data were converted into the proper form for analysis. The ARTS editor was used to obtain two types of data for each aircraft track:

i. Data related to the aircraft track, such as aircraft position, track, and speed as a function of time.

ii. Data related to the aircraft type and flight number contained in the inter-facility messages.

Extraction of Specific Aircraft Data: Dedicated software, designated "CBA250Types" for **Class B** Airspace **250-KT** Aircraft **Types**) especially developed for this study was used to extract all relevant data and store it in files by aircraft type. Each file contains data from one particular aircraft type such as Boeing B737. Included are CPA distances from transient aircraft operating within 50 NM of KIAH. This step is essential for the analysis performed later without the 250-KT speed restriction. The flow chart shown in figure 10 describes this process in a schematic way. Figure 11 illustrates the large amount of data that were processed. The tracks depicted in figure 12 are color-coded and depict arrivals (BLUE) departures (RED) over-flights (GREEN) and non-scheduled transient aircraft (BLACK).

Figure 12 shows some of the aircraft files generated by CBA250Types. Files named with a ".TXT" extension contain particular aircraft type data (such as B737.TXT, B738.TXT, etc.) while files named with a ".PER" extension (such as B737.PER, B738.PER, etc.) contain the required performance factor value to convert aircraft type data to a non-restricted departure speed.

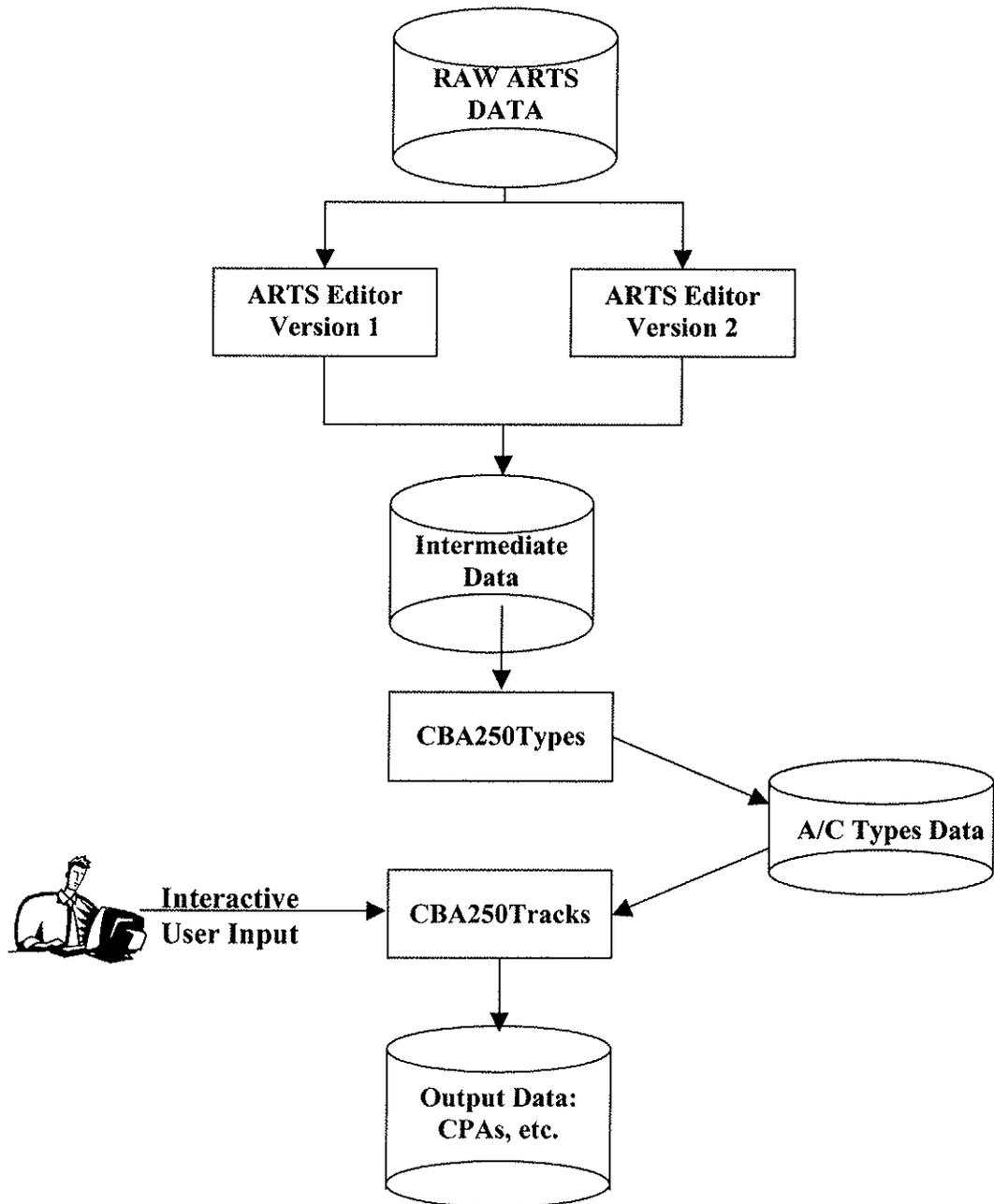


Figure 10: CBA250 Data Processing Flow Chart

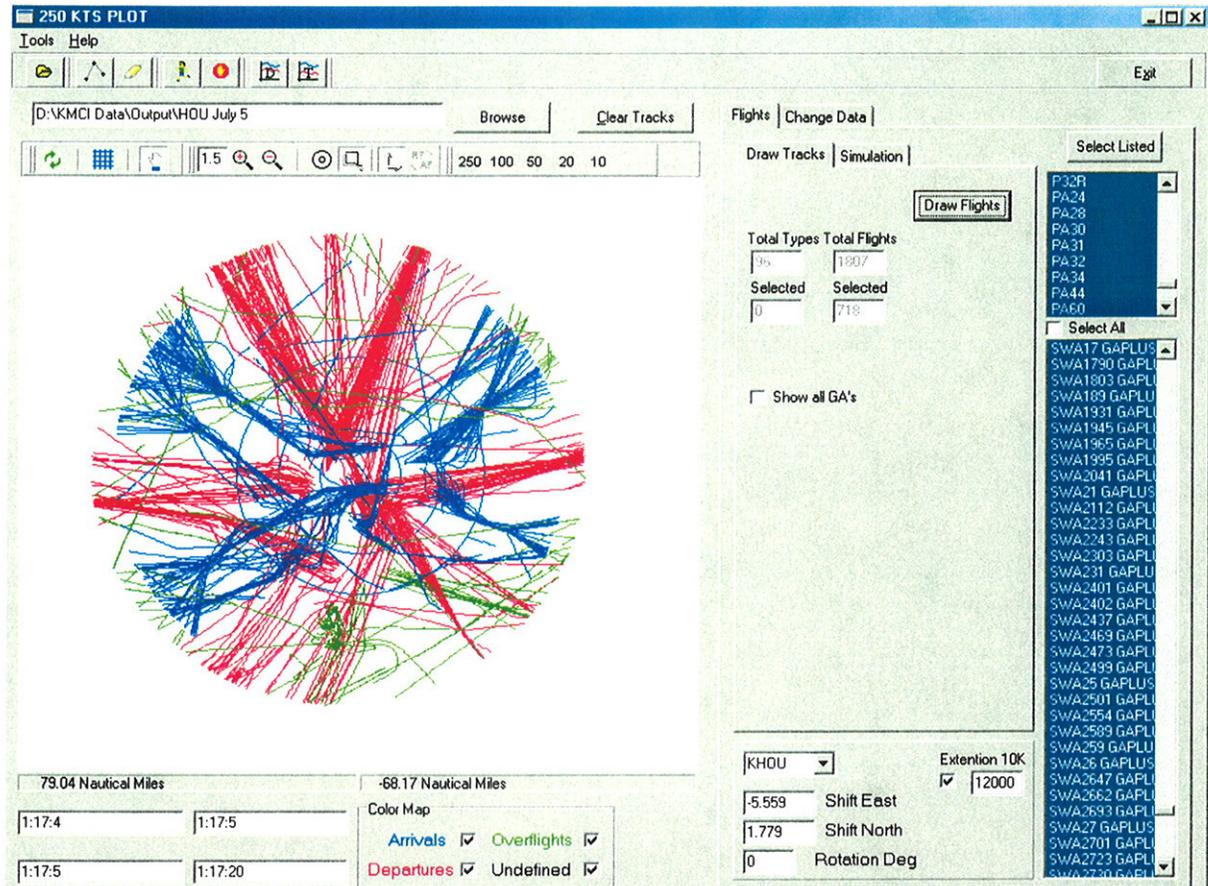


Figure 11: Traffic at and Around KIAH

4.0. MONTE CARLO SIMULATION

The Monte Carlo simulation was designed to produce CPA data pertaining to departures without the 250-KT speed restriction for comparison to CPA data pertaining to departures with the 250-KT speed restriction. Special software designated “CBA250Plots” for **Class B Airspace 250-KT Plots** was used to execute a fast simulation of the air traffic around the airport. The simulation was run using the original radar tracks with their original time stamped data, but with the vertical tracks modified through use of the performance ratios for each aircraft type. CPA data relative to transient aircraft in the area at the time of the departing flight were recorded.

Because transient aircraft are not scheduled flights and can occur at practically any time, the same set of radar tracks is re-run at least 60 more times with the initial time of general aviation flights varied at random time intervals within a span of ± 6 hours.

This has the effect of causing an interaction of each departure with several transient flights other than just the ones present during the departure. The evaluation is made on an area around the center of the airport that is bounded by two circles with radii of 26 and 34 NM (see figure 11).

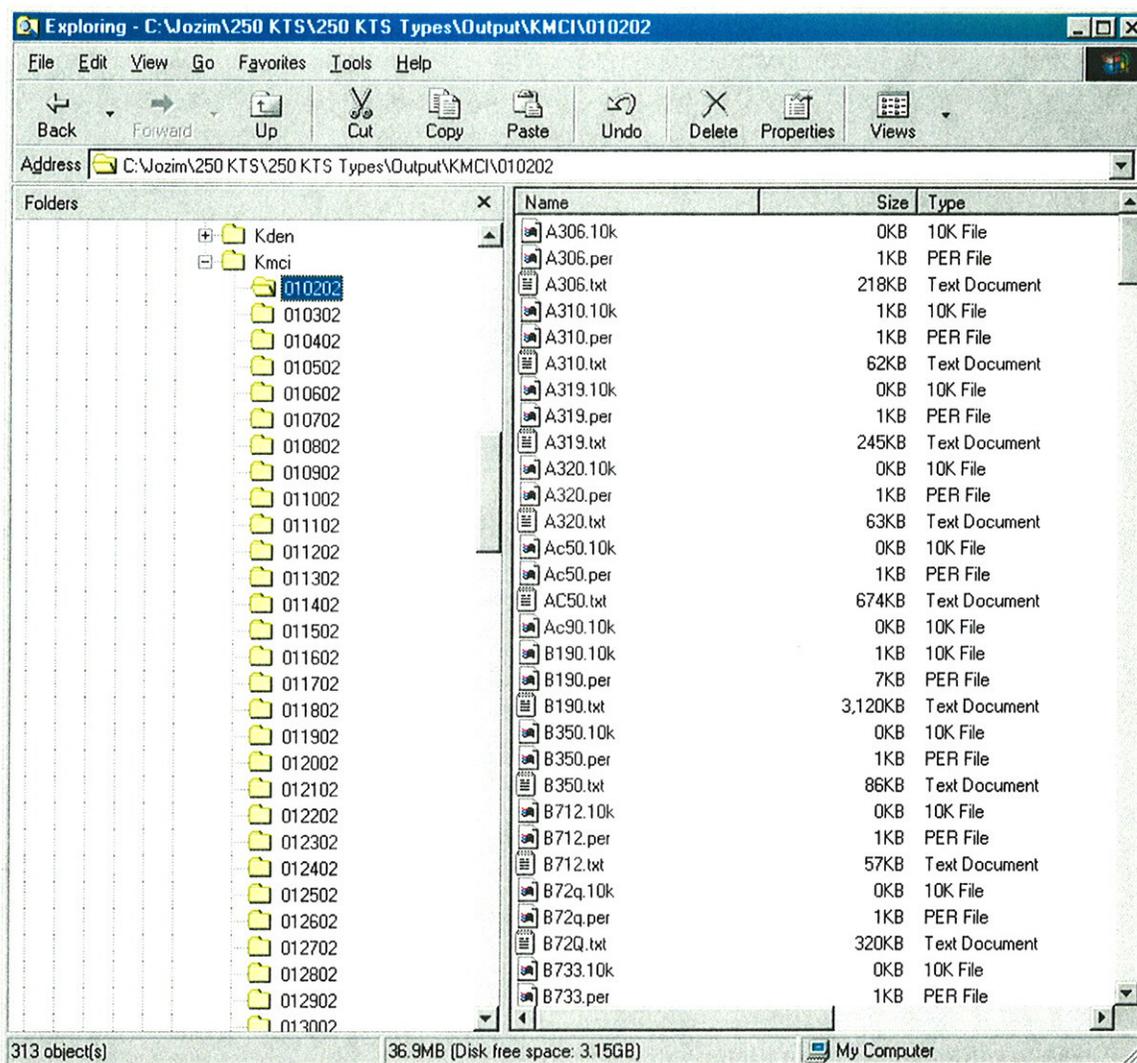


Figure 12: Files Generated by CBA250Types

This process generates a large set of CPA data. Many of them are so large that they are not germane to the analysis process. Therefore, only that CPA data that were less than 10 NM were included in the analysis. Whenever the ground track of a departure passed within $\frac{1}{2}$ NM of a transient aircraft, an additional filter was employed. If the altitude difference was less than or equal to 2,000 feet, the CPA data were included. If the altitude difference was more than 2,000 feet, the CPA data were not included. This filter was employed since the aircraft were adequately separated by altitude and the inclusion of their CPA data resulted in an unrealistic number of small CPA data.

The same filtering process was used for the original radar track data recorded with the 250-KT speed restriction and for the simulated track data recorded without the 250-KT speed restriction.

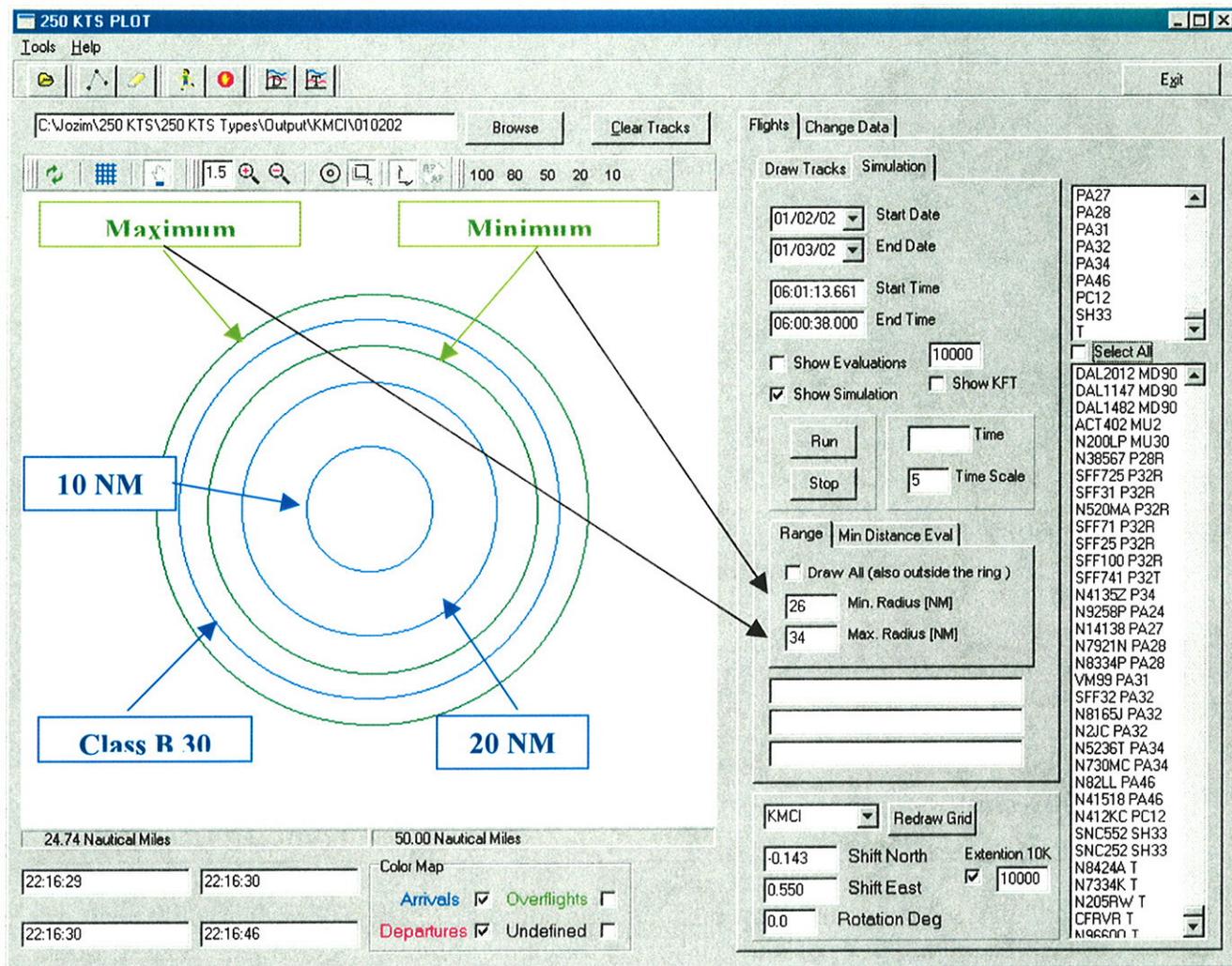


Figure 13: Definition of Relevant Areas Around Airport

The Monte Carlo simulation was performed using software specially designed for the task designated “CBA250Plots” for Class B Airspace 250-KT Plots. The simulation was performed using the original time stamped data with the original altitudes. The simulation was performed a second time using the original time stamped data with the altitudes adjusted to match the KIAH performance ratios. The program also generates summary output data files containing critical information regarding CPA data between scheduled aircraft and transient aircraft so that the distributions of the data could be analyzed and compared.

5.0. ANALYSIS OF THE CPA DATA

The KIAH CPA data were divided into two data sets. The first set contained simulated data for aircraft departing at speeds not exceeding 250-KT. The second set contained simulated data for aircraft departing at speeds exceeding 250-KT. Descriptive statistics were computed for each set and the results are summarized in table 9. An examination of table 9 indicates that the means, standard deviations, skewness values, and kurtosis values are very similar. The skewness and kurtosis values indicate that neither data set can be considered to have been produced by a normal or Gaussian distribution.

	<i>≤250-KT</i>	<i>>250-KT</i>
Mean NM	5.638069	6.16476
Median NM	6.331185	6.57643
Std Deviation NM	2.58348	2.63613
Kurtosis	-1.28023	-1.15298
Skewness	-0.26276	-0.34011
Range NM	9.137079	8.67753
Minimum NM	0.819611	1.30775
Maximum NM	9.95669	9.98528
Count	120	111

Table 9: Descriptive Statistics of KIAH CPA Data

A statistical test was performed to determine whether the differences in the two data sets are significant. Since the two sets cannot be considered to be from normal distributions, two non-parametric tests, the Mann-Whitney U test and Levene's test, were used.

The Mann-Whitney U test tests for differences in location or means of the two samples. It tests the null hypothesis, H_0 : the two samples have the same mean, against the alternate hypothesis, H_1 : the two samples have different means. A probability value p is computed. If the value of p is less than 0.05, the null hypothesis, H_0 , is rejected and the means are considered to be different.

The result of the Mann-Whitney test applied to the two sets of KIAH CPA data is shown in table 10. The data assigned to Case 1.00 are the CPA data recorded with the 250-KT speed restriction. The data assigned to Case 2.00 are the CPA data recorded without the 250-KT speed restriction. The upper box of the table presents the mean rank and rank sum of each data set. The lower box of the table presents the Mann-Whitney U statistic and the Wilcoxon W statistic. The Mann-Whitney U test and the Wilcoxon W test are equivalent and are sometimes referred to as the Wilcoxon-Mann-Whitney test.

When the sample sizes are large, a normal z-value can be used to approximate the significance level for the test. In this case, the calculated z is compared to the standard normal significance levels. The computed z-value appears as the next to the last line of the lower box. The bottom line of the table indicates that the value of p corresponding to $z = -1.635$ is $p = 0.102$. Therefore, the null hypothesis cannot be rejected and the means of the two populations are considered to be equal.

Test Statistics ^a

	HOU_CPA
Mann-Whitney U	5830.500
Wilcoxon W	13090.500
Z	-1.635
Asymp. Sig. (2-tailed)	.102

a. Grouping Variable: CASE

Ranks

	CASE	N	Mean Rank	Sum of Ranks
HOU_CPA	1.00	120	109.09	13090.50
	2.00	111	123.47	13705.50
Total		231		

Table 10: Mann-Whitney U Test of KIAH CPA Data

Since the Mann-Whitney U test is most sensitive to differences in location or mean, an additional test, Levene's test, was conducted to test for differences in variance or standard deviation. Although Levene's test is conducted using the One-Way Analysis of Variance, a parametric test, it is not sensitive to thick tails and can be considered to be non-parametric. It tests the null hypothesis, H_0 : the variances of multiple samples are identical, against the alternate hypothesis, H_1 : the variances of multiple samples are different. If the significance is less than 0.05, at least one variance may be different and the null hypothesis is rejected. Table 11 summarizes the results of Levene's test of the KIAH CPA data. Since the significance is 0.946, the null hypothesis cannot be rejected and the two standard deviations are considered to be equal.

Test of Homogeneity of Variances

HOU_CPA			
Levene Statistic	df1	df2	Sig.
.005	1	229	.946

Table 11: Levene's Test of Homogeneity of Variances

6.0. CONCLUSION

A Monte Carlo simulation was conducted using radar track data of departures from KIAH. The radar track data were from departures with the 250-KT speed restriction in effect. The purpose of the simulation was to produce data from simulated departures without the 250-KT speed restriction in effect, that could be compared to the radar track data from departures with the 250-KT speed restriction.

If it can be established that the two distributions are essentially the same, then it can be inferred that the risk of collision is the same. If it can be established that the mean of one distribution is larger than the mean of the other, it can be inferred that the distribution having the smaller mean represents the higher risk. If it can be established that the variance of one distribution is larger than the variance of the other, it can be inferred that the distribution having the larger variance represents the higher risk.

Statistical tests performed on the two data sets indicate that no differences in mean or standard deviation could be detected. Additionally, the simulation was performed in a random manner without Air Traffic Control participation. In actual departure operations, only specific identified aircraft that have received an ATC instruction will be allowed to exceed 250-KT below 10,000 feet. Air traffic controllers providing ATC instructions to the aircraft will be fully aware of individual aircraft allowed to exceed 250-KT below 10,000 feet. Therefore, the risk of an encounter between an aircraft departing at a speed exceeding 250-KT and a transient aircraft, is acceptable and statistically equivalent to the risk of an encounter between an aircraft departing at a speed less than or equal to 250-KT and a transient aircraft.

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