

# Comparison of Arrival Tracks at Different Airports

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**Abstract**—This paper analyzes arrival flight track data at Chicago (ORD) and Atlanta (ATL) airports. We investigate distributions of vertical and lateral position at different distances from the runway threshold in instrument meteorological conditions (IMC) and visual meteorological conditions (VMC). In IMC, the observed standard deviations at different distances are similar between the two airports. The results reported in this paper are also similar to those reported at St. Louis (STL) in [1]. Visual comparison of the observed distributions also shows a close similarity. This provides some indication that distributions observed at one airport in IMC may generalize to other airports. In VMC, there are some differences between the distributions. We also fit probability density functions (PDFs) to lateral and vertical positions. In general, the normal distribution provides the best fit among the normal, lognormal, gamma, and Weibull families. The quality of the fit is better in IMC closer to the runway threshold.

**Keywords**- flight tracks; probability density functions

## I. INTRODUCTION

The objective of this paper is to measure properties of flight tracks at two major U.S. airports and compare the results. Since it is challenging to measure flight tracks at all airports, a natural question arises – are the flight tracks at one airport representative of the flight tracks at other airports? If similar statistical properties are observed at different airports, this provides evidence that statistical properties observed at one airport may possibly be “extrapolated” to other airports. Such evidence does not prove such an assertion, but simply lends evidence in that direction. On the other hand, if statistical properties at different airports are different, this provides evidence that airports may need to be individually measured.

This paper compares arrival flight track data at two major U.S. airports, Chicago (ORD) and Atlanta (ATL). The basic observation is that observed standard deviations are reasonably similar between the two airports during instrument meteorological conditions (IMC). The results in this paper are also similar to results presented in [1] for STL. (The results in [1] were obtained from an ASDE-X system that was augmented by off-airport multilateration sensors to enhance the accuracy of measurements along the arrival corridors.) The similarity of the results provides some preliminary indication that statistical properties of flight tracks may be similar at other major U.S. airports during IMC.

## II. METHODOLOGY

This paper uses an existing algorithm and methodology for processing track data. Initial and updated versions of the algorithms are given in [2] and [3]. These previous papers have analyzed multilateration data at DTW. Here, we apply the algorithms to flight track data for ORD and ATL. We have been able to apply the existing algorithms to this analysis with few modifications.

Another study that has analyzed distributions associated with flight tracks on approach is [4]. Other studies that have analyzed statistical distributions of aircraft separations on arrival, both in terms of distance and time are [5-12]. Statistical measurements of position deviations have also been made in the en-route environment (e.g., [13-15]).

## III. DATA SUMMARY

This paper uses pre-processed flight track data at ATL and ORD as a basis for analysis of flight tracks. Flight track data is typically generated from an ASDE-X system that synthesizes data from a number of sources including multilateration sensors and surveillance radar. The intended coverage area includes the airport surface as well as arrival corridors out to 5 nm from runway thresholds. Accuracy on the surface is 20 feet (one standard deviation) or better. Away from the threshold within the coverage area, accuracy is as good as or better than existing sensors (e.g., surveillance radar).

The data for each day consist of several comma-separated text files, each containing a single table with the following fields: aircraft ID, time,  $x$ -coordinate,  $y$ -coordinate, altitude, aircraft type (manufacturer and model), and wake category. The wake category (heavy, B757, large, small) is inserted using a mapping table created from previous work based on the aircraft type. The origin of the coordinate system is the airport control tower (Fig. 1 shows the ORD airport diagram). The  $x/y$ -coordinate measurements are based in part on multilateration data. The altitude measurements are based on barometric pressure and not on multilateration measurements. The fields must be modified slightly in order to use the algorithms developed in previous studies [2,3].

We analyze arrivals at ATL, runways 9R, 27L, 8L, and 26R, and arrivals at ORD, runways 10, 28, 4R, and 14R. These are main runways for arrivals based on the most commonly used configurations. In total, 39,278 arrivals are

observed (22 days for ATL and 31 days for ORD). Some arrivals are removed due to various data-integrity checks (track is too short, gaps in the track, etc.). This leaves 31,566 arrivals viewed as valid to be analyzed. Table 1 shows a summary of flight tracks observed for all runways under both IMC and VMC.

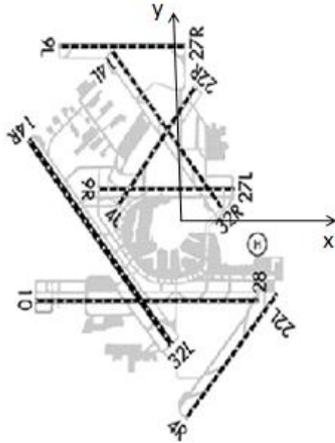


Figure 1. ORD airport diagram (www.airnav.com)

TABLE I. TRACKS SUMMARY(COUNTS)

Airport	Runway	IMC	VMC	TOTAL
ATL	8L	1167	3837	5004
	9R	1169	3287	4456
	26R	469	3422	3891
	27L	589	3935	4524
ORD	10	527	4629	5156
	28	198	2335	2533
	4R	180	3132	3312
	14R	207	2483	2690

For illustration purposes, Table 2 shows an example of the processing steps and data for one day of data at ATL, runway 9R. (See [2,3] for more details on these steps.) The first row is the number of data points (rows) in the original file. The second row is the number of points remaining after discarding points outside of a defined box. Points outside of the box are assumed to belong to operations on other runways. The coordinates of the box are specific to the runway being investigated. The third row is the number of distinct arrival tracks extracted from the data. The final row is the number of tracks remaining after discarding tracks that fail a data quality check (e.g., the tracks are too short or there are gaps in the data).

TABLE II. DATA SUMMARY (ONE DAY, ATL 9R)

# of points in original file	4,730,919
# of points after boxing	139,959
# of candidate tracks	478
# of valid tracks	473

#### IV. ANALYSIS OF FLIGHT TRACKS

The weather conditions (VMC and IMC) associated with a track are defined by comparing the time of the first point of the track with airport weather information in the Aviation System Performance Metrics (ASPM) database. Fig. 2 shows a top-level view of all 527 flight tracks at ORD, runway 10 in IMC. In IMC, aircraft fly through the final approach fix (approximately 5 nm from the threshold) straight to the runway. As expected, the lateral positions converge to the centerline of the runway as aircraft get closer to the threshold.

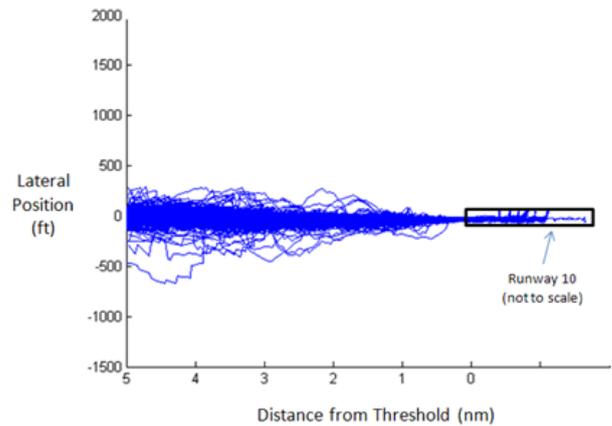


Figure 2. Top-level view of all tracks, ORD, runway 10, IMC

Fig. 3 compares the lateral distribution in VMC and IMC at 4 nm from the threshold of runway 10 at ORD. The IMC distribution is concentrated more closely about the centerline, while the VMC distribution has a larger number of points in the tails of the distribution. In VMC, it is possible for aircraft to curve in after the final approach fix, which leads to heavier tails of the VMC distribution. Similar results are seen at other distances from the threshold, and at ATL.

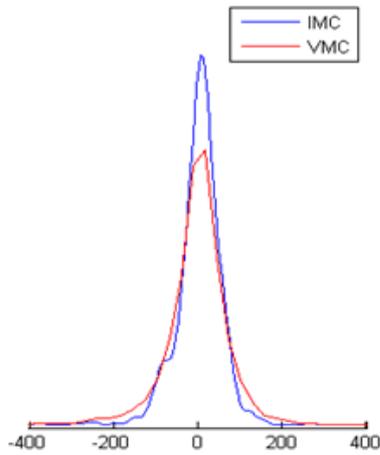


Figure 3. Density of lateral position

To obtain distributional fits for the data, we first break the data down by airport (ATL/ORD), by weather conditions (VMC/IMC), and by distance to the threshold (0, 1, 2, 3, 4, 5 nm). In each case, we determine the best fit among the following families of distributions: normal, lognormal, Weibull, and gamma. The best fit is defined with respect to minimizing the maximum likelihood estimation. Fig. 4 shows an example of the probability density function (PDF) fits at ATL, 3 nm from the threshold, during IMC. (The data for all runways at ATL are combined in these results.) The best fit in this case is the normal distribution. The gamma distribution is the second best fit.

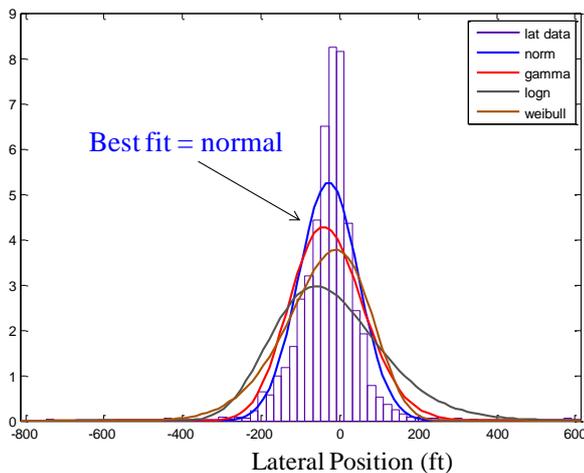


Figure 4. Sample PDF fits for lateral position, ATL, IMC

Fig. 5 shows an example comparing the distributional fits at several distances from the threshold. In each case, the normal distribution (the blue curve) provides the best fit among the four candidate families. Note that the scale is not exactly the same among the three graphs. The purpose is to illustrate the PDF fits relative to the observed histograms, rather than to provide the absolute values. Close to the runway threshold, the normal distribution provides a better fit. At further distances from the threshold, the quality of the fit is not

as good, though the normal distribution is still the best fit among the four candidate distributions. In particular, at further distances, the observed distribution is more narrow in the body than what would be predicted by a normal distribution. The observed extreme values are also more extreme than what would be predicted by a normal, though this is easier to see in the next figure. Similar results are observed for ORD.

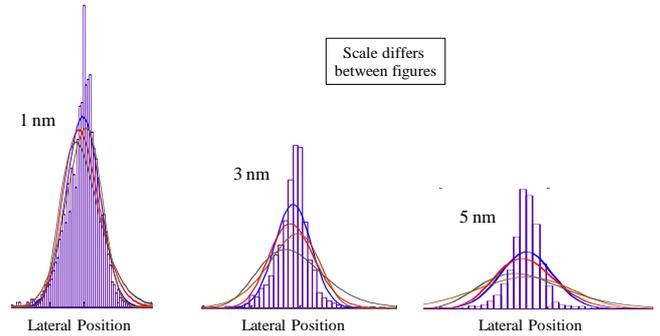


Figure 5. Sample PDF fits for lateral position, ATL, IMC

Fig. 6 shows a plot of the observed data versus quantiles of a standard normal distribution (a quantile-quantile plot). If the data were normally distributed, the data would fall on a straight line. In the figure, the data are nearly normally distributed, since most of the data are close to the straight line. The end points are above the line on the right and below the line on the left. This means that the extreme points of the observations are larger in magnitude than what would be predicted by a normal distribution. That is, the tails are slightly heavier than a normal distribution.

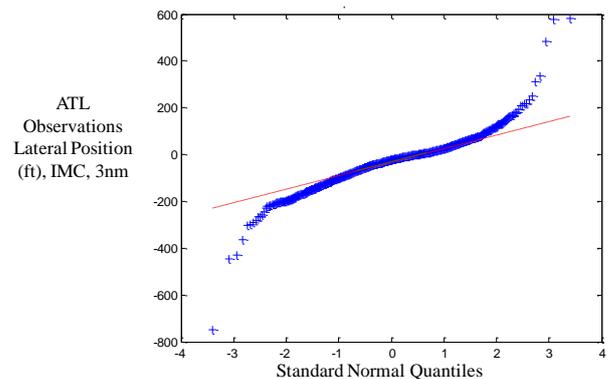


Figure 6. Observed lateral position versus normal quantiles, ATL, IMC, 3nm

While we do not show all combinations of results here, the normal distribution is typically the best fit among the four candidate distributions. This is particularly true in IMC and closer to the runway threshold. The quality of the fit typically degrades at further distances from the threshold. The tails of the observed distributions are typically heavier than what is predicted by the normal fit. That is, similar to Fig. 6, analogous plots at different distances at both airports show similar trends in the tails of the distributions.

V. COMPARISON BETWEEN AIRPORTS

In this section, we compare results between the two airports ATL and ORD. We do not report any results using DTW data from previous studies, because the accuracy of that data (collected in 2003) may not be sufficient for analysis significantly beyond the runway threshold.

As an initial comparison, Table 3 shows the standard deviation of lateral position of aircraft in IMC. Our results are similar to those reported at St. Louis (STL) in [1] as well. Note that there are some differences in the data sources between this paper and [1]. In [1] (STL), the ASDE-X system is augmented by off-airport multilateration sensors to enhance the accuracy of measurements along the approach corridor. In our data (ATL and ORD), there is no such augmentation, though the intended coverage area includes arrival corridors out to 5 nm from the threshold with an accuracy equal to or better than existing radar. Thus, in principle, the data accuracy in this paper may not be as good as in [1]. However, the similarity of values in Table III indicates that the precision may be good enough for the purpose of evaluating the variability in the tracks.

A second difference is that weather conditions in this paper are defined based on the VMC/IMC flag in the ASPM database. In [1], the weather conditions are defined using Automated Surface Observing System (ASOS) data, where “hard IMC” at STL means less than 4 statute miles in visibility or less than 1,200 ft ceiling.

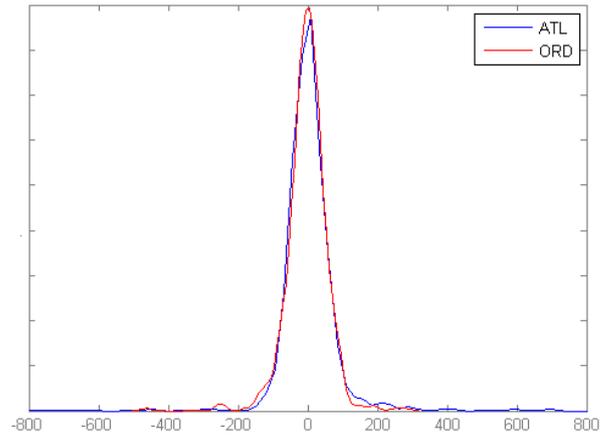


Figure 7. Comparison of lateral distribution, 5 nm, IMC

Table 4 gives the standard deviation of vertical position of aircraft landing on both runways under IMC. We do not include data at the threshold since altitude is only reported in increments of 25 feet, so the lack of precision dominates the estimate of standard deviation at the threshold. In [1], the standard deviations are reported only at a subset of the distances. Again, there is general agreement in the reported values.

TABLE III. STANDARD DEVIATION OF LATERAL POSITION (FT)

	Runway 8L at ATL, IMC	Runway 10 at ORD, IMC	STL, from [1], “hard IMC”
Distance from threshold (nm)	Standard deviation (ft)	Standard deviation (ft)	Standard deviation (ft)
0	8	7	14
1	20	22	20
2	35	34	30
3	60	47	44
4	61	63	50
5	110	58	66

The observed standard deviations reported in Table III are similar across each row, except possibly in the 5-nm case. We investigate this case further. Fig. 7 compares the observed distributions of lateral position at 5 nm in IMC. Visually, the distributions look nearly identical. One difference is that ATL has several larger observations that extend beyond 400 feet from the centerline, whereas ORD has fewer such observations (though this is difficult to see from the figure). These large observations greatly increase the observed standard deviation, which accounts for the differences in the standard deviation between ATL and ORD and STL. This illustrates why moment-based measures, which are sensitive to large observations, can be misleading. Aside from these points, the distributions are visually nearly identical in the figure.

TABLE IV. STANDARD DEVIATION OF VERTICAL POSITION (FT)

	Runway 8L at ATL, IMC	Runway 10 at ORD, IMC	STL, from [1], “hard IMC”
Distance from threshold (nm)	Standard deviation (ft)	Standard deviation (ft)	Standard deviation (ft)
1	26	26	30
2	33	31	
3	48	40	50
4	55	61	
5	64	76	118

Figs. 8 and 9 show a comparison in VMC of the observed standard deviations for lateral and vertical positions. The figures include data from ATL, runway 8L, and ORD, runway 10 (no results are reported in [1] for VMC). For vertical position, the results are nearly identical. For lateral position, there is a difference between the standard deviations at the two airports / runways. This might be because pilots have more flexibility in visual conditions regarding the path flown to the runway, so the path may depend on a number of airport/runway-specific factors such as the geometry of the location to enter the terminal airspace.

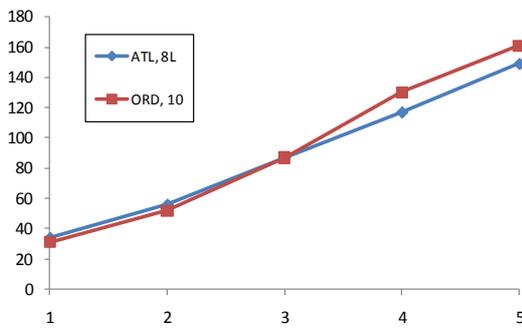


Figure 8. Standard deviation of vertical position in VMC

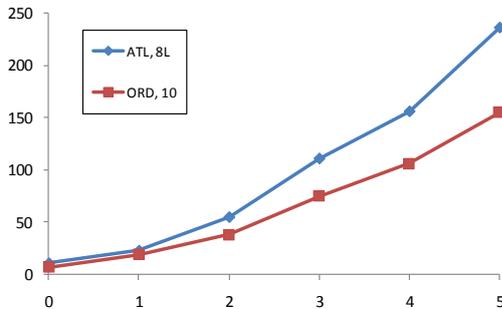


Figure 9. Standard deviation of lateral position in VMC

### CONCLUSIONS

This paper analyzed arrival flight tracks from ASDE-X data at Chicago (ORD) and Atlanta (ATL) airports. We investigated distributions of vertical and lateral position at different distances from the runway threshold in instrument meteorological conditions (IMC) and visual meteorological conditions (VMC). In IMC, the observed standard deviations were similar between the two airports. The results were also similar to those reported at St. Louis (STL) in [1], based on data from an ASDE-X system augmented with off-airport sensors to increase accuracy of measurements in the arrival corridors. Visual comparison of the observed distributions at ATL and ORD also showed a close similarity. This provides some indication that distributions observed at one airport in IMC may generalize to other airports. This does not prove such an assertion, but simply provides some evidence in that direction. In VMC, some differences were observed in lateral position between different runways at different airports. This might be expected, since there is more flexibility in the flight path in visual conditions. Thus, it may be more difficult to generalize VMC distributions from one airport to others.

We also fit probability density functions (PDFs) to lateral and vertical positions. In general, the normal distribution provided the best fit among the normal, lognormal, gamma, and Weibull families. The quality of the fit was better in IMC

closer to the runway threshold and not as good at further distances from the threshold.

### ACKNOWLEDGMENT AND DISCLAIMER

This work has been supported by NASA and Northwest Research Associates (NwRA) through sub-agreement #NwRA-08-S-114 and Integrated Airport Capacity Management (IACM) project with Metron Aviation. The opinions and conclusions in this paper are solely those of the authors and not necessarily those of NwRA or NASA. The authors thank Rafal Kicingier (Metron Aviation, Inc.) and Vivek Kumar (CATSR, GMU) for help in analyzing the data.

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