Comparison of Arrival Tracks at Different Airports

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***Abstract*—The statistical behavior of flight tracks is a critical component of some safety-analysis methods. This paper analyzes arrival flight tracks obtained from ASDE-X data at ORD and ATL airports. We estimate the standard deviation of lateral and vertical position of aircraft at different points away from the threshold in IMC. The lateral position of the aircraft at different points from the runway threshold approximately follows a normal distribution in IMC.**

Keywords-safety; flight tracks; distribution

I. Introduction

The statistical variability of flight tracks is an important component in the construction of safety analyses. Since the system must be safe for all flights – not just "average" flights – the statistical variability of the flight tracks must be accurately measured and quantified. 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. Of course, 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 strong evidence that airports need to be individually measured.

This paper compares arrival flight tracks at two major U.S. airports, ORD and ATL. The basic conclusion is that statistical properties are reasonably similar between the two airports during instrument meteorological conditions (IMC). The results given in this paper are also similar to results presented in [1], obtained from multilateration measurements at STL. This provides some 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 multilateration data. An initial version of the algorithm is given in [2,3]. An updated version of the algorithm is given in [4]. An added component of the updated algorithm is a heuristic for processing the vertical component of the measurements. These previous papers have analyzed multilateration data at DTW. In this paper, we have been able to apply the algorithms from the previous papers with little modifications. The algorithms are applied here to ASDE-X data taken at ORD and ATL.

Other studies that have analyzed multilateration data include [1] and [5]. A number of other researchers have measured the statistical distributions of aircraft separations on arrival, both in terms of distance and time [6-12]. Statistical measurements of position deviations have also been made in the en-route environment (e.g., [13-15].)

III. Data Summary

This paper uses ASDE-X data as a basis for analysis of flight tracks. The data has been pre-processed by Metron Aviation, Inc. The data for each day consist of several different files in CSV (comma-separated-value) format. We combine several files containing data for the same day to one single file in text format. After rearranging the order of the columns, the output files consist of a single table with seven fields. These fields must be modified slightly in order to use the algorithms developed in previous studies [2-4]. The changes are described below.

- Aircraft ID. The aircraft identification consists of airline carrier and a series of numbers indicating a unique physical aircraft.
- Time. The input field is given in the format hh.mm.ss.000 AM[PM]' in GMT. In the output file, we convert time to seconds since midnight of the current day (in GMT).
- *x*- and y-coordinates (meters). The *x*-axis is aligned with true east. The *y*-axis is aligned with true north. The origin of the coordinate system is the airport control tower (Fig. 1 shows the ORD airport diagram).
- Height (feet). This field indicates the altitude of aircraft above the runway.
- Aircraft Type: This field indicates the manufacture and model of each aircraft.
- Wake Category: By comparing the mapping table created in previous work based on aircraft type, the wake category of Heavy, B757, Large and Small is inserted.

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TABLE I. TRACKS SUMMARY(COUNTS)

		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

In this paper, we analyze arrivals at ATL, runways 9R / 27L and 8L / 26R, and arrivals at ORD airport, runways 10 / 28, 4R and 14R. In total, 39,278 arrivals are observed (22 days for ATL and 31 days for ORD). However, due to missing data, value pop-ups and bad data, 31,566 arrivals are viewed as valid to be analyzed. All runways mentioned above are main runways for arrivals based on the most commonly used configurations in both airports. Table 1 shows a summary of flight tracks observed for all runways under both IMC and VMC.

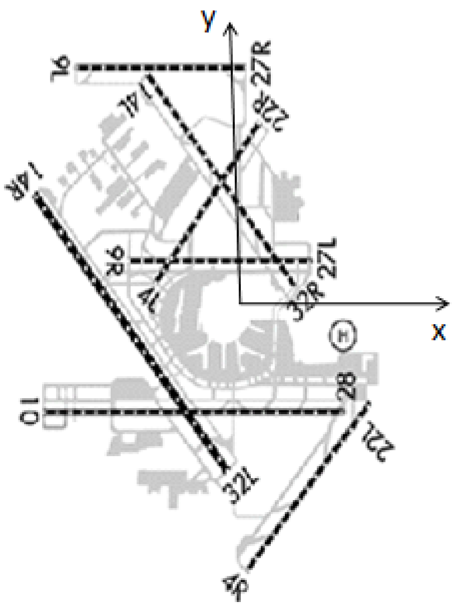

Figure 1. ORD airport diagram (www.airnav.com)

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

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

Table 2 illustrates an example of the processing steps and data for one day of data at ATL, runway 9R.

- The first row is the number of data points (rows) in the original files. Each row contains the aircraft position (longitude, latitude and height) at a specific time.
- The second row is the number of points remaining after discarding points outside of a defined box. The box is specific to the runway being investigated. Points outside of the box are assumed to belong to operations on other runways. (See [2] or [4] for more details on these steps.)
- 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; see also [2] or [4]).

IV. RESULTS

All fight tracks we obtained from the algorithm can be divided into two groups based on weather conditions (IMC and VMC). Whether a flight track is under IMC or VMC condition is defined by comparing the time of the first point of the track with airport weather information in the ASPM database.

Figs. 2 and 3 show a top-level view of flight tracks in IMC (runway 9R at ATL and runway 10 at ORD). In IMC, aircraft fly through the final approach fix (approximately 5nm from the threshold) straight to the runway. This is consistent with the figures, although there are a small number of tracks that appear to curve in after the approach fix. Some other exceptions are also observed in the analysis of other runways. In VMC, it is possible for aircraft to curve in after the final approach fix (Fig 4). As we expect, the lateral position of the aircraft converges to the centerline of the runway as aircraft get closer to the threshold of the runway.

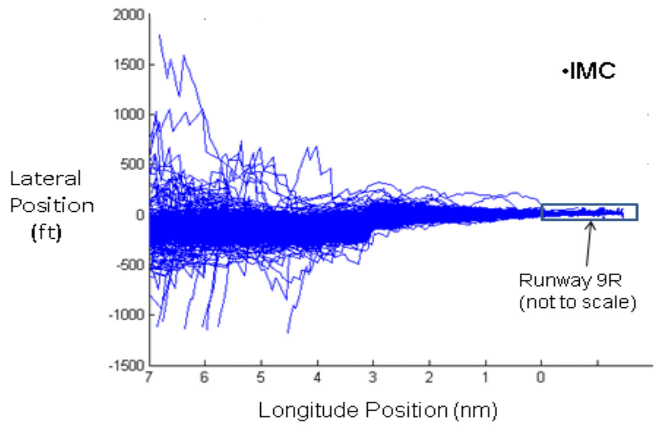

Figure 2. Lateral position of aircraft, ATL, runwal 9R, IMC

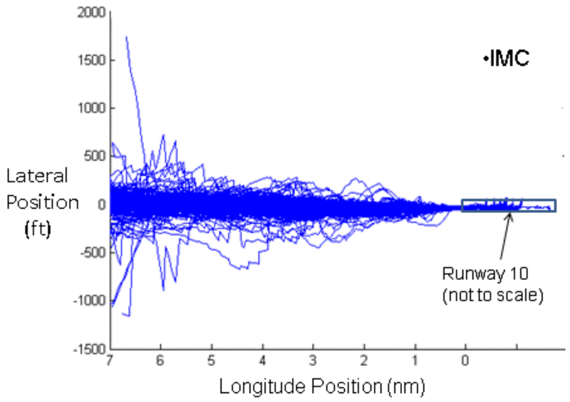

Figure 3. Lateral position of aircraft, ORD, runway 10, IMC

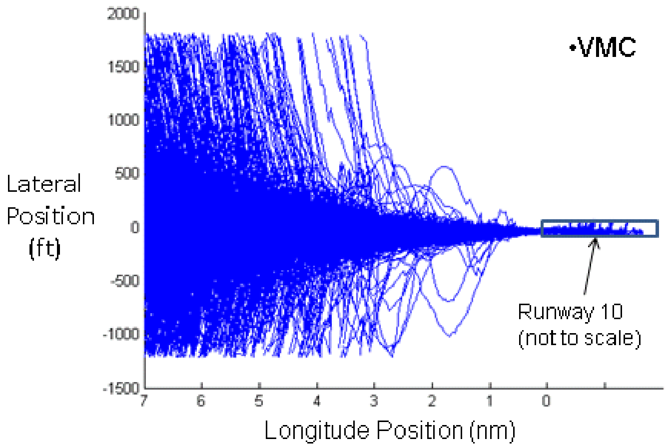

Figure 4. Lateral position of aircraft, ORD, runway 10, VMC

Table 3 shows the mean and standard deviation of lateral position of aircraft from 0 to 6 nautical miles from the threshold. According to table, the lateral position of aircraft landing on both runways under IMC condition has a smaller standard deviation than International Civil Aviation Organization (ICAO) localizer and glide slope tolerances [16]. Our results are similar to those reported in [1], particularly within 4 nm of the threshold. There are some larger discrepancies at 5 nm and 6 nm.

Table 4 gives the standard deviation of vertical position of aircraft landing on both runways under IMC condition. The standard deviation from 0 to 6 nautical miles from threshold for both runways is alike.

TABLE III. STANDARD DIVIATION OF LATERAL POSITION

	Runway 8L at ATL	**Runway 10 at ORD**	**STL, from [1]**
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
6	96	73	124

TABLE IV. STANDARD DIVIATION OF VERTICAL POSITION

	Runway 8L at ATL	**Runway 10 at ORD**
Distance from threshold (nm)	**Standard deviation (ft)**	**Standard deviation (ft)**
0	27	6
1	26	26
2	33	31
3	48	40
4	55	61
5	64	76
6	75	102

Figs. 5 and 6 show the lateral and vertical components of position at three nautical miles away from the threshold of runways in IMC condition. Each blue dot represents a landing track which crosses the threshold of the runway. Linear interpolation is done when the individual track points do not lie exactly at the 3-nm crossing point. There are 1167 operations in IMC for ATL based on three weeks of data and 527 operations in IMC for ORD based on 1 month data.

Figs. 7 and 8 show the lateral and vertical components of position at the threshold of runways in IMC condition. Fig. 8 demonstrates a stratification of vertical position of aircraft which is due to the precision of the altitude measurements. Relatively speaking, the limited precision has a larger relative effect near the ground than at higher altitude.

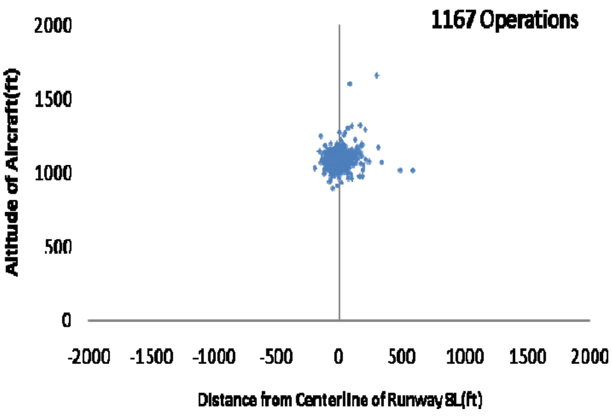

Figure 5. Lateral and vertical position at 3nm for ATL, runway 8L

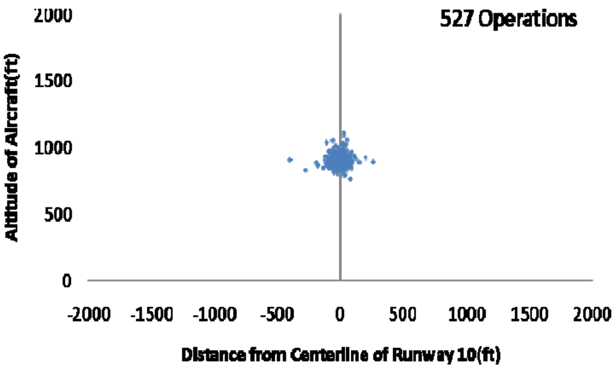

Figure 6. Lateral and vertical position at 3nm for ORD, runway 10

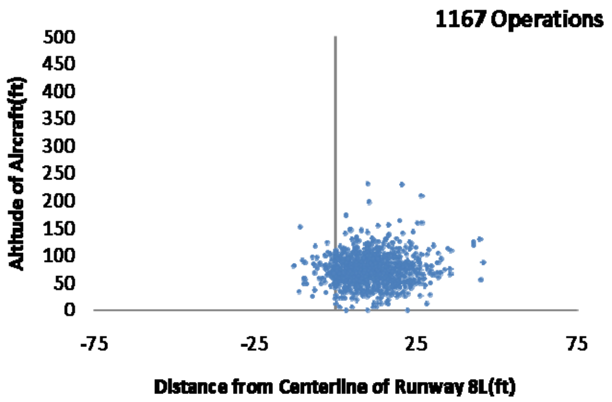

Figure 7. Lateral and vertical position at threshold for ATL, runway 8L

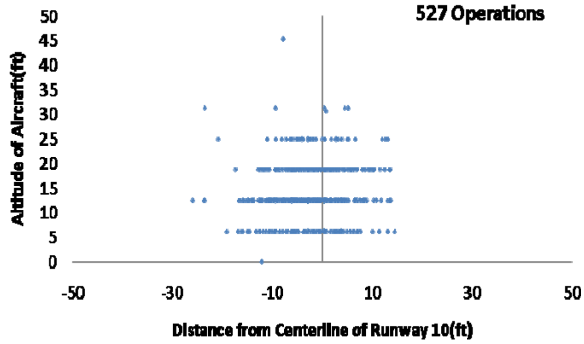

Figure 8. Lateral and vertical position at threshold for ORD, runway 10

Fig. 9 shows the density function of lateral position in both IMC and VMC at 4 nm away from the threshold of runway 10 at ORD airport. The tails of the VMC distribution are higher than the tails of the IMC distribution corresponding to the situation that aircraft curve into the fixed glide slope later under VMC. Similar results are seen for other distances from the threshold.

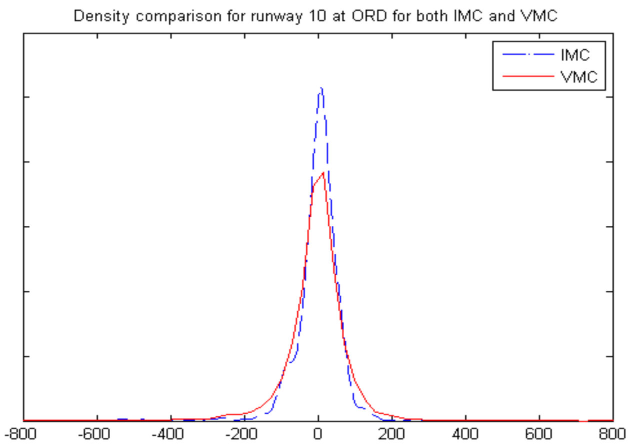

Figure 9. Density of lateral position

Now we focus on distributions of aircraft under IMC at different points away from threshold. It turns out that each distance has its own best fit distribution using the Arena input analyzer. However, a normal distribution fits well for all distributions at both airports. Fig. 10 shows a histogram of lateral position at 1 nm away from runway 10. In this case, the normal distribution fits the data very well whose corresponding p-value is less than 0.01. Similarly, the best distribution fits for lateral position at 3 nm is a gamma distribution. Its corresponding p-value is less than 0.005. However, the normal distribution also fits well with a p-value of 0.005.

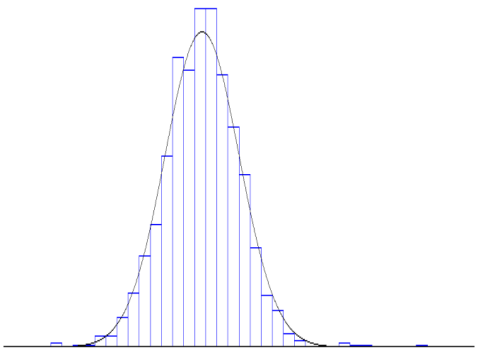

Figure 10. Distribution fit

Fig. 11 compares the observed distributions of data (not the fitted density functions) at 2 nm away from the runway threshold between ATL (8L) and ORD (10) in IMC. The distributions are in the same shape which verifies Table 2 showing that the standard deviations are similar.

Fig. 12 compares the observed distributions of data at 5 nm. Visually, the distributions look nearly identical. However, although it is difficult to see, ATL has several observations that extend beyond plus-or-minus 500 feet from the centerline, whereas ORD does not. These outliers greatly increase the standard deviation observed at ATL. This explains why the standard deviation at ATL (110 ft, Table 2) is roughly twice that observed at ORD (58 ft), even though the distributions look nearly identical. This also illustrates why moment-based measures, which are sensitive to large outliers, can be misleading.

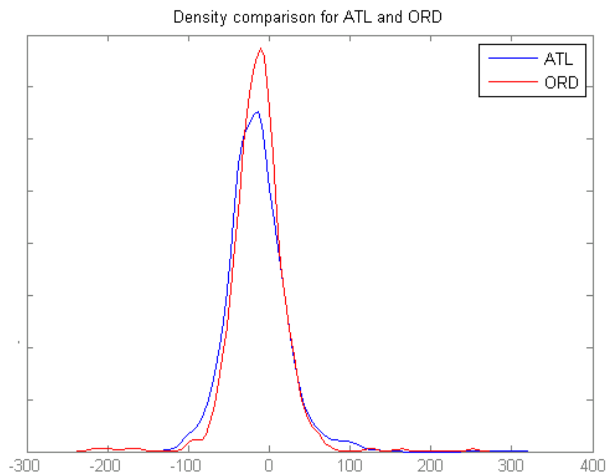

Figure 11. Distribution comparison

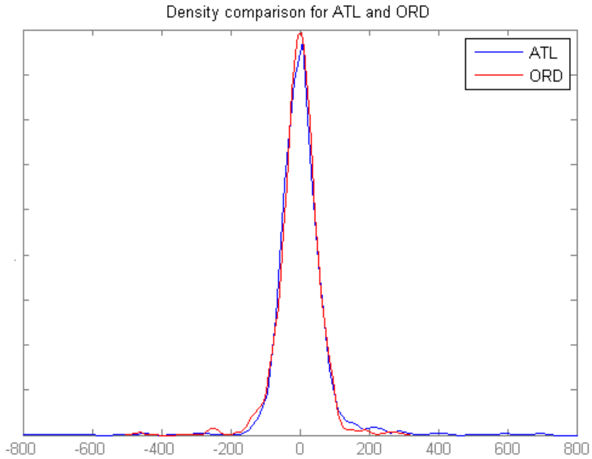

Figure 12. Distribution comparison

CONCLUSION

This paper gave a comparison of flight tracks at ATL and ORD airport based on ASDE-X data. In IMC, aircraft strickly follow the glide slode for arrival. The lateral position of the aircraft at different points from the runway threshold approximately follows a normal distribution in IMC. The tails of the distribution (on runways 8L ATL and 10 ORD) in VMC are “fatter” than in IMC. The statistical variability of lateral position is similar at the two different airports.

The statistical variability of vertical position is also similar at the two different airports. Some differences happen at the threshold and 6 nm away from the threshold. The difference at the threshold is mainly because of the reliability of data when aircraft are close to ground while the difference at 6 nautical miles is because the aircraft have not yet reached the point of the outer marker.

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