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A Simulation Study on Identifying Aircraft Touchdown Point by Using In-flight Recorded Data

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Abstract

Accurate information of operational aircraft touchdown points is critical to the safety of terminal area operations. Although the current aviation system tracks a number of landing parameters for commercial operations, the operational touchdown performance is not readily measured and recorded. The research described herein designed an algorithm to compute the aircraft touchdown point, and demonstrated its effectiveness with 72 landing runs performed on a high-fidelity full-flight simulator. These simulated flights were conducted with a Latin Square experiment design. The accuracy of the computational methods was evaluated by comparing the calculated touchdown points to the high precision position reference recorded by the flight simulator. The largest discrepancy between recorded and calculated touchdown points was 246 feet, the smallest was 0.5 feet, and the average was 117 feet.

I. Introduction

Incidents and accidents with varying degrees of severity continued to occur during the landing phase of flight [1, 2]. According to a worldwide review of commercial jet aircraft runway safety published by the Australian Transportation Safety Board [3], runway excursions, including overruns and veer-offs, account for a quarter of all incidents and accidents in air transport, 96 percent of all runway accidents, 80 percent of fatal runway accidents, and 75 percent of related fatalities. Therefore, adequate determination of operational aircraft landing performance is critical to the safety of terminal area operations. In general, the landing process consists of touchdown and rollout/turnoff. Although the current aviation system tracks a number of landing parameters for commercial operations, the operational touchdown performance is not readily measured and recorded. Specifically, the high precision aircraft position (e.g., GPS) information is seldom recorded in the in-flight data recorder. The research described herein discussed an effective algorithm to compute the aircraft touchdown point via backtracking the landing trace. The goal was to provide an algorithmic solution to identify the touchdown and turnoff points. The computations were demonstrated with 72 landing runs collected by a high-fidelity full-flight simulator. The fidelity rendered in the advanced full-flight simulator has provided an indispensable tool for aviation training. With the flexibility of digital data collection, the flight simulator is able to record a complete set of landing parameters including the high precision aircraft position information, enabling the analysis of the computations for aircraft touchdown points. In Section II, experiment design and data collection are described. In Section III, the algorithm of the computational methods is described, and the results are presented. Section IV contains the discussion.

II. Data

A set of 72 simulated aircraft landing traces at the LaGuardia Airport (LGA) were collected specifically for the study. The parameters that were considered contributing factors of landing performance included aircraft weight, visibility, wind directions, and precipitation on the runway. The 72 landings were configured as various

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combinations of these parameters by a Latin Square experiment design. Specifically, the values of the parameters are:

- Runways: 13, 22, 31;
- Wind: calm, head wind (10 knots), cross wind (10 knots), and tail wind (10 knots);
- Precipitation on runway: dry or wet;
- Visibility: clear, moderate low;
- Aircraft gross weight: 130,000 or 144,000 tons.

The flight simulation was conducted at FAA Flight Operations Simulation and Analysis Branch, Oklahoma City, OK. The landing simulation started in the approach phase at approximately 3 miles form the runway threshold. After touchdown, the simulation continued through turning off and taxiing via taxiways A and B till stopping at a predetermined parking location. One of the important features of full-flight simulator was the capability of recording the high precision position reference information. The aircraft position reference allowed the analysis of the accuracy concerning the computational analysis algorithms. In addition to the position data, the flight simulator recorded a wealth of flight information. Of relevance to this project, there were Ground Speed (knots), Main Gear Squat (0 = in air, -1 = on ground), Aircraft Magnetic Heading (degrees), Aircraft Latitude (degrees), and Aircraft Longitude (degrees). It is worth noting that the flight parameters in the simulation runs were recorded at a higher update rate and with more precision than typically collected by the in-flight data recorders. For example, the in-flight data recorder updates most flight parameters at a rate of 1 Hz, but the simulator collects the data at a rate of 5 Hz or faster. Furthermore, because of the capacity concerns, the ground speed was recorded in the in-flight recorder with only the integral part, truncating the fractional information after the decimal point. In the flight simulator, this information was collected with 4 digits after the decimal. In order to match the corresponding information recorded in the in-flight recorder, four out of every five records were discarded deliberately so as to reduce the data sampling rate to 1 Hz, and the recorded fractional information of the ground speed was truncated in the computational analysis (described in Section III). Of the 72 recorded data files, one was corrupted, and thus there were 71 usable simulated landing traces.

III. Computational Methods

The computational methods incorporated the Geographical Information System (GIS) of LGA [4]. Figure 1 shows the geographical data pertained to the runways and taxiways of LGA, which are represented in a spherical coordinate system involving the meridians of longitude and the parallels of latitude. The algorithm used the following strategy to identify the touchdown points.

- Using the LGA GIS information, the runways and taxiways of LGA were divided into two kinds of segments: straight lines and curves.
- For a landing trace, the touchdown time was identified as the first record where the squat switch was closed.
- On the ground, when the aircraft was accelerating or decelerating, the ground speeds (V) between two consecutive records showed considerable difference; similarly, when the aircraft was making turns, consecutive magnetic headings (H) exhibited rapid changes.
- Cubic spline fitting was used to calculate the trace of the aircraft.

Specifically, let (X_0, Y_0) be the coordinates of the touchdown point; its coordinates were arbitrarily assigned to (0, 0), and its true values were to be determined later. The aircraft movement from time *s* to time *s+1* is calculated from the speed/heading of four time point: *s-1, s, s+1,* and *s+2* as follows. First, the instantaneous speed/heading at each time point is directly converted the movements in the X- and Y-directions by the following equations:

$$\mathrm{X}_t = \mathrm{V}_t \cdot \sin\left(\frac{\pi}{180} \cdot \mathrm{H}_t\right),$$

$$\mathrm{Y}_t = \mathrm{V}_t \cdot \cos\left(\frac{\pi}{180} \cdot \mathrm{H}_t\right),$$

for *t* = *s-1, s, s+1,* and *s+2*. Then, a cubic polynomial is fitted to the four (instantaneous) movements in the X-direction:

$$X_s(t) = a_s + b_s t + c_s t^2 + d_s t^3 .$$

Then the movement of the aircraft in the X-direction from time *s* to time *s+1* is the area under the curve $X_s(t)$, which is calculated by numerical integration. The movement in the Y-direction is similarly calculated. Then the aircraft trace on the ground was divided into straight lines and curves as well. Figure 2 shows a typical landing trace established by the ground speeds and magnetic headings.

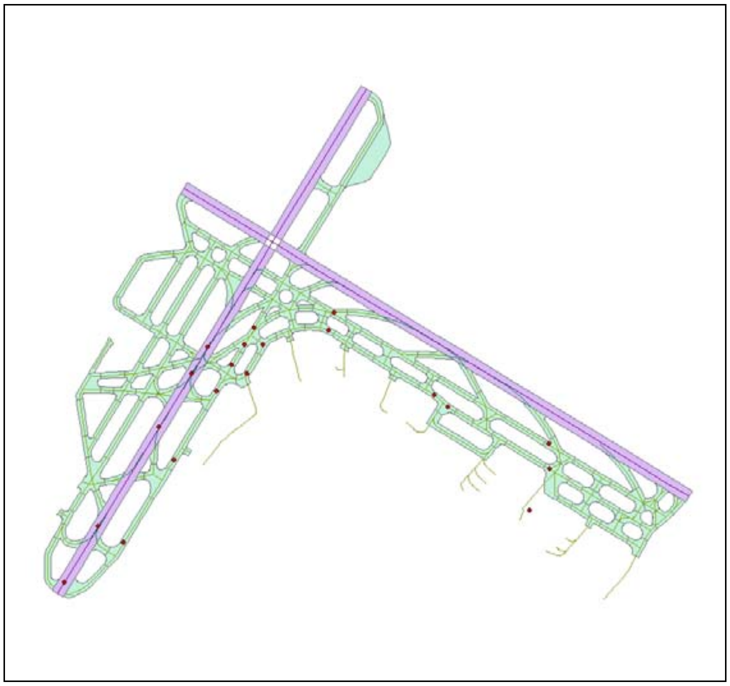

Figure 1 Geographical Information System (GIS) Diagram for LGA

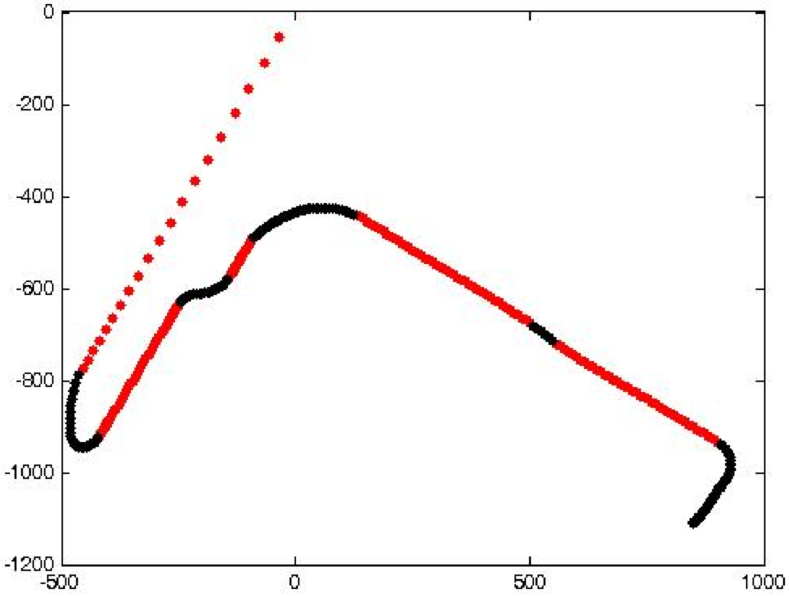

Figure 2 Geographical Representation of a Landing Trace

The segments of a landing trace (Figure 2) were matched to the segments of the runways/taxiways (Figure 1), where the kinds of segments (straight lines or curves) and the lengths of the segments were taken into consideration. Specifically,

1. On the airport GIS map, red marks were put at points on the runways and the taxiways where aircraft may make turns.
2. The red marks were organized in an acyclic directed network, and each red mark was a node in the network.
3. The source of the network was the runway.
    a. The children of the source were the five exit points.
    b. The grandchildren of the source were the red marks on the first taxiway parallel to the runway.
    c. The other red marks were similarly organized, and they all converged to the drain of the network.
4. The drain of the network was the terminal area.

With these arrangements, the segments of the landing trace were mapped onto the airport map, and the best match was selected and the touchdown position (i.e., the distance from the runway threshold) was back-calculated from the match. To further explore the computational errors, the difference between the reference and back-calculated touchdown points was analyzed for all the 71 landing runs. The largest discrepancy is 246 feet, the smallest is 0.5 feet, and the average is 117 feet. Figure 3 shows the histogram of the distance between reconstructed touchdown point (TP) and the high precision reference TP.

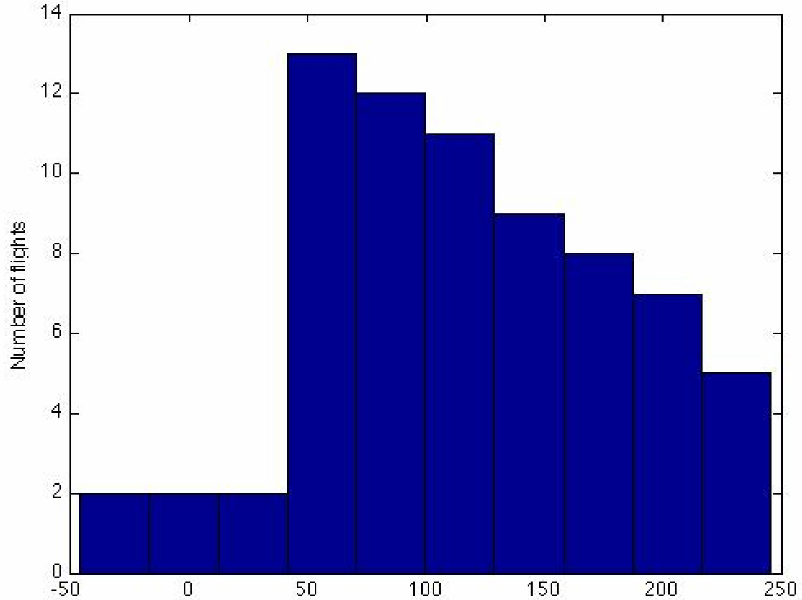

Figure 3 Histogram of Difference between Calculated and Reference Positions of Touchdown Point

IV. Discussion

In this study, a computation algorithm was proposed and a fully automatic procedure was developed to identify the operational aircraft touchdown point by backtracking the landing trace. This unsupervised procedure has effectively processed the test data collected via pilot-in-the-loop flight simulation runs and obtained correct results. Specifically, the analysis showed a good agreement between the computed and the recorded reference values concerning the aircraft touchdown location. While the typical operational flight information (e.g., the in-flight data recorder) only records the position information from the Internal Navigation System (INS), which suffers from integration drift and accumulates great errors in position, our proposed method provides a useful tool to supplement the identification of operational touchdown point for supporting the analysis of runway safety issues [5, 6].

In recorded data from operational landing, the status of the squat switch is updated once per second. Thus there is possibility up to one second of delay from the time when the squat switch sensor detects the closure to when the squat status is updated on the recorder. At the typical touchdown speed of 140 knots, the aircraft may have traveled as far as 200 feet during this period of time. This distance would be the unavoidable uncertainty in calculated touchdown points.

It was noticed that the back-calculated touchdown points tended to be shorter than the reference values as shown in Figure 3, indicating that the algorithm usually identified the touchdown point closer to the runway threshold than the simulator's reference position. This might be primarily caused by the errors of estimating the traveling distance via the ground speed and magnetic heading. In the back-tracking algorithm the new position was calculated from the previous calculated position, these errors were cumulative and increased at a rate roughly proportional to the number of position updates during the deceleration after touchdown. Since the touchdown point was determined by the distance traveled from touchdown to turnoff, the accumulation of errors would be finite. As discussed in Section II, various factors that might impact the deceleration patterns after touchdown were carefully designed to be representative of potential real-world operations for civilian aircraft pilots. It was observed that only 20 – 25 position updates were required from touchdown and turnoff. More variations would be involved for traveling along different taxiways to the parking location. Nevertheless, the accumulation of estimation errors did not introduce troubles for recognizing the correct taxi routes.

It is worth noting that the reference position (latitude/longitude) information in this study was recorded with 13 digits after the decimal by the flight simulator, yielding a resolution of 1.6 feet. However, because of the capacity concerns, such information was recorded in the in-flight recorder with only three digits after the decimal (in degrees), resulting in a resolution of 276 feet. This study shows that the average difference between the calculated and the reference touchdown points is 117 feet, and the largest difference is 246 feet, suggesting that the computation would yield very similar results as the high precision GPS information if only 3 digits of precision after the decimal can be recorded. The initial results are very encouraging. The future plan will be to obtain operational landing data with accurate position information such as the satellite navigation signals to further enhance and validate the computational methods.

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