# AIRSPACE RISK MANAGEMENT USING SURVEILLANCE TRACK DATA: STABILIZED APPROACHES

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## Abstract

The outcome of operations in a designated airspace is a function of the cooperation between flights in the airspace and the coordination of Air Traffic Control (ATC). A critical airspace is the approach airspace in which flights are sequenced and separated to minima to maximize utilization of the available runways. Airline procedures call for flights to meet "stable approach criteria" at 1000 ft. and 500 ft. above ground level (AGL). ATC procedures define the trajectories flown, including airspeed, to maximize throughput through the airspace and runways. The ability to achieve the stabilized approach criteria is therefore a function of the coordination of the flight crews and ATC.

This paper describes a method for analysis of stabilized approaches using surveillance track data. Risk events and factors related to stabilized approach criteria are defined. A case study of 8,219 approaches is conducted at a runway of slot controlled airport with a dominant carrier. The results quantify the portion of the approaches which violate the stabilized approach criteria. Results show that 27.8% of the approaches exhibited more than 10 knots change in groundspeed after sequencing 1000 ft. AGL, 14.1% after sequencing 750' AGL, and 4.4% after sequencing 500' AGL. The flights with rate of descent in excess of 1000 feet per minute (fpm.) are also studied. The effects of factors such as the speed at Final Approach Fix (FAF) and the runway centerline/glidepath acquisition position are analyzed. Results show that a flight that acquires glidepath after FAF has a higher probability of having an excessive speed change from 1000 ft. AGL to the runway threshold. Aircraft weight classes are also studied. The results indicate a lower landing speed and higher deceleration rate for small aircraft. The implications of these results and the limitations of using surveillance track data for this purpose are discussed.

## 1 Introduction

The outcome of operations in a designated airspace is an emergent property of cooperation between flights in the airspace and the coordination of ATC. ATC must separate the flights according to the required separation minima and sequence the flights to maximize throughput of the airspace and downstream airspace (e.g. runway). Flight crews must configure the aircraft appropriately for the maneuvers required by each trajectory segment to maintain a lift-generating energy state, coordinate the required trajectory to achieve the flight plan, remain within the constraints of the navigation procedure, maintain separation with other flights, and coordinate immediate and future trajectories with ATC.

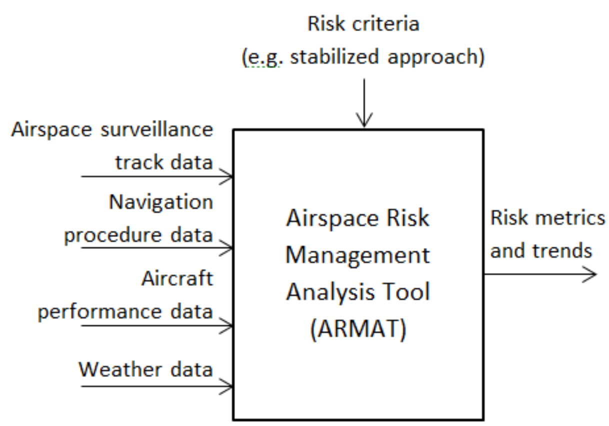


**Figure 1. Airspace Risk Management Analysis Tool**

These airspace operations are subject to hazards related to: (1) traffic separation, (2) terrain and obstacle avoidance, and (3) aircraft performance. Specifically, the aircraft must be configured (e.g. flaps and slats) to achieve the desired energy-state on entry and during execution of a required maneuver (e.g. holding pattern). A system to monitor approach trajectories to identify outliers and cluster trends could be useful to manage airspace risk (Figure 1).

The approach airspace is a particularly complex region. ATC must sequence and separate flights to maximize throughput utilization of the runways. Flight crews must configure the aircraft for the sequence of maneuvers leading up to the flare and landing. The interaction between ATC procedures and flight deck operations has been a contributing factor in several recent accidents (e.g. SW 1455, TK 1951).

Due to the rapid tempo in the sequence of maneuvers during approach, sound procedures call for the flight crew to abort the approach if "stabilized approach" criteria are not met at 1000 ft. AGL and 500 ft. AGL. Specifically, for stabilized approach criteria to be satisfied, by 1000 ft. AGL, the aircraft must be in the planned landing configuration (landing gear down and landing flaps), must be in the VTARGET speed range (i.e. +10/-5 knots), must be on the appropriate glidepath with a normal rate of descent less than 1000 fpm., and must be maintaining the final approach course with wings level (unless maneuvering is required for a course change). If "stabilized approach" criteria are not met, a go-around/missed approach is mandated.

Although the flight crews are responsible for configuring the aircraft for a stabilized approach, ATC provides the environment in which the approach is conducted and may find it useful to monitor airspace risk. The best source of data for monitoring stabilized approach criteria is Flight Data Recorder (FDR), also known as Flight Operations Quality Assurance (FOQA). This data, however, is considered proprietary by the airlines and is also subject to limitations in use by airline pilot union contracts. Surveillance track data, however, is now available from flight tracking (e.g. FlightStats, FlightAware, etc.) and could be used for this purpose.

This paper describes algorithms used to assess the degree to which stabilized approach criteria are satisfied for an approach airspace using surveillance track data. A case study for 8,219 approaches to one runway at a slot controlled U.S. airport with a dominant carrier (i.e. uniform stabilized approach criteria) exhibited the following performance:

- 72.2% of the approaches met the stabilized approach criteria of no speed change greater than 10 knots after sequencing 1000 ft. AGL.
- 85.9% of the approaches met the stabilized approach criteria of no speed change greater than 10 knots after sequencing 750 ft. AGL.
- 95.6% of the approaches met the stabilized approach criteria of no speed change greater than 10 knots after sequencing 500 ft. AGL.
- 98.1% of the approaches met the stabilized approach criteria of rate of descent less than 1000 fpm. after sequencing 1000 ft. AGL.
- 99.3% of the approaches met the stabilized approach criteria of rate of descent less than 1000 fpm. after sequencing 750 ft. AGL.
- 99.8% of the approaches met the stabilized approach criteria of rate of descent less than 1000 fpm. after sequencing 500 ft. AGL.
- 90.1% of the approaches acquired the runway centerline and the glidepath prior 6 nm. of the runway threshold.
- A higher speed at FAF may cause an excessive speed change from 1000 ft. AGL to runway threshold.
- Late acquisition of glidepath may cause an excessive speed change from 1000 ft. AGL to runway threshold.
- Aircraft categorized by weight class "Small" were more likely to fail to meet the stabilized approach criteria. These flights had to decelerate the furthest from the ATC issued approach speed to the low landing speed for this class of aircraft.

These results highlight two important ideas about risk in the NAS. First, like many other places in NAS operations the risk lies at the interface between operations: in this case in the transition from ATC approach flow control and flight deck configuration of the aircraft for landing. Second, the difficulty in adhering to the stabilized approach criteria is the result of applying deterministic criteria to measuring an inherently stochastic process.

Despite some limitations in the precision of the surveillance track data, these results demonstrate the feasibility of using this data set to measure, track, and trend airspace risk.

The paper is organized as follows: Section 2 describes previous research in airspace risk management. Section 3 describes the algorithms used for analysis of surveillance track data for airspace risk management of stabilized approach. Section 4 describes the results of a case-study for a runway at a slot controlled U.S. airport with a dominant carrier. Section 5 discusses the implication and limitations of this approach.

# 2 Methods of Airspace Risk Analysis

Methods for airspace risk management using surveillance track data can be organized into two categories: simulation-based methods and data analysis methods.

### *Simulation-based Methods*

Simulation-based methods use statistical properties derived from flight tracks to conduct stochastic simulations of the approach process. These statistical characteristics are fitted with probability distributions. For example, Jeddi et al. [1] used multilateration data to study the landing operations at Detroit Metropolitan Wayne County airport with Landing Time Intervals and Runway Occupancy Time studied. With key statistical features modeled, hypothetical flight tracks are generated to simulate the landing operations. With large amount of tracks generated, the probability of specific risk events (e.g. wake encounter) is estimated.

### *Data Analysis Methods*

The data analysis methods use full data to study potential or specific risk events. This approach can be further categorized into data mining methods and heuristic methods.

#### Data Mining Approach

Data mining methods focus on discovering potentially undefined and unknown behaviors which can be precursors of incidents or accidents. The concept is to detect statistical outliers for parameters in on-board flight data or abnormal patterns in flight track data. For example, Matthews et al. [2] have developed an automated tool for anomalous flights detection using surveillance track data. Usually, the detected anomalies need to be examined by subject matter experts for validation.

#### Heuristic Approach

The heuristic approach is developed with specific safety rules defined in advance. The methods then test the surveillance track data using the algorithms developed based on the rules to study the risk events of interest. For example, Sherry et al. [3] have studied abnormal operations of go-arounds and aborted approaches using surveillance track data.

Stabilized approach criteria provide a well-defined set of heuristics (e.g. airspeed, rate of descent, etc.) along with quantifiable factors. This paper describes a heuristic approach to study unstabilized approaches by extracting related features from surveillance track data. The next section will describe the methods developed for the study of the potential risks during unstabilized approach using surveillance track data.

# 3 Methodology

This section describes a method for using surveillance track data to monitor factors leading to stabilized approaches.

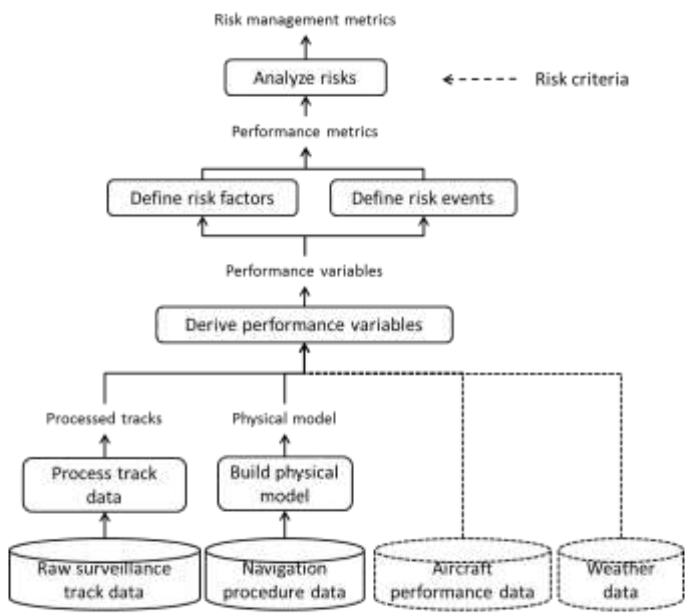


**Figure 2. Methodology Overview**

The methodology, summarized in Figure 2, starts with processing raw surveillance track data and other relevant data. (The weather database and aircraft database will be integrated in future work). The outputs of these functions are the derived performance variables (e.g. groundspeed, rate of descent), which are inputs to the next level of processing, where risk events and factors are defined. With specific risk events defined using derived variables, the performance metrics are calculated and become input to the risk analysis. With these performance metrics, the system risk management metrics can be analyzed.

## 3.1 Data Sources

**Navigation Procedure Data**

Navigation procedure data come from the FAA's National Flight Data Center (NFDC). Table 1 summarizes the key airport and runway information from the data, which is used for building the wireframe model of the final approach segment for each runway.

The key fields used in this research include airport information such as airport name, location and elevation, and runway information such as runway name, true alignment, visual glidepath angle, elevation, threshold crossing height and runway threshold location.

**Surveillance Track Data**

The surveillance track data used in this research is provided by the FAA National Offload Program (NOP). Some key fields are extracted from the raw track data for this study. They are track index, aircraft type, destination airport, seconds past midnight, latitude, longitude and altitude (Table 1).

**Table 1. Summary of Key Fields in Surveillance Track Data**

| Field | Description | Sample value |
|---|---|---|
| **Track index** | Flight track identification | 20070111000339 N902242BTA2087 |
| **Destination airport** | Destination airport | LGA |
| **Seconds past midnight** | Time in seconds past midnight | 297 |
| **Latitude** | Latitude in decimal | 40.70711 |
| **Longitude** | Longitude in decimal | -74.14420 |
| **Altitude** | Altitude in 100 ft. | 15 |

## 3.2 Processing of Raw Data

### 3.2.1 Processing Raw Surveillance Track Data

There are some limitations in the raw surveillance track data. The precision levels of the original data are low. For example, the sampling interval in the raw surveillance data is between 4 and 5 seconds, and the value is recorded to a precision of one second. The latitude and longitude values are given to five decimal places. Altitude values are given as number of flight levels, which have a precision of 100 feet.

To work with these limitations, we linearly interpolate between successive data points to obtain an updated track with a sampling interval of 1 second. For example, let $x_i$ represent the lateral position of the aircraft at time $i$ (where $i$ is an integer, in seconds). Suppose that $i$ and $j$ represent successive time stamps from the original data, with $i < j$ (both $i$ and $j$ are integers). To estimate the lateral position at an intermediate point, $i + n < j$, we use the following:

$$x_{i+n} = x_i + \frac{n}{j-i}(x_j - x_i) .$$

A similar process is used to obtain the interpolated points for vertical position.

### 3.2.2 Processing Navigation Procedure Data

With airport and runway information obtained from NFDC, a three-dimensional final approach wireframe model is built for each runway. The modeled zone is defined by the specific heading, elevation, threshold crossing height, threshold position, and glidepath angle at each runway (Figure 3). This wireframe model consists of two segments, namely a final approach segment and a level flight segment. The final approach segment starts from FAF (approximately 6 nm. from runway threshold) to runway threshold. The level flight segment starts from 12 nm. to FAF.

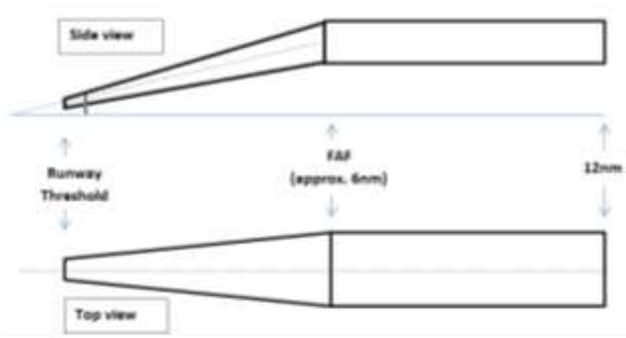


**Figure 3. Model of Approach Segment**

The lateral and vertical sizes of this zone are determined from actual cross-sectional positions of landing tracks at different distances from the runway threshold. Figure 4 shows example scatterplots for crossing positions of arrival tracks at 6 nm. from the runway threshold and at the runway threshold. These distributions are used to determine the dimensions of the approach zone. Specifically, each dimension of the zone is sized to contain approximately 95% of all arrival flight trajectories in that dimension (out to the FAF). For the runway used in this analysis, the estimated cross section sizes (half width) at 6 to 12 nm. from runway threshold are 500 ft. lateral and 250 ft. vertical. At the runway threshold, the lateral and vertical sizes are set 120 ft. and 70 ft.

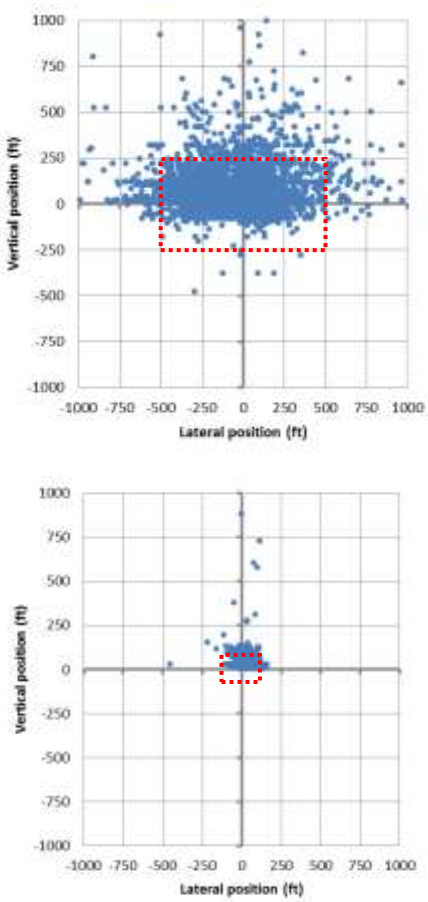


**Figure 4. Scatterplot of Cross-sectional positions at Different Distances from Runway Threshold**

### 3.2.3 Landing Runway Identification

To identify the landing runway for each arrival flight, the following algorithm is applied. First, we search backward from the last track point (on or near landing runway threshold) of a flight. We check if the track point is inside any modeled wireframe. If inside, the algorithm starts to check the following variables: distance traveled inside a wireframe $d$, time spent inside a wireframe $t$, angle difference with runway centerline $\alpha$, and distance from corresponding runway threshold $D$. The criteria are summarized in Table 2. If all of these conditions are satisfied by the track points followed before the aircraft is outside the current wireframe, then the landing runway of the flight is the runway corresponding to the modeled wireframe the flight was inside.

### 3.2.4 Flight Track Qualification

The surveillance track data contain some flights with incomplete tracks. For the next processing and analysis, we focus only on the qualified flight tracks which satisfy following criteria:

- The landing runway is identified.
- The track has entered one or more wireframe approach zones.
- The altitude of first track point is greater than 3000 ft. AGL.
- The altitude of last track point is less than 500 ft. AGL.
- The distance from the first track point to the landing runway threshold is larger than 6 nm.
- The distance from the last track point to the landing runway threshold is smaller than 3 nm.

The case study in Section 4 shows that most of the flights (99.3%) in the surveillance track data have their tracks satisfying these qualification conditions.

**Table2. Parameters and Criteria for Landing Runway Identification**

| Parameters | Description | Criteria | Current threshold |
|---|---|---|---|
| $d$ | Distance traveled inside a wireframe | $d > d_{threshold}$ | 50 meters |
| $t$ | time spent inside a wireframe | $t > t_{threshold}$ | 3 seconds |
| $\alpha$ | angle difference from runway centerline | $\alpha < \alpha_{threshold}$ | π/4 |
| $D$ | distance from corresponding runway threshold | $D < D_{threshold}$ | 3 nautical miles |

### 3.3 Derive Performance Variables

The raw surveillance data contain basic variables of time, latitude, longitude and altitude. For further analysis, more variables such as groundspeed, rate of descent and heading angle need to be derived.

To estimate the groundspeed of a track point, we simply average the groundspeed of its two adjacent segments. For example, to calculate groundspeed at $P_2$ in Figure 5, we average the speed from $P_1$ to $P_2$ and the speed from $P_2$ to $P_3$:

$$v_2 = \frac{(v_{12} + v_{23})}{2}$$

where

$$v_{12} = \frac{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}}{t_2 - t_1}$$

Here $t_i$ is the time in seconds at point $P_i$. $X$ and $y$ are the Cartesian coordinates for $P_i$.

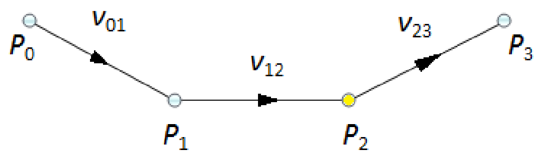


**Figure 5. Calculation of the Groundspeed at a Point**

Similarly, the vertical speed at a point is estimated by averaging the vertical speed values of the two adjacent segments.

To derive the heading angle $\theta$ of a track point, we define north as 0. Clockwise from north, the value of $\theta$ (in radians) grows from 0 to $2\pi$ (Figure 6). To calculate $\theta$, we average the heading angles formed by the two adjacent segments. Depending on the situation, the heading angle of $P_1$ is either $\theta_1 = \frac{(\theta_{01}+\theta_{12})}{2}$ or $\theta_1 = \frac{(\theta_{01}+\theta_{12})}{2} \pm \pi$, where $\theta_{01}$ and $\theta_{12}$ are the heading angles of segment $P_0P_1$ and $P_1P_2$ respectively. The estimated heading direction at $P_1$ is indicated by the dashed arrow in Figure 6.

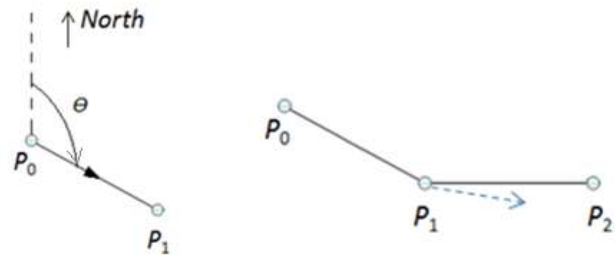


**Figure 6. Calculation of the Heading Angle at a Point**

One issue in estimating these variables is the noise in the data. To reduce the variation in groundspeed and rate of descent, we use an averaging interval to smooth out the noise. Figure 7 shows the smoothing effect of different averaging intervals, applied to the derived groundspeed for an example track. As the length of the averaging interval increases, the noise is reduced. However, the ability to distinguish speed changes over short time intervals is also reduced. To preserve the original information and reduce the noise as much as possible, we choose the averaging interval $n$ = 30s. The method of calculating *averaged* groundspeed at point $P_j$ can be summarized in the following formula:

$$GS(P_j) = \sum_{i=j-\frac{n}{2}}^{j+\frac{n}{2}} v_i \,/(n+1)$$

If we focus on the groundspeed in the direction of the runway centerline only, the groundspeed projected onto the runway centerline can be defined using formula below:

$$PGS(P_j) = \sum_{i=j-\frac{n}{2}}^{j+\frac{n}{2}} v_i cos(\theta_i - \theta_{runway}) \,/(n+1)$$

where $\theta_{runway}$ is the heading angle of the runway centerline.

The same noise reduction technique is also applied to derive the average rate of descent at a track point $ROD(P_j)$.

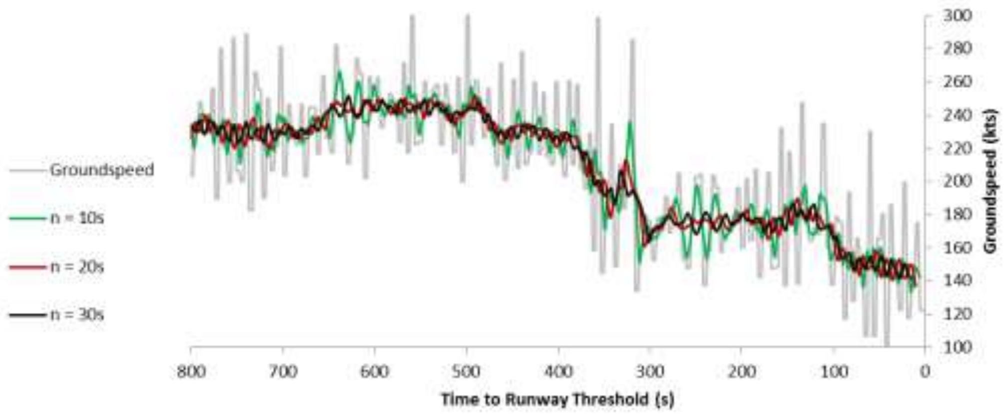


**Figure 7. Averaging Time Intervals and Their Effects on Noise Reduction**

## *3.4 Airspace Risk Management Metrics*

Performance metrics are calculated by counting the risk events that occur during the approach process. For the case of stabilized approaches, the events include:

- Changes in speed from one location to another location (e.g. 1000 ft. AGL to runway threshold),
- Rate of descent in excess of a threshold (e.g. 1000 fpm.) and last for a time period,
- Alignment with runway centerline,
- Alignment with glidepath,
- Go-around trajectory flown (if any).

Factors for analyzing stabilized approaches include:

- Location of acquisition of the glidepath
- Location of acquisition of the runway centerline
- Speed at FAF
- Aircraft weight class

The impact of these factors on the risk events will be analyzed in Section 4.

### 3.4.1 Risk Events Definition

*Identification of key track points*

The surveillance track data are composed of track points. Each point contains position, time, and derived information including groundspeed and rate of descent. To define the risk events related to stabilized approaches using surveillance track data, it is essential to first identify those track points which correspond to a set of key locations or events of the landing flight.

We first identify the track point $P_{entrance}$ which corresponds to the moment when an aircraft first enters the modeled wireframe zone. Then, we search for the track points for key locations along the approach path (e.g. 6 nm. from the runway threshold) and the track point at the runway threshold. To do this, we find the track point $P_i$ that is closest in proximity to the target distance, subject to the constraint that the time from $P_{entrance}$ to the time of $P_i$ is less than a predefined time limit $t_{limit}$. Currently $t_{limit}$ is set to 200 seconds. For a go-around flight, this constraint can ensure that the points identified at these key locations are from the time period of its first attempt to land.

Next, we search for the track point where the flight captures a target altitude $z_{target}$, such as 1000 ft. AGL during its final approach. The algorithm for identifying such $P_{altitude}$ is summarized below:

1. Let $z(P_j)$ and $t(P_j)$ be the altitude and time of an arbitrary point $P_j$.
2. Search backward in time through the set of track points.
3. If $z(P_j) > z_{target}$ and $z(P_{j+1}) < z_{target}$ and $|t(P_{entrance}) - t(P_j)| < t_{limit}$, $P_j$ is considered the point where the flight first captures the target altitude during final approach. The point is named $P_{altitude}$.
4. If no point $P_{altitude}$ is detected, then use the track point at corresponding location $P_{location}$ along the final approach path to approximate $P_{altitude}$ (e.g. $P_{3nm}$ for $P_{1000ft}$).

With $P_{altitude}$ found, related performance variables can be obtained. For example, the average groundspeed at the moment when a landing aircraft captures 1000 ft. AGL is $GS(P_{1000ft})$.

*Risk Event of Excessive Speed Change*

We assume constant wind speed and direction during the final approach. With such an assumption, the change in groundspeed approximates the change in true airspeed, since the wind speed component is canceled out when subtracting two speed quantities. This logic assumes that flights are on a path with constant heading. Future work is to include wind data to derive the airspeed for more precise results.

In this research, we focus on a high deceleration rate along the runway centerline. We define the risk event of abnormal speed change from 1000 ft. AGL to threshold as

$$PGS(P_{1000\text{ft}}) - PGS(P_{\text{threshold}}) > 10 \text{ knots}.$$

If this event occurs for a given flight, we consider it a higher-than-normal deceleration rate which does not satisfy the stabilized approach requirement.

*Risk Event of Excessive Rate of Descent*

The method to calculate the averaged rate of descent $ROD(P_j)$ at track point $P_j$ is similar to the method for the averaged groundspeed. We use an averaging time interval of $n$ seconds to reduce noise in the data. Let $w_i$ be the raw observation of rate of altitude change at each point. The nagative sign before $w_i$ indicates that $ROD$ is for descending rate not climbing rate. The average rate of descent is defined as:

$$ROD(P_j) = \sum_{i=j-n/2}^{j+n/2} -w_i / (n+1),$$

where

$$w_i = \frac{1}{2}\left( \frac{h_i - h_{i-1}}{t_i - t_{i-1}} + \frac{h_{i+1} - h_i}{t_{i+1} - t_i} \right).$$

We start to monitor the $ROD(P_j)$ from $P_{1000ft}$. If a landing aircraft has a descent rate greater than 1000 fpm. for longer than a prescribed period of time, say, 10 seconds, then it is considered a risk event.

A sample altitude profile for a landing flight with an excessive rate of descent is shown in Figure 8, where the dashed line indicates the maximum rate of 1000 fpm. This maximum value is exceeded for more than 10 seconds since the aircraft reached 1000 ft. AGL. Therefore, the defined event of excessive rate of descent occurs.

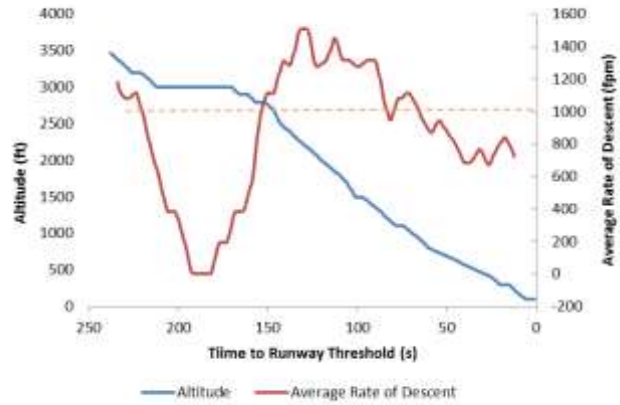


**Figure 8. Excessive Rate of Descent**

*Risk Event of Glidepath and Runway Centerline Alignment Problem*

If the distance from the first entrance point of landing aircraft $P_{entrance}$ to the landing runway threshold is less than 6 nm., then the flight may not have a stabilized approach. In this case, if the aircraft enters the modeled final approach segment from above, it captures the glidepath late, having a higher than normal flight path; If it enters from the left or right side, it acquires the runway centerline late. These two situations are respectively defined as the risk event of being high and short.

*Go-arounds*

Using the wireframe-modeled final approach segment, an algorithm is developed for detecting a go-around based on the algorithm used in [3]. Generally, there are two necessary conditions for a flight track to be categorized as a potential go-around. The first one is a circling pattern, which can be expressed using the variables defined as:

$$\sum_{j=j_{\text{entrance}}}^{j_{\text{last}}} \theta_j - \theta_{j-1} > \theta_{\text{threshold}},$$

where $\theta_{threshold}$ is the threshold value for the cumulative change of heading angles, which is set at $1.83\pi$ for this research (i.e., slightly less than $2\pi$).

The second condition is that the flight enters the same wireframe approach zone for twice or more. If the track meets these two conditions, then it is a potential go-around.

### 3.4.2 Risk Factors

Risk factors are chosen to study potential correlations with risk events. Currently we focus on several risk factors, some of which may be affected by ATC instructions.

The first one is the speed of flights at the FAF. We approximate the location of the FAF at 6 nm. from runway threshold. A higher speed at the FAF may lead to a higher speed at 1000 ft. AGL and become a precursor of excessive speed change risk event.

The second factor is the runway centerline and glidepath acquisition locations. If the flight intercepts the runway centerline late or captures the glidepath late, it may not have time to adjust the speed to meet the stabilized approach criteria. To study these possibilities, we look at the lateral and vertical acquisition positions for landing flights and check their distances from runway threshold. With the modeled wireframe, we can relax one dimension to detect the entrance event in the other dimension.

Last, we look at the weight class of landing flights. Risk events such as excessive speed change can be related with different aircraft types.

## 4. Results of Analysis of Newark Airport

This section discusses a case-study for 28 days of approach operations to runway 22L at Newark Liberty International Airport (EWR). This airport is dominated by a single carrier with the same stabilized approach criteria across its fleet.

Among the 18,426 arrival flights in the surveillance track data, 8,276 landed on runway 22L. Tracks with a complete data set that could be used in the analysis counted 8,219 (99.3%). The statistics for major risk events are shown in Table 3. The approaches get more stabilized as the flights get closer to runway threshold. After sequencing 500 ft. AGL, 95.56% of the approaches met the stabilized approach criteria of no speed change greater than 10 knots, and 99.82% of the approaches met the stabilized approach criteria of rate of descent less than 1000 fpm. 90.14% of the approaches acquired the runway centerline and the glidepath prior 6 nm. of the runway threshold.

**Table3. Summary of Key Results**

| Risk Events | Counts | Percentage |
|---|---|---|
| Speed change from 1000 ft. AGL to runway threshold > 10 knots | 2288 | 27.84% |
| Speed change from 750 ft. AGL to runway threshold > 10 knots | 1159 | 14.10% |
| Speed change from 500 ft. AGL to runway threshold > 10 knots | 365 | 4.44% |
| Excessive rate of descent from 1000 ft. AGL | 154 | 1.87% |
| Excessive rate of descent from 750 ft. AGL | 58 | 0.71% |
| Excessive rate of descent from 500 ft. AGL | 15 | 0.18% |
| Short acquisition | 402 | 4.89% |
| High acquisition | 484 | 5.89% |
| Go-around | 26 | 0.32% |

### *4.1 Stabilized Approach at 1000 ft. AGL*

Table 4 summarizes the statistics for the combinations of the four risk events for stabilized approaches for flights passing through 1000 ft. AGL. Sixty-six percent (66.13%) of the flights satisfied all four criteria. Excessive change in speed (i.e. greater than 10 knots) is violated by 27.84% of the flights (Figure 9). These results are subject to several caveats: (a) The results are based on groundspeed, not airspeed, and (b) the noise in the estimated averaged ground speed may be on the order of ±10 knots (see Figure 7). Thus, some of the observations of excessive speed change may be the result of limitations in the data.

A *change* in groundspeed is equivalent to a *change* in airspeed under constant wind conditions. Unless wind gusts or rapid changes in wind direction occurred, using groundspeed as a proxy for airspeed is a reasonable approach. Some of the observations of excessive speed change may be the result of limitations in the data with regard to the presence of noise.

**Table4. Statistics for Flights on Approach at 1000 ft. AGL**

| RISK EVENTS | | | | STATISTICS | | | |
|---|---|---|---|---|---|---|---|
| **Groundspeed** | **Rate of Descent** | **Position Relative to Glidepath** | **Position relative to Runway Centerline** | **Number of Flights** | **Percentage** | **Number of Go-arounds** | **Rate of Go-arounds** |
| No change | Within limits | On Glidepath | On Runway Centerline | 5435 | 66.13% | 18 | 0.33% |
| | | | Not On Runway Centerline | 221 | 2.69% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 196 | 2.38% | 1 | 0.51% |
| | | | Not On Runway Centerline | 52 | 0.63% | 1 | 1.92% |
| | Excessive | On Glidepath | On Runway Centerline | 49 | 0.60% | 0 | 0.00% |
| | | | Not On Runway Centerline | 2 | 0.02% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 23 | 0.28% | 0 | 0.00% |
| | | | Not On Runway Centerline | 10 | 0.12% | 0 | 0.00% |
| Greater than 10 knots | Within limits | On Glidepath | On Runway Centerline | 1970 | 23.97% | 5 | 0.25% |
| | | | Not On Runway Centerline | 67 | 0.82% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 123 | 1.50% | 1 | 0.81% |
| | | | Not On Runway Centerline | 31 | 0.38% | 0 | 0.00% |
| | Excessive | On Glidepath | On Runway Centerline | 40 | 0.49% | 0 | 0.00% |
| | | | Not On Runway Centerline | 8 | 0.10% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 38 | 0.46% | 0 | 0.00% |
| | | | Not On Runway Centerline | 11 | 0.13% | 0 | 0.00% |

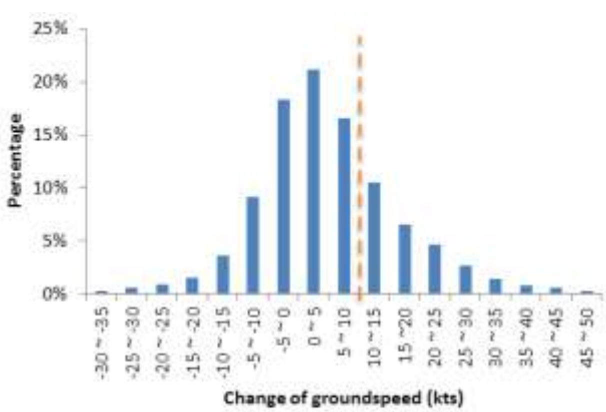


**Figure 9. Histogram for Groundspeed Change from 1000 ft. AGL to Runway Threshold**

The effect of speed at FAF on the speed change is shown in Figure 10. There is a general "trend" which indicates that a higher speed at 6 nm. may lead to a larger speed change from 1000 ft. AGL to the runway threshold. This is because a higher speed at 6 nm. can lead to a higher speed at 1000 ft. AGL, which requires a larger speed reduction. While there is a trend, the correlation between these two factors is somewhat modest ($R^2 = 0.27$).

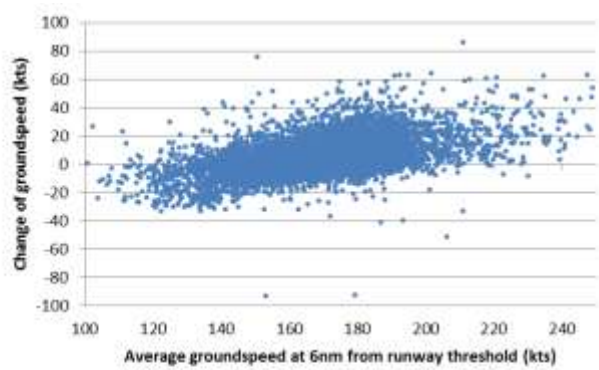


**Figure 10.Effects of Speed at FAF on Speed Change from 1000 ft. AGL to Runway Threshold**

Figure 11 shows that acquiring the runway centerline after the FAF has little impact on the likelihood of a speed change greater than 10 knots. That is, flights that experience a close runway-centerline intercept have about the same probability (23.0%) of an excessive speed change as flights that intercept the centerline prior to 6 nm. (27.9%).

Flights with a late descent to the glidepath have a higher probability of having an excessive speed change (39.6%) than those acquire glidepath normally (27.0%). This indicates that a late vertical acquisition distance is more probable in causing an excessive speed change.

For the last two columns in the table, go-around flights are too rare to reveal any correlations of statistical significance with other factors in the table.

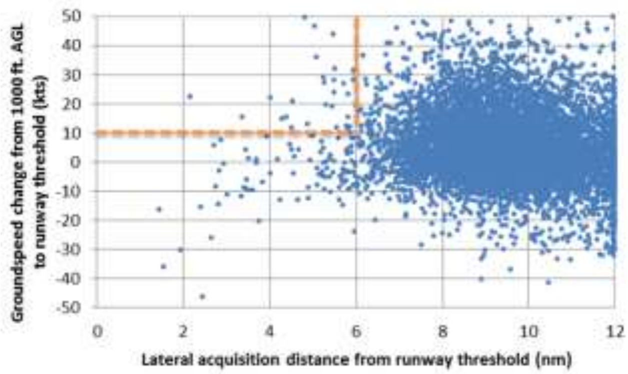


**Figure 11. Scatterplot of Lateral Acquisition Position vs. Groundspeed Change from 1000 ft. AGL to Runway Threshold**

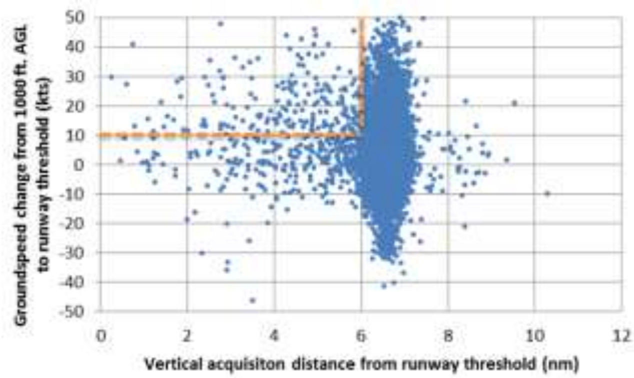


**Figure 12 Scatterplot of Vertical Acquisition Position vs. Groundspeed Change from 1000 ft. AGL to Runway Threshold**

### *4.2 Stabilized Approach at 750 ft. AGL*

The statistics for the combinations of the risk events for stabilized approaches for flights passing through 750 ft. AGL are summarized in Table 5. Fourteen percent (14.10%) of the flights exhibited excessive speed change. This measure of the flight performance may be a more realistic measure than the 1000' AGL criteria which is a deterministic measure of an inherently stochastic process.

**Table 5. Statistics for Flights on Approach at 750 ft. AGL**

| RISK EVENTS | | | | STATISTICS | | | |
|---|---|---|---|---|---|---|---|
| **Groundspeed** | **Rate of Descent** | **Position Relative to Glidepath** | **Position relative to Runway Centerline** | **Number of Flights** | **Percentage** | **Number of Go-arounds** | **Rate of Go-arounds** |
| No change | Within limits | On Glidepath | On Runway Centerline | 6464 | 78.65% | 18 | 0.28% |
| | | | Not On Runway Centerline | 260 | 3.16% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 274 | 3.33% | 2 | 0.73% |
| | | | Not On Runway Centerline | 81 | 0.99% | 1 | 1.23% |
| | Excessive | On Glidepath | On Runway Centerline | 16 | 0.19% | 0 | 0.00% |
| | | | Not On Runway Centerline | 2 | 0.02% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 14 | 0.17% | 0 | 0.00% |
| | | | Not On Runway Centerline | 6 | 0.07% | 0 | 0.00% |
| Greater than 10 knots | Within limits | On Glidepath | On Runway Centerline | 1006 | 12.24% | 5 | 0.50% |
| | | | Not On Runway Centerline | 34 | 0.41% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 83 | 1.01% | 0 | 0.00% |
| | | | Not On Runway Centerline | 16 | 0.19% | 0 | 0.00% |
| | Excessive | On Glidepath | On Runway Centerline | 8 | 0.10% | 0 | 0.00% |
| | | | Not On Runway Centerline | 2 | 0.02% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 9 | 0.11% | 0 | 0.00% |
| | | | Not On Runway Centerline | 1 | 0.01% | 0 | 0.00% |

## 4.*3 Stabilized Approach at 500 ft. AGL*

The statistics for the combinations of the four risk events for stabilized approaches for flights passing through 500 ft. AGL are summarized in Table 6. Excessive change in speed (i.e. greater than 10 knots) is violated only by 4.4% (Figure 13).

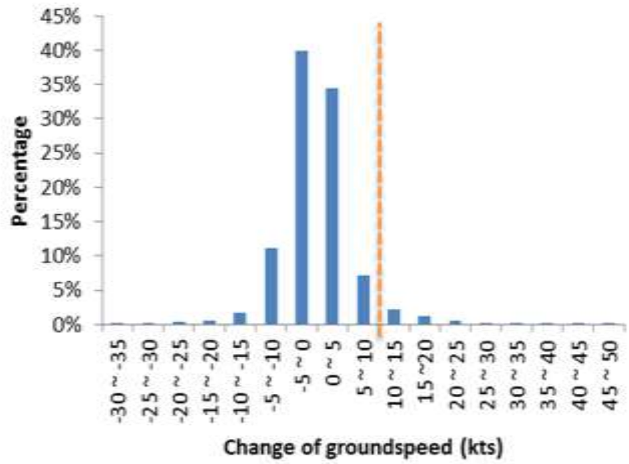


**Figure 13. Histogram for Groundspeed Change from 500 ft. AGL to Runway Threshold**

It has shown that the normal approaches with no abnormal behaviors in groundspeed change, rate of descent, high in altitude and late turn have grown to 87.20%. The secondary largest category is still from the high deceleration in groundspeed, which accounts for about 4.44% of all approaches. Factors of localizer and glideslope capture method have smaller effects on unstabilized approaches.

## *4.4 Stabilized Approach Criteria and Weight Class Analysis*

To study the effect of aircraft weight class on stabilized approach, we look at the groundspeed change from 750 ft. AGL to the runway threshold. Flights with groundspeed change of more than 10 knots from 750 ft. AGL to the runway threshold were experienced by 14.1% of the flights. However, forty-seven percent (47.0%) of the flights classified as “Small” by weight class did not meet this stabilized approach criteria. Compared to small category, less of the flights categorized as “Heavy,” “B757” and “Large” categories did not meet stabilized approach criteria (Table 7).

**Table 6. Statistics for Flights on Approach at 500 ft. AGL**

| RISK EVENTS | | | | STATISTICS | | | |
|---|---|---|---|---|---|---|---|
| **Groundspeed** | **Rate of Descent** | **Position Relative to Glidepath** | **Position relative to Runway Centerline** | **Number of Flights** | **Percentage** | **Number of Go-arounds** | **Rate of Go-arounds** |
| No change | Within limits | On Glidepath | On Runway Centerline | 7167 | 87.20% | 22 | 0.31% |
| | | | Not On Runway Centerline | 288 | 3.50% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 346 | 4.21% | 2 | 0.58% |
| | | | Not On Runway Centerline | 96 | 1.17% | 1 | 1.04% |
| | Excessive | On Glidepath | On Runway Centerline | 4 | 0.05% | 0 | 0.00% |
| | | | Not On Runway Centerline | 2 | 0.02% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 5 | 0.06% | 0 | 0.00% |
| | | | Not On Runway Centerline | 3 | 0.04% | 0 | 0.00% |
| Greater than 10 knots | Within limits | On Glidepath | On Runway Centerline | 322 | 3.92% | 1 | 0.31% |
| | | | Not On Runway Centerline | 8 | 0.10% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 29 | 0.35% | 0 | 0.00% |
| | | | Not On Runway Centerline | 5 | 0.06% | 0 | 0.00% |
| | Excessive | On Glidepath | On Runway Centerline | 1 | 0.01% | 0 | 0.00% |
| | | | Not On Runway Centerline | 0 | 0.00% | 0 | 0.00% |
| | | Above Glidepath | On Runway Centerline | 0 | 0.00% | 0 | 0.00% |
| | | | Not On Runway Centerline | 0 | 0.00% | 0 | 0.00% |

**Table 7. Percentage of Abnormal Speed Change and Landing Speed by Weight Class**

| Weight Class | Percent Flights with Excessive Speed Change | Average Groundspeed at Runway Threshold |
|---|---|---|
| Heavy | 20.9% | 134.5 knots |
| B757 | 15.1% | 129.0 knots |
| Large | 12.0% | 132.0 knots |
| Small | 47.0% | 122.5 knots |

The average groundspeed at the runway threshold for flights categorized as Small is ten or more knots lower than the groundspeed for heavier classes. To maintain runway utilization and runway throughput, flights are instructed to hold the similar airspeed leading up to the Final Approach Fix. The result is that Small weight class flights must decelerate further to achieve their designated landing speed. As is shown in Figure 14, the small aircraft shows a steeper slope which indicates a high deceleration rate.

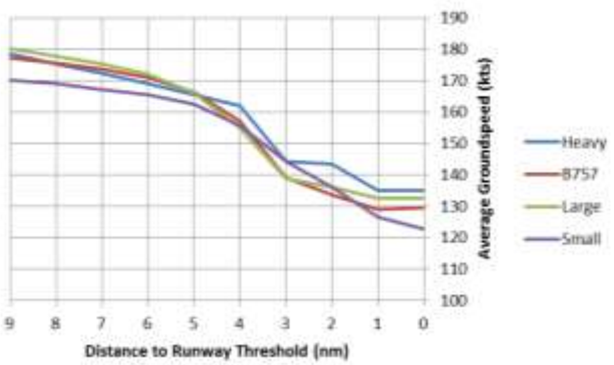


**Figure 14. Groundspeed Profile for Different Aircraft Weight Classes**

## 5 Conclusions

This paper demonstrated the feasibility of using surveillance track data to measure, track, and trend airspace risk. The algorithms described in this paper focused on the stabilized approach criteria: runway centerline, glidepath, rate of descent, and speed change. The surveillance track data does not provide sufficient data to assess the flap/slat and landing configuration of the aircraft.

The position of the flight relative to the runway centerline can be measured directly by the latitude/longitude provided in the surveillance track data subject to the fidelity of this data. The glidepath, likewise, is measured based on the altitude data. The altitude has minimum value of 100 ft., so is accurate only within 100 ft. increments. Due to the 100 ft. values of the altitude, the derived rate of descent is subject to a minimum fidelity of 100 ft. divided by the update rate of the data. For these reasons the “smoothing” and “filtering” algorithms are critical in developing accurate statistics.

These results highlight two important phenomenon. First, the <u>risk in the system is at the interfaces in the operations</u>. In this case the hand-off of speed control from ATC approach flow to flight deck configuration of the aircraft for landing. Second, the determination of stabilized approach criteria is <u>deterministic for an inherently stochastic process</u>. It would be better practice to provide stochastic criteria for stabilized approach that provides the flightcrew with the stochastic measures to determine if risk-free criteria are met.

Additions to the algorithms include the improved filtering techniques, calculation of true airspeed by the addition of wind data, and the addition of aircraft performance calculations to determine minimum safe operating speeds.

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