METHOD AND APPARATUS FOR PROBABILISTIC ALERTING OF AIRCRAFT UNSTABILIZED APPROACHES USING BIG DATA

BACKGROUND

[0001] For each flight, an aircraft is required to perform an approach and landing. Sixty six percent of all accidents occur during the approach phase. To mitigate this problem, airlines require pilots to check the status of the trajectory for “stability” at 1000 feet and 500 feet above ground level. The stable approach criteria include six independent sets of data located on displays on the flight deck. If the stable approach criteria are not met, the pilot should abort the approach and fly a “go-around.” A go-around increases monetary flight costs and significantly increases pilot workload, so if there is doubt about whether the approach is stable or not, pilots assume it is stable and proceed with the approach. There is not one single indication that the approach is considered stable (the pilot has to look in 6 different locations), and by the time the pilot checks these criteria it is too late. These and other shortcomings are addressed by the present disclosure.

SUMMARY

[0002] It is to be understood that both the following general description and the following detailed description are exemplary and explanatory only and are not restrictive. Provided are methods and systems that can provide a single indicator of whether stabilized approach criteria have been met. In aspect, the methods and systems can provide information prior to 1000’ and 500’ check points as to whether the flight will meet stabilized approach criteria. The methods and systems enable pilots to make adjustments to avoid an unstable approach.

[0003] Additional advantages will be set forth in part in the description which follows or may be learned by practice. The advantages will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments and together with the description, serve to explain the principles of the methods and systems:

Figure 1 is a graph illustrating typical approach trajectory;
Figure 2 is a side view of the wireframe zone for approach;
Figure 3 is a scatterplot of aircraft crossing positions at 6 nm; Figure 4 is a venn diagram for actual and predicted unstable approaches; and Figure 5 is an exemplary operating environment.

DETAILED DESCRIPTION

[0005] Before the present methods and systems are disclosed and described, it is to be understood that the methods and systems are not limited to specific methods, specific components, or to particular implementations. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting.

[0006] As used in the specification and the appended claims, the singular forms “a.” “an” and “the” include plural referents unless the context clearly dictates otherwise. Ranges may be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another embodiment includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another embodiment. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0007] “Optional” or “optionally” means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

[0008] Throughout the description and claims of this specification, the word “comprise” and variations of the word, such as “comprising” and “comprises,” means “including but not limited to,” and is not intended to exclude, for example, other components, integers or steps. “Exemplary” means “an example of” and is not intended to convey an indication of a preferred or ideal embodiment. “Such as” is not used in a restrictive sense, but for explanatory purposes.

[0009] Disclosed are components that can be used to perform the disclosed methods and systems. These and other components are disclosed herein, and it is understood that when combinations, subsets, interactions, groups, etc. of these components are disclosed that while specific reference of each various individual and collective combinations and permutation of these may not be explicitly disclosed, each is
specifically contemplated and described herein, for all methods and systems. This applies to all aspects of this application including, but not limited to, steps in disclosed methods. Thus, if there are a variety of additional steps that can be performed it is understood that each of these additional steps can be performed with any specific embodiment or combination of embodiments of the disclosed methods.

[0010] The present methods and systems may be understood more readily by reference to the following detailed description of preferred embodiments and the examples included therein and to the Figures and their previous and following description.

[0011] As will be appreciated by one skilled in the art, the methods and systems may take the form of an entirely hardware embodiment, an entirely software embodiment, or an embodiment combining software and hardware aspects. Furthermore, the methods and systems may take the form of a computer program product on a computer-readable storage medium having computer-readable program instructions (e.g., computer software) embodied in the storage medium. More particularly, the present methods and systems may take the form of web-implemented computer software. Any suitable computer-readable storage medium may be utilized including hard disks, CD-ROMs, optical storage devices, or magnetic storage devices.

[0012] Embodiments of the methods and systems are described below with reference to block diagrams and flowchart illustrations of methods, systems, apparatuses and computer program products. It will be understood that each block of the block diagrams and flowchart illustrations, and combinations of blocks in the block diagrams and flowchart illustrations, respectively, can be implemented by computer program instructions. These computer program instructions may be loaded onto a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions which execute on the computer or other programmable data processing apparatus create a means for implementing the functions specified in the flowchart block or blocks.

[0013] These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including computer-
readable instructions for implementing the function specified in the flowchart block
or blocks. The computer program instructions may also be loaded onto a computer
or other programmable data processing apparatus to cause a series of operational
steps to be performed on the computer or other programmable apparatus to produce
a computer-implemented process such that the instructions that execute on the
computer or other programmable apparatus provide steps for implementing the
functions specified in the flowchart block or blocks.

[0014] Accordingly, blocks of the block diagrams and flowchart illustrations
support combinations of means for performing the specified functions, combinations
of steps for performing the specified functions and program instruction means for
performing the specified functions. It will also be understood that each block of the
block diagrams and flowchart illustrations, and combinations of blocks in the block
diagrams and flowchart illustrations, can be implemented by special purpose
hardware-based computer systems that perform the specified functions or steps, or
combinations of special purpose hardware and computer instructions.

[0015] The approach and landing phase is one of the most complex procedures in
airline operations. To mitigate the potential risks, airlines have established
“stabilized approach” criteria that require the flight crew to check four conditions at
1000’ above ground level (AGL) and 500’ AGL. If any of these conditions are not
satisfied, the flight crew is required to abort the approach. This adds to the
operational cost of the flight and reduces safety margins.

[0016] Nowcasting unstable approaches prior to the stable approach altitudes (e.g. at
10nm, 6nm from the runway threshold) can provide lead time for flight crew to
make adjustments to avoid a potential unstable approach. Kinematic models, already
used in the Flight Management System (FMS) to predict future aircraft state are not
practical as these models cannot account for events that will occur during flight
progress (e.g. flap/lat extension, ATC clearances ...).

[0017] Disclosed herein are methods and systems for analysis of massive amounts
of surveillance track data for a given approach to assess the feasibility of using
historical flight track data to nowcast the likelihood of a stable approach given the
situation at 10nm, 6nm, and 3nm from the runway threshold. For example, the
logistic regression model provided herein was able to nowcast the 1000’ AGL
aerplane state with accuracy of 61.7% at 10nm, 73.6% at 6nm, and 83% at 3nm, and
the 500’AGL aircraft state with accuracy of 82.1%, 82.7% and 83%.

[0018] The approach and landing phase is one of the most complex procedures in airline operations [1]. During this phase of flight, the crew is required to monitor a rapidly evolving situation and make split second decisions based on a large number of factors. Further, decisions made early in the procedure have a big impact on the downstream trajectory.

[0019] To mitigate the potential risks, airlines have established “stabilized approach” criteria that require the flight crew to check four conditions at 1000’ above ground level (AGL) and 500’ AGL: (1) aligned with the extended runway center-line, (2) on the glide path, (3) within a tolerance of the landing airspeed, and (4) not excessive an rate of descent.

[0020] If any of these conditions are not satisfied, the flight crew is required to abort the approach and perform a Go Around. Go Arouneds are expensive, estimated to add an average of $1200 to the cost of the flight [2], and reduce safety margins with another complex procedure – the Go Around.

[0021] Nowcasting unstable approaches prior to the stable approach altitudes can provide lead time to the flight crew to make adjustments to avoid a potential unstable approach and addresses the Commercial Aviation Safety Team (CAST) Safety Enhancements SE 23 Approach and Landing (ALAR) Flight Crew Training and SE 30 Mode Awareness and Energy State Management Aspects of Flight Deck Automation [3].

[0022] Using kinematic models, already used by the Flight Management System (FMS) to predict future aircraft state is not practical as these models cannot account for events that will occur during flight progress (e.g., flap/slat and extension, ATC clearances). An alternative approach is to use massive amounts of historical flight track data to assess the likelihood of a stable approach given the situation at 10nm, 6nm and 3nm from the runway threshold.

[0023] The methods and system disclosed can analyze historic surveillance track data for a given approach to assess the feasibility of using historical flight track data to nowcast the likelihood of a stable approach given the situation at 10nm, 6nm and 3nm from the runway threshold.

[0024] Analysis surveillance track data for 8,158 approaches to Newark International Airport (EWR) Runway 22L showed that 52.4% flights satisfy the
stabilized approach criteria between 1000’ AGL and runway threshold, and 82.3% between 500’ AGL and runway threshold [4].

Provided is method for nowcasting the likelihood of meeting the stabilized approach criteria at 1000’ and 500’ assessing whether the flight is following the desired approach profile at 10, 6 and 3nm (i.e. on-speed, on lateral and vertical flight-path). Further provided is a logistic regression model using a plurality of parameters (e.g., ten) (groundspeed, rate of descent, heading, altitude, lateral position, first glide path acquisition location, first runway center-line acquisition location, aircraft weight, runway centerline/glide path tracking, level segment flight time) to improve the accuracy of the nowcast.

At 10 nm, the nowcast is accurate 61.7% of the time for 1000’ AGL and 82.1% for 500’ AGL. For approaches that end-up unstable, the nowcast is accurate 62.7% of the time at 1000’ AGL and 40% at 500’ AGL.

At 6 nm, the nowcast is accurate 73.6% of the time for 1000’ AGL and 82.7% for 500’ AGL. For approaches that end-up unstable, the nowcast is accurate 76% of the time at 1000’ AGL and 52.6% at 500’ AGL.

At 3 nm, the nowcast is accurate 83.1% of the time for 1000’ AGL and 83% for 500’ AGL. For approaches that end-up unstable, the nowcast is accurate 86.1% of the time at 1000’ AGL and 53% at 500’ AGL.

This analysis shows the degree of accuracy that can be achieved using historical flight track data to nowcast stabilized approaches before reaching 1000’ AGL and 500’ AGL. Integration of “probabilistic” information into “deterministic” flight deck procedures can be useful on the flight deck.

The Approach Phase of Flight

The approach phase of flight transitions the aircraft from a clean configuration (flaps and slats retracted) at 250 knots to the flap/slat landing configuration at the reference landing speed for the aircraft. During this transition the aircraft must acquire the extended runway center-line and glide path (typically 3 degrees). A typical trajectory for the approach is shown in FIG. 1.

Setting up and flying the approach is complicated by close proximity of traffic on the approach and their associated wake vortices, as well as departure and surface traffic, weather phenomenon (i.e. wind, visibility, ceilings), aircraft performance, and aircraft system status.
To mitigate these risks, airline best-practices have established stable approach criteria that are applied in approach procedure: At 1000’/500’ AGL the aircraft ground speed should be within ±10 knots of landing ground speed; From 1000’/500’ AGL to the runway threshold, the rate of descent should not be greater than 1000 feet per minute for more than 10 seconds; The aircraft should acquire the glide path by maintaining its position within the defined vertical boundary; The aircraft should acquire the runway centerline by maintaining its position within the defined lateral boundary. If any of these four conditions is not satisfied, the flight crew are required to abort the approach and perform a Go Around.

An analysis of 8,158 approaches to Newark International Airport (EWR) Runway 22L using surveillance track data and change in ground speed as a proxy for change in airspeed, showed that 52.4% flights satisfy the stabilized approach criteria between 1000’ AGL and runway threshold, and 82.3% between 500’ AGL and runway threshold.

The methods and systems provided can increase the number of stable approaches by providing advance indications of not satisfying the stable approach criteria at 10nm, 6nm, and 3nm from the runway threshold.

Kinematic models, already in the Flight Management System (FMS), to predict future aircraft state is not practical as these models cannot account for events that will occur during flight progress (e.g. flap/slat and extension, ATC clearances, …). An alternative approach is to use massive amounts of historical flight track data to assess the likelihood of a stable approach given the situation at 10nm, 6nm and 3nm from the runway threshold.

Surveillance Flight Track Data & Procedure Data

Flight Track Data

Flight Data Recorder (FDR) and/or Flight Operational Quality Assurance (FOQA) can comprise data sources for the methods and systems disclosed. Without access to the FDR/FOQA data, surveillance track data can be used.

For example, twenty eight days of surveillance track data from the FAA’s National Offload Program for N90 TRACON were used. The key fields used are the track index, aircraft type, destination airport, seconds past midnight, latitude, longitude and altitude.

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 values of
latitude and longitude are precise to the fifth decimal places. Altitude values are
stored in number of flight levels, i.e. with precision level of 100 feet. To improve the
fidelity of the data, linear interpolation between each pair of successive raw track
points with the time interval of 1 second was added. The data was also smoothed by
estimating each track point’s horizontal/vertical position to be an averaged value of
a series of track points centered at the current track point to reduce the potential
variations in raw tracks. The average interval was set to be 10 seconds.

[0042] From the interpolated and smoothed tracks, several basic variables can be
derived: ground speed, rate of descent and heading angle.

[0043] For more information on processing of data see Wang et. al. [4]

[0044] Procedure Data

[0045] The Approach navigation procedure was derived from the Approach Chart
and Airport diagram provided by the FAA’s National Flight Data Center. The key
fields include: runway elevation, glide path angle, and threshold crossing height are
used for constructing a wire-frame for the final approach segment for each runway
(Fig. 2).

[0046] The dimensions of the wire-frame were derived from the approach chart and
the statistical distributions (Fig. 3). The Final Approach Fix of runway 22L is at
about 10 nm from runway threshold. The 6 nm boundary was extended up to 10 nm.
Beyond 10 nm, the altitude of the wire-frame is unchanged to model the level flight
segment.

[0047] Stable Approach Criteria

[0048] The stable approach criteria used in the algorithm is as follows: The aircraft
should acquire the glidepath by maintaining its position within the defined vertical
boundary of the wire-frame; The aircraft should acquire the runway centerline by
maintaining its position within the defined lateral boundary of the wire-frame: At
1000’/500’ AGL the aircraft ground speed should remain within ±10 knots of the
groundspeed at the runway threshold (i.e. landing ground speed). Since this analysis
is intended to measure the change in airspeed, the change in groundspeed is used as
a proxy; From 1000’/500’ AGL to the runway threshold, the rate of descent should
not be greater than 1000 feet per minute for more than 10 seconds. If any of these
four conditions is not satisfied, the unstable approach occurs at corresponding
altitude.

Methodology for Nowcasting Unstable Approaches

In an aspect, nowcasting unstable approaches can comprise selecting one or more aircraft features from flight track data to build a model to map the values of these features to the occurrence of unstable events. These features can either be state variables (e.g. speed) at the specific nowcasting location, or historical variables prior to the current location. Example state variable and historical performance features used for the nowcast are listed in Table 1.

In this table, $x_2$ to $x_6$ represent the state variables at the nowcasting location, and $x_7$ to $x_{10}$ represent the historical performance variables before nowcasting location.

<table>
<thead>
<tr>
<th>Features</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$</td>
<td>Maximum takeoff weight (lb.)</td>
</tr>
<tr>
<td>$x_2$</td>
<td>Ground speed at prediction location (knot)</td>
</tr>
<tr>
<td>$x_3$</td>
<td>Rate of descent (feet per minute)</td>
</tr>
<tr>
<td>$x_4$</td>
<td>Lateral deviation from runway centerline (ft.)</td>
</tr>
<tr>
<td>$x_5$</td>
<td>Vertical deviation from glidepath (ft.)</td>
</tr>
<tr>
<td>$x_6$</td>
<td>Heading angle difference from runway centerline (degree)</td>
</tr>
<tr>
<td>$x_7$</td>
<td>Distance from lateral acquisition point to current location (zero if not acquired) (nm.)</td>
</tr>
<tr>
<td>$x_8$</td>
<td>Distance from vertical acquisition point to current location (zero if not acquired) (nm.)</td>
</tr>
<tr>
<td>$x_9$</td>
<td>Level segment flight time (s)</td>
</tr>
<tr>
<td>$x_{10}$</td>
<td>Measure of runway centerline/glidepath tracking (number of times an aircraft entering the modeled wireframe zone)</td>
</tr>
</tbody>
</table>

A logistic regression model is developed to establish the relationship between these features and the outcome of stable/unstable approaches. The mathematical expression is given in following equation:

$$h(x) = \frac{1}{1+e^{-\beta x}}$$
In this equation, \( h_\theta(x) \) is the probability of a flight with features \( x \) to end up in an unstable approach. \( \theta \) and \( x \) are vectors containing the coefficients and feature values. \( e \) is the natural constant. The degree of polynomial \( \theta x \) is set to 2, so the potential interactions between features are considered in the model. This results in a total number of 65 features. The optimal coefficients can be found by minimizing the cost function \( J(\theta) \) given below:

**Equation 2**

\[
J(\theta) = -\frac{1}{m} \sum_{i=1}^{m} \left[ \log h_\theta(x_i^{(i)}) + (1 - y_i^{(i)}) \log (1 - h_\theta(x_i^{(i)})) \right]
\]

In this formula, \( m \) is the number of training samples and \( i \) is the index for samples. \( y_i \) is the actual outcome of sample \( i \), which is equal to 1 if sample flight \( i \) ends up with unstable approach, otherwise \( y_i = 0 \). \( \log \) is the natural logarithm. The Gradient Descent method is applied to find the optimal coefficient \( \theta \). The coefficients updating procedure is shown below:

**Equation 3**

\[
\theta_j := \theta_j - \alpha \frac{1}{m} \sum_{i=1}^{m} (h_\theta(x_i^{(i)}) - y_i^{(i)}) x_j^{(i)}
\]

where \( j \) is the index for features and parameter \( \alpha \) controls the step length. The term following \( \alpha \) is the gradient \( \frac{\partial J(\theta)}{\partial \theta_j} \).

**A Case Study of EWR Runway 22L**

Example nowcast methods and systems were developed for flights landing at Runway 22L at EWR airport. The data processing and criteria are implemented in a C++ algorithm, and logistic regression is implemented in a MATLAB algorithm. The 28 days of available records, included 18,426 landing flights to EWR airport. Among these flights, 8,158 flights landed at Runway 22L. The majority of these flights were Large aircraft (73.8%).

To evaluate the performance of the nowcast, a random set of 5,000 flights out of 8,158 flights is chosen for training the coefficients of the logistic regression model. The trained model is tested using the remaining 3,158 flights.

Results from the logistic regression nowcasting at 10 nm, 6 nm, and 3nm from runway threshold for unstable approach events at 1000' / 500' are shown in Table 2 to Table 4. The percentages show the accuracy of the nowcast for 1000'
and 500' AGL. The shaded cells show the accuracy of the nowcasts, the unshaded cells show the errors in the nowcasts. The columns for 1000' and 500' add up to 100%.

[0059] In the test set of data, at 1000' AGL 46.99% of the flights were unstable. The nowcast at 10nm correctly identified 21.5%, and was not correct for 25.49%. At 500' AGL 17.63% of the flights were unstable. The nowcast from 10nm for unstable approaches was correct for 0.63% and was not correct for 17%. This a consequence of the small number of unstable approaches in the test set as well as the distance from the 500' point.

[0060] The nowcast improved as the flights progressed from 10nm to 6nm to 3nm. For the 1000' point the correct nowcast for unstable approaches improved from 21.5% to 30.05% to 35.81. The incorrect nowcast decreased from 25.49% to 16.94% to 11.18%.

<table>
<thead>
<tr>
<th>Table 2: Nowcast at 10 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nowcast</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Unstable</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Stable</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Stable Unstable</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Stable</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3: Nowcast at 6 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nowcast</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Unstable</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Stable</td>
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<tr>
<td></td>
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<tr>
<td>Stable</td>
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<td>--------</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Stable</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Table 4: Nowcast at 3 nm

<table>
<thead>
<tr>
<th>Nowcast</th>
<th>Actual</th>
<th>1000’</th>
<th>500’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable</td>
<td>Unstable</td>
<td>1131</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(35.81%)</td>
<td>(5.54%)</td>
</tr>
<tr>
<td>Stable</td>
<td>182</td>
<td></td>
<td>155</td>
</tr>
<tr>
<td></td>
<td>(5.76%)</td>
<td></td>
<td>(4.91%)</td>
</tr>
<tr>
<td>Stable</td>
<td>Unstable</td>
<td>353</td>
<td>382</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(11.18%)</td>
<td>(12.10%)</td>
</tr>
<tr>
<td>Stable</td>
<td>1492</td>
<td></td>
<td>2446</td>
</tr>
<tr>
<td></td>
<td>(47.25%)</td>
<td></td>
<td>(77.45%)</td>
</tr>
</tbody>
</table>

[0061] From these tables several performance metrics can be derived: overall accuracy, precision, and recall.

[0062] **Overall Accuracy**

[0063] The overall accuracy of the model can be measured by the proportion of the total number of correctly nowcast stable/unstable approaches among all flights (Table 5). The accuracy for the 1000’ AGL nowcast improves as the location is closer. The accuracy for the 500’ AGL nowcast remains constant.

Table 5 Overall Accuracy

<table>
<thead>
<tr>
<th>Nowcast location</th>
<th>1000’ AGL</th>
<th>500’ AGL</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nm</td>
<td>61.7%</td>
<td>82.1%</td>
</tr>
<tr>
<td>6 nm</td>
<td>73.6%</td>
<td>82.7%</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>3 nm</td>
<td>83.1%</td>
<td>83.0%</td>
</tr>
</tbody>
</table>

[0064] The accuracy results for 500’ AGL events are counter-intuitively higher than the 1000’ AGL results. This is because there are more stable approaches at 500’ than stable approaches at 1000’. This biases the measure of accuracy.

[0065] **Precision**

[0066] Precision is a measure that answers the question: Given a nowcast result, what is the probability it is correct? For example, when nowcasting 1000’ AGL events at 6 nm, the precision of nowcasting unstable approaches can be calculated as $949/(949+299) = 76\%$. **Table 6** summarizes the results.

<table>
<thead>
<tr>
<th>Table 6 Precisions for Nowcasting Unstable Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nowcast location</td>
</tr>
<tr>
<td>10 nm</td>
</tr>
<tr>
<td>6 nm</td>
</tr>
<tr>
<td>3 nm</td>
</tr>
</tbody>
</table>

[0067] **Recall**

[0068] Recall is another metric for nowcast performance, which answers the question: For a specific event, given that it occurs, what is the probability that it is correctly predicted to occur? For example, when predicting 1000’ AGL events at 6 nm, the recall of nowcasting unstable approaches can be calculated as $949/(949+535) = 63.9\%$. That is for the actual unstable approaches, 63.9% can be correctly predicted at 6 nm using current model. **Table 7** summarizes the Recall metrics.

<table>
<thead>
<tr>
<th>Table 7 Recalls for Nowcasting Unstable Approaches</th>
</tr>
</thead>
</table>

13
<table>
<thead>
<tr>
<th></th>
<th>1000’ AGL</th>
<th>500’ AGL</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nm</td>
<td>45.8%</td>
<td>3.6%</td>
</tr>
<tr>
<td>6 nm</td>
<td>64.0%</td>
<td>16.5%</td>
</tr>
<tr>
<td>3 nm</td>
<td>76.2%</td>
<td>31.4%</td>
</tr>
</tbody>
</table>

[0069] The goal in tuning the logistic regression is maximize the number of flights in which the nowcast accurately predicts the actual outcome (i.e. intersection in FIG. 4).

[0070] The logistic regression method disclosed herein for nowcasting unstable approaches can use historic flight track data. A case study for EWR 22L runway exhibited an accuracy of 83% for nowcasts at 500’ AGL, but an accuracy range from 62% at 10nm to 83% at 3nm for 1000’ AGL. Next steps are to reduce the incorrect nowcast of a stable approach when the actual trajectory is unstable (25% at 10nm for 1000’ AGL). These accuracy, precision and recall metrics provide a baseline for nowcast performance. Using additional features with the regression and utilizing better fidelity data can improve nowcast performance. Such a level of accuracy for a nowcast is useful on the flight deck. The logistic regression model can be extended by inclusion of additional parameters including wind conditions, traffic, aircraft configuration, and instructions from ATC. This and future logistic regression models can be applied to other approaches at other airports.

[0071] Other methods can also be applied to the data such as Support Vector Machines, Bayesian Network models. Bayesian Network models can backward-chain and enable the analysis of the factors that lead to an unstable approach at 500’ due to an over speed condition.

[0072] The logistic regression model can be modified to provide a recommendation to the flight crew to adjust the trajectory to avoid an unstable approach. For example, more specific information on likelihood of not meeting the airspeed criteria can allow the flight crew to take mitigative actions.

[0073] References


[0078] In an exemplary aspect, the methods and systems can be implemented on a computer 401 as illustrated in FIG. 5 and described below. Similarly, the methods and systems disclosed can utilize one or more computers to perform one or more functions in one or more locations. FIG. 5 is a block diagram illustrating an exemplary operating environment 500 for performing the disclosed methods. This exemplary operating environment 500 is only an example of an operating environment and is not intended to suggest any limitation as to the scope of use or functionality of operating environment architecture. Neither should the operating environment 500 be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the exemplary operating environment 500.

[0079] The present methods and systems can be operational with numerous other general purpose or special purpose computing system environments or configurations. Examples of well known computing systems, environments, and/or configurations that can be suitable for use with the systems and methods comprise, but are not limited to, personal computers, server computers, laptop devices, and multiprocessor systems. Additional examples comprise set top boxes, programmable consumer electronics, network PCs, minicomputers, mainframe computers, distributed computing environments that comprise any of the above systems or devices, and the like.

[0080] The processing of the disclosed methods and systems can be performed by software components. The disclosed systems and methods can be described in the
general context of computer-executable instructions, such as program modules, being executed by one or more computers or other devices. Generally, program modules comprise computer code, routines, programs, objects, components, data structures, and/or the like that perform particular tasks or implement particular abstract data types. The disclosed methods can also be practiced in grid-based and distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules can be located in local and/or remote computer storage media including memory storage devices.

[0081] Further, one skilled in the art will appreciate that the systems and methods disclosed herein can be implemented via a general-purpose computing device in the form of a computer 501. The computer 501 can comprise one or more components, such as one or more processors 503, a system memory 512, and a bus 513 that couples various components of the computer 501 including the one or more processors 503 to the system memory 512. In the case of multiple processors 503, the system can utilize parallel computing.

[0082] The bus 513 can comprise one or more of several possible types of bus structures, such as a memory bus, memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. By way of example, such architectures can comprise an Industry Standard Architecture (ISA) bus, a Micro Channel Architecture (MCA) bus, an Enhanced ISA (EISA) bus, a Video Electronics Standards Association (VESA) local bus, an Accelerated Graphics Port (AGP) bus, and a Peripheral Component Interconnects (PCI), a PCI-Express bus, a Personal Computer Memory Card Industry Association (PCMCIA), Universal Serial Bus (USB) and the like. The bus 513, and all buses specified in this description can also be implemented over a wired or wireless network connection and one or more of the components of the computer 501, such as the one or more processors 503, a mass storage device 504, an operating system 505, nowcasting software 506, nowcasting data 507, a network adapter 508, system memory 512, an Input/Output Interface 510, a display adapter 509, a display device 511, and a human machine interface 502, can be contained within one or more remote computing devices 514a,b,c at physically separate locations, connected through buses of this form, in effect implementing a fully
distributed system.

[0083] The computer 501 typically comprises a variety of computer readable media. Exemplary readable media can be any available media that is accessible by the computer 501 and comprises, for example and not meant to be limiting, both volatile and non-volatile media, removable and non-removable media. The system memory 512 can comprise computer readable media in the form of volatile memory, such as random access memory (RAM), and/or non-volatile memory, such as read only memory (ROM). The system memory 512 typically can comprise data such as nowcasting data 507 and/or program modules such as operating system 505 and nowcasting software 506 that are accessible to and/or are operated on by the one or more processors 503.

[0084] In another aspect, the computer 501 can also comprise other removable/non-removable, volatile/non-volatile computer storage media. The mass storage device 504 can provide non-volatile storage of computer code, computer readable instructions, data structures, program modules, and other data for the computer 501. For example, a mass storage device 504 can be a hard disk, a removable magnetic disk, a removable optical disk, magnetic cassettes or other magnetic storage devices, flash memory cards, CD-ROM, digital versatile disks (DVD) or other optical storage, random access memories (RAM), read only memories (ROM), electrically erasable programmable read-only memory (EEPROM), and the like.

[0085] Optionally, any number of program modules can be stored on the mass storage device 504, including by way of example, an operating system 505 and nowcasting software 506. One or more of the operating system 505 and nowcasting software 506 (or some combination thereof) can comprise elements of the programming and the nowcasting software 506. Nowcasting data 507 can also be stored on the mass storage device 504. Nowcasting data 507 can be stored in any of one or more databases known in the art. Examples of such databases comprise, DB2®, Microsoft® Access, Microsoft® SQL Server, Oracle®, mySQL, PostgreSQL, and the like. The databases can be centralized or distributed across multiple locations within the network 515.

[0086] In another aspect, the user can enter commands and information into the computer 501 via an input device (not shown). Examples of such input devices comprise, but are not limited to, a keyboard, pointing device (e.g., a computer
mouse, remote control), a microphone, a joystick, a scanner, tactile input devices such as gloves, and other body coverings, motion sensor, and the like. These and other input devices can be connected to the one or more processors 503 via a human machine interface 502 that is coupled to the bus 513, but can be connected by other interface and bus structures, such as a parallel port, game port, an IEEE 1394 Port (also known as a Firewire port), a serial port, network adapter 508, and/or a universal serial bus (USB).

[0087] In yet another aspect, a display device 511 can also be connected to the bus 513 via an interface, such as a display adapter 509. It is contemplated that the computer 501 can have more than one display adapter 509 and the computer 501 can have more than one display device 511. For example, a display device 511 can be a monitor, an LCD (Liquid Crystal Display), light emitting diode (LED) display, television, smart lens, smart glass, and/or a projector. In addition to the display device 511, other output peripheral devices can comprise components such as speakers (not shown) and a printer (not shown) which can be connected to the computer 501 via Input/Output Interface 510. Any step and/or result of the methods can be output in any form to an output device. Such output can be any form of visual representation, including, but not limited to, textual, graphical, animation, audio, tactile, and the like. The display 511 and computer 501 can be part of one device, or separate devices.

[0088] The computer 501 can operate in a networked environment using logical connections to one or more remote computing devices 514a,b,c. By way of example, a remote computing device 514a,b,c can be a personal computer, computing station (e.g., workstation), portable computer (e.g., laptop, mobile phone, tablet device), smart device (e.g., smartphone, smart watch, activity tracker, smart apparel, smart accessory), security and/or monitoring device, a server, a router, a network computer, a peer device, edge device or other common network node, and so on. Logical connections between the computer 501 and a remote computing device 514a,b,c can be made via a network 515, such as a local area network (LAN) and/or a general wide area network (WAN). Such network connections can be through a network adapter 508. A network adapter 508 can be implemented in both wired and wireless environments. Such networking environments are conventional and commonplace in dwellings, offices, enterprise-wide computer networks,
intranets, and the Internet.

For purposes of illustration, application programs and other executable
program components such as the operating system 505 are illustrated herein as
discrete blocks, although it is recognized that such programs and components can
reside at various times in different storage components of the computing device 501,
and are executed by the one or more processors 503 of the computer 501. An
implementation of nowcasting software 506 can be stored on or transmitted across
some form of computer readable media. Any of the disclosed methods can be
performed by computer readable instructions embodied on computer readable
media. Computer readable media can be any available media that can be accessed
by a computer. By way of example and not meant to be limiting, computer readable
media can comprise “computer storage media” and “communications media.”
“Computer storage media” can comprise volatile and non-volatile, removable and
non-removable media implemented in any methods or technology for storage of
information such as computer readable instructions, data structures, program
modules, or other data. Exemplary computer storage media can comprise RAM,
ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital
versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape,
magnetic disk storage or other magnetic storage devices, or any other medium which
can be used to store the desired information and which can be accessed by a
computer.

The methods and systems can employ artificial intelligence (AI) techniques
such as machine learning and iterative learning. Examples of such techniques
include, but are not limited to, expert systems, case based reasoning, Bayesian
networks, behavior based AI, neural networks, fuzzy systems, evolutionary
computation (e.g. genetic algorithms), swarm intelligence (e.g. ant algorithms), and
hybrid intelligent systems (e.g. Expert inference rules generated through a neural
network or production rules from statistical learning).

While the methods and systems have been described in connection with
preferred embodiments and specific examples, it is not intended that the scope be
limited to the particular embodiments set forth, as the embodiments herein are
intended in all respects to be illustrative rather than restrictive.

Unless otherwise expressly stated, it is in no way intended that any method
set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that an order be inferred, in any respect. This holds for any possible non-express basis for interpretation, including: matters of logic with respect to arrangement of steps or operational flow; plain meaning derived from grammatical organization or punctuation; the number or type of embodiments described in the specification.

[0093] Throughout this application, various publications are referenced. The disclosures of these publications in their entireties are hereby incorporated by reference into this application in order to more fully describe the state of the art to which the methods and systems pertain.

[0094] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the scope or spirit. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit being indicated by the following claims.
CLAIMS

What is claimed is:

1. Methods, systems, and apparatuses as disclosed herein.
ABSTRACT OF THE DISCLOSURE

Traditional approaches to predicting aircraft trajectories using kinematic models cannot work due to the complexity of the approach maneuver including flaps/slats, landing gear, ATC vectors, winds, and other traffic. The methods and systems disclosed can utilize Big Data Analytics (e.g., massive amounts of data of flights on each approach) to nowcast the approach stability given the state of the flight prior to the 1000'/500' check points.
FIG. 3