Artificial Intelligence to Expedite Data Analysis on Runway Incursions and Excursions

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INTRODUCTION

"Data enhances the FAA's ability to identify and respond to potential safety issues and to better identify safety trends in aviation. It is key in our efforts to move to a predictive system, not just preventative."

– FAA Acting Administrator Billy Nolen,
Hearing Before the U.S. Senate,
March 8, 2023

"This year [from January to May 23, 2023] alone, there have been a total of 365 incursions....the close call categories A and B on the rise."

– Jennifer Homendy,
Transcription from NTSB roundtable,
May 23, 2023

PRESENTATION OUTLINE

Motivation | Approach | Key Findings | Next Steps

Improve Safety

Deep dive into pressing safety issues for FAA

Define the problem and scope of project

Data & AI Algorithms

Explanation of algorithms & analytical processes

Reproducibility of our experimentation

Results & Conclusions

Highlight results of study and extract conclusions

Propose improvements on current standards

Future Research

Future modeling work

Implementation of our work at scale

MOTIVATION

Near Collision at JFK Airport Between Delta, American Planes Under Investigation

Delta aircraft aborted takeoff and came within 1,000 feet of American Airlines plane on runway Friday night, FAA says

Southwest, FedEx Planes Came Within a Thousand Feet in Austin on Saturday

Federal safety board is dispatching investigators to Texas after the close call between two planes

By *Micah Maidenberg* Follow *and* *Alison Sider* Follow

Updated Feb. 5, 2023 at 4:44 pm ET

MOTIVATION

Spate of Runway Near Misses Casts Shadow Over Summer Travel

Airlines and regulators are scrambling with incidents on track to break records; personnel strains stemming from the pandemic may be a factor

By Andrew Tangel , Micah Maidenberg Follow *and Alison Sider*

May 25, 2023 12:01 am ET

MOTIVATION

"As we look at the recent incidents of the last year or so, and as NTSB and FAA continue to investigate, we can't wait for the next catastrophic event to seek the warning signs of today, fully determine the contributing factors, and swiftly address them."

– Secretary of Transportation Pete Buttigieg,
Remarks at FAA Safety Summit,
March 15, 2023

PROBLEM STATEMENT

- Examine the underlying factors behind runway incursions, runway excursions, and unstable approaches based on the existing data sources namely ASRS, Sherlock, and METAR datasets
- Using artificial intelligence to reveal useful patterns, and eventually lead to important recommendations to increase safety and ultimately improve flight operations
- Lay the groundwork for additional artificial intelligence analysis

NARROWING SCOPE

- Demonstrate a prototype of an AI application to analyze a small set of data that may be improved in the future and eventually operationalized

- Highlight changes that need to be made from within the FAA's data collection system to facilitate this kind of analysis

OVERVIEW

INCIDENT REPORT GROUPING

UNSTABLE APPROACH CALCULATIONS

Aviation Safety Reporting System (ASRS)	Sherlock Data Warehouse: ASDE-X	Meteorological Aerodrome Report (METAR)
Jan 2000 - Dec 2019 All incursion and excursion reports	1st Saturdays of each month in 2022 LAX only	Jan 2022 - Dec 2022 LAX only

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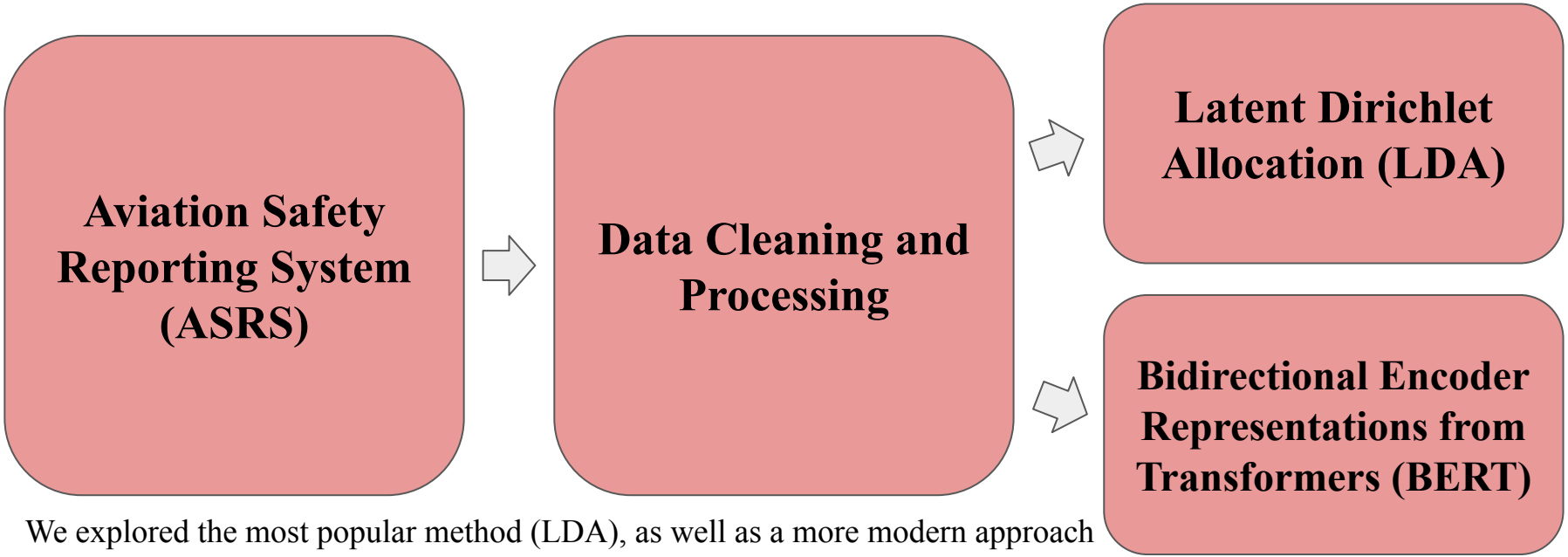
INCIDENT CLUSTERING PROCESS



We explored the most popular method (LDA), as well as a more modern approach based on using a large language model (BERT)

ASRS DATA

ACN

- Unique identifying number for reports

Anomaly

- Incursion/Excursion

Narrative

- Summary of event given from POV of personnel involved

DATA CLEANING & PROCESSING: LDA

Process:

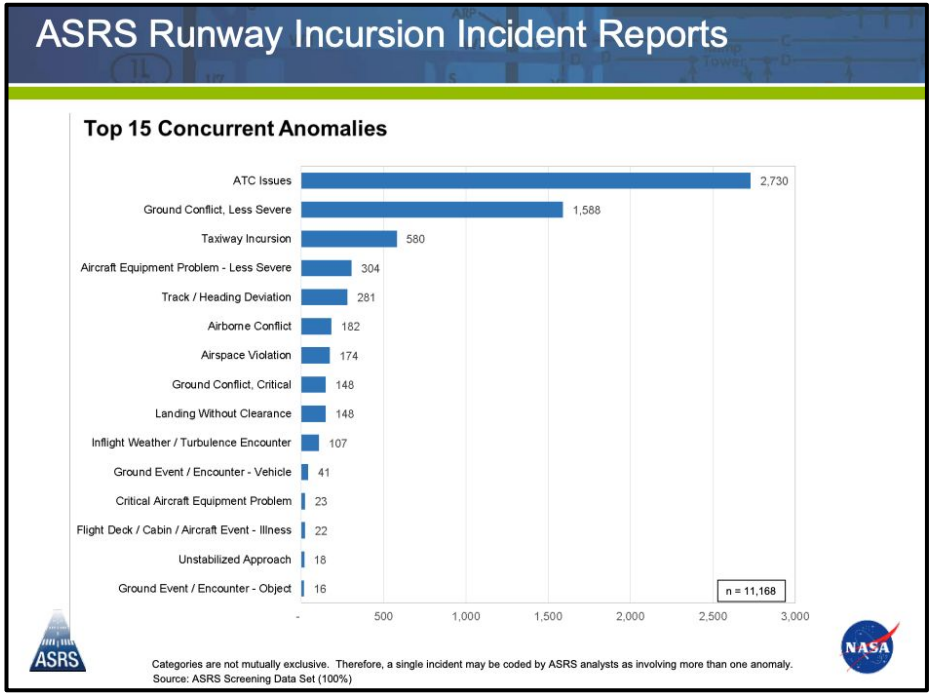
- ➢ Filter each anonymous ASRS report by event type (into incursions, excursions, and both)
- ➢ Remove irrelevant columns to focus on contributing narratives (can be multiple)

Issues:

- ➢ Lemmatization failed to encapsulate all variations of a given word
  - ○ E.g. Taxiway, txwy, taxiway, etc.

EXISTING ANOMALIES

- ATC issues (human factors) are the most common anomalies
- In addition – equipment problems, weather conditions, and even crew member illness
- We will see many of these topics repeated throughout our LDA and BERT results



RESULTS: LDA

Highlights of Top 20 Keywords for 5-gram:

Topic	Incursion Incidents	Excursion Incidents	Combined Incidents*
#1	crossed_hold_short_line_rwy gnd_ctl_clred_us_taxi 180_deg_turn_hold_short	twr_clred_us_tkof_rwy 10_kts_gusting_20_kts applying_full_power_aircraft_started	crossed_hold_short brakes_stop_plane short_line_runway
#2	clred_us_pos_hold_rwy twr_told_us_hold_short twr_clred_us_pos_hold	20_kts_gusting_30_kts gust_wind_lifted_right_wing applied_full_r_rudder_full	ifr_flt_plan taxi_lights_damage hold_short_rwy

** Showing trigram for combined incidents*

RESULTS: TOPIC MODELING WITH LDA

Exploratory analysis of different models and comparing their perplexity metrics:

Model	Incursion Incidents	Excursion Incidents	Combined Incidents
Bigram	31,608.93	22,831.72	770.65
Trigram	18,628.52	15,081.76	92.99
4-gram	37,707.14	3,383.02	18.12
5-gram	**5,716.40**	**554.26**	**3.73**

CONCLUSION: LDA

Key Takeaways from LDA:

- ASRS would benefit from vocabulary standardization
- Across all n-grams tested, models preferred 2 topics for clustering
- To improve results using LDA, our team anticipates a lot more pre-processing will be needed
- Future experimentation would explore different algorithm parameters and metrics

DATA CLEANING & PROCESSING: BERTopic

- Handled missing values and irrelevant columns and stopwords
- Identified standard abbreviations and replaced with the full words using a predefined abbreviation dictionary
- No tokenization, lemmatization or removing words that occur too often is required as the model captures context-dependent relationships between words

DATA MODELING: BERTopic

- Before fine-tuning:
  - Incursion: 'runway_aircraft_taxiway_taxi', 'cherokee_runway_cleared_17l'
  - Excursion: 'runway_aircraft_taxiway_landing' , 'threshold_displaced_runway_displaced threshold'

- Modified the parameters in the UMAP model (e.g., n_neighbors, n_components, min_dist, and metric), vectorizer model (e.g., ngram_range, stop_words, and max_df), sentence transformer, and the embedding model

- Expanded n-gram range, employed the 'all-mpnet-base-v2' embedding model

RESULTS: BERTopic - Incursion Incidents

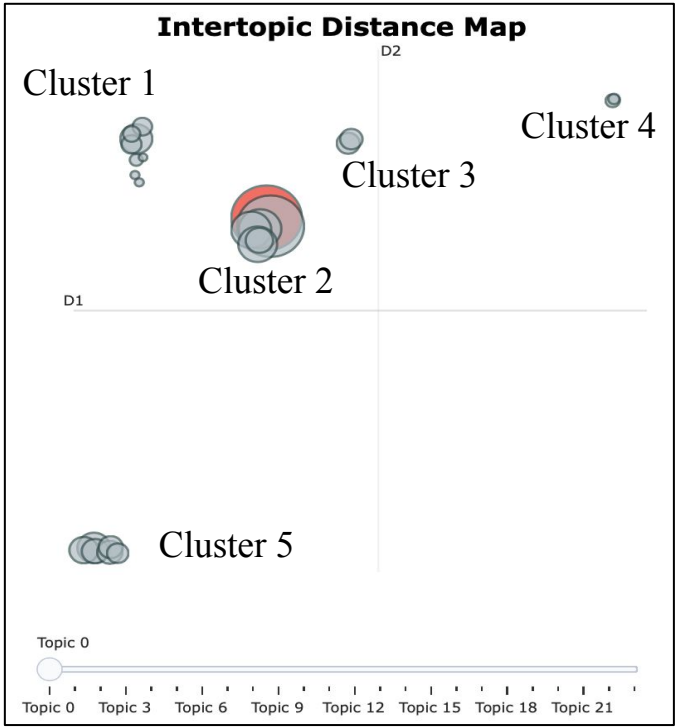
Cluster 1: Airport infrastructure, signage, operational factors

Cluster 2: Communication with air traffic controllers

Cluster 3: Weather conditions

Cluster 4: Aircraft approach procedures

Cluster 5: Traffic management and situational awareness



RESULTS: BERTopic - Excursion Incidents

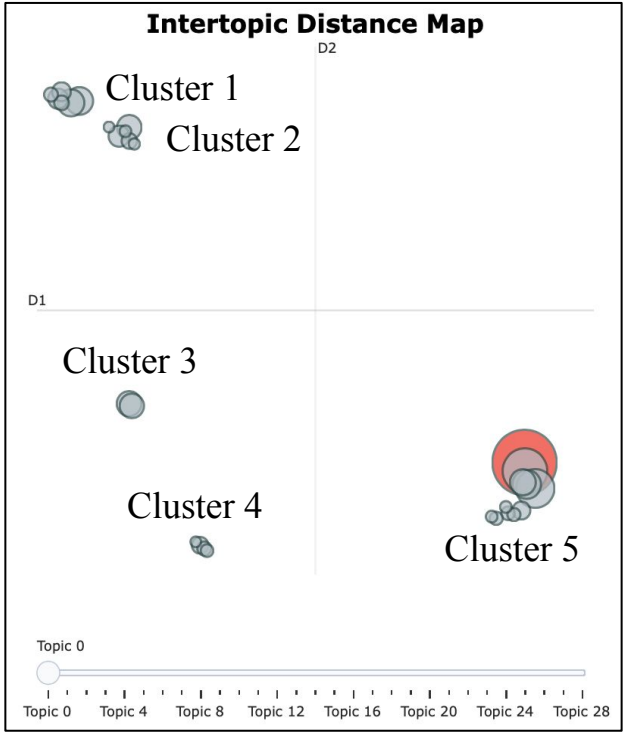
Cluster 1: Flight rules

Cluster 2: Aircraft performance

Cluster 3: Weather conditions

Cluster 4: Runway and taxiway conditions

Cluster 5: Pilot skill and experience

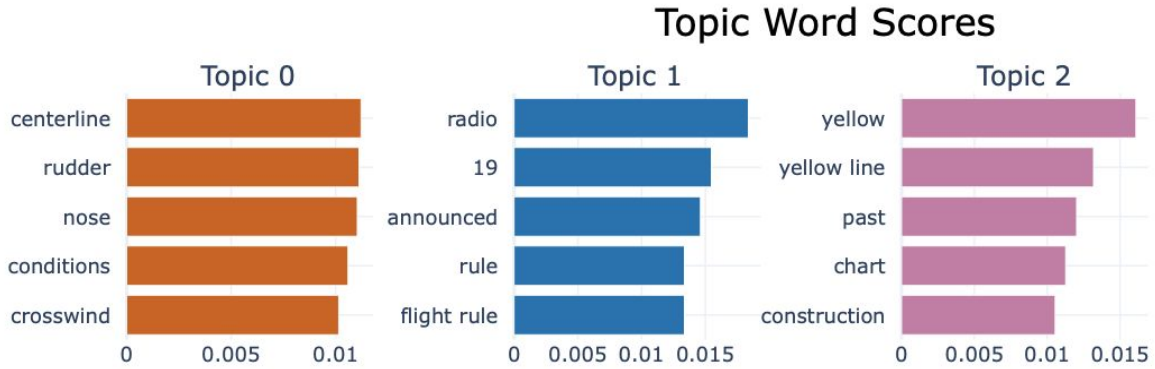


RESULTS: BERTopic - Combined Incidents

Cluster 1: Aircraft control and stability

Cluster 2: Effective communication between personnel

Cluster 3: Airport infrastructure



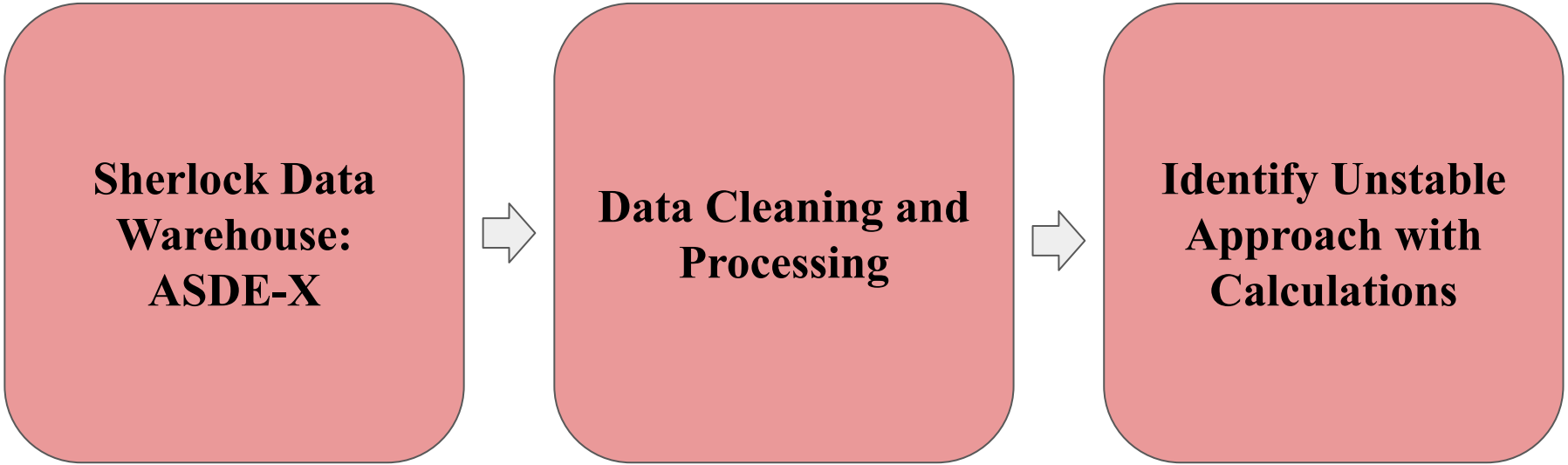
CONCLUSION: BERTopic

Key Takeaways from BERT:

- The clustered topics underscore the importance of effective communication, aircraft control, and adherence to airport procedures in maintaining safe airport operations
- These findings inspired investigation on unstable approaches as they may share similar contributing factors with runway incursions and excursions

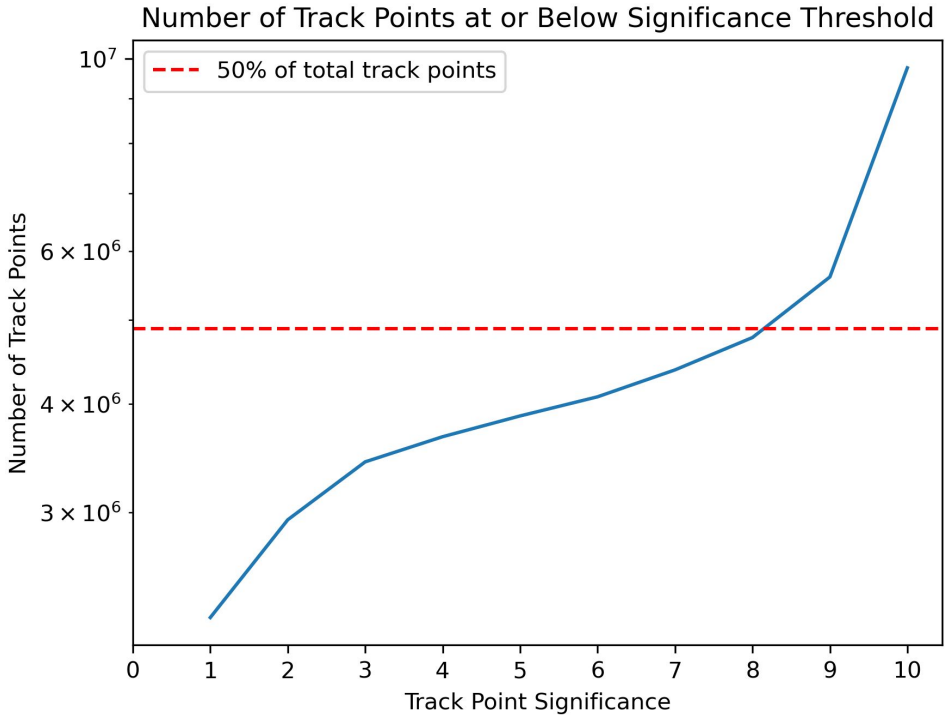
It is important to remember that these are meant to be PROACTIVE methods and will be most effective implemented on a system-wide scale!

UNSTABLE APPROACH METHODOLOGY



METHODOLOGY: Data Processing

- Keep track point records with significance score 1-5
- Arriving commercial flights only
- Identify each flight by date and flight key
- Unit conversions



METHODOLOGY: Top of Descent Events

- Variable ‘rateOfClimb’ was -250 feet per second

- Landing event was calculated as the first instance where ‘alt’ was $\leq$ 128 feet (the elevation of LAX airport)

METHODOLOGY: Additional Data

- METAR for altitude correction, which was later found unnecessary
- Instrument Approach Procedures (ILS) of all LAX runways for optimal bearing, optimal glidescope, and the ground distance and elevation of the waypoints
- Google Maps for runway threshold coordinates

METHODOLOGY: Formula for Calculations

- Bearing:

  $\theta = \text{atan2}(\sin(\Delta\lambda) \cdot \cos(\varphi_2) , \cos(\varphi_1) \cdot \sin(\varphi_2) - \sin(\varphi_1) \cdot \cos(\varphi_2) \cdot \cos(\Delta\lambda))$

  λ = longitude, φ_1 = runway latitude, and φ_2 = aircraft latitude

- Bearing variation:

  2.5 degrees / 5 dots localizer = 0.5 degrees/dot localizer

METHODOLOGY: Formula for Calculations

- Ground distance:

  $a = \sin^2(\Delta\varphi / 2) + \cos(\varphi_1) \cdot \cos(\varphi_2) \cdot \sin^2(\Delta\lambda / 2)$

  $c = 2 \cdot \text{atan2}(\sqrt{a}, \sqrt{1-a})$

  $d = R \cdot c$ where φ = latitude, λ =longitude, R = Earth's radius

- Glidescope:

  $\theta = \text{atan2}(\text{altitude}, \text{ground distance})$

  Altitude from IFF dataset, ground distance from Haversine formula

- Glidescope variation:

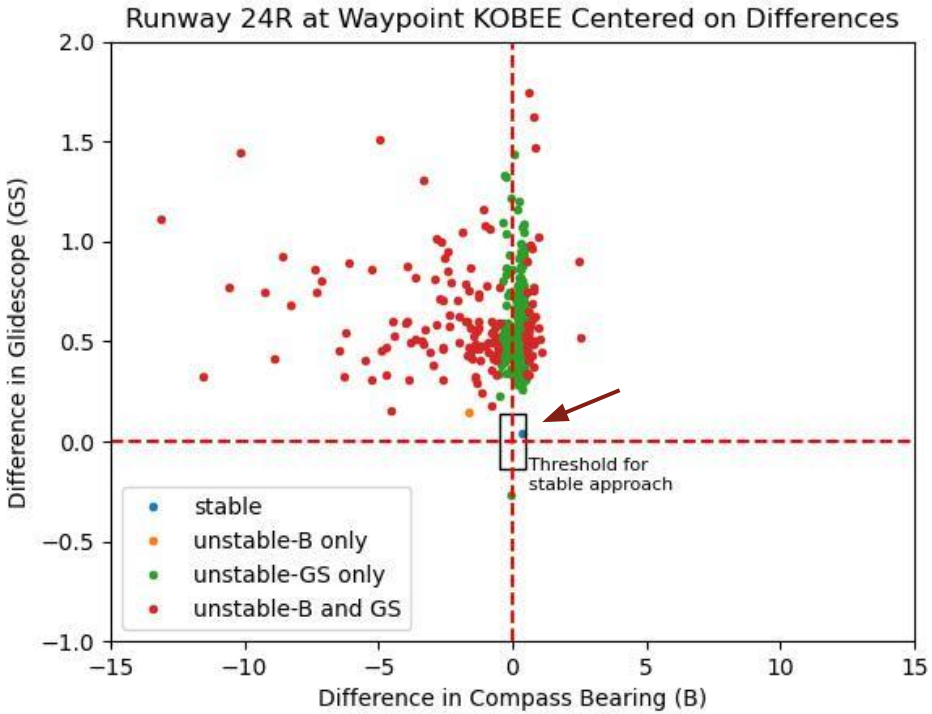
  0.7 degrees / 5 dots glideslope = 0.14 degrees/dot localizer

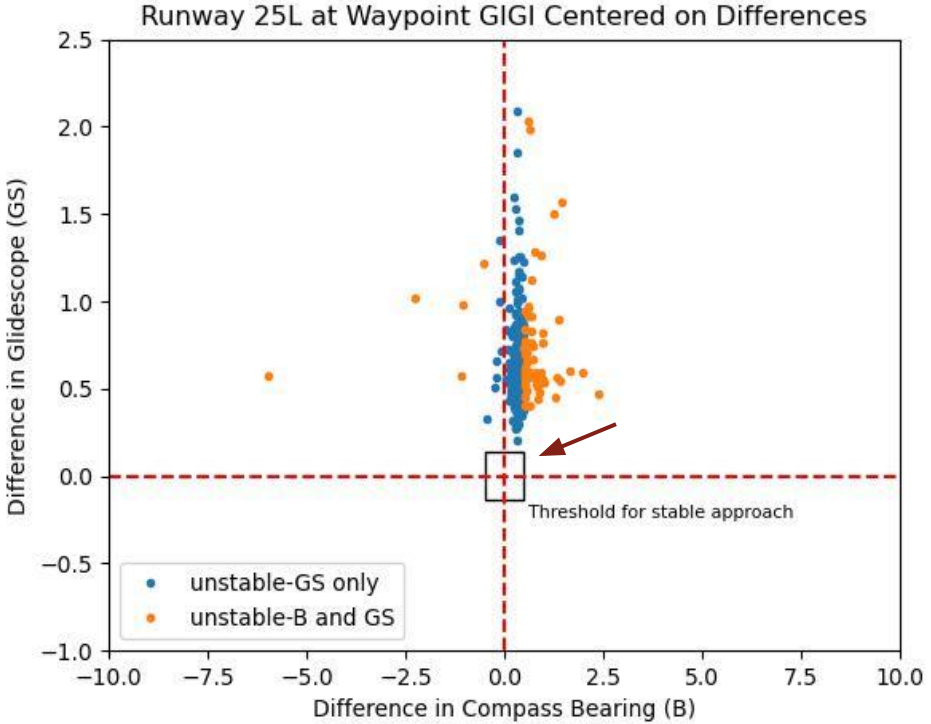
RESULTS: Unstable Approaches

Unstable Approaches at LAX by Category:

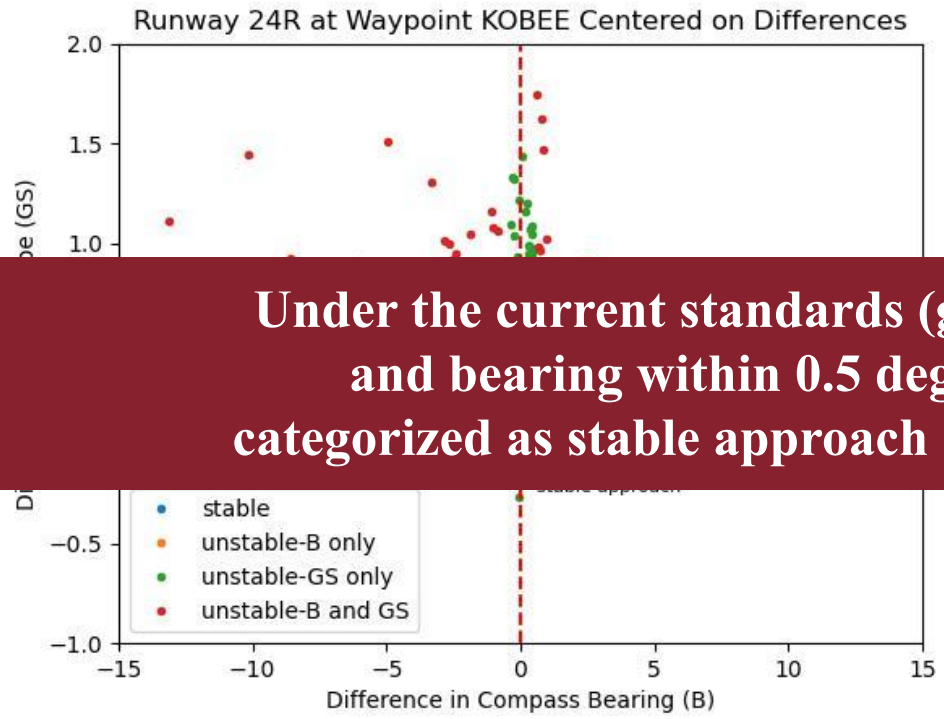
	Based on Bearing	Based on Glidescope	Both
Number of Stable Occurrences	3,150	4	1
Number of Unstable Occurrences	267	3,413	3,416

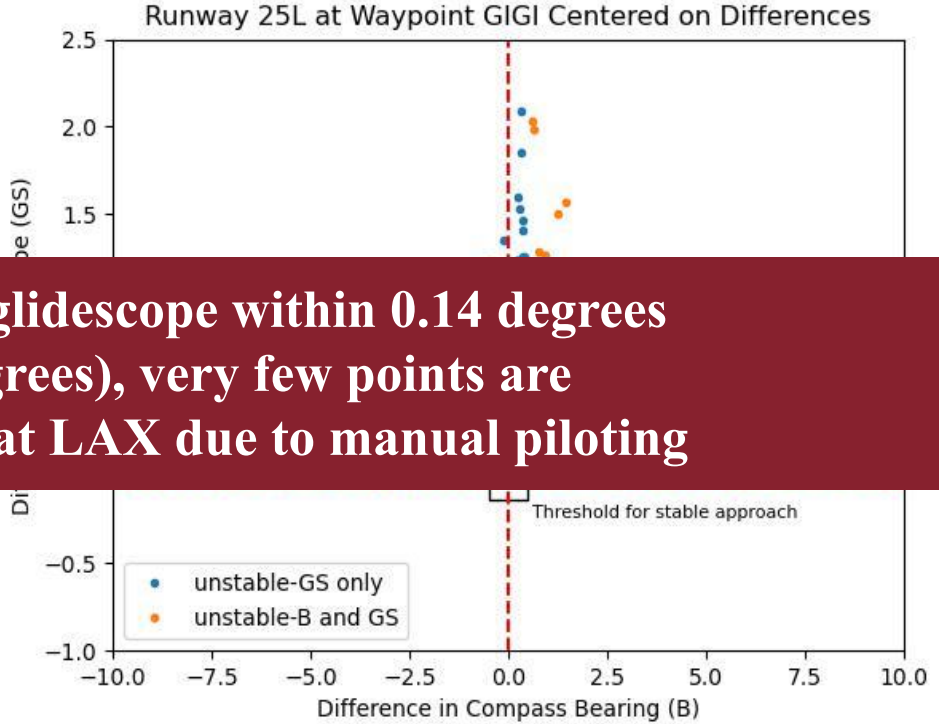
RESULTS: Unstable Approaches





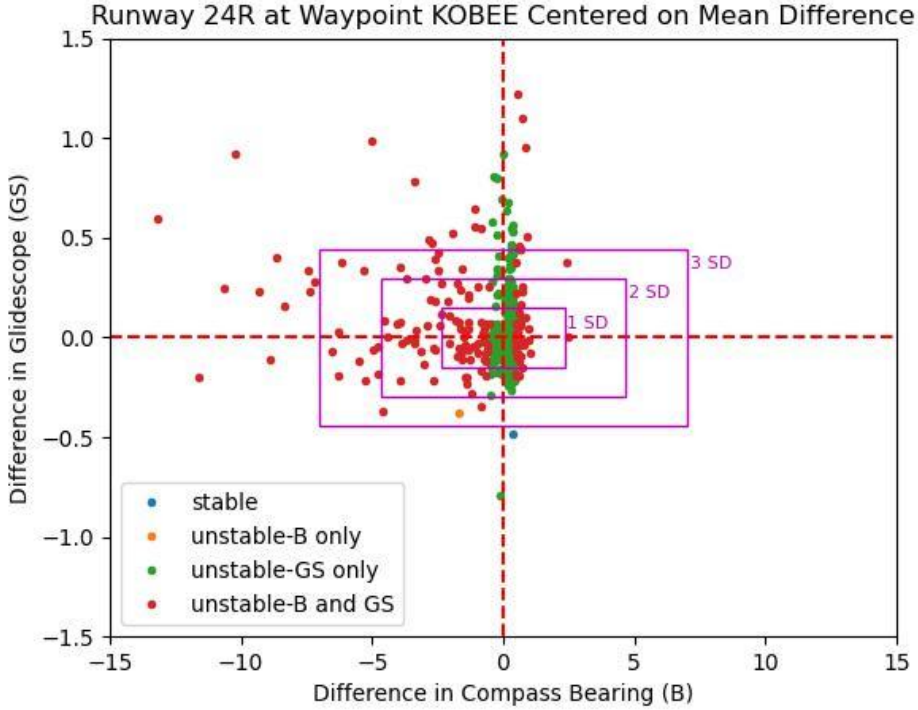
RESULTS: Unstable Approaches

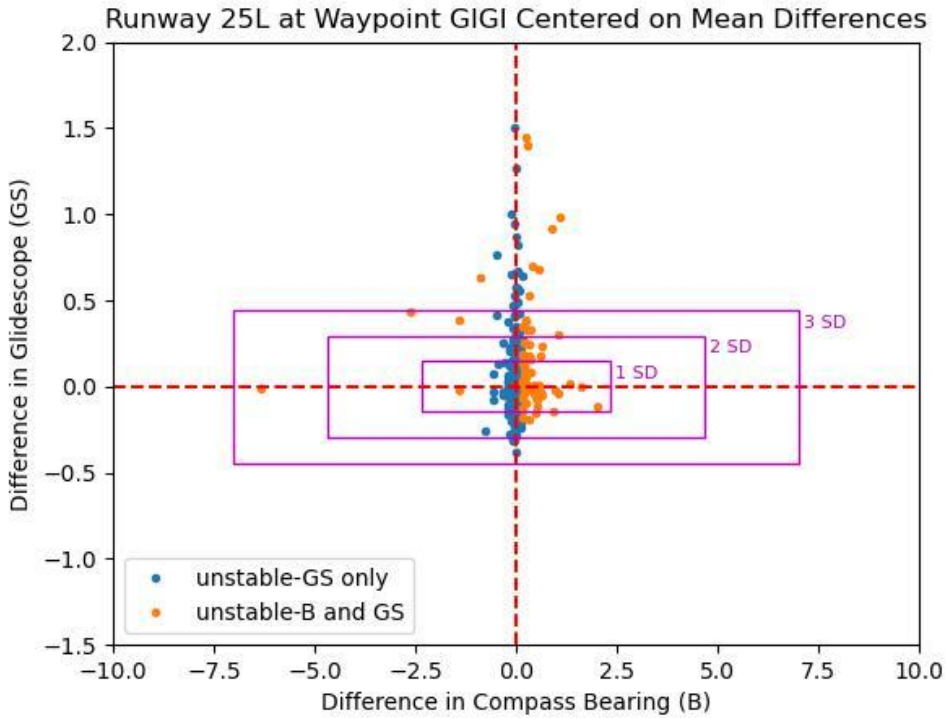




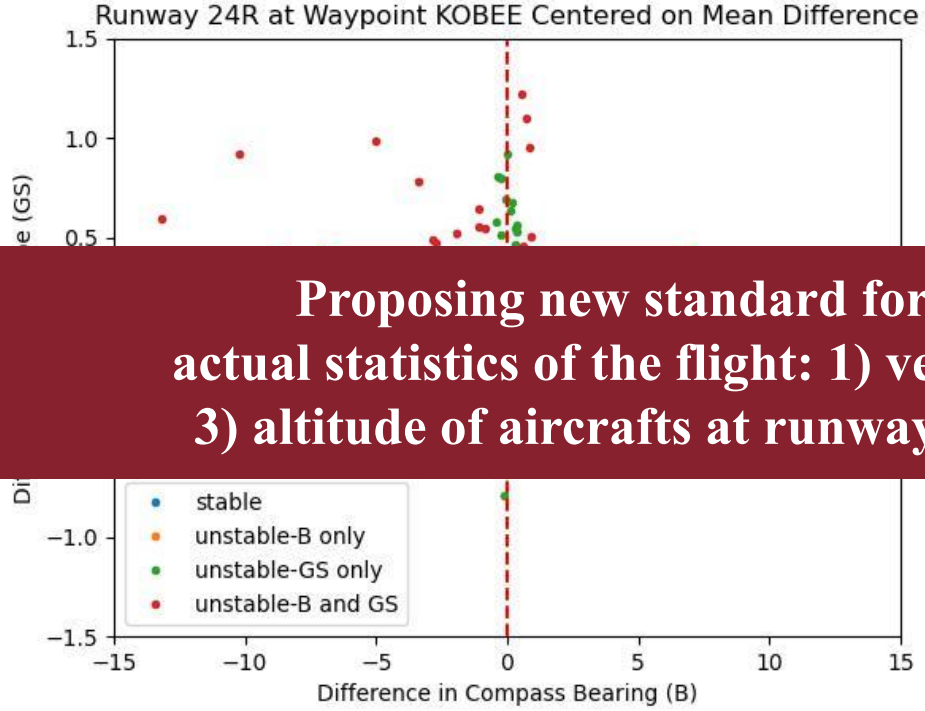
Under the current standards (glidescope within 0.14 degrees and bearing within 0.5 degrees), very few points are categorized as stable approach at LAX due to manual piloting

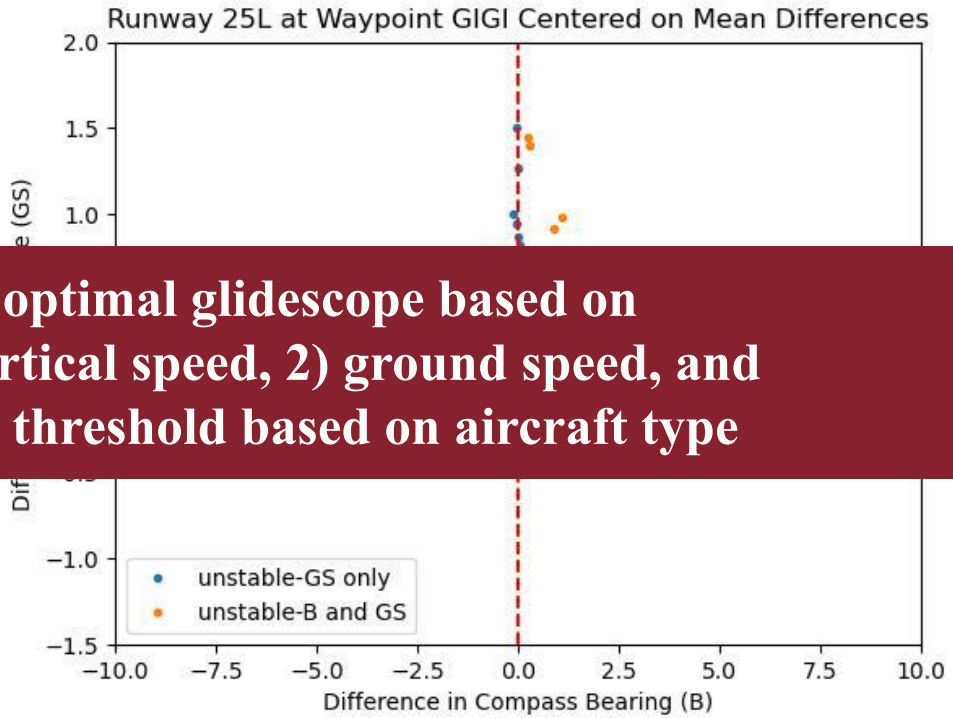
RESULTS: Unstable Approaches





RESULTS: Unstable Approaches





Proposing new standard for optimal glidescope based on actual statistics of the flight: 1) vertical speed, 2) ground speed, and 3) altitude of aircrafts at runway threshold based on aircraft type

CONCLUSION: Unstable Approaches

Key Takeaways from Unstable Approaches:

- ➢ Notation and unit standardization is lacking in existing Sherlock database
- ➢ Explicit documentation on whether altitude values are pressure corrected would greatly benefit data interpretability
- ➢ Unique identifiers should be propagated for each flight for ease of identification

CONCLUSION: Unstable Approaches

Key Takeaways from Unstable Approaches:

- ILS procedures stored in a relational table for easy access in addition to its PDF format would greatly increase data accessibility
- Current cutoff of unstable approach may be too rigid for manual piloting, new standards should be considered for further analysis

FUTURE RESEARCH FOCUS

- Further research with ASRS incorporates topic analysis into the database
- Clustering algorithms can tease out what contributes to unstable approach and lay the groundwork for METAR being included in the analysis as well
- Other machine learning models and algorithms, including other language models and tools, could be tried in the future
- Larger-scale experiments could be set up to accelerate new findings

SUMMARY

- Although a major accident has not occured in recent history, incursions, excursions, and similar incidents are on the rise
- Artificial intelligence can allow us to extract underlying information from the databases we have started to analyze here
- Moving forward, we will be able to identify previously unknown causes for the incidents the FAA is dealing with today
- Many possibilities to use AI to prevent incursions rather than for post-facto analysis

Thank You!