MIT
International Center for
Air Transportation

Examples of Using Data Analytics for Improving the Safety Efficiency and Environmental Impact of Air Transportation

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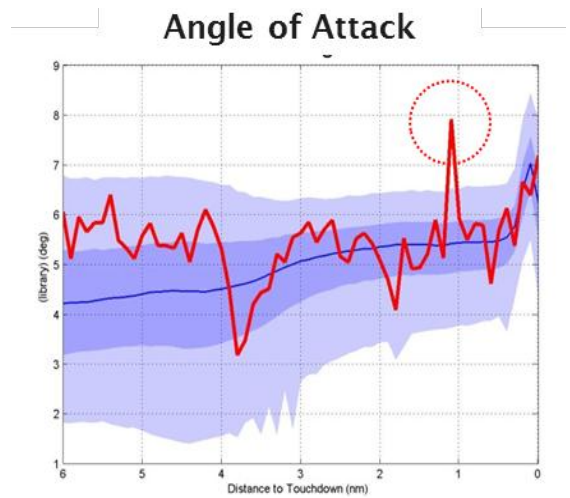
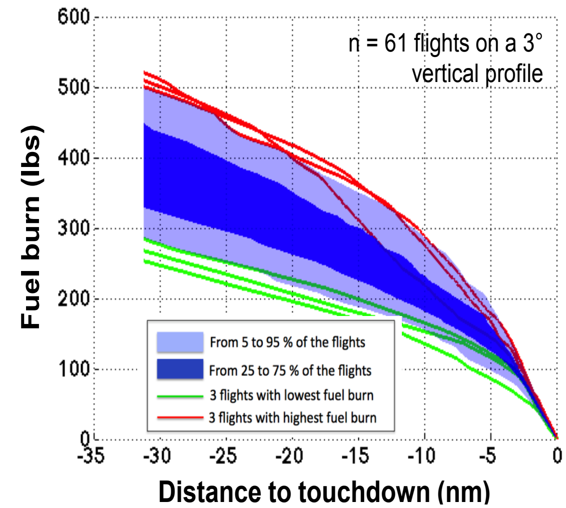
Examples of Data Analytics To Improve Operational Performance

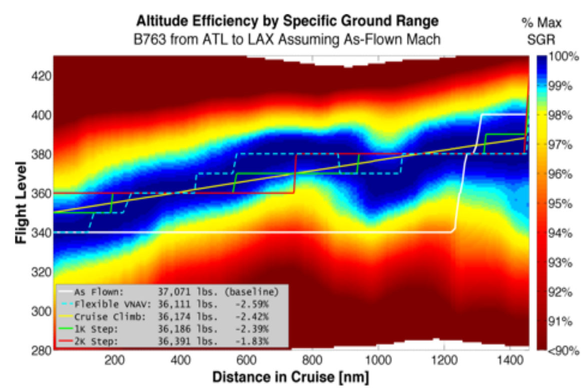
- Examples:
- Safety
- Environmental & Fuel Efficiency
- Airport & Air Traffic Performance
- Airport Community Noise Analysis



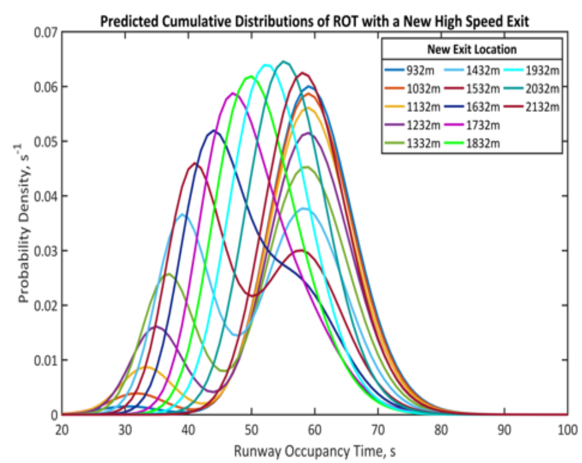
DFDR Anomaly Detection



Delayed Deceleration Approach



Cruise Altitude & Speed Optimization



Runway Occupancy Time Optimization

Examples

- **Safety**
  - **Flight Data Recorder Anomaly Detection** *(Lishuai Li)*
  - **Degraded Breaking Conditions** *(Nicolas Meijers)*
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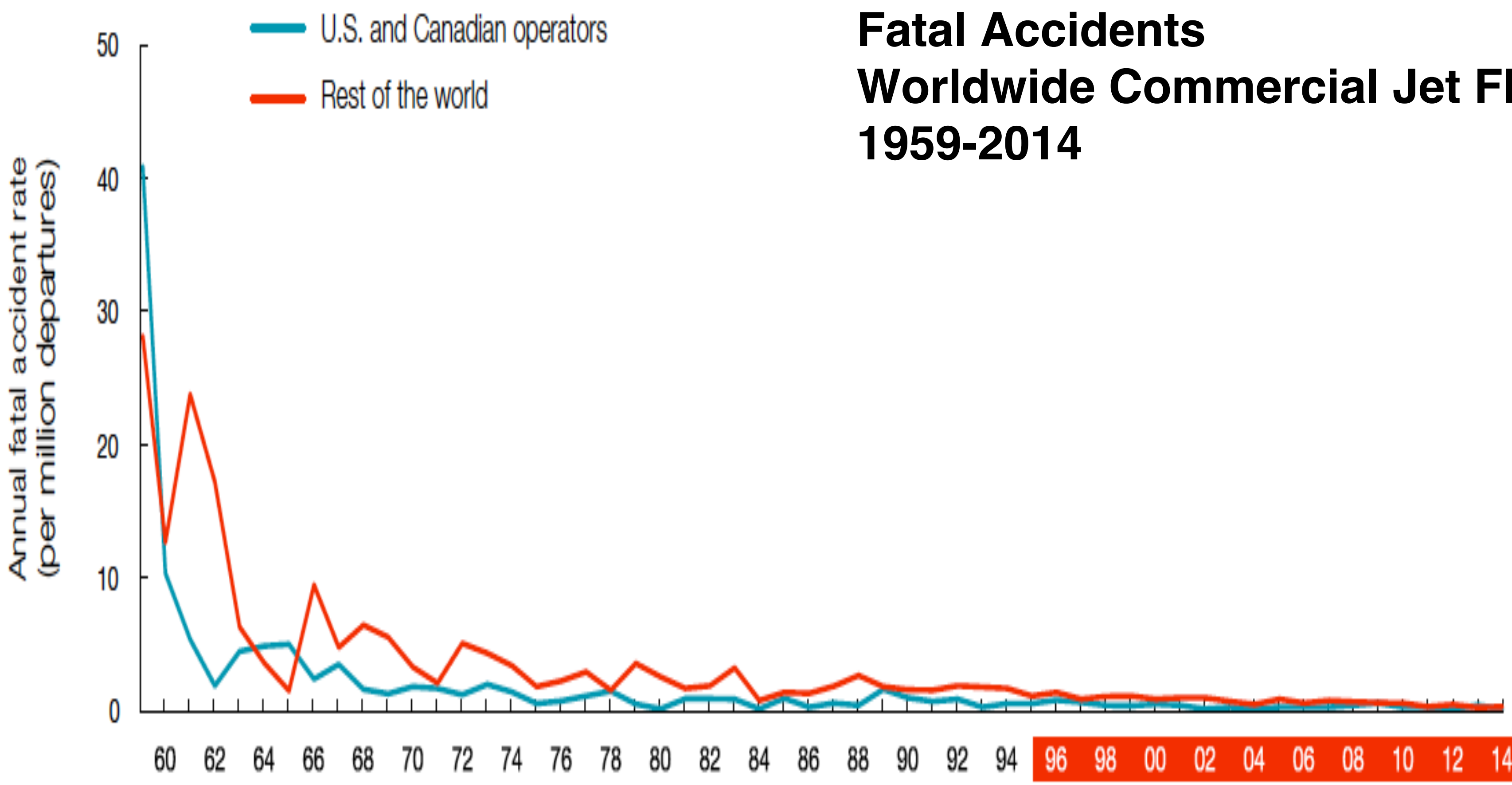
Commercial Aviation Safety Has Continuously Improved

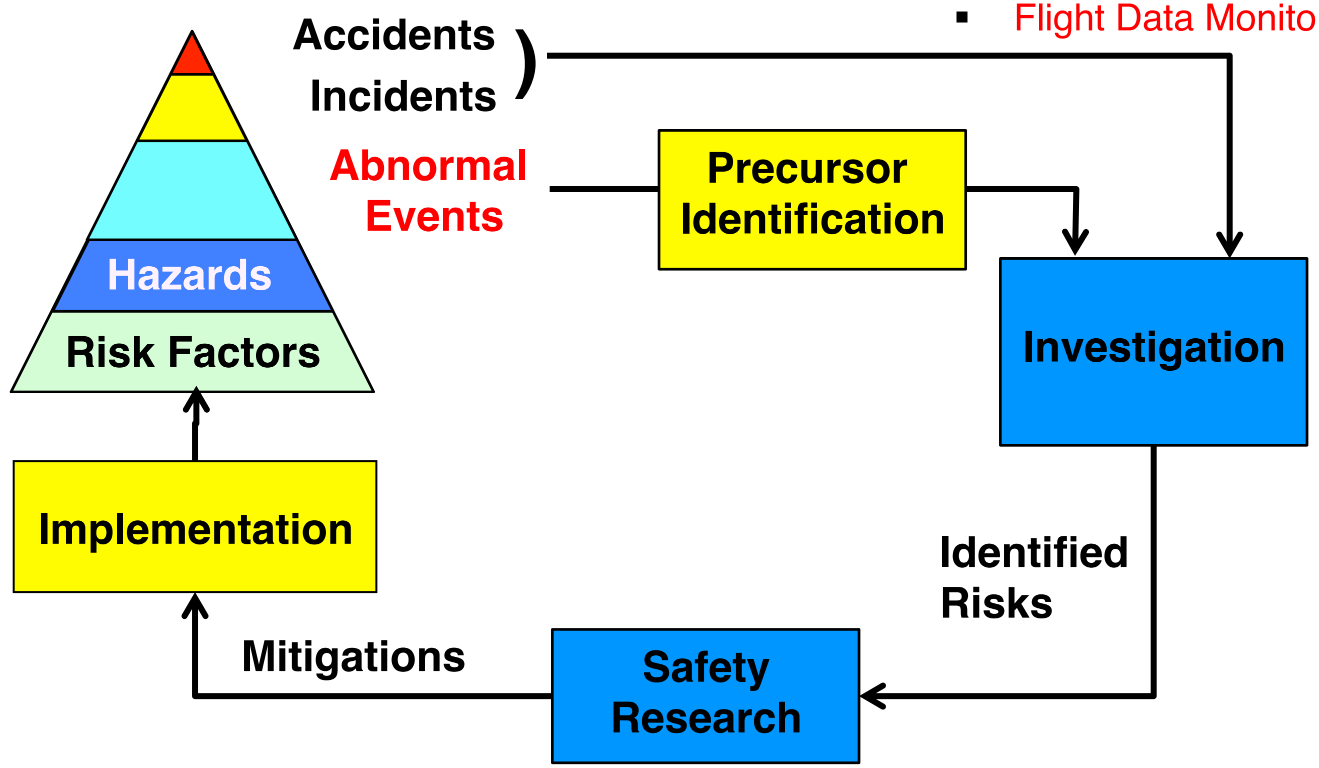
Fatal Accidents
Worldwide Commercial Jet Fleet
1959-2014



Source: 2014 Boeing Statistical Summary

Monitoring and Identification of Emerging Risks

- **ICAO Annex 6**
  - Safety Management Systems
  - Flight Data Monitoring



Anomaly Detection as Precursor

Identification of Anomalous Flights in Digital Flight Data Recorder Data

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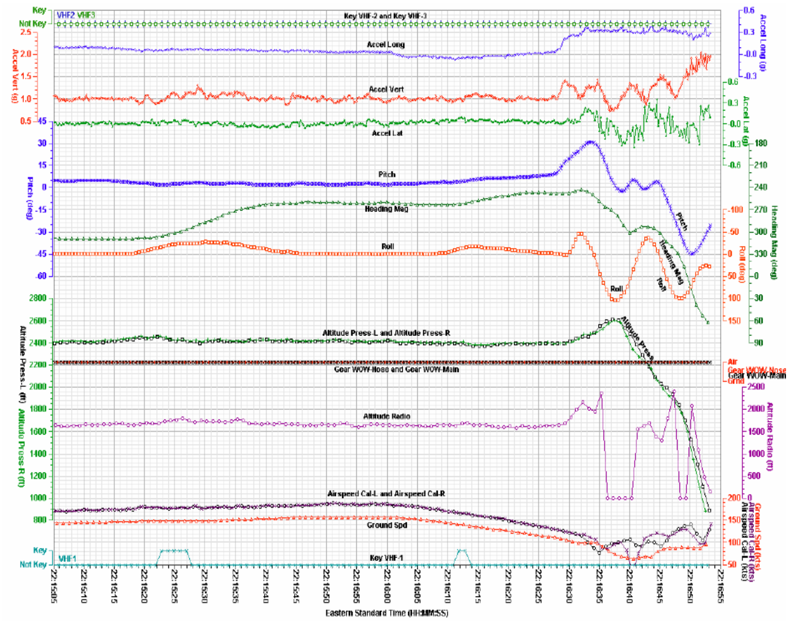
- Background:
  - Massive flight data collected through FOQA/FDM; rich information
  - Complicated to analyze
    - 100+ ~ 1000+ parameters for each flight
- Current practice: Exceedance Detection
  - Detect when a threshold is exceeded under certain conditions
  - List of events believed to be unsafe
  - Limited to known Safety Issues

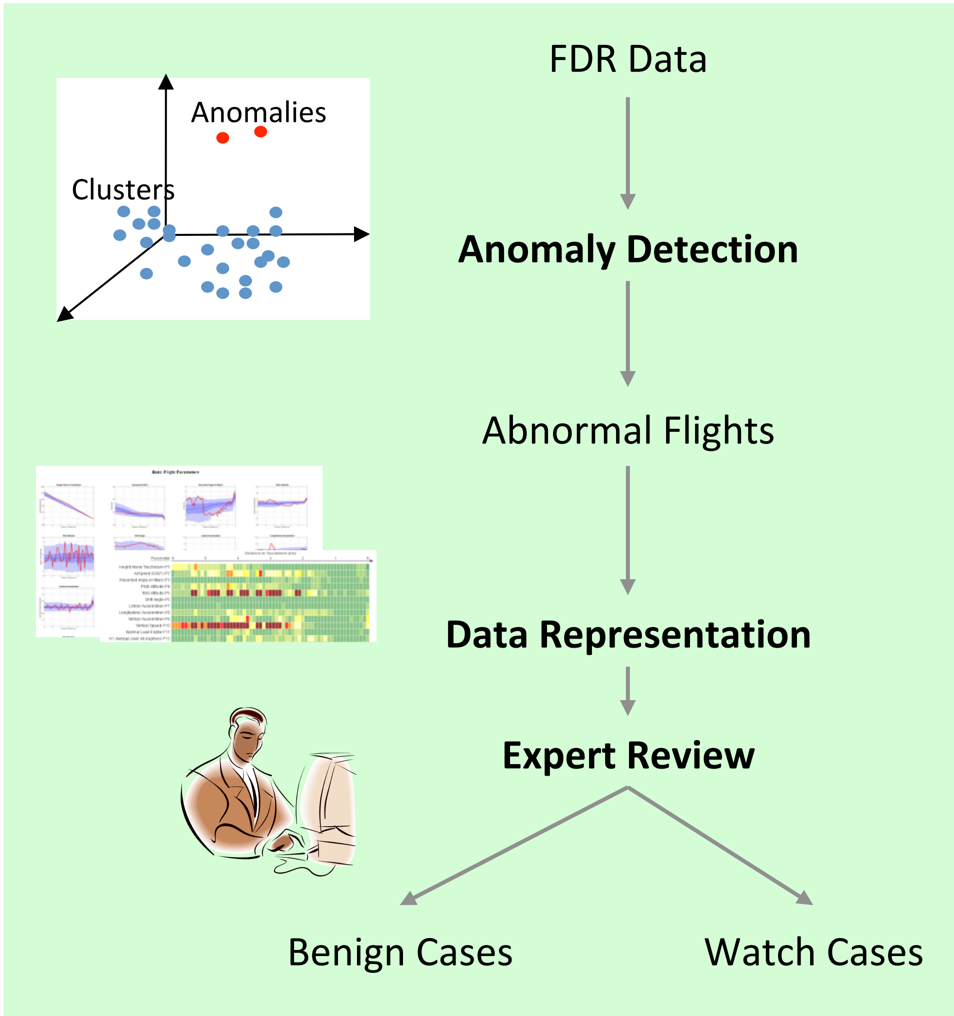
Example FDR data *



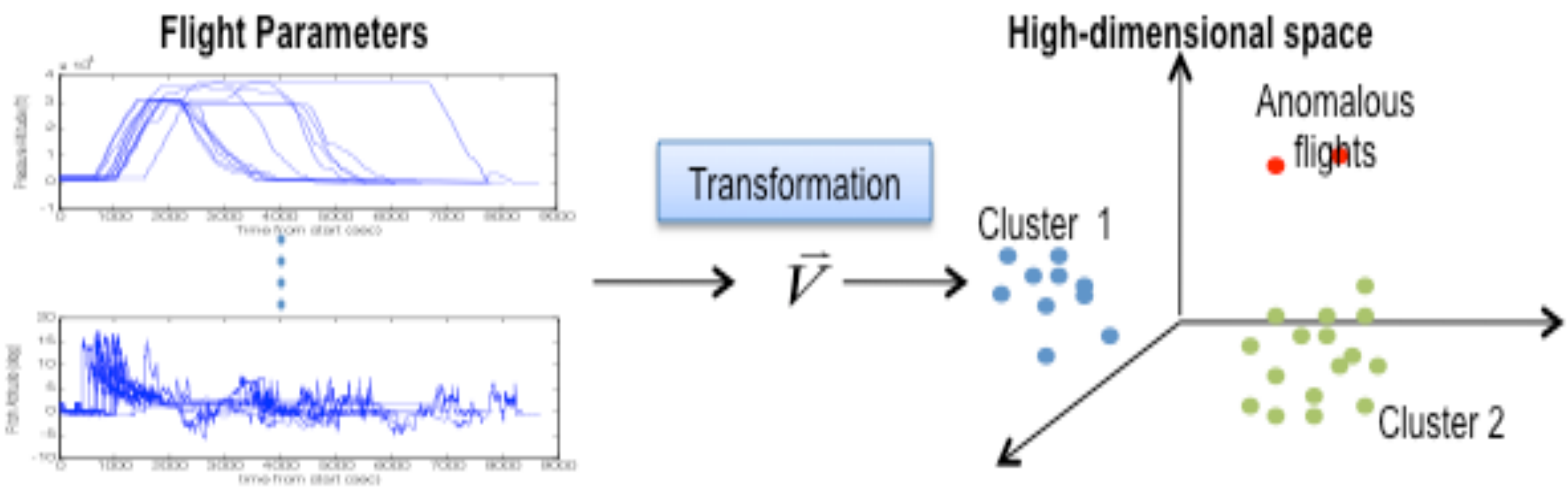
Event Code	Description
07A	Approach Speed Low Within 2 mins of T/D
07B	Approach Speed Low Below 25ft Radio
08A	Climb Out Speed High Below 400ft AAL
08B	Climb Out Speed High 400' to 1000' AAL
08C	Climb Out Speed Low 35' AGL to 400' AAL

*** Reference: NTSB, "FDR Group Chairmen's Factual Report, DCA09MA027," 2009**

Anomaly Based Monitoring using Data Mining Techniques



DFDR Data Mining
Cluster Analysis Approach

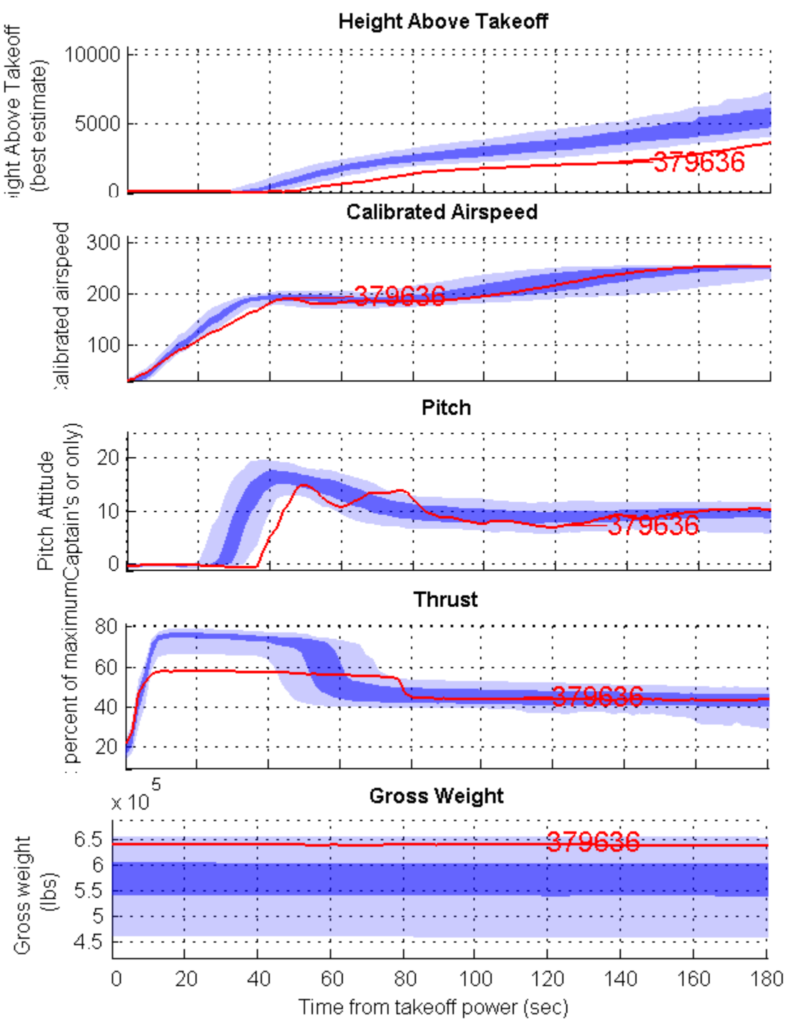


- Approach
  - Divide data by flight phase; make time series comparable
  - Integrate time series into a vector in a high-dimensional space
  - Cluster analysis of flights
    - Cluster similar flights together
    - Identify anomalous flights that are different from the majority
- No requirement for pre-defined parameter thresholds
- Also used Gaussian Mixture Models

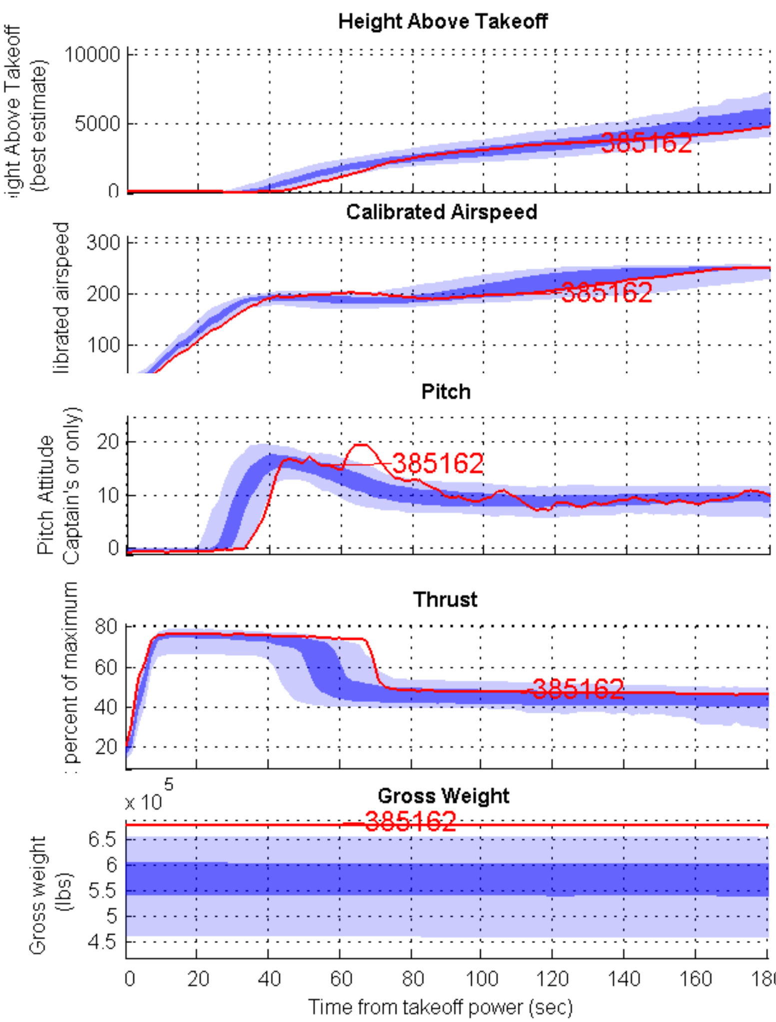
Example Results

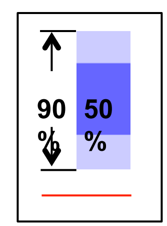
B-777 Takeoff

- Low Power Takeoff



- Heavy Takeoff, Double Rotation

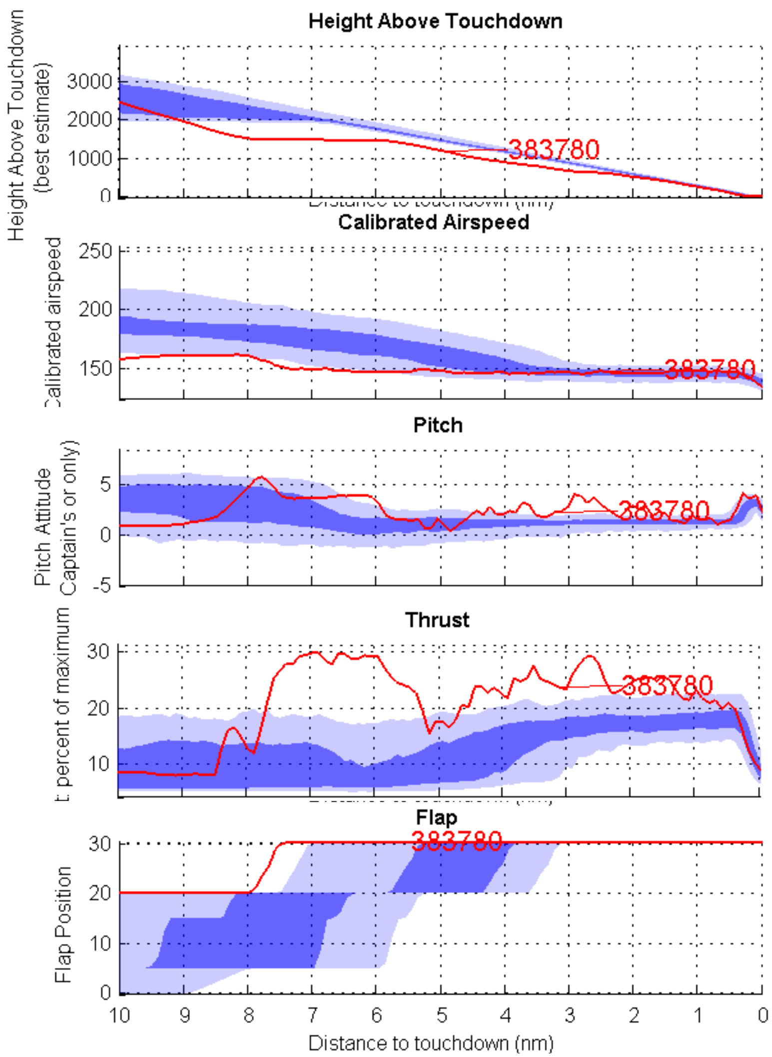




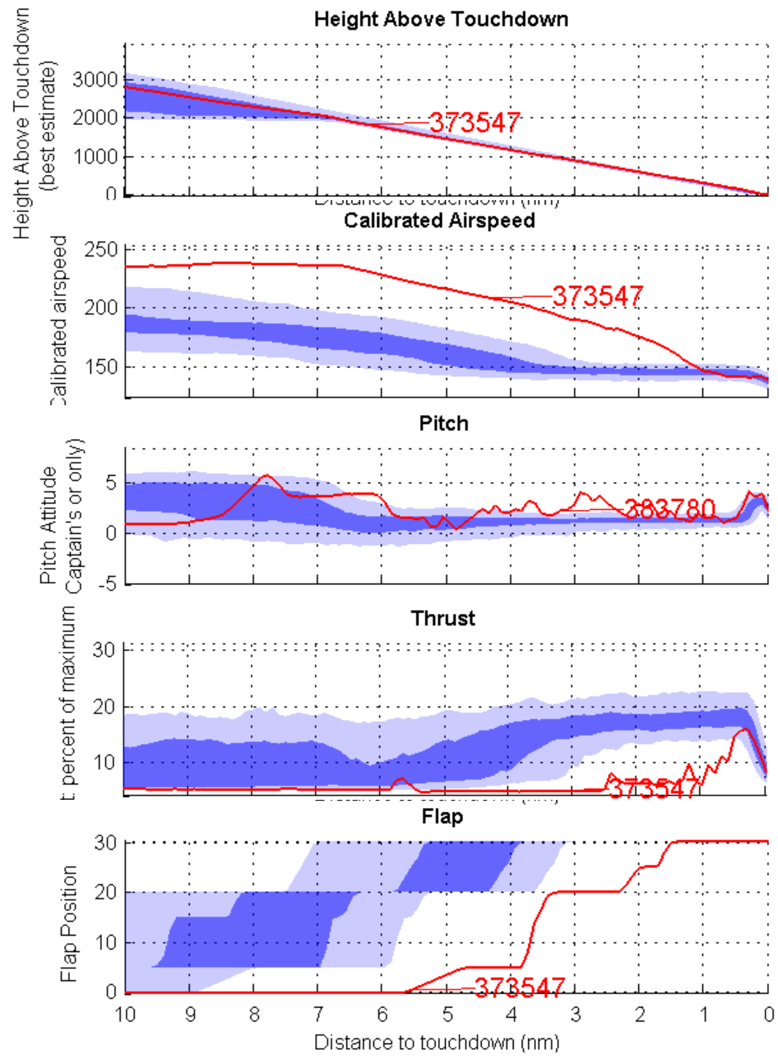
Example Results

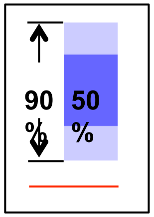
B-777 Approach

- Low Approach

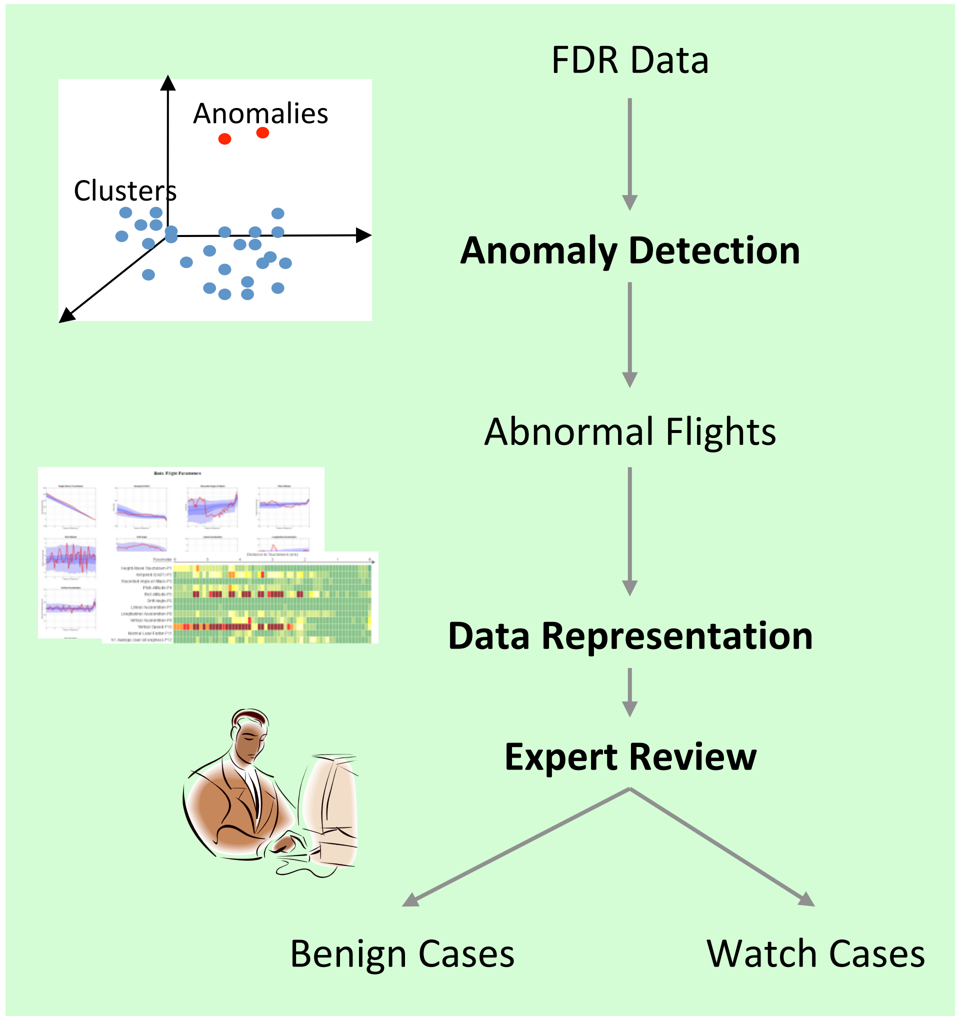


- Fast Approach

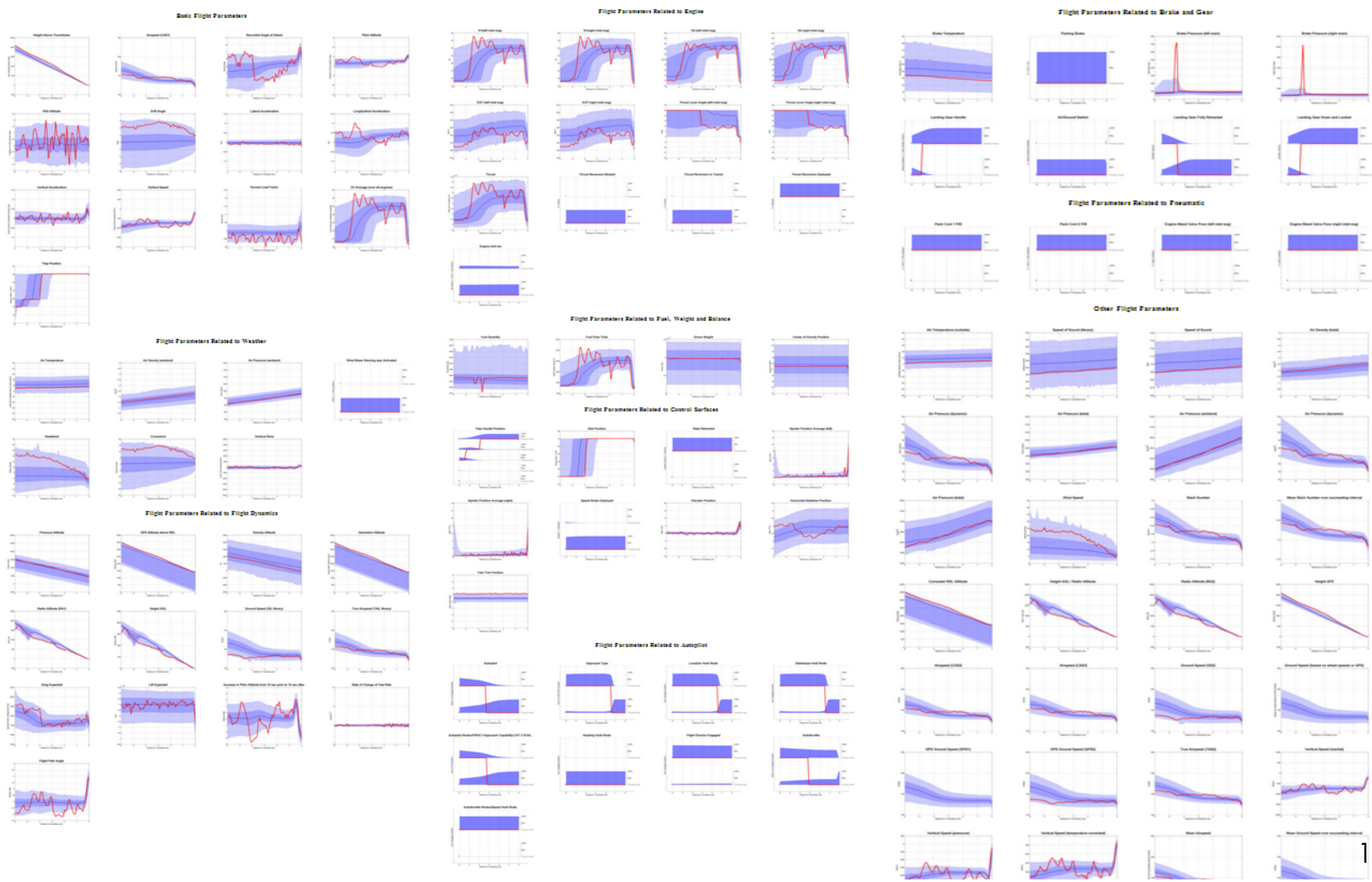




Anomaly Based Monitoring using Data Mining Techniques

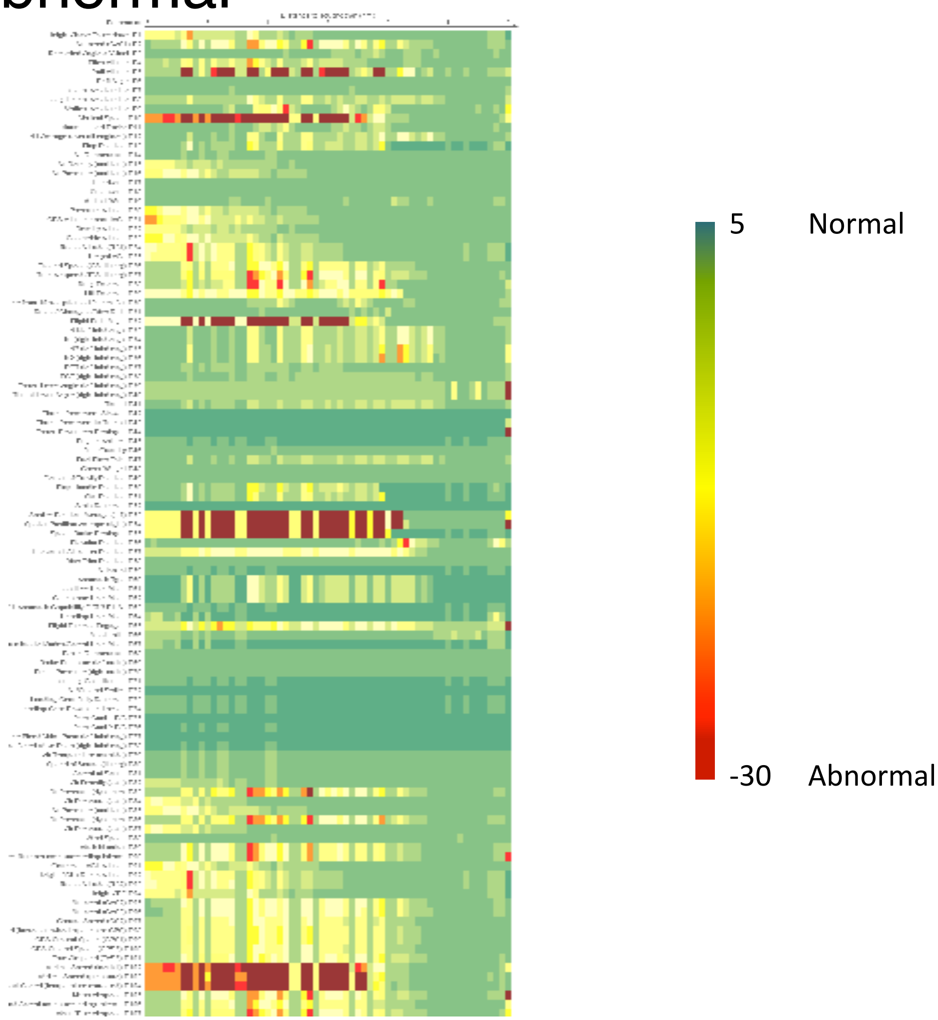


Flight parameters to review for a flight

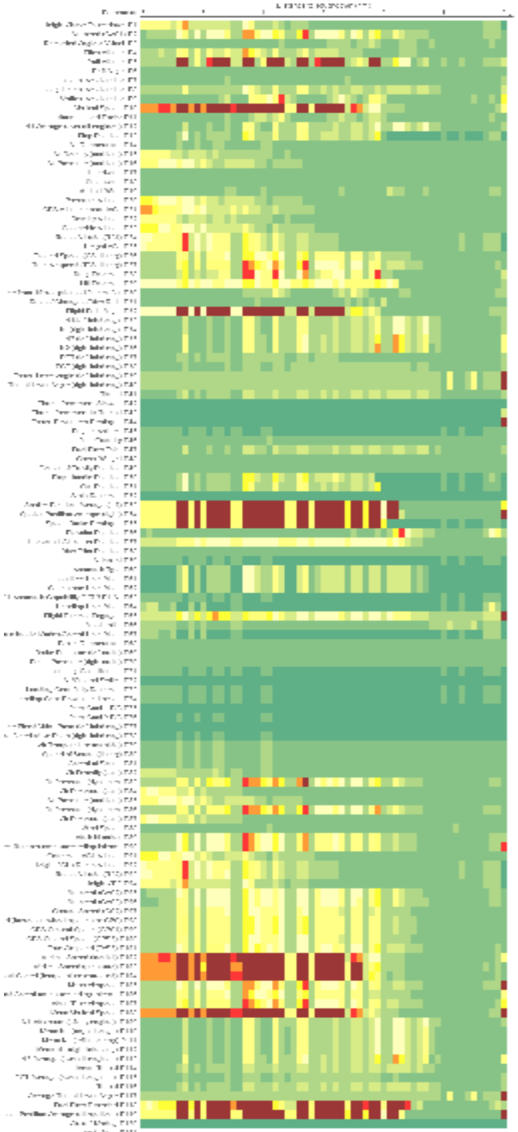


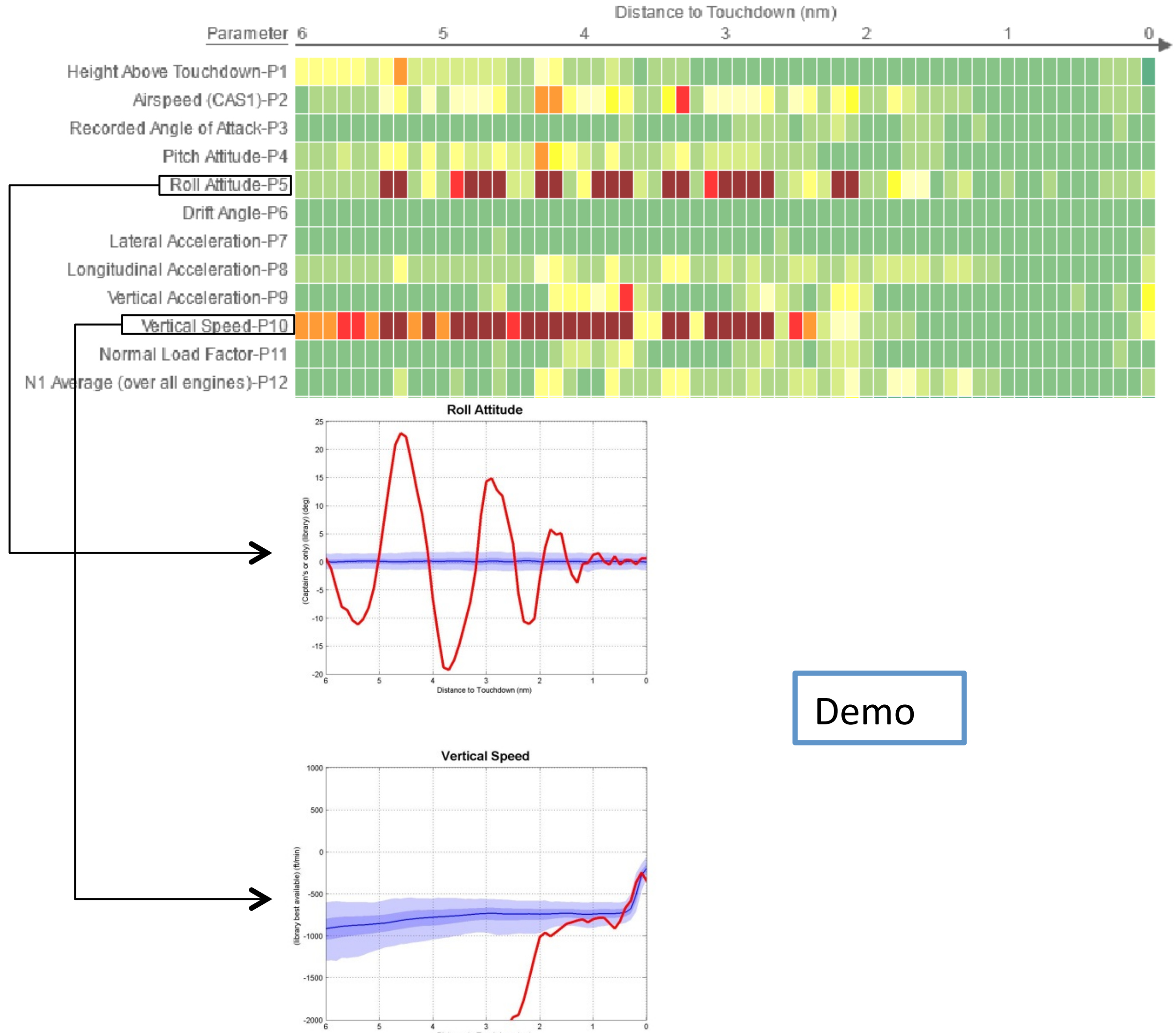
Flight Abnormality Visualization

- A visualization tool has been developed to guide domain experts to quickly locate anomalies - which parameters at what time are abnormal



Flight Abnormality Visualization Example





Demo

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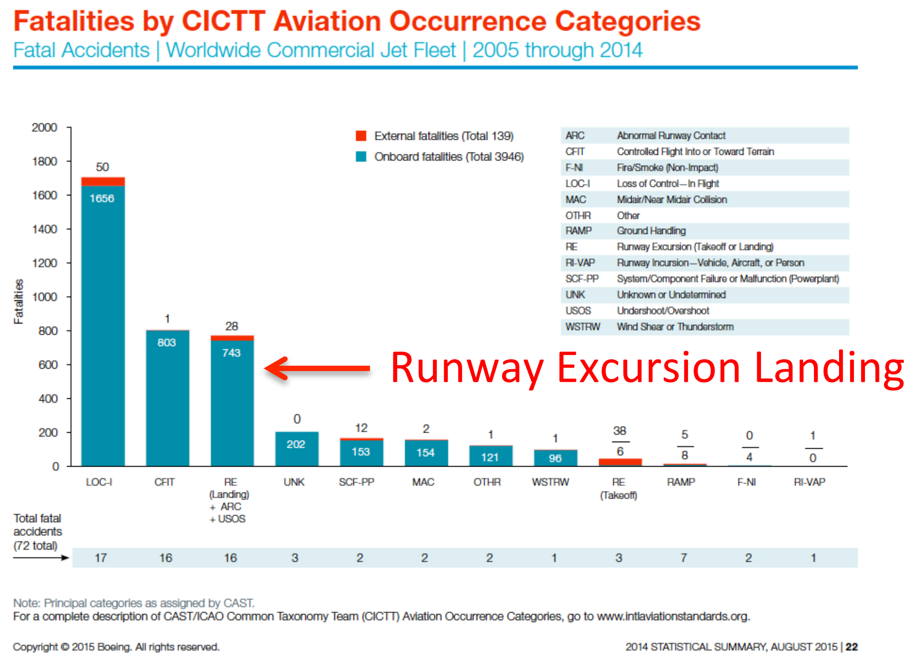
Identification of Degraded Braking Conditions

- Runway Excursion a Leading Cause of Fatal Commercial Accidents
- Rain, snow or contamination can result in degraded braking and runway excursion
  - e.g. Southwest Airlines 1248 (MDW)
- Limited success in predicting braking conditions
  - TALPA
- Further efforts needed to **understand and predict degraded braking**



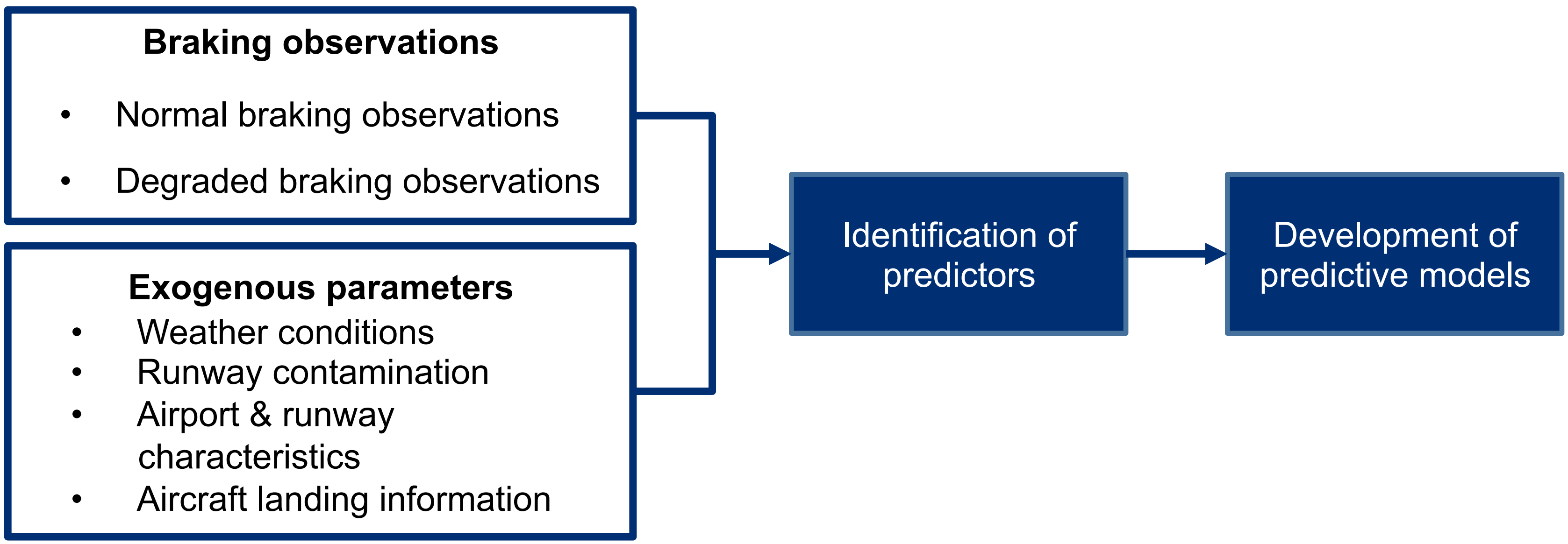
Source: CBS Chicago

Data-Driven Approach to Degraded Braking

Exploring data mining approaches using **large databases** to **characterize degraded braking** at a **macro-scale**:

1. **Identification** of degraded braking
2. **Analysis** of recurrent patterns
3. **Prediction** of degraded braking

Predictive Modelling Scheme



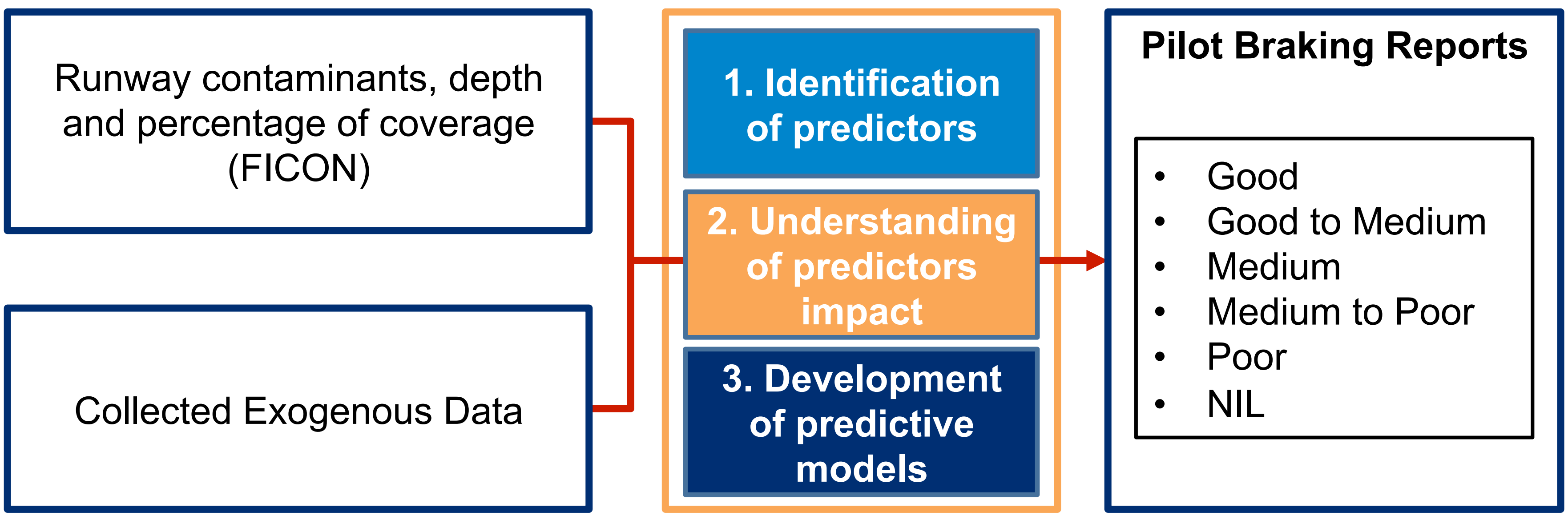
➢ Main challenge: Gather **reliable truth information about braking performance**

Using Pilot Braking Reports as Truth Data

Initial work on understanding and predicting degraded braking:

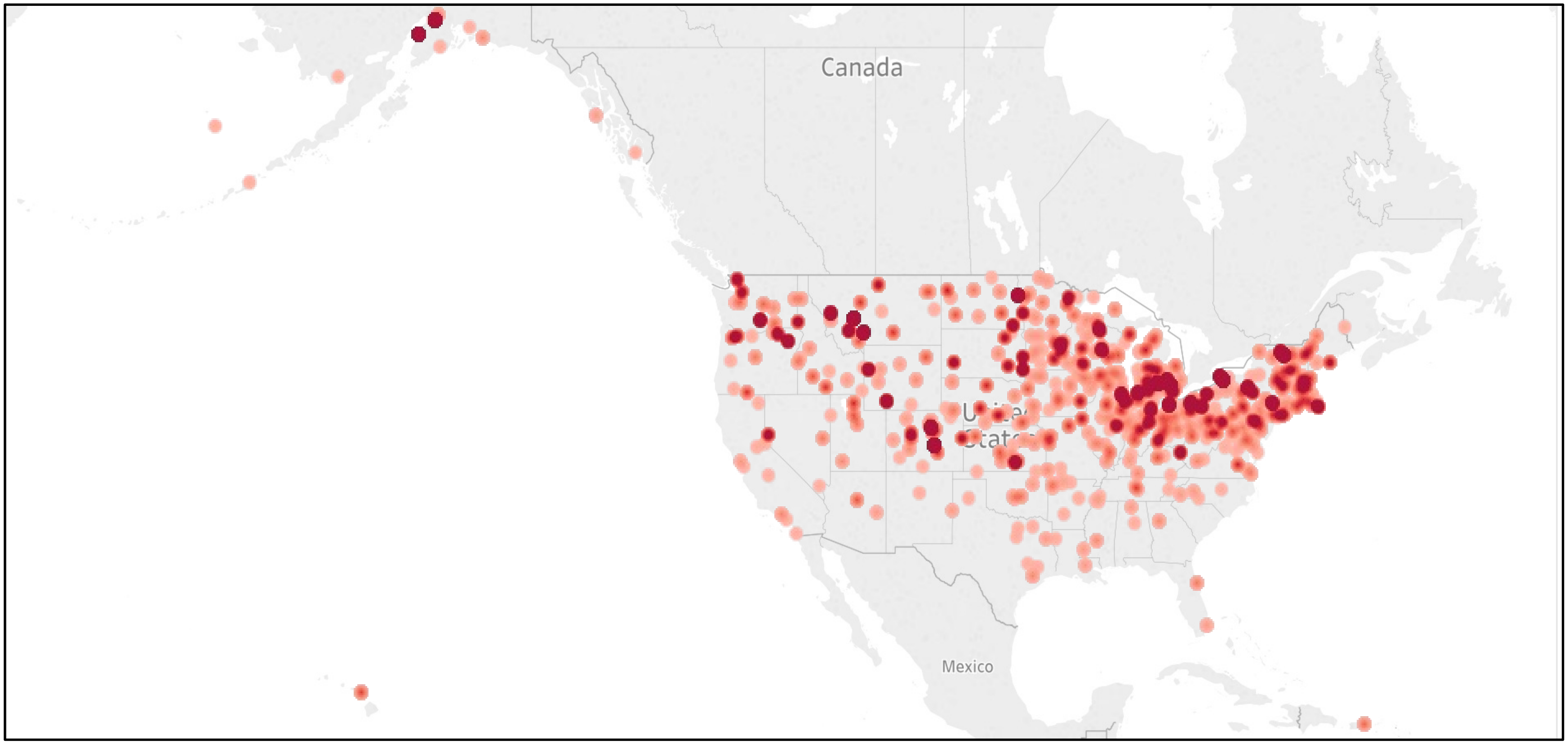
- Based on **Pilot Braking Reports** & **Field Condition Reports (FICON)**
- **Proof of concept with Pilot Braking Reports** used as a **"truth" for degraded braking**

1. Analysis of **dependency of Pilot Braking Reports with FICON** Data & **exogenous parameters** collected at US airports
2. Development of predictive models



FICON NOTAM Reports

- **Received 288,000 US FICON NOTAMs** for 2017-2018 winters from FAA (**5,241** with Pilot reports)



FICON NOTAM Reports

Contaminant Type & Remainder Contaminant	Contaminant Coverage & Depth	Treatment	Braking Action	Runway Condition Code
• Wet • Water Over Ice • Water • Frost • Slush • Ice • Wet Ice • Wet Snow • Wet Snow Over Ice • Dry Snow Over Ice • Compacted Snow • Dry Snow • Water Over Compacted Snow • Wet Snow Over Compacted Snow • Slush Over Ice • Dry Snow Over Compacted Snow • Slippery When Wet • Ash • Oil • Sand • Mud	• % of covered area • Depth (Inches) for some contaminants	• Plowed • Scarified • Swept • Sanded • Deiced Liquid • Deiced Solid	• Nil • Poor • Medium to Poor • Medium • Good to Medium • Good	0 1 2 3 4 5 6
➢ Per runway third	➢ Per runway third			➢ Per runway third

Initial Modelling of Braking Action

Use of an **Ordinal Logistic Regression** model to predict Braking Action

- Prediction of **Odds of Braking Action** for each landing

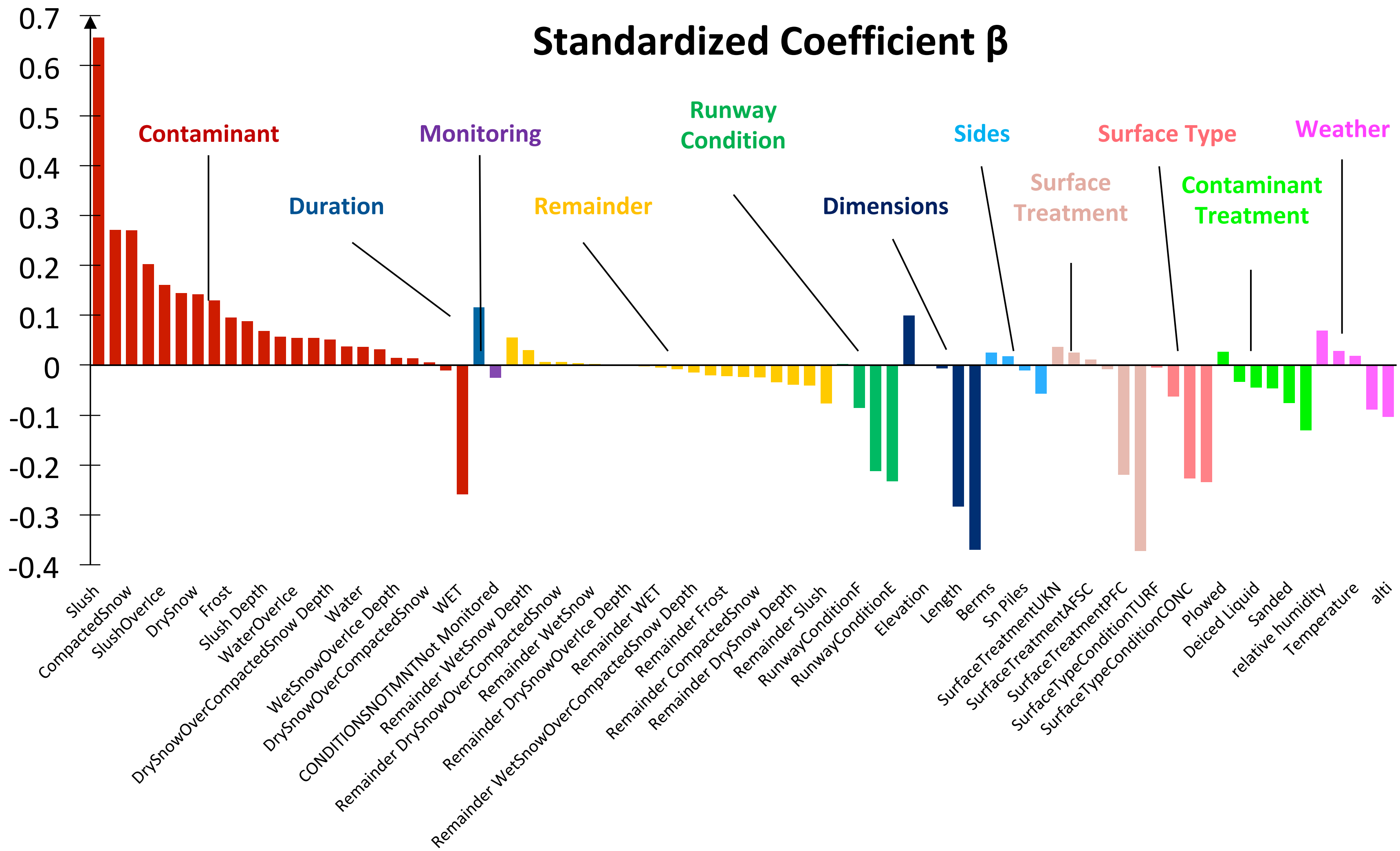
- Braking Action between j-1 & j predicted when

- Analysis of the **impact of each factor** on the odds with **a single coefficient β**

- Method provides:
  - ➢ Simple **understanding of the impact of each factor on the odds** to observe a category of braking

Predicted Braking Action	Threshold Value ()
NIL	
	-5.43 (j=1)
POOR	
	-2.32 (j=2)
MEDIUM TO POOR	
	-1.43 (j=3)
MEDIUM	
	0.14 (j=4)
GOOD TO MEDIUM	
	0.95 (j=5)
GOOD	

Identifying Dominant Predictors



Initial Model Performance

Observed \ Predicted	NIL	POOR	MEDIUM TO POOR	MEDIUM	GOOD TO MEDIUM	GOOD
NIL	0.0%	2.1%	0.5%	0.5%	0.0%	0.0%
POOR	0.0%	4.7%	1.2%	2.8%	0.9%	0.2%
MEDIUM TO POOR	0.0%	1.7%	1.4%	1.9%	1.2%	1.4%
MEDIUM	0.0%	0.7%	0.9%	6.8%	6.1%	6.6%
GOOD TO MEDIUM	0.0%	0.2%	1.7%	2.6%	3.1%	4.7%
GOOD	0.0%	0.2%	0.5%	2.8%	10.1%	32.3%

Confusion Matrix (48% direct match, 81% within 1 classification group)

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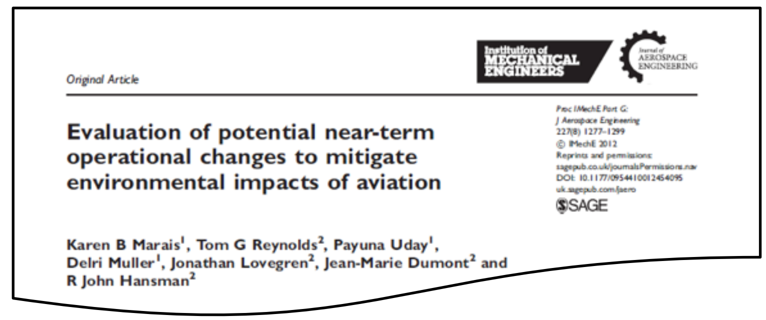
Identification of Operational Mitigations to Reduce Environmental Impact

- Funding: FAA Office of Environment & Energy (FAA/AEE)
- High-Level objective: Identify & evaluate operational mitigations to reduce environmental impacts of aviation in the near/mid-term with minimal implementation barriers
- Prior work: Identified/evaluated over 60 mitigations
- Current research focus: Quantify benefits and barriers to implementation of:
  - Delayed Deceleration Approach
  - Cruise Altitude and Speed Optimization (CASO)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Original Article

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DOI: 10.1177/0954410012454095
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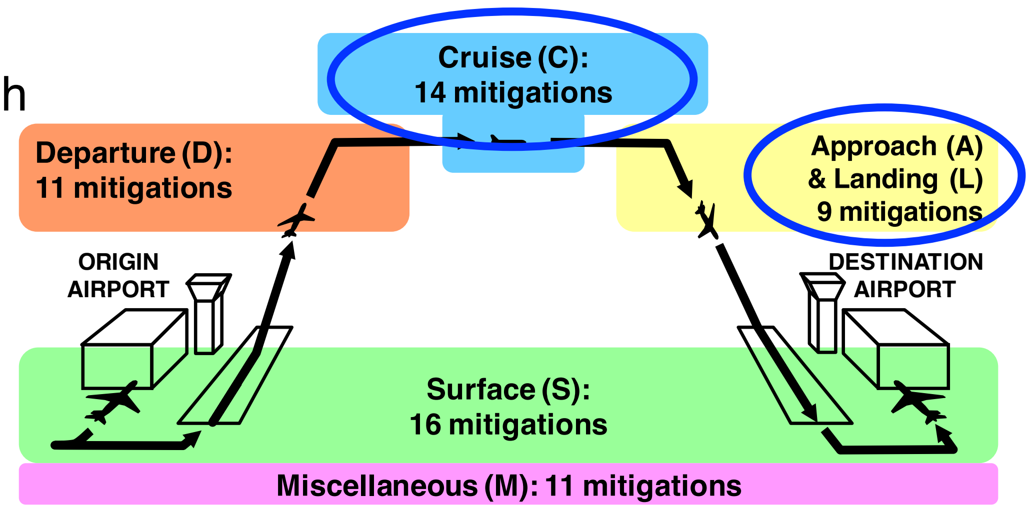
SAGE

Evaluation of potential near-term operational changes to mitigate environmental impacts of aviation

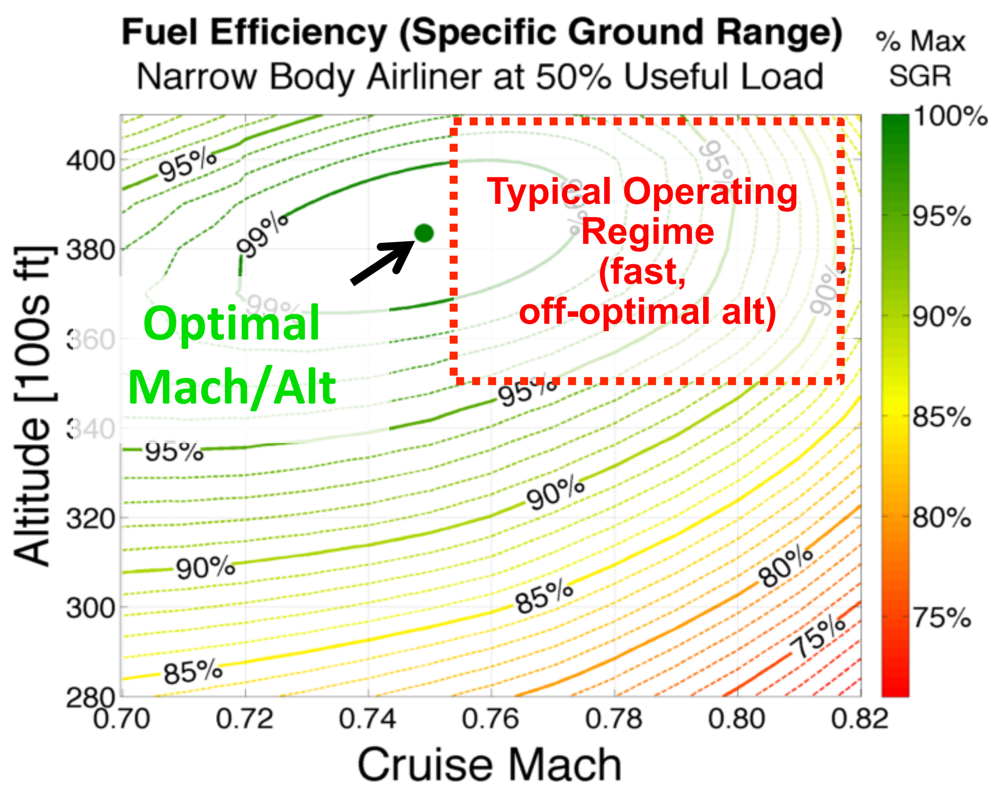
Karen B Marais[1], Tom G Reynolds[2], Payuna Uday[1], Delri Muller[1], Jonathan Lovegren[2], Jean-Marie Dumont[2] and R John Hansman[2]



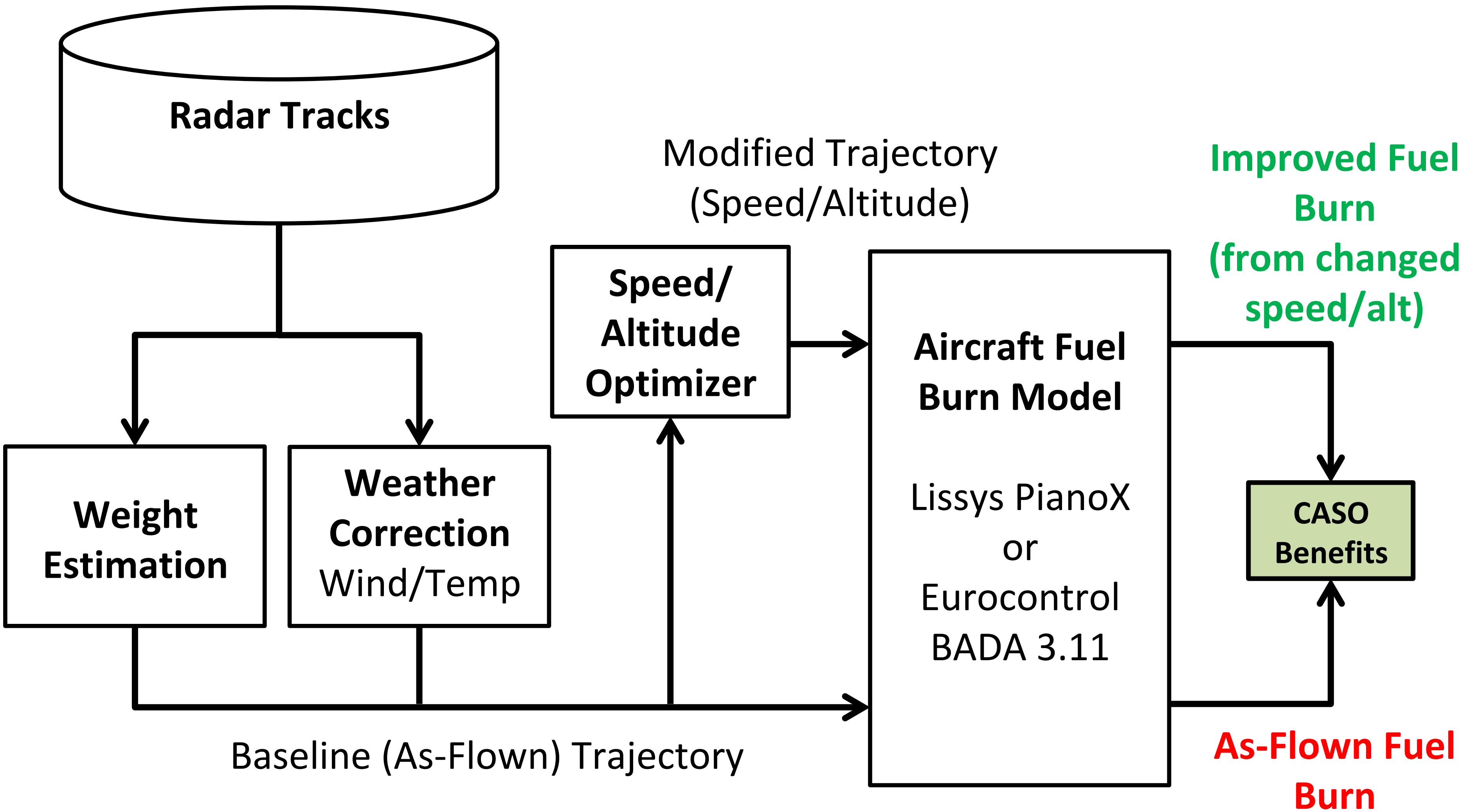
Cruise Altitude and Speed Optimization

- **2012 Radar analysis shows 56% of domestic flight time spent in high-altitude cruise**
- **Efficiency Metric: "Specific Ground Range"**
  - Maximizes ground distance per unit of fuel consumption
  - Accounts for wind and temperature
- **Typical airliner cruise conditions are not fuel-optimal with respect to speed and altitude**
  - Opportunities in flight planning, dispatch, and cockpit procedures
  - Potential applications in the NextGen ATM framework

Typical Narrow Body Jet Efficiency Contours



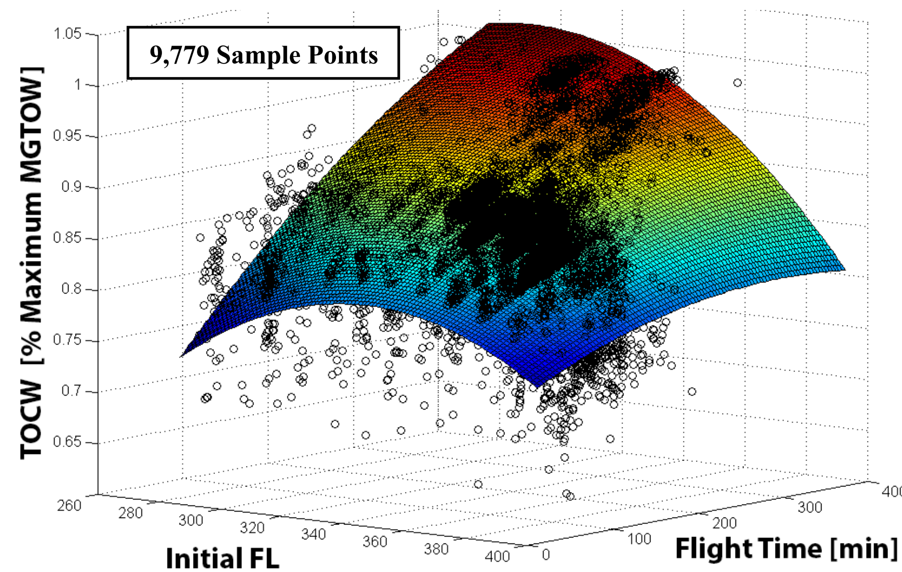
CASO Analysis Approach



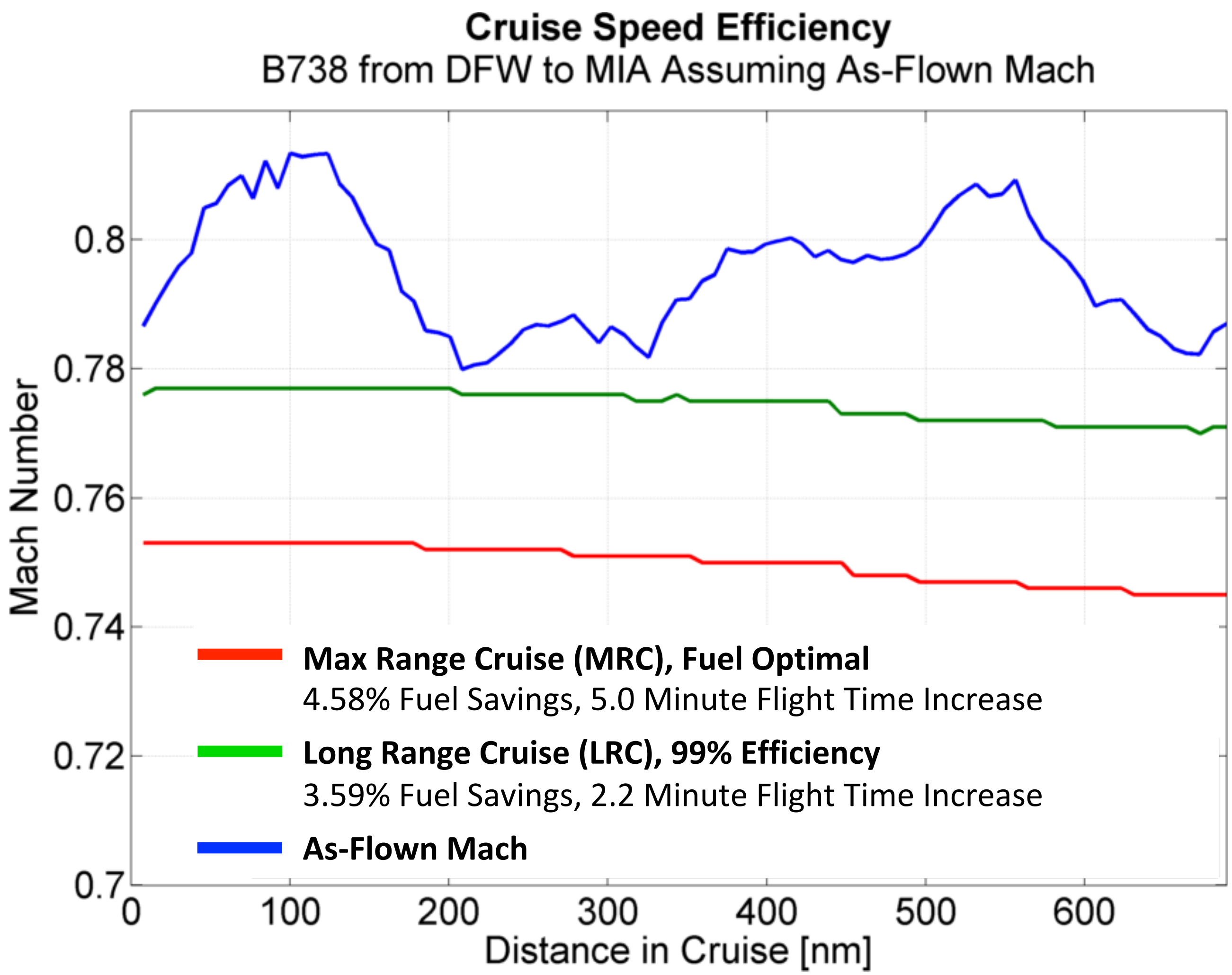
Estimating Aircraft Weight

- **Fuel consumption is dependent on aircraft weight**
- **Weight is not reported in public data sources**
- **Estimation method: regression surface using data provided by three major US airlines**
  - Regression variables
    1. Total flight time
    2. Initial cruise altitude
  - 35,131 sample flights including domestic US and long haul flights

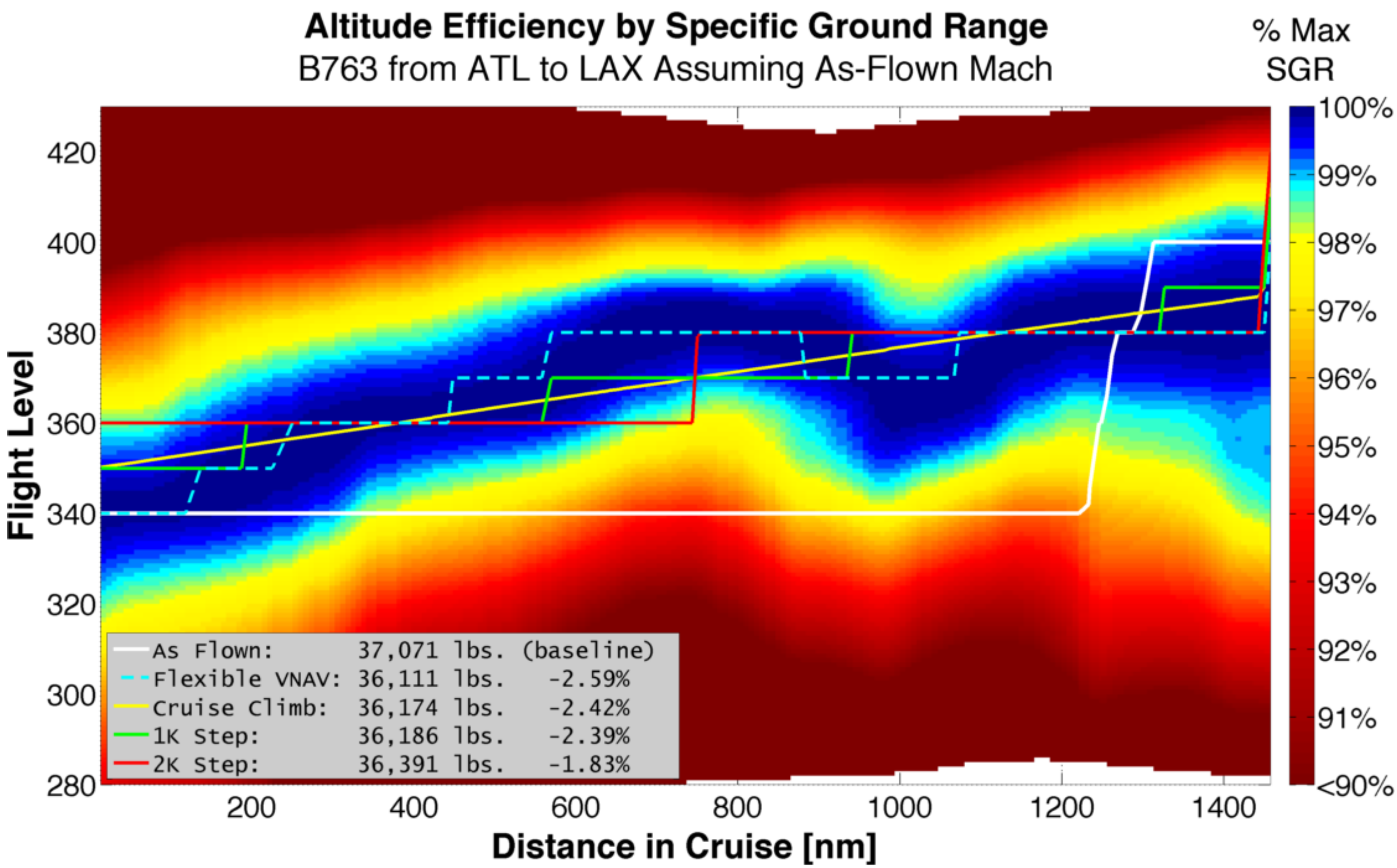
Example: A320 Weight Estimation Surface



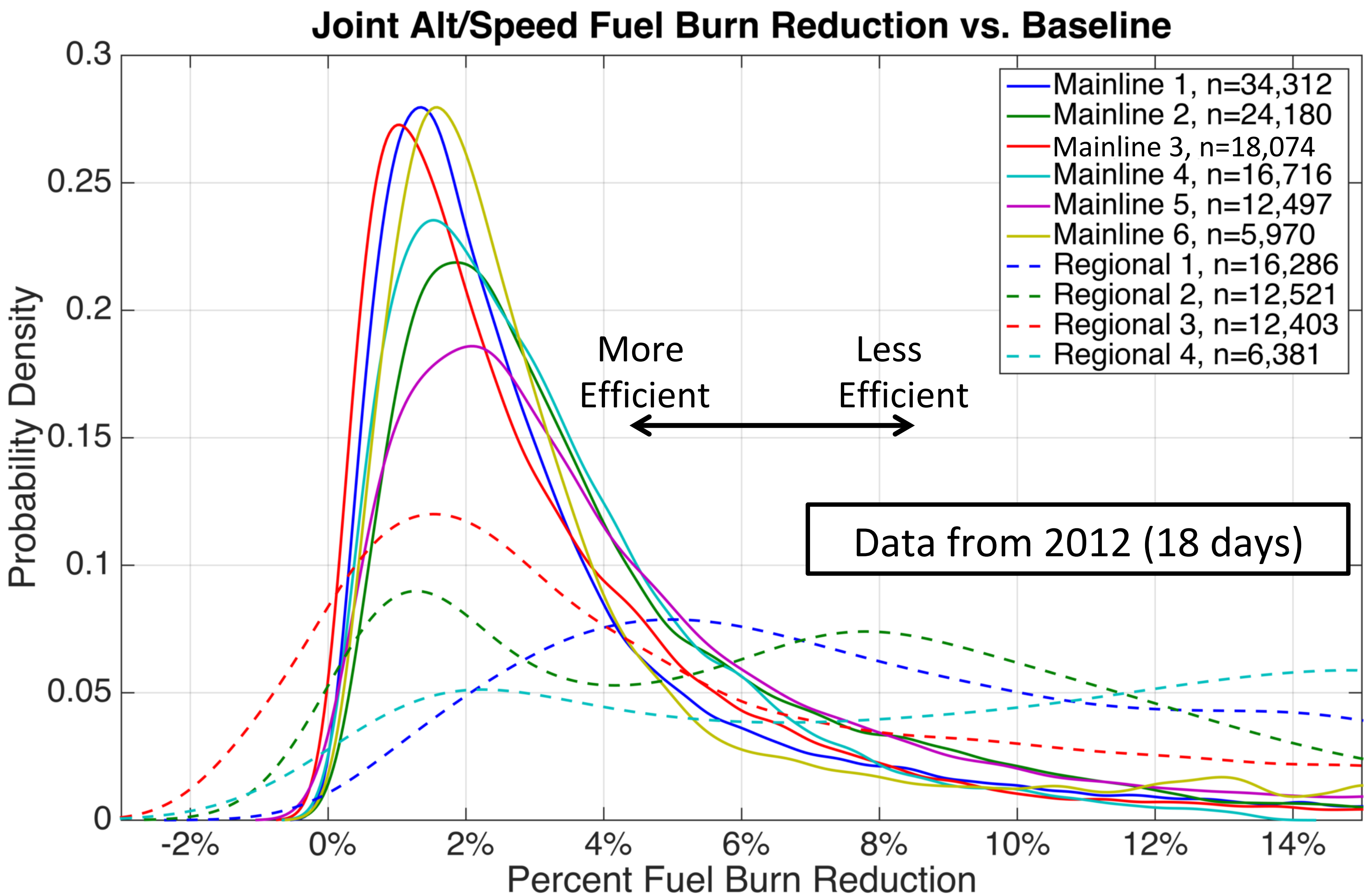
Single-Flight Speed Optimization



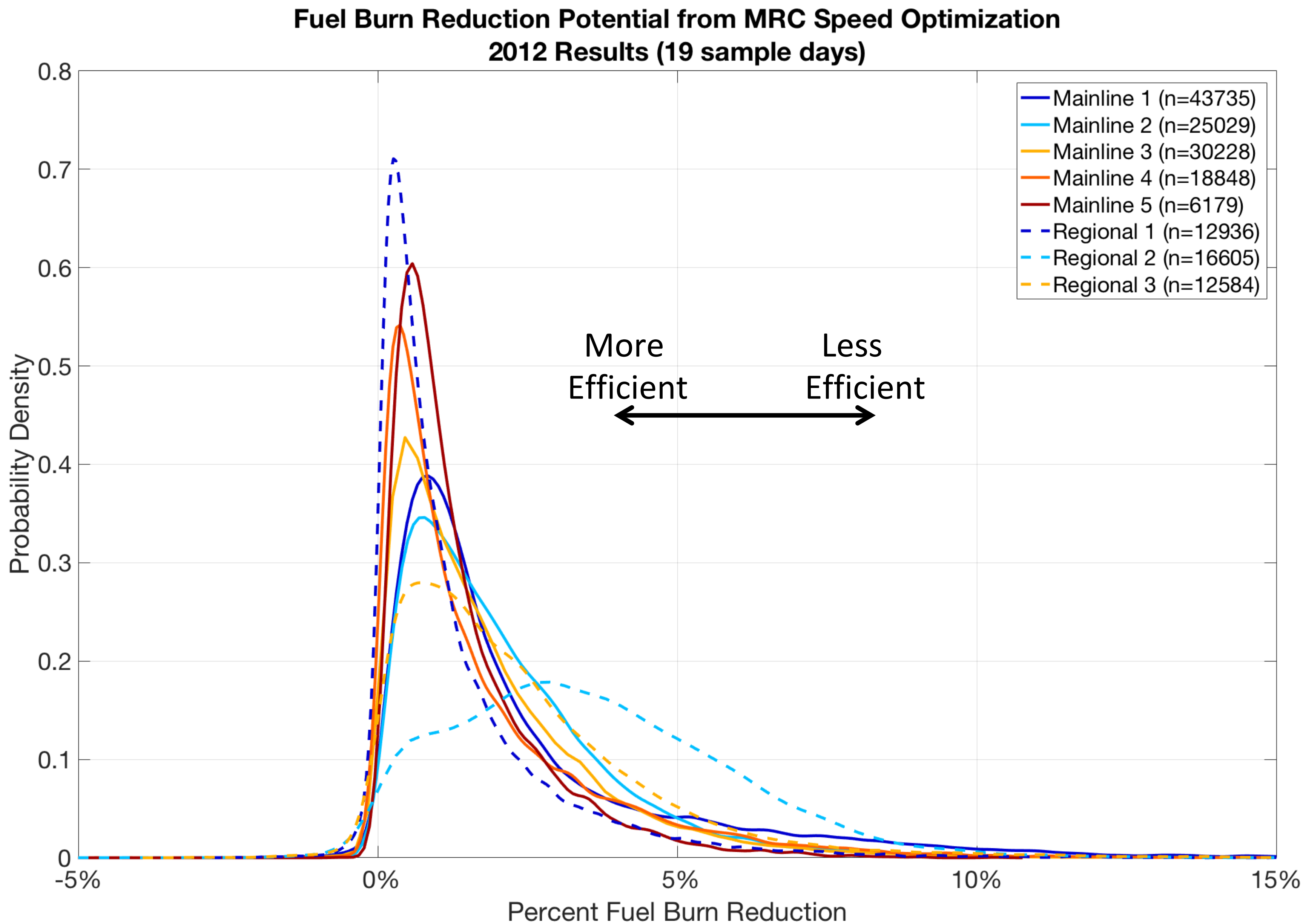
Altitude Optimization Tunnel



Joint Altitude and Speed Optimization for 2012 Data By Airline



Aggregate Speed Efficiency: 2012 Data



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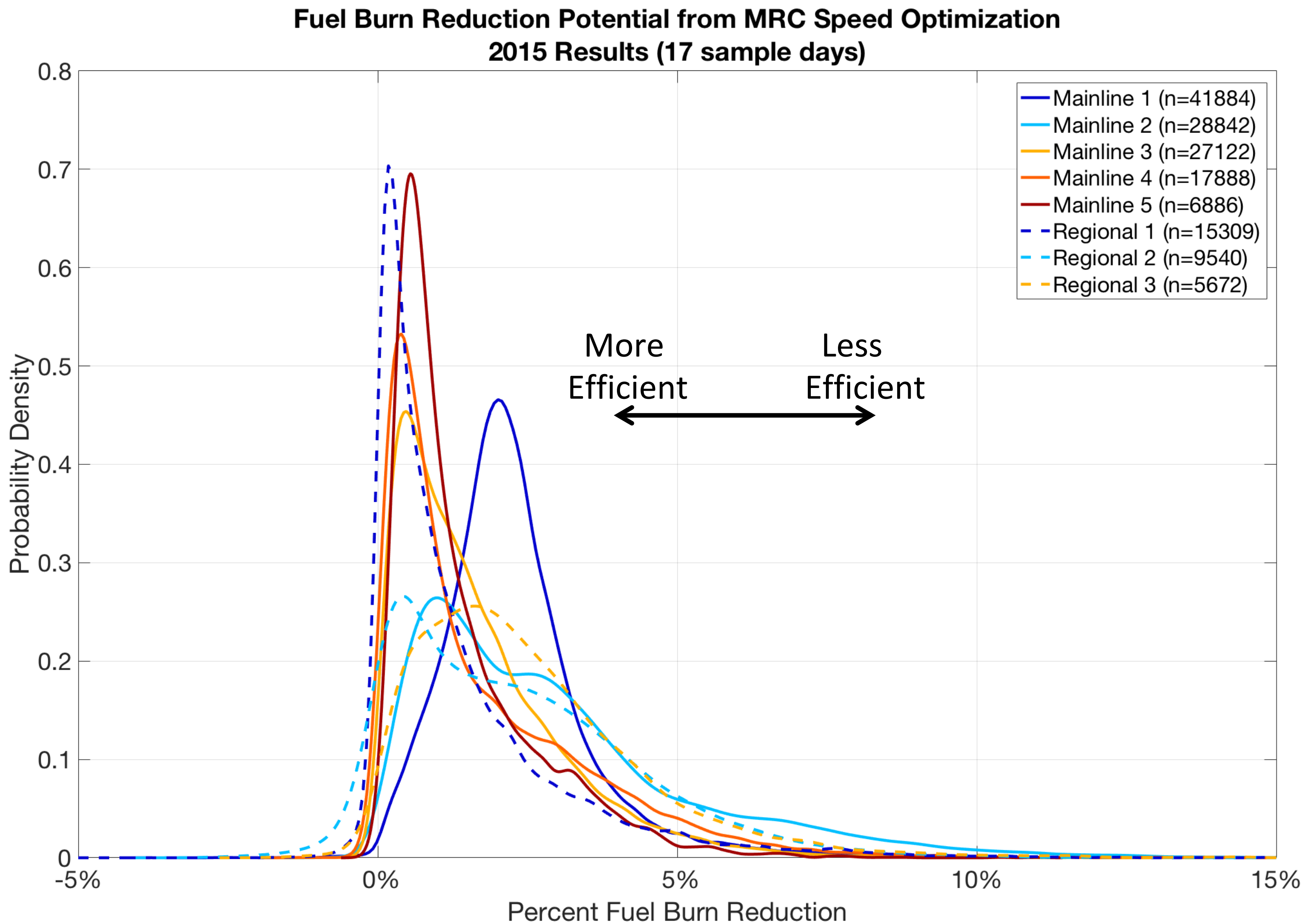
Aggregate Speed Efficiency: 2015 Data



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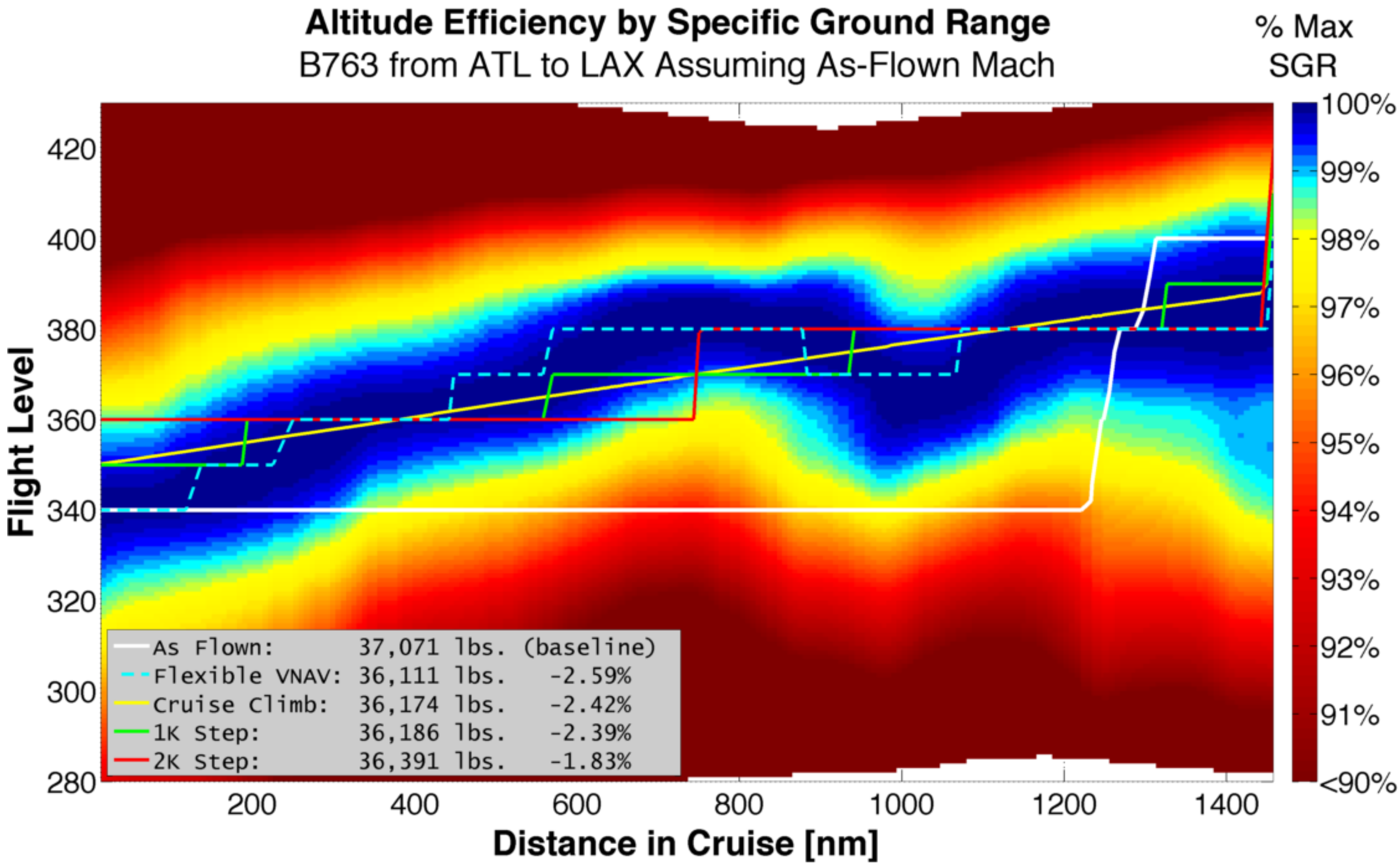
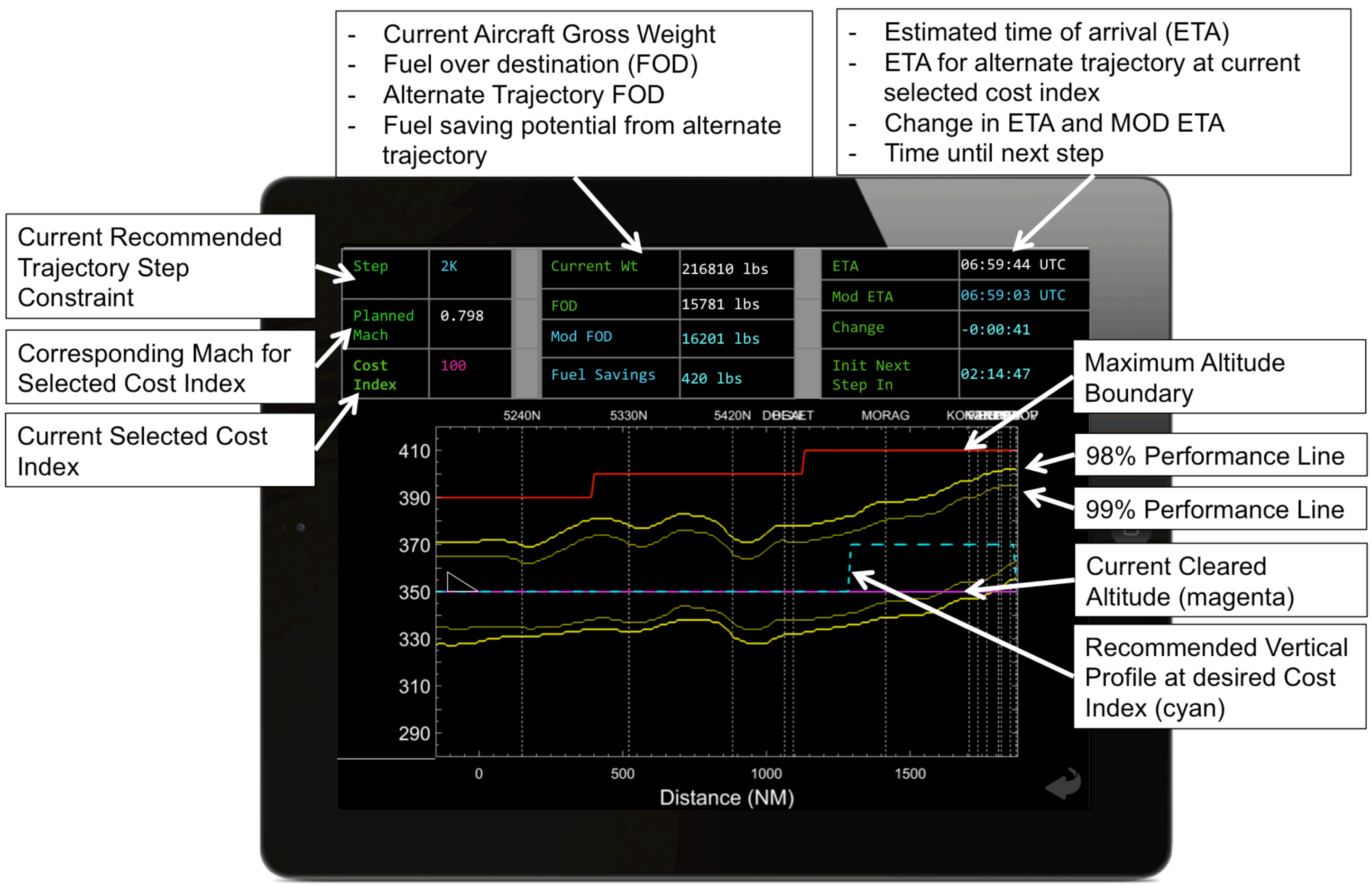
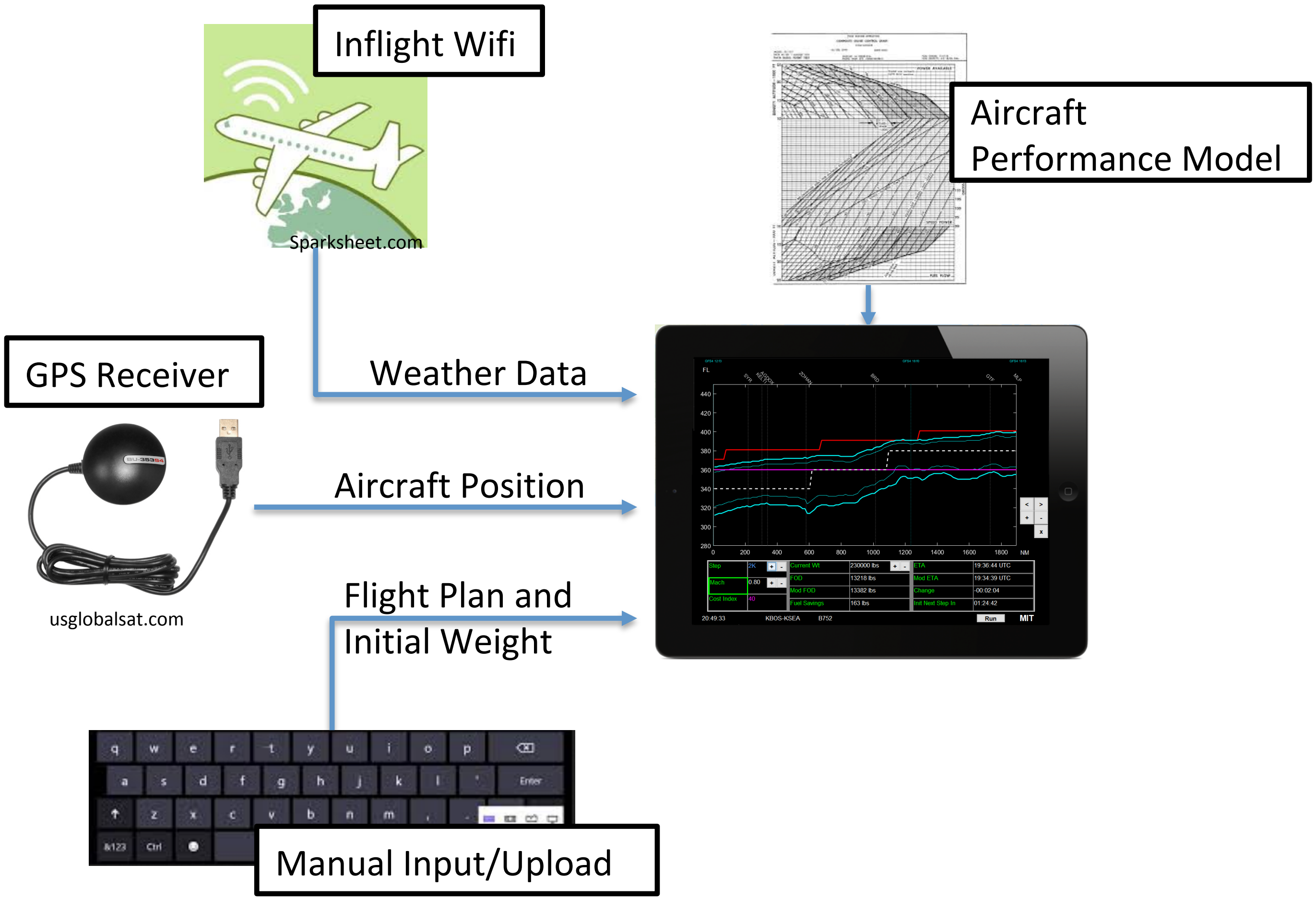


Prototype EFB Decision Support Tool

- Apply Cruise Altitude and Speed Optimization algorithm in an EFB tool to aid in pilot decision making
- Computes current and future aircraft fuel and schedule performance

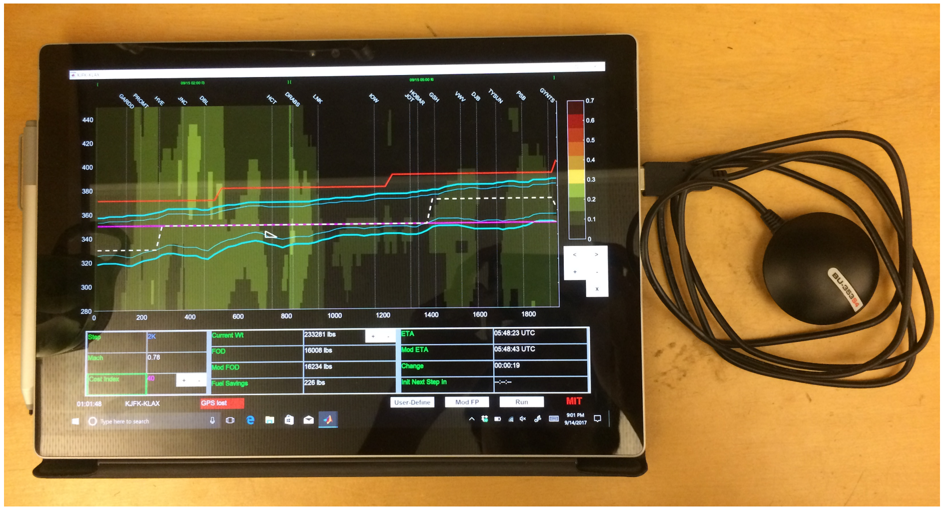


Prototype System



Standalone setup independent of aircraft systems developed for testing, but future integration with aircraft systems envisioned

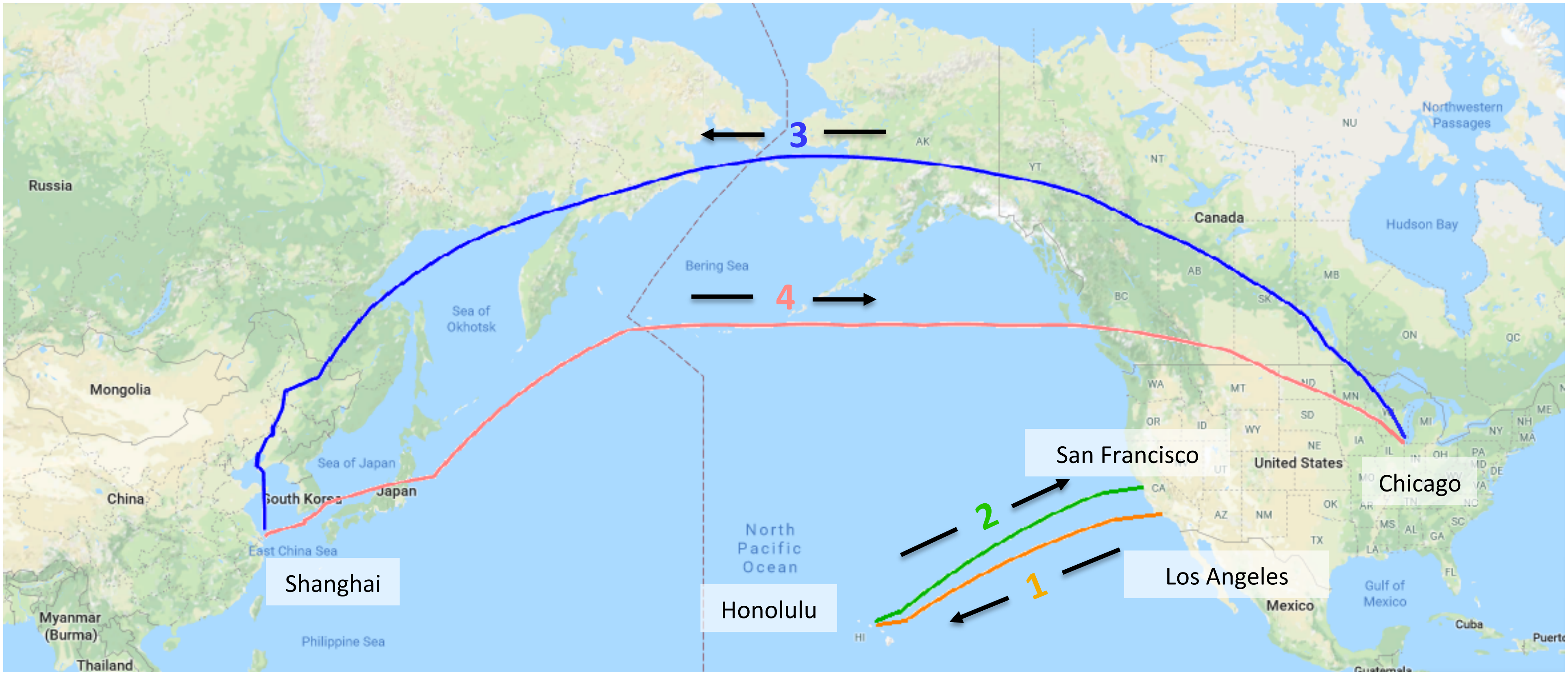
Prototype System for Preliminary Flight Trials



- Operational coordination opportunity with airlines
  - NDA signed with a major carrier
  - Preliminary flight trials flown

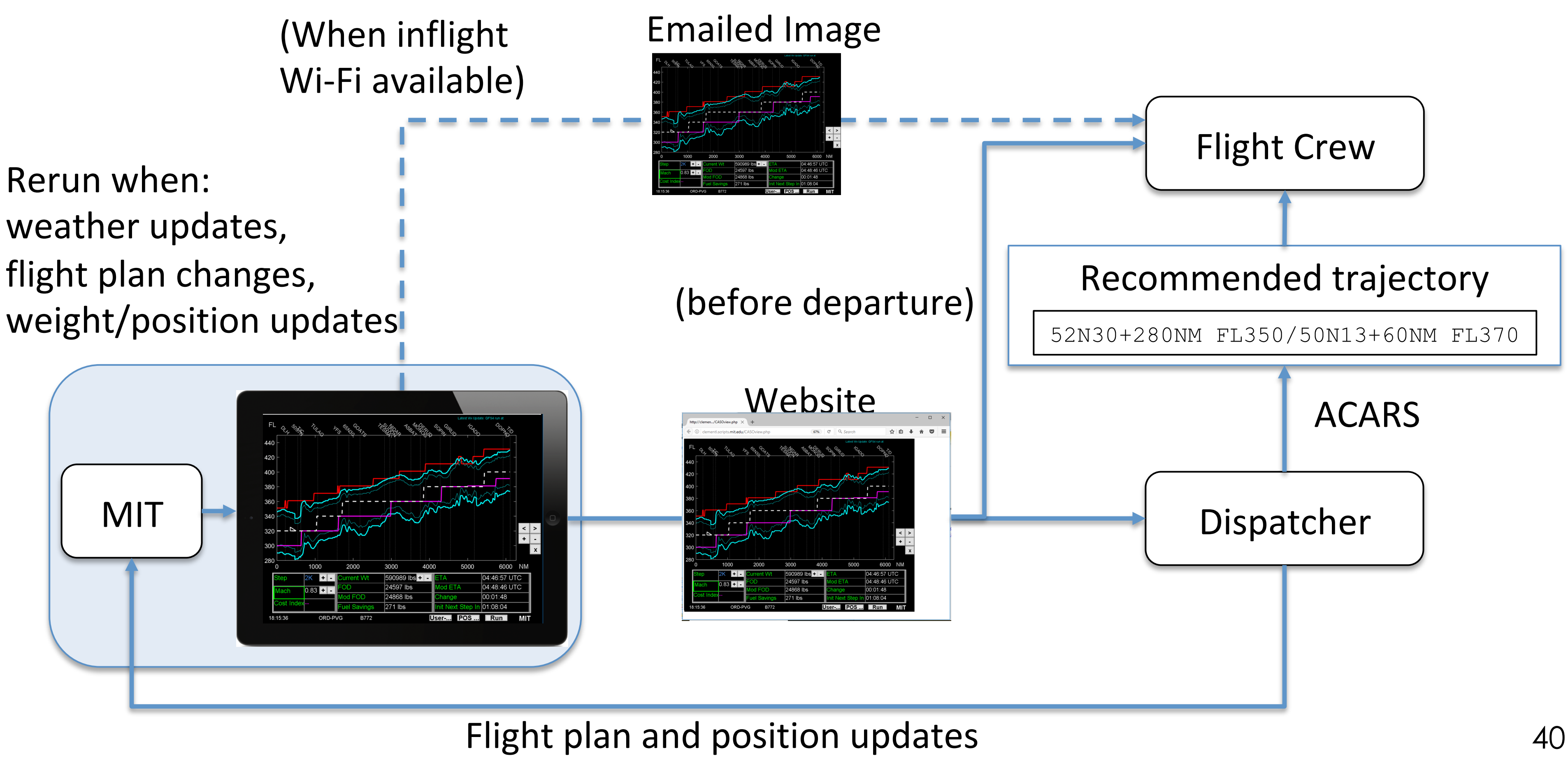
Preliminary Flight Trials

- Four flights currently conducted:
  - B772
  - LAX-HNL, HNL-SFO, ORD-PVG, PVG-ORD

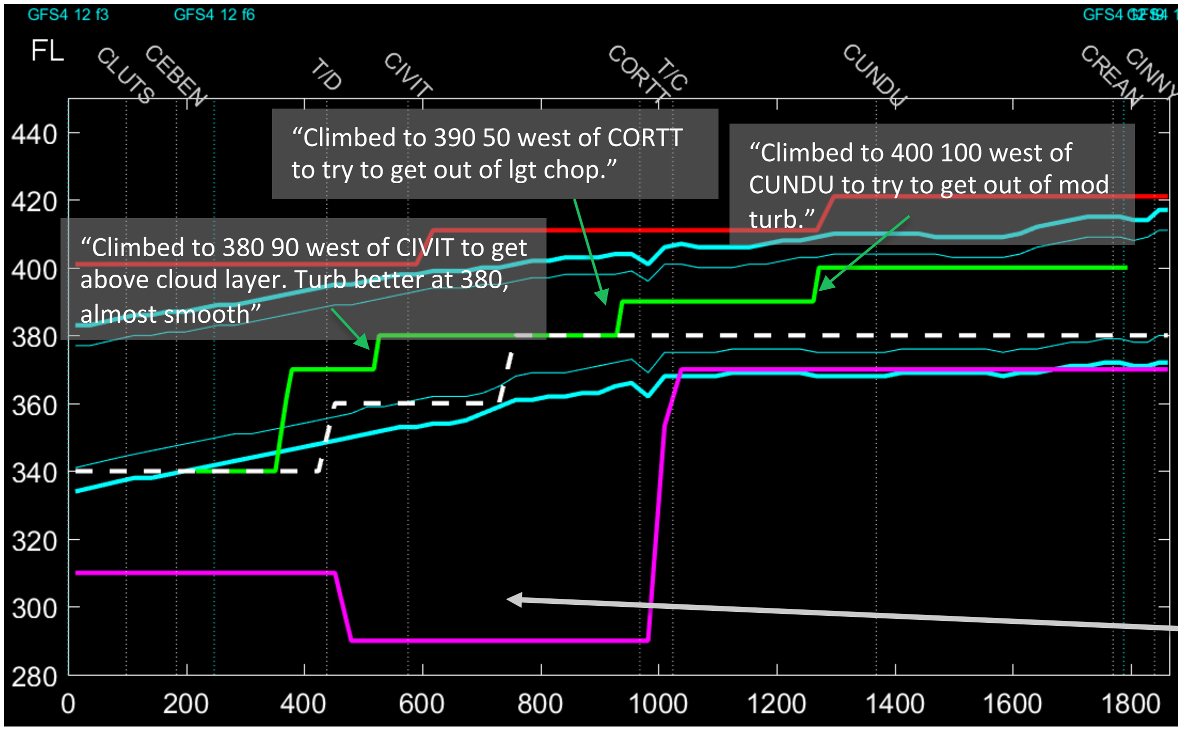


Flight Trial Set-Up

- Decision support tool run on a computer on the ground and information sent to crews and dispatchers, pending approval for jumpseat access



HNL-SFO Results



As-Flown
CASO Recommended
Flight Plan

Note: Turbulence not displayed during flight due to lack of formatted turbulence data

DISPATCHER REMARKS
15 MINUTES ADDED AS ETOPS PAD
FL290 DUE TURBS HIGHER

Performance from CEBEN to CREAN

Trajectory (Source)	Δ Fuel Burn (lbs)	Δ Time (min)
Flight Plan (Flight Plan prediction)	0	0
CASO Recommended (CASO prediction)	3659 lbs savings	1 min. longer
As-Flown (recorded)	3820 lbs savings	4 min. longer

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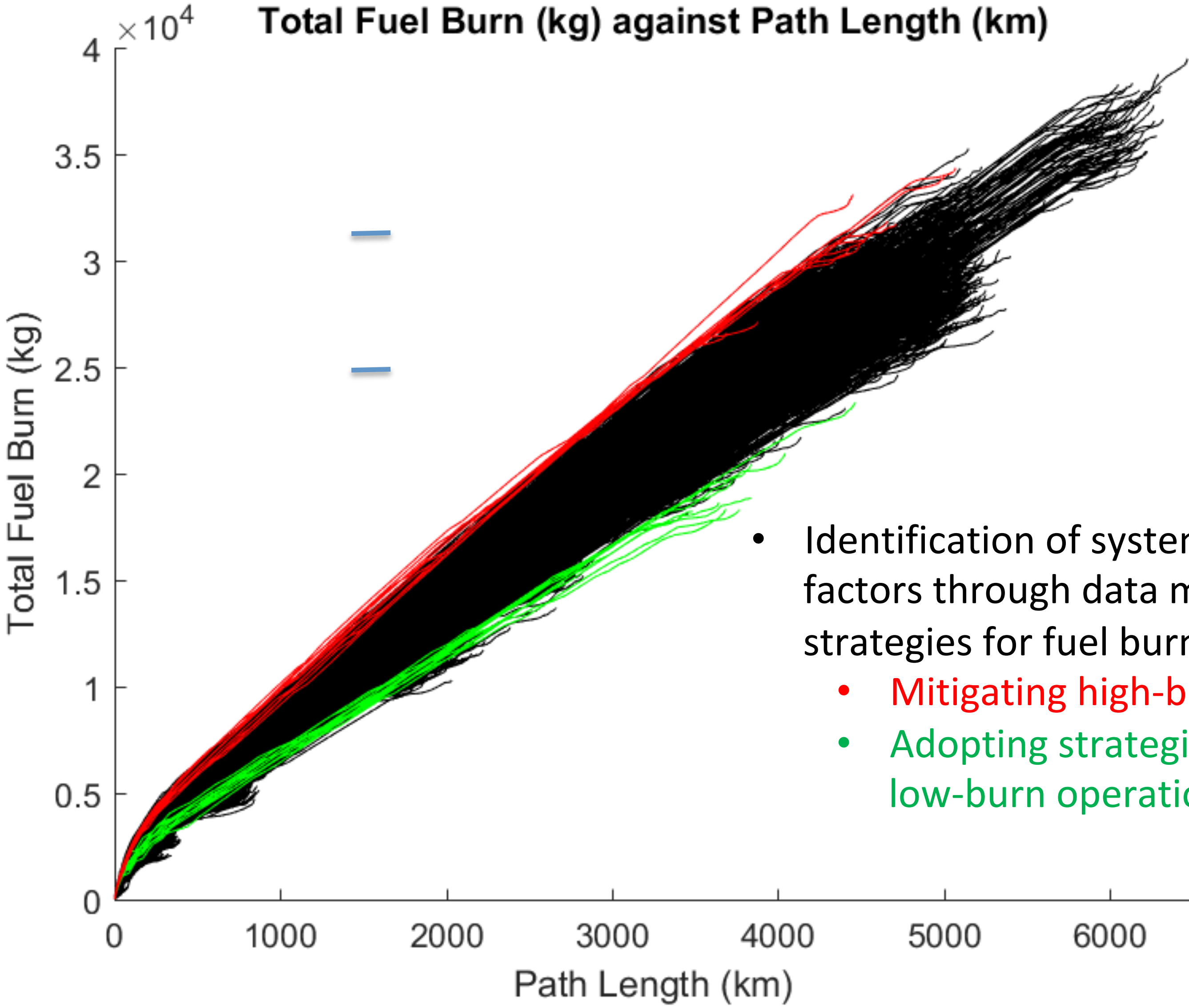
DFDR Fuel Burn Variability Example

A-330-200

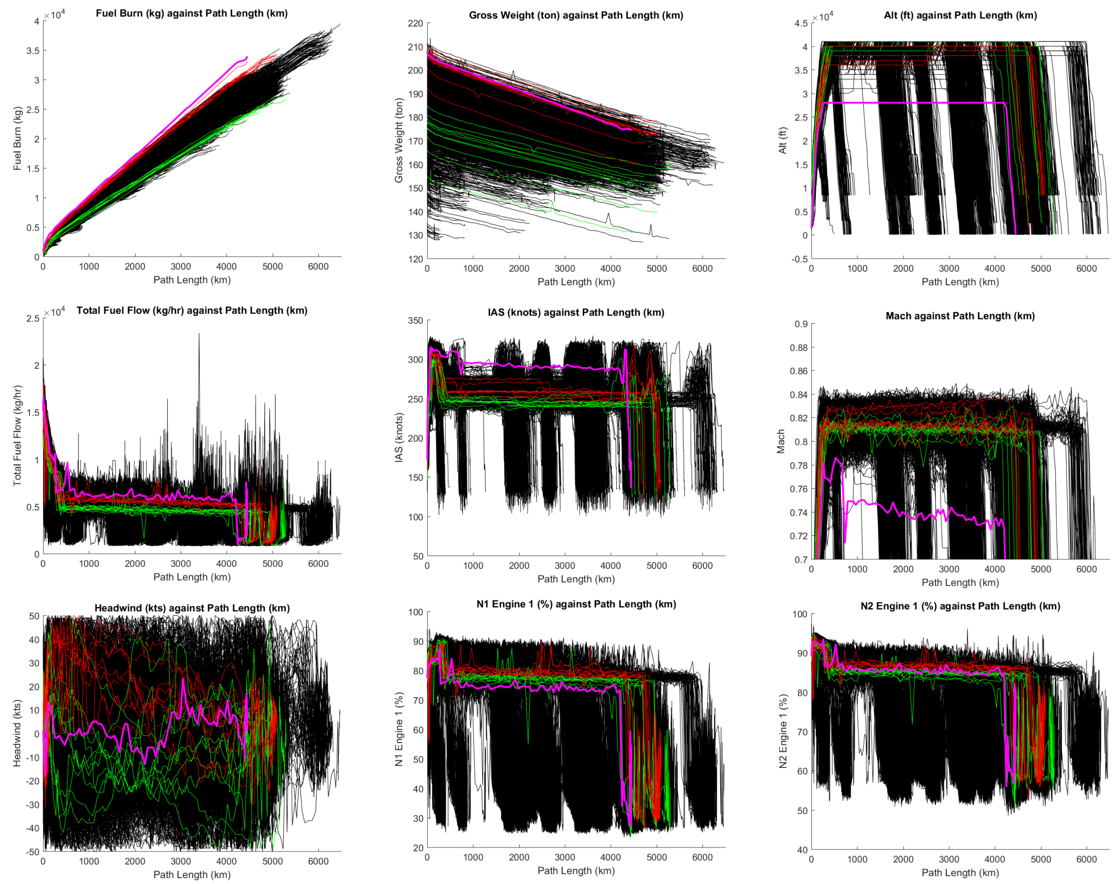


- Identification of systemic operational factors through data mining can inform strategies for fuel burn reduction
  - Mitigating high-burn operations
  - Adopting strategies observed in low-burn operations

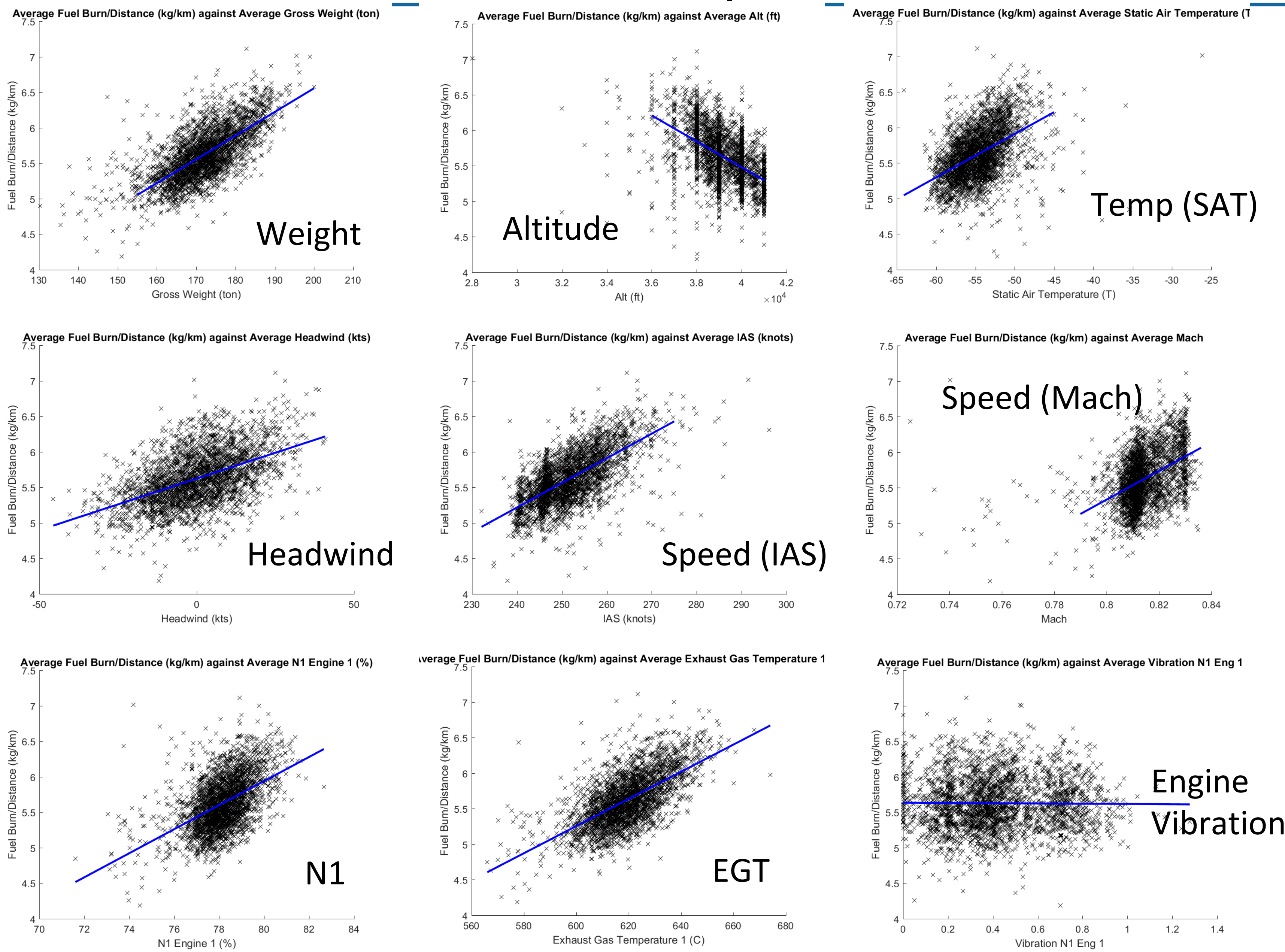
Example Flight Data Recorder Data

- Flight Data Recorders provide large set of internal states at relatively high resolution

- Data from collaboration with an airline
  - 278,404 flights
  - 14 Aircraft types
  - 2-5 mile resolution

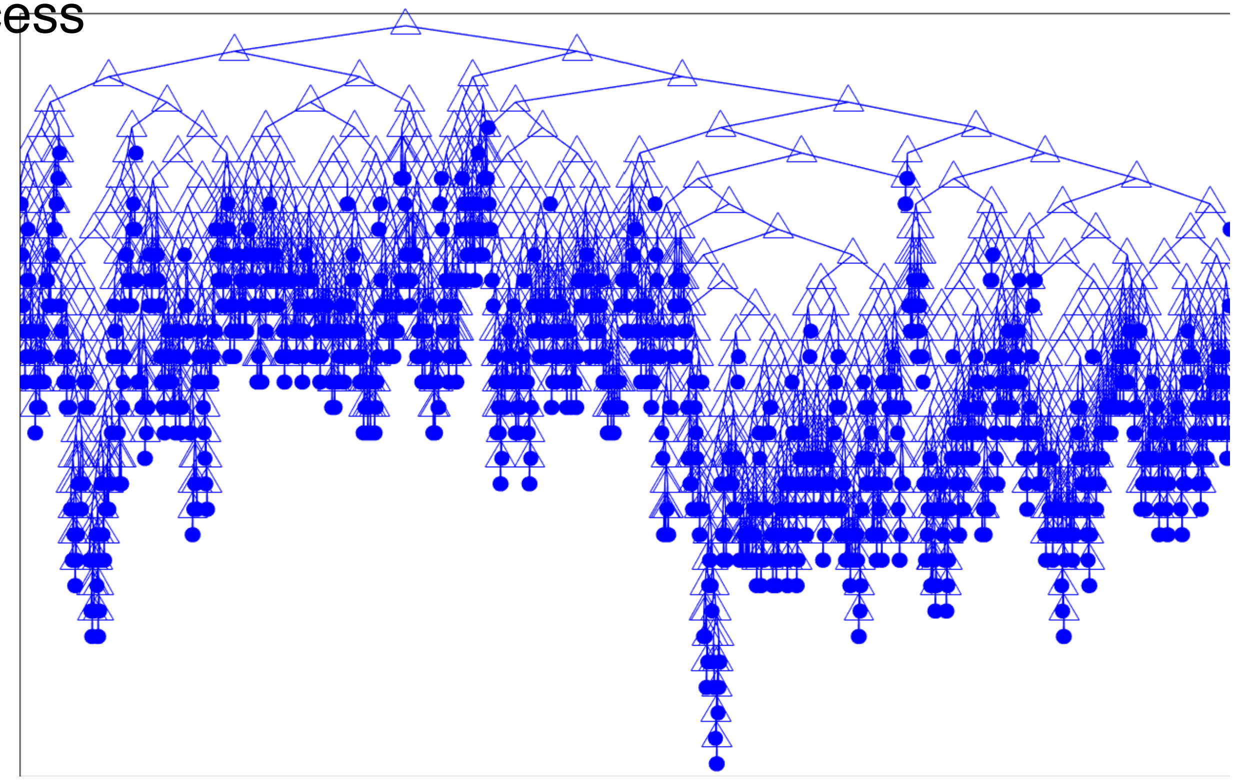


Example Correlations with Average Specific Fuel Consumption (kg/km)



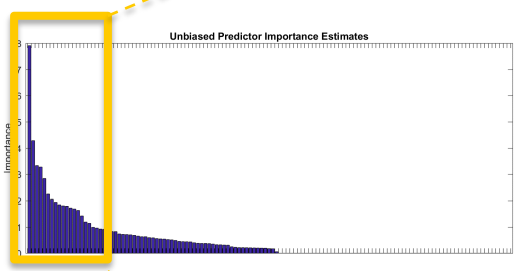
Random Forest Identification of Influence Factors

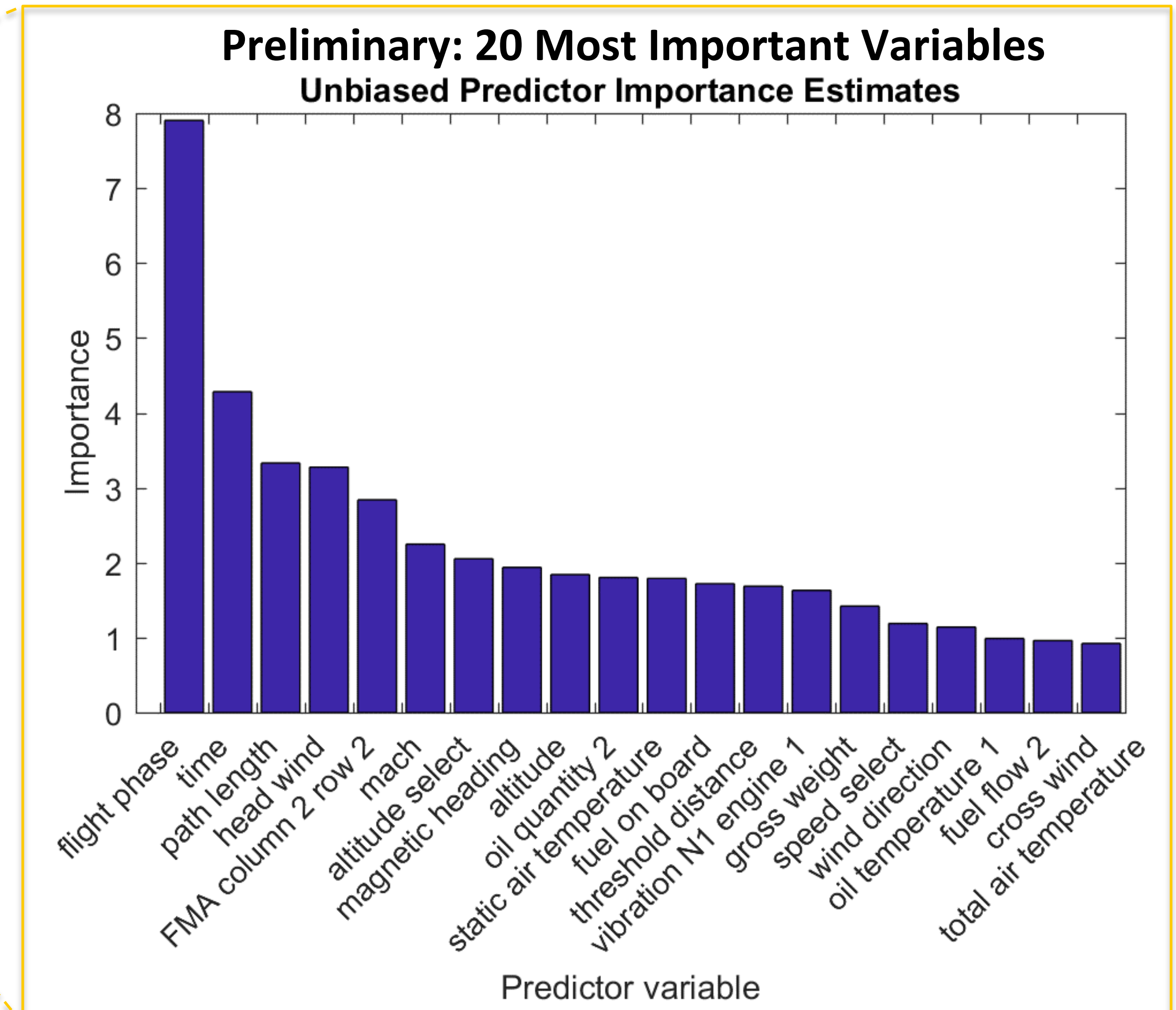
- Preliminary analysis
  - One widebody aircraft type
  - 20,000 segment observations from ~200 flights
  - Predicted variable: segment fuel burn
  - Trained 100 trees for 100 cycles
  - Analysis in process



Very Preliminary Results from Random Forest Identification (unverified)

- Very preliminary results from random forest to identify important factors





Trained on 20,000 FDR segment observations for segment fuel burn

Examples

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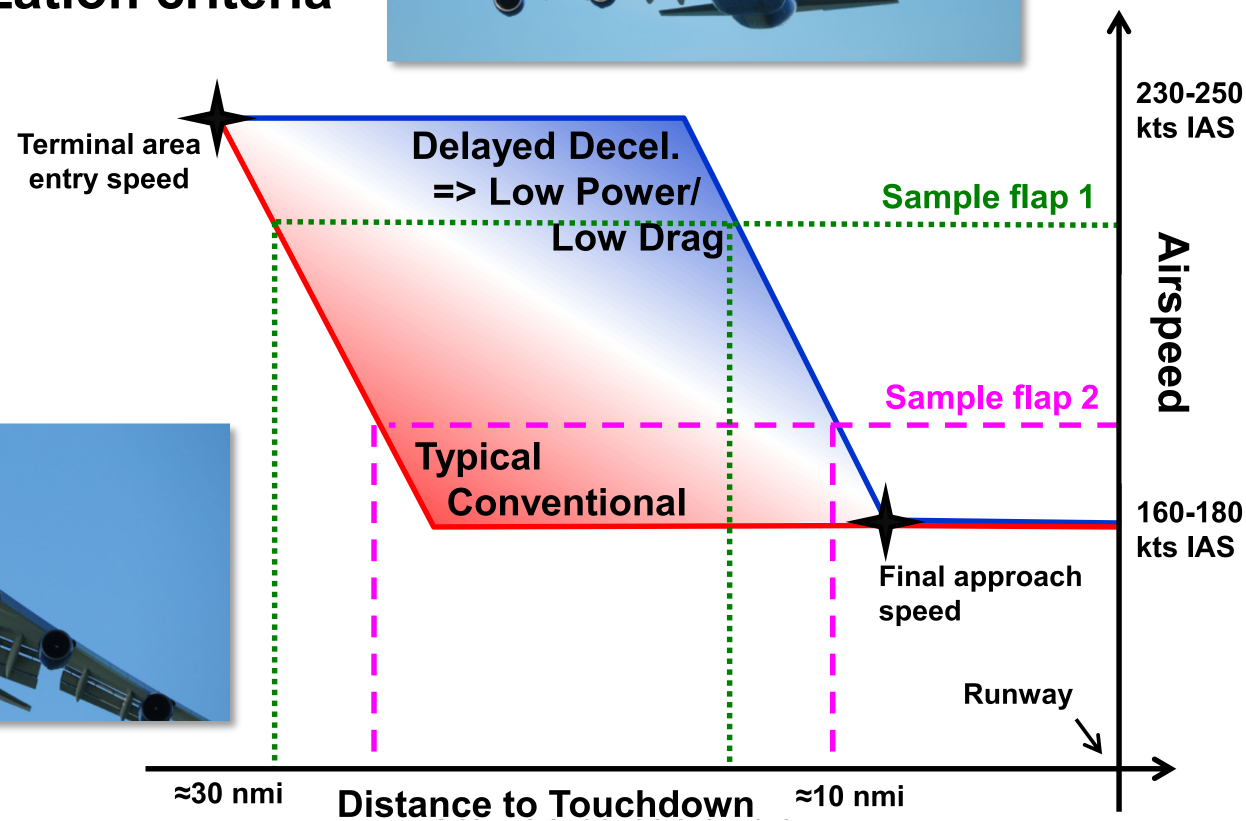
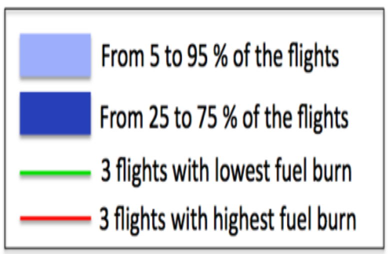
Delayed Deceleration Approach (DDA)

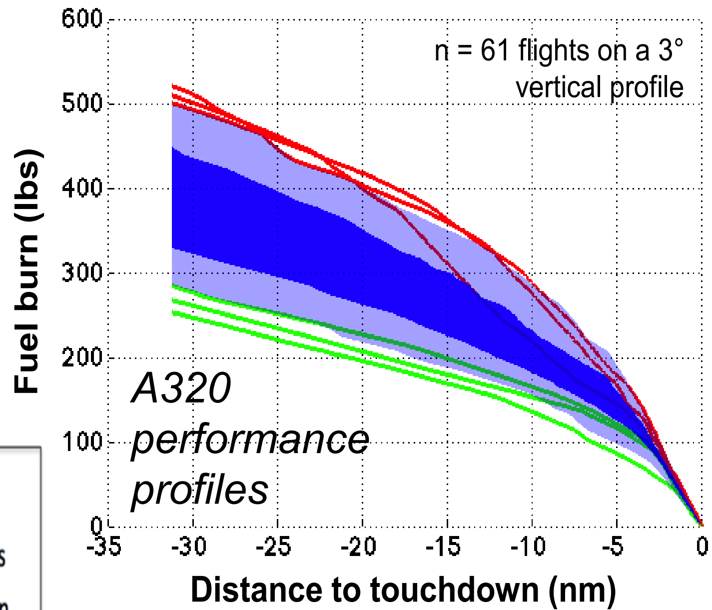
- **Keep aircraft "clean" for longer on approach when appropriate without impacting terminal area entry or final approach stabilization criteria**
  - **Between these speed gates, opportunity for encouraging more efficient approach speed profiles**

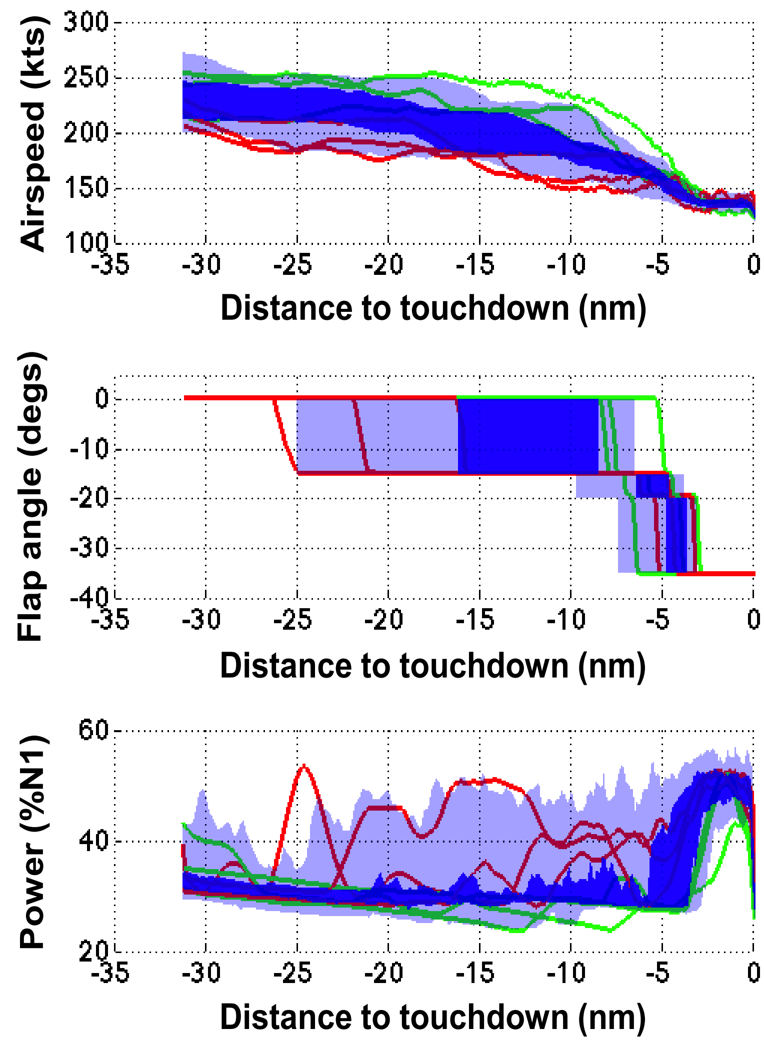


DDA Fuel Benefits Potential

European A320 Flight Data Recorder Analysis
(similar results for B757 & B777)







- **Lowest fuel burn flights (green profiles) associated with delayed deceleration**

30-50% fuel burn reduction potential from DDAs from 10,000 ft to touchdown, similar to Continuous Descent Approach (CDA)

Examples

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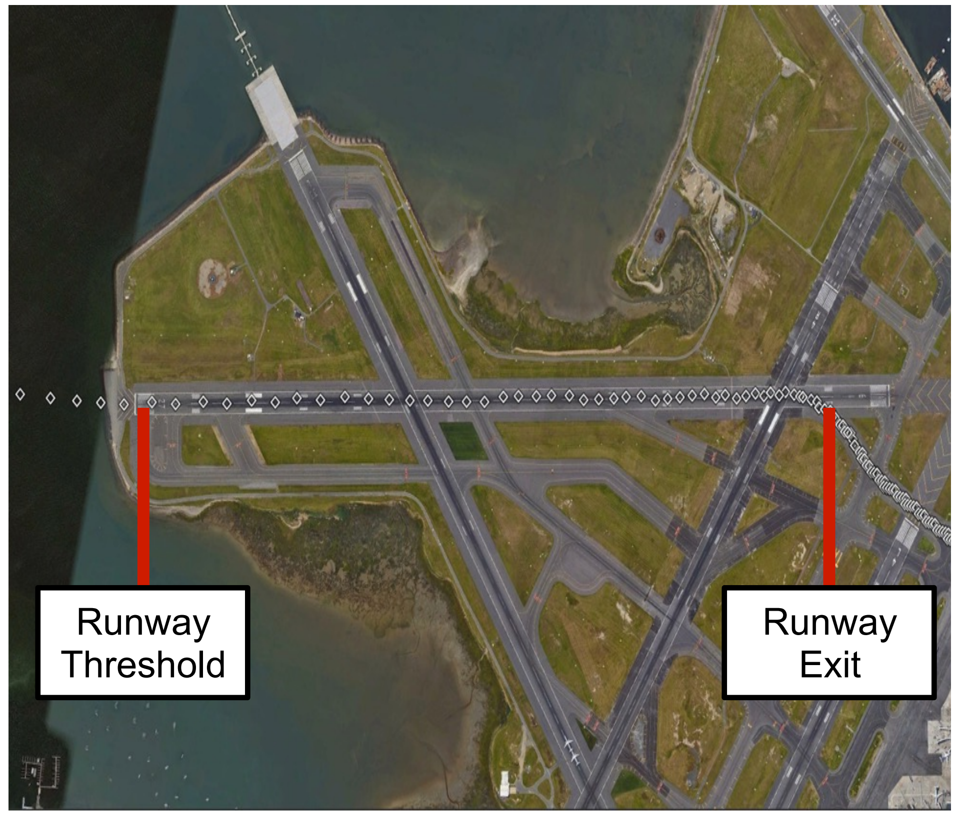
Runway Occupancy Time Optimization

- **Runway Occupancy Time (ROT)** is an **increasing limitation to Runway Capacity**
- **Understand factors driving ROT** & develop **predictive models to optimize ROT**
- Analysis of **3 million landings** around US Airports using ASDE-X radar tracks

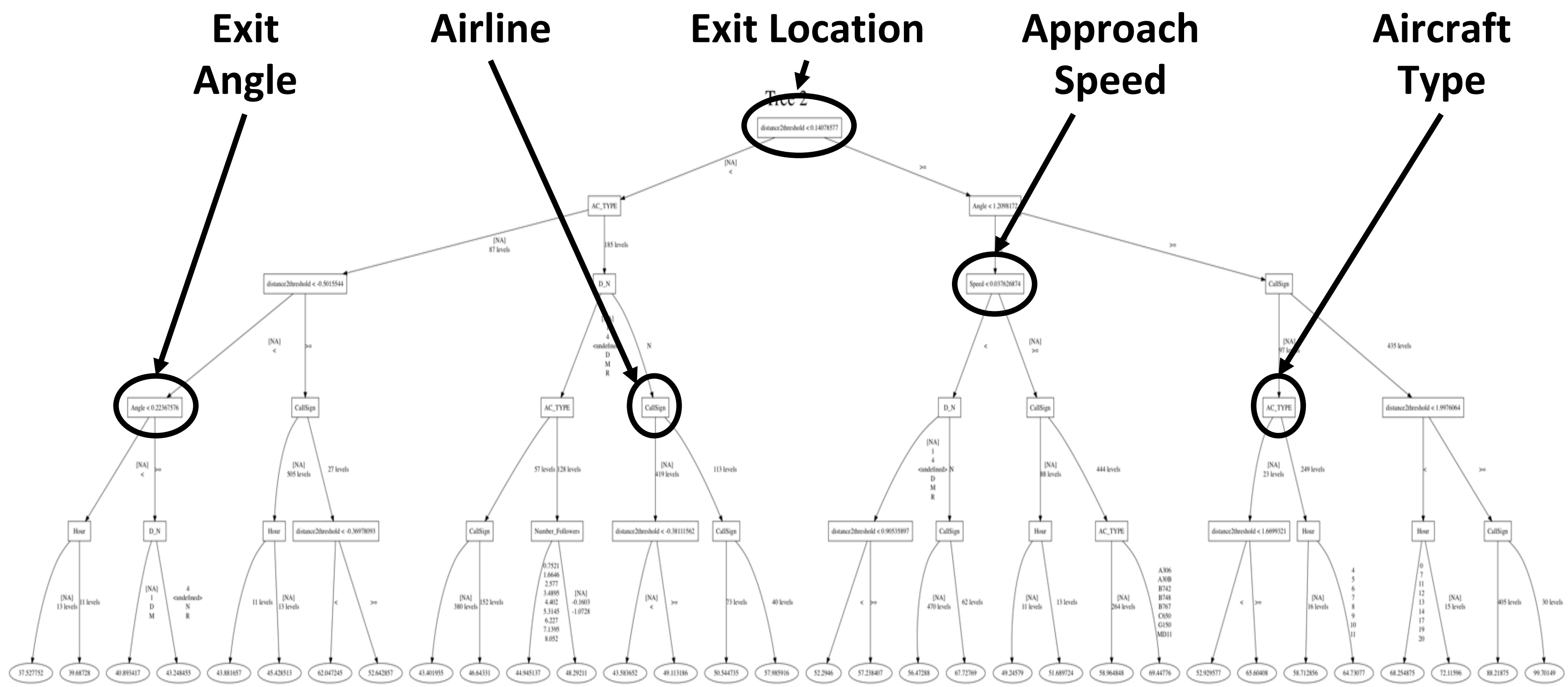
Example: 1 day of ASDE-X tracks

Example: single landing flight



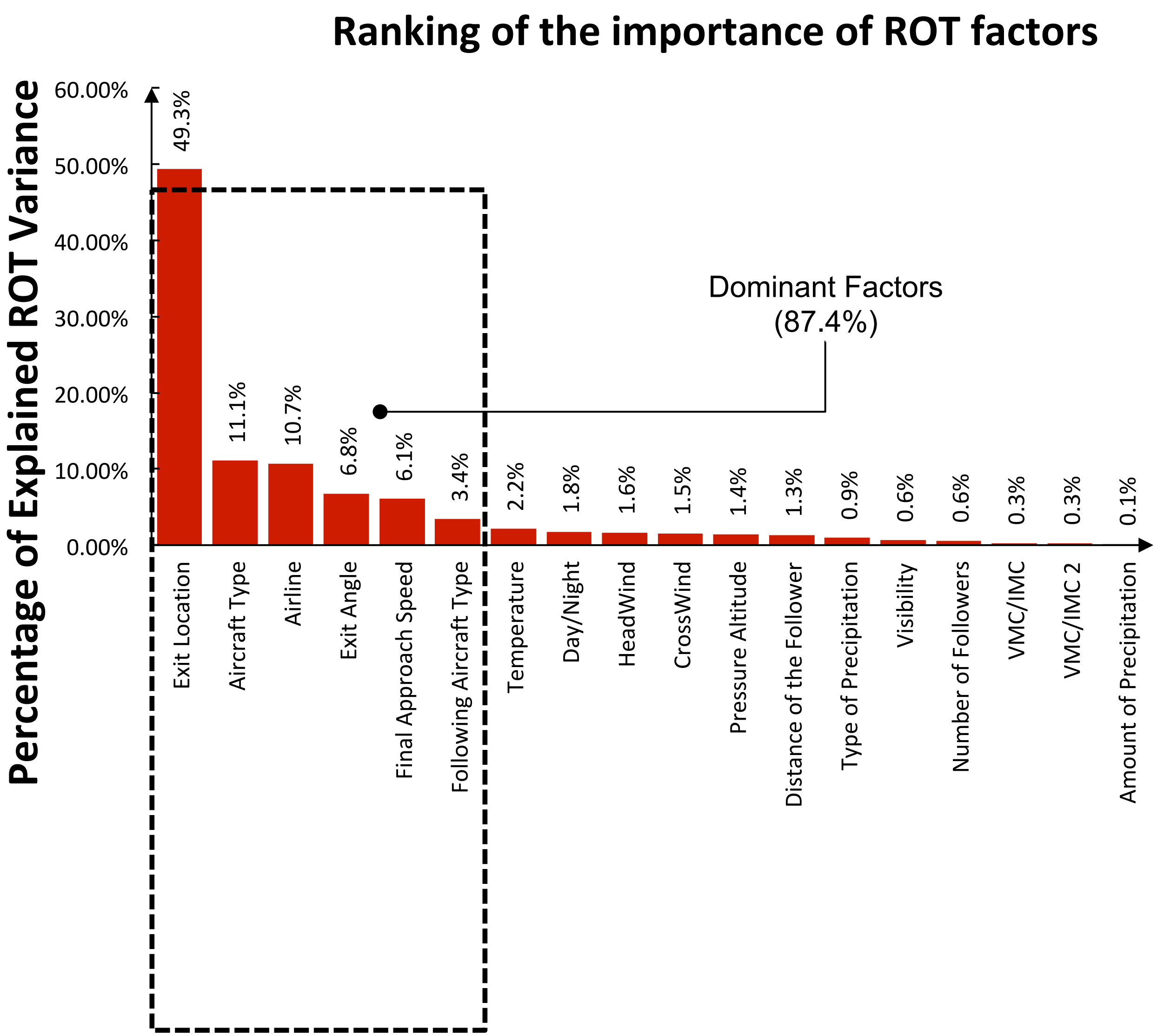
Identifying Factors Driving ROT Using Random Forest

- Estimation of the **relative importance of different factors** to explain the variance of ROT
  - Using the collected **ROT database for US Airports**
  - Using a **random forest algorithm** : forest of 300 trees of max depth 25



➢ Most important predictors appear more often in trees & contribute more to variance decrease

Identifying Factors Driving ROT Using Random Forest



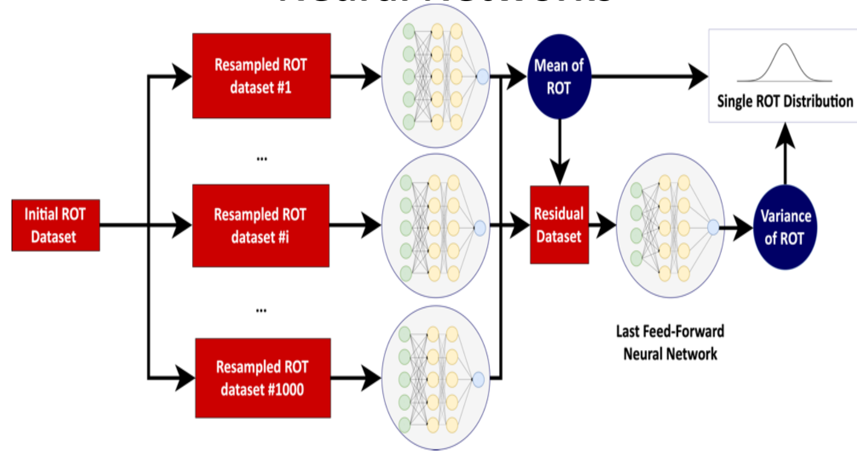
- **Most important predictor:**
  - Exit location
- **Major impact on ROT:**
  - Aircraft type
  - Airline
  - Exit angle
  - Final Approach speed
  - Type of following aircraft

Optimizing ROT using Predictive ML Models

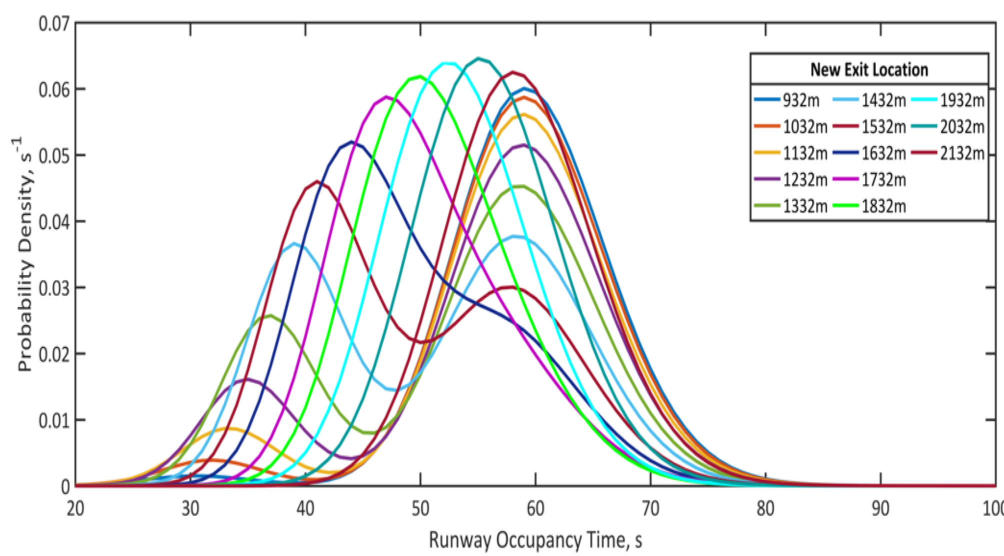
- **Development of Machine Learning predictive models able to predict ROT** based on airport configuration, fleet mix & environment

- Use of predictive models to **propose optimal changes to runway exit systems** of airports

Predictive runway occupancy time model using Neural Networks



Example of predicted ROT distributions at major European airport



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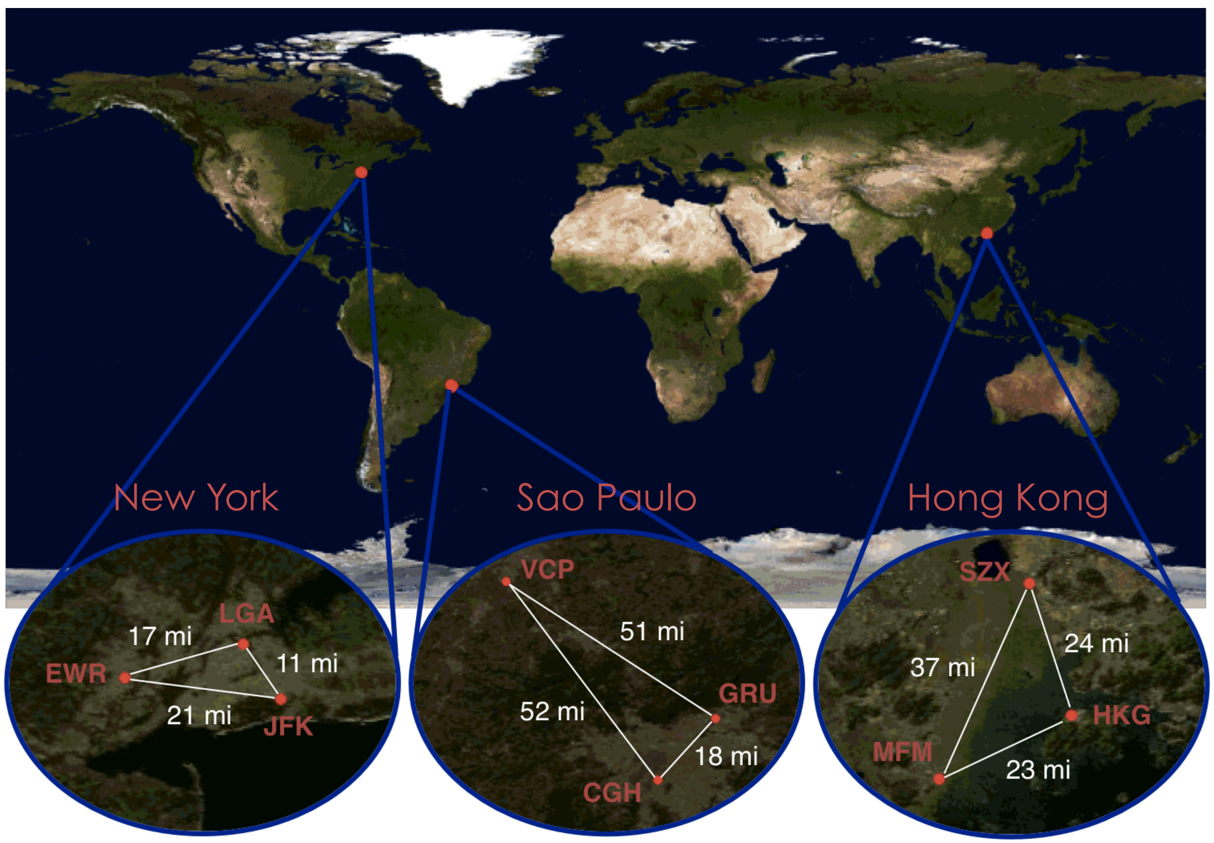
Comparative Analysis of 3 Metroplexes

New York, Hong Kong, Sao Paulo

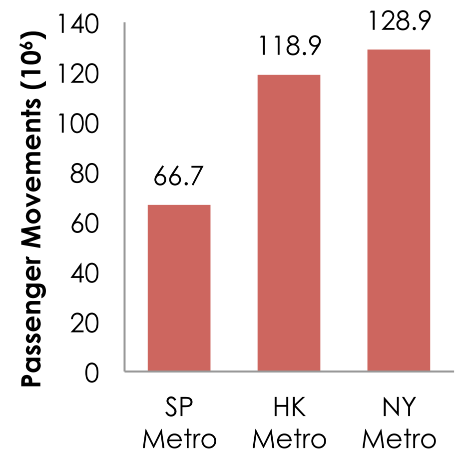
- 60 days of flight tracks at the NY, HK and SP metro airspace
  - 55% fair weather days and 45% weather-impacted days

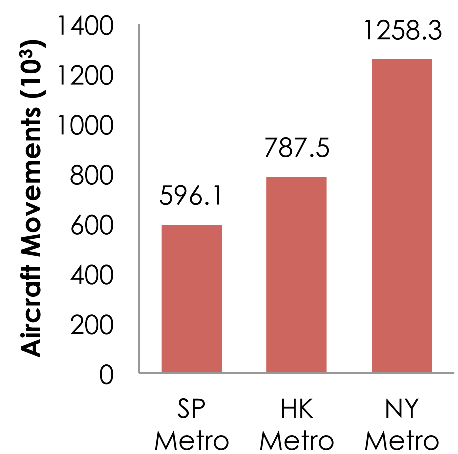


JFK – John F. Kennedy
EWR – Newark
LGA – LaGuardia

GRU – Guarulhos
CGH – Congonhas
VCP – Viracopos

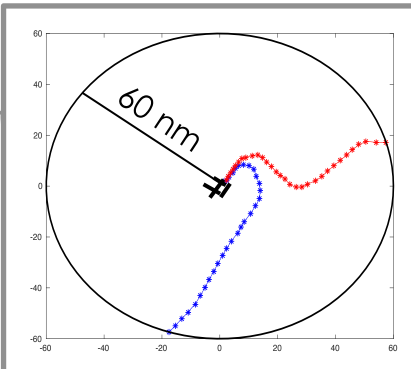
HKG – Hong Kong
SZX – Shenzhen Bao'an
MFM – Macau





Flight Trajectory Data Analytics Framework

RAW DATA: OBSERVED FLIGHT TRACKS (ETMS) FOR 69 DAYS



FILTERED AND RESAMPLED FLIGHT TRACKS

$F_1 = (x_{11}, y_{11}, x_{12}, y_{12}, \ldots, x_{1n}, y_{1n})$

$F_2 = (x_{21}, y_{21}, x_{22}, y_{22}, \ldots, x_{2n}, y_{2n})$

$\vdots$

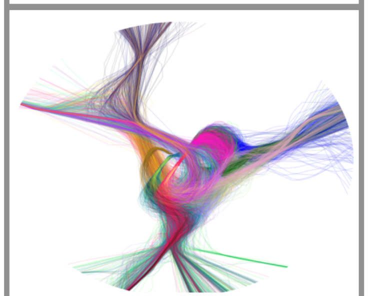
$F_m = (x_{m1}, y_{m1}, x_{m2}\ y_{m2}, \ldots, x_{mn}, y_{mn})$

TRAINING DATA: 14 days

TEST DATA: 55 days

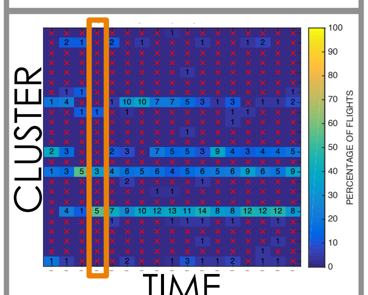
CLUSTERING AT SPATIAL SCALE
-DBSCAN-

AIRSPACE STRUCTURE



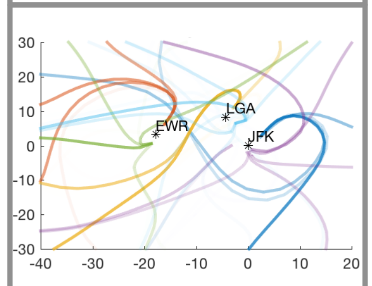
CLASSIFICATION
-RANDOM FORESTS-

FLOW PATTERN MATRIX/VECTOR



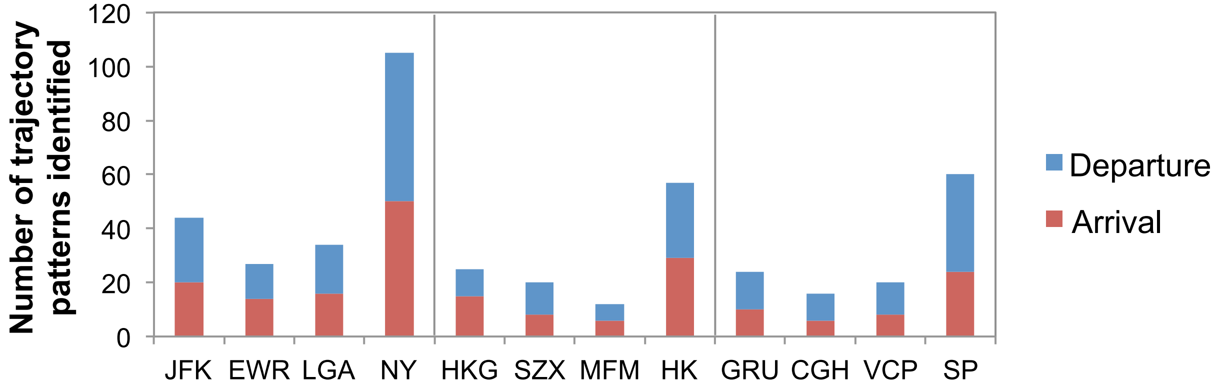
CLUSTERING AT TEMPORAL SCALE
-HIERARCHICAL CLUSTERING-

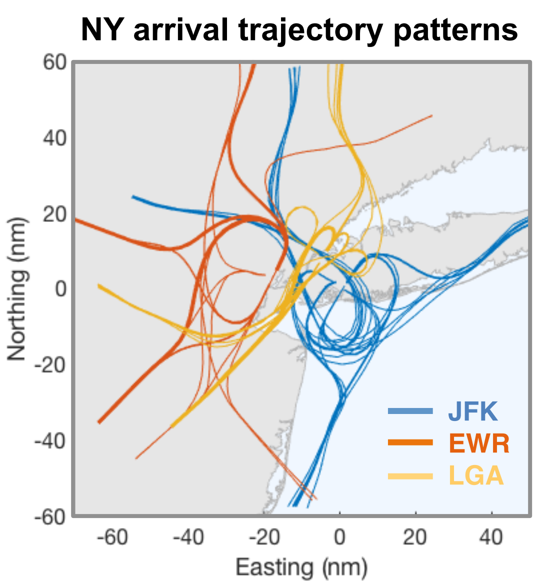
METROPLEX FLOW PATTERNS

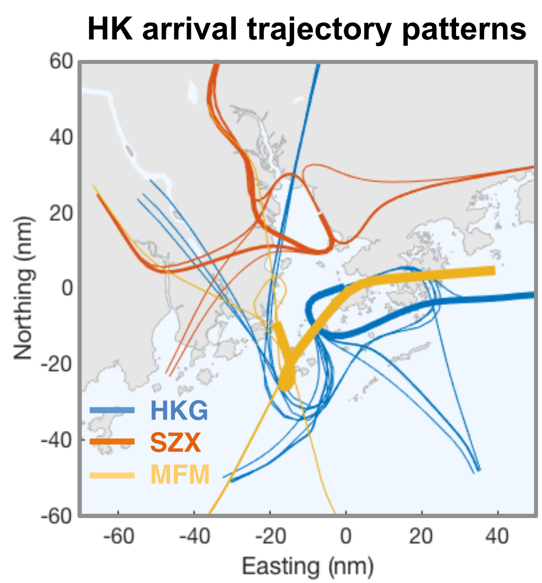


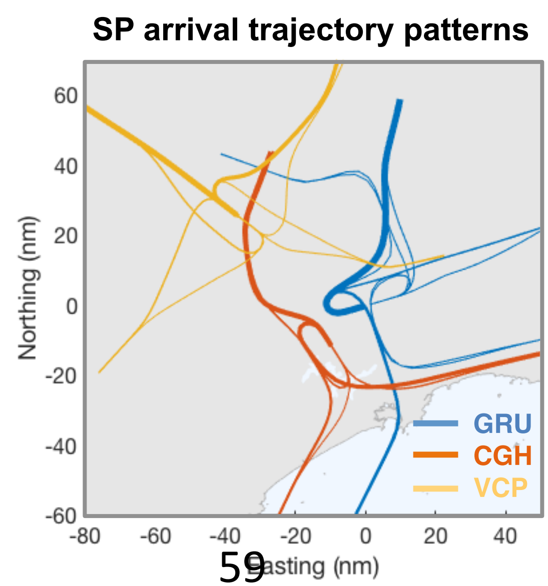
Analysis of Terminal Airspace Structure

- Spatial trajectory patterns identified with trajectory clustering
  - NY stands out with the highest number of routes; SP and HK have more similar structure



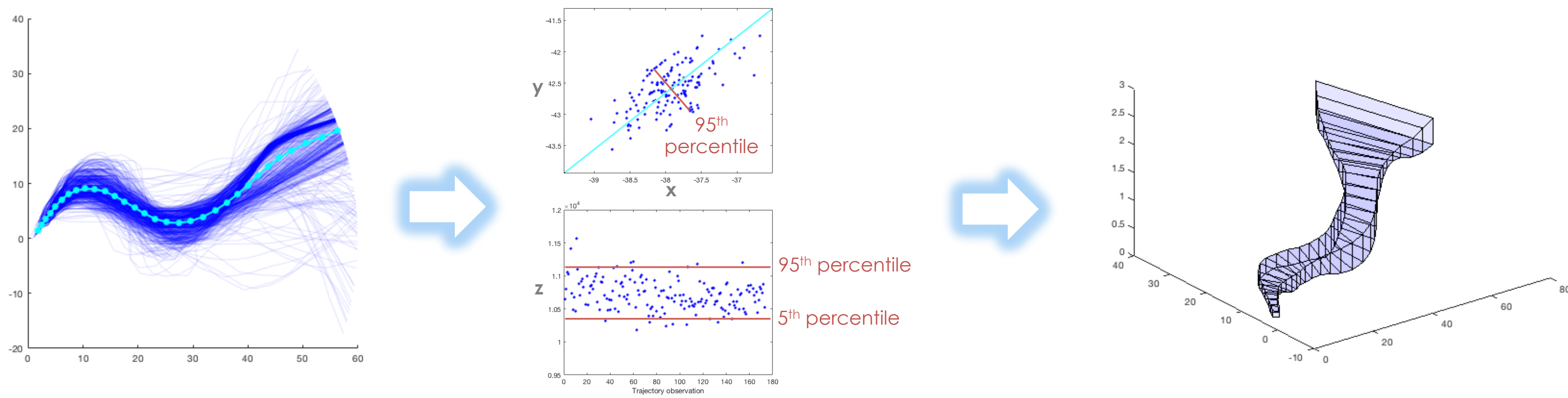






Analysis of Terminal Airspace Structure

- 3D trajectory tubes created based on lateral and vertical dispersion of trajectories in each cluster



- Route intersections identified with pairwise analysis of trajectory tubes
  - NY has the most conflicted airspace structure (especially JFK-LGA)
  - Airspace structures of HK primary airports are highly de-conflicted

	JFK	EWR	LGA
JFK		42	130
EWR	42		91
LGA	130	91	

	HKG	SZX	MFM
HKG		12	28
SZX	12		30
MFM	28	30	

	GRU	CGH	VCP
GRU		53	10
CGH	53		16
VCP	10	16	

Analysis of Traffic Flow Dynamics

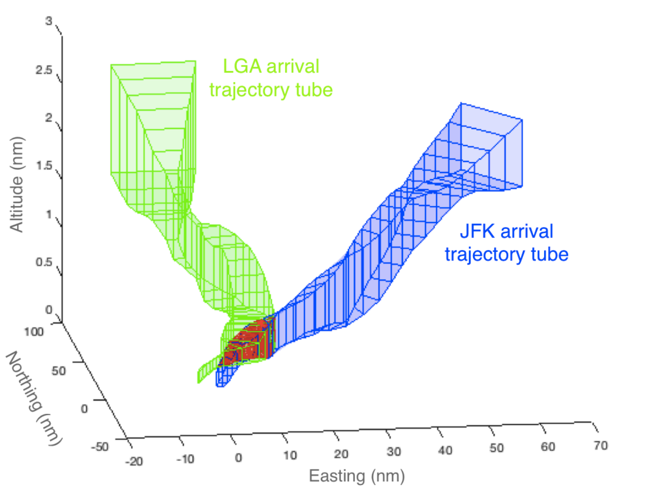
- Knowledge about traffic flow patterns used to identify relevant flow interactions between the metroplex airports
- Route intersections translated into two types of flow interactions

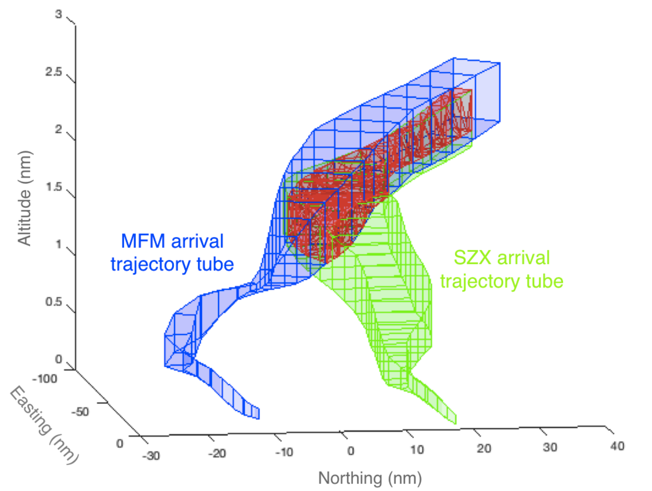
Flow Dependency

If, for all MFP, routes are not used simultaneously

Flow Crossing

If, for at least one MFP, routes are used simultaneously



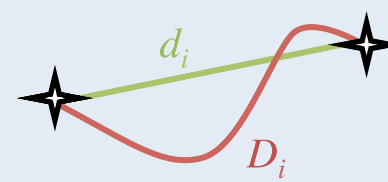


Performance Analysis

Efficiency

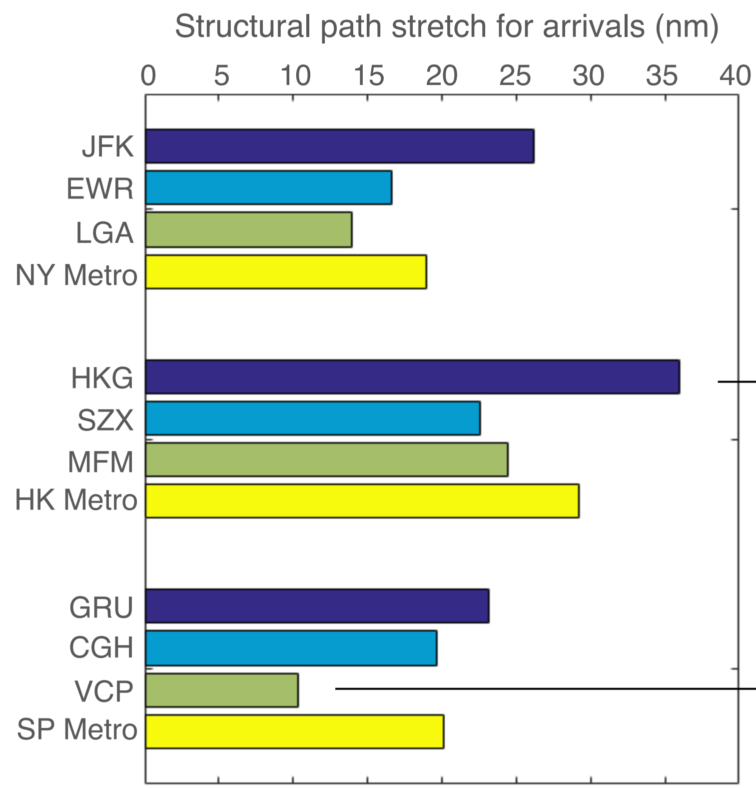
- Metroplex airspace design efficiency
  - HK stands out with the least efficient airspace design (especially driven by HKG)
  - VCP presents the most efficient design

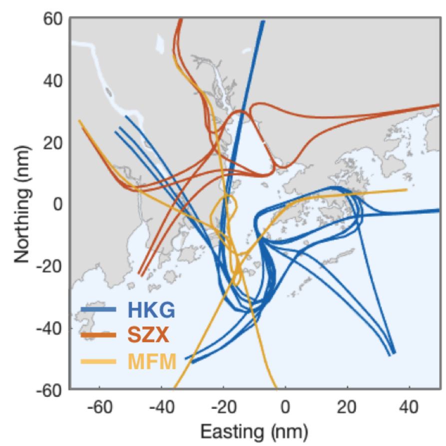
Structural path stretch metric:

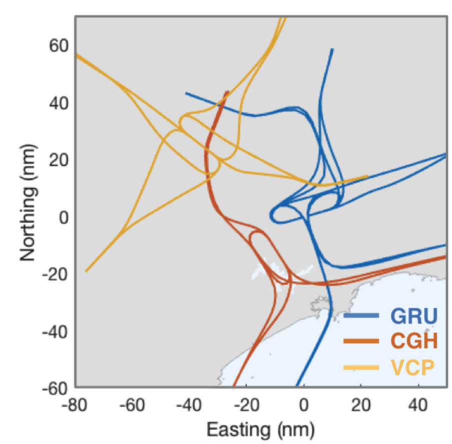


$$s_i = D_i - d_i$$

$$S = \sum_{i=1}^{N} p_i s_i$$







Performance Analysis

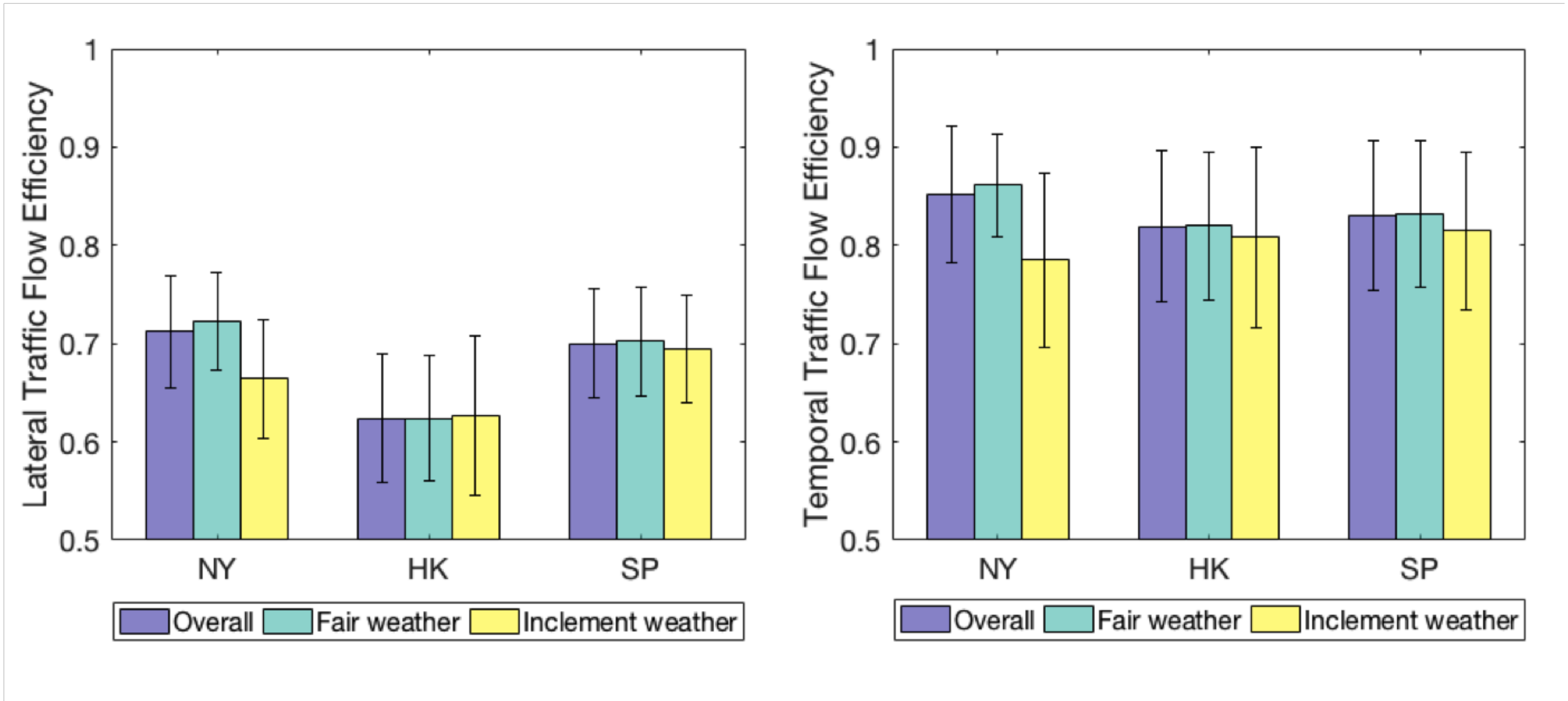
Efficiency

- Traffic flow efficiency (lateral & temporal)
  - NY presents the highest traffic flow efficiency overall, but is more impacted by weather
  - HK shows considerably lower lateral efficiency

Traffic flow efficiency metric:

$$Eff_{lateral} = \sum_{i=1}^{N} d_i \Big/ \sum_{i=1}^{N} D_i$$

$$Eff_{temporal} = \sum_{i=1}^{N} t_i \Big/ \sum_{i=1}^{N} T_i$$



Data Mining Framework

Clustering at Temporal Scale

Hourly Flow Pattern Vectors

Vector composed of dominant trajectory clusters from each arrival gate to each airport during the specified time scale:

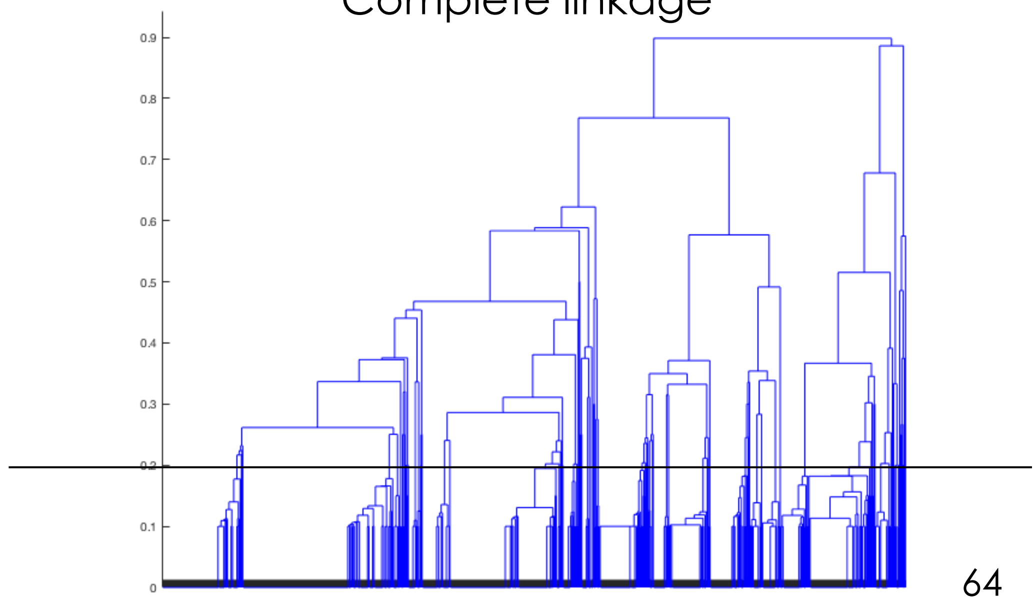
$(C^{south\text{-}JFK}, C^{south\text{-}EWR}, C^{south\text{-}LGA}, \ldots, C^{north\text{-}JFK}, C^{north\text{-}EWR}, C^{north\text{-}LGA})$

Dissimilarity Matrix

Hamming distance
(fraction of features that differ)

Hierarchical Clustering

Complete linkage



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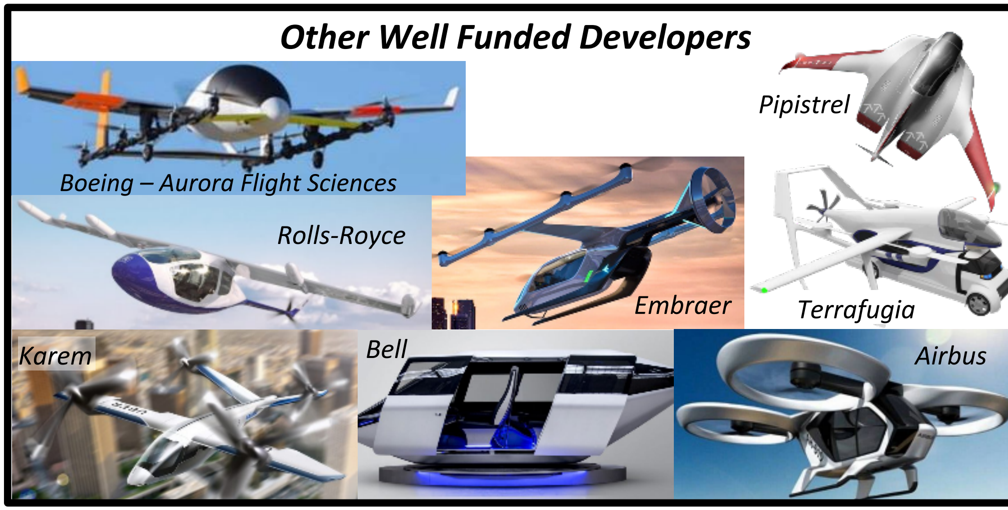
Urban Air Mobility and eVTOL Aircraft Development

MIT ICAT

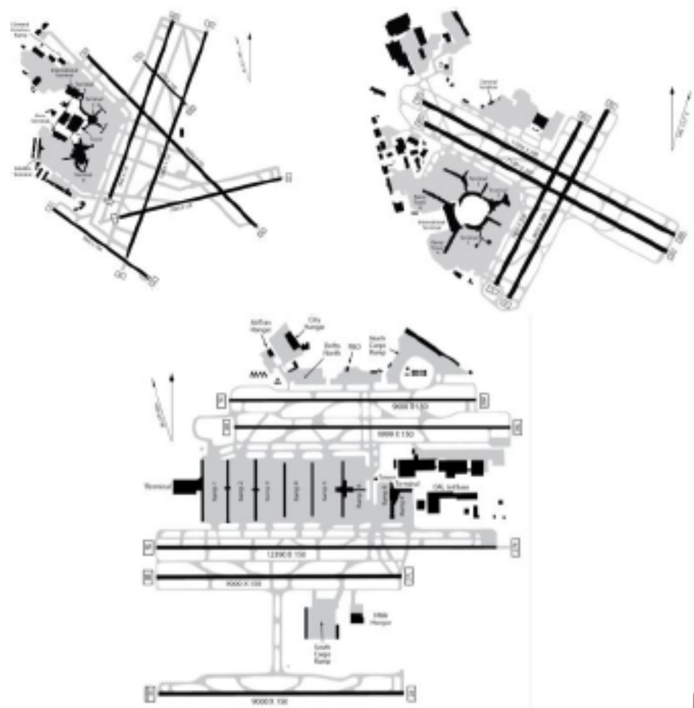
Over 100 companies (of varying credibility) have announced vehicles



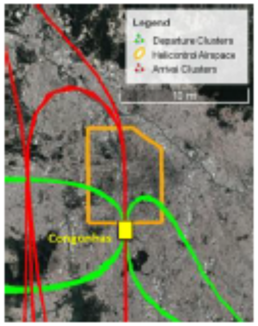
MIT estimates over $2 Billion invested in UAM vehicles, infrastructure, and technology

Approach to Evaluate UAM Airport and Airspace Integration

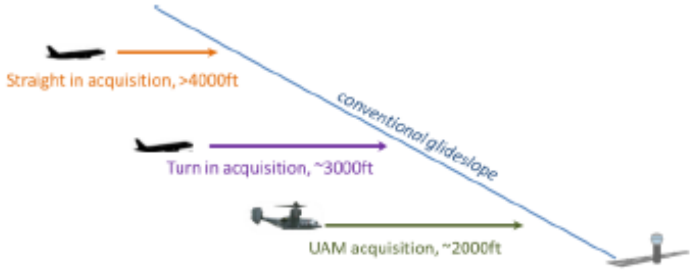
1. **Case studies at Boston, Atlanta, and San Francisco**



2. **Evaluate air traffic control, airfield infrastructure, terminal buildings, and ground access to support UAM**

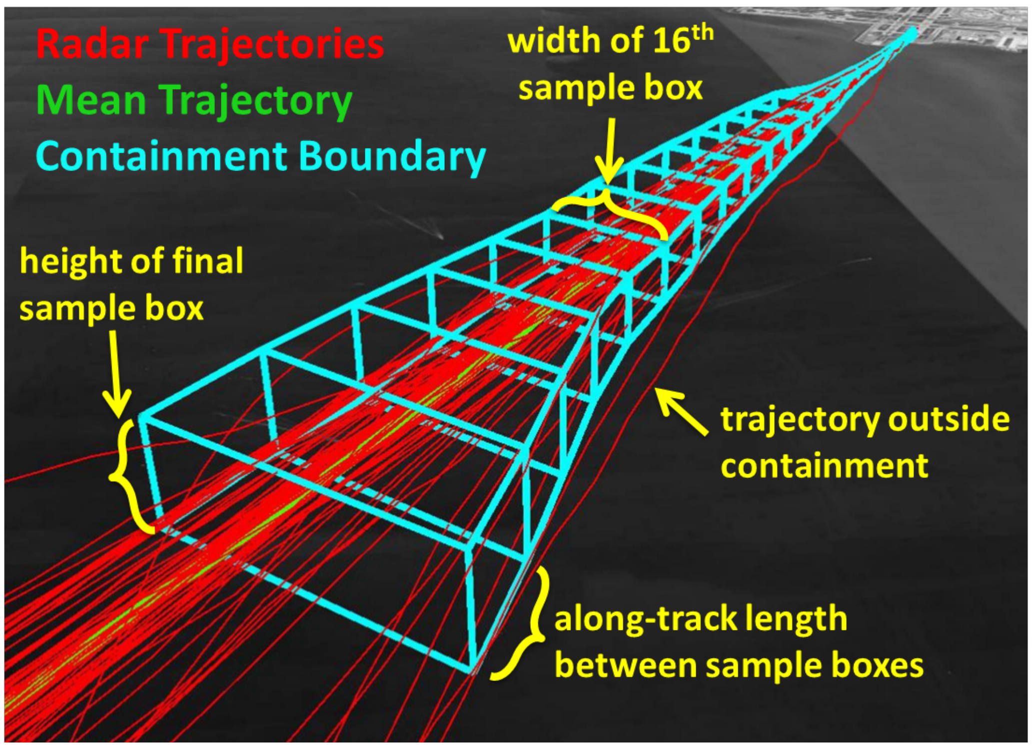


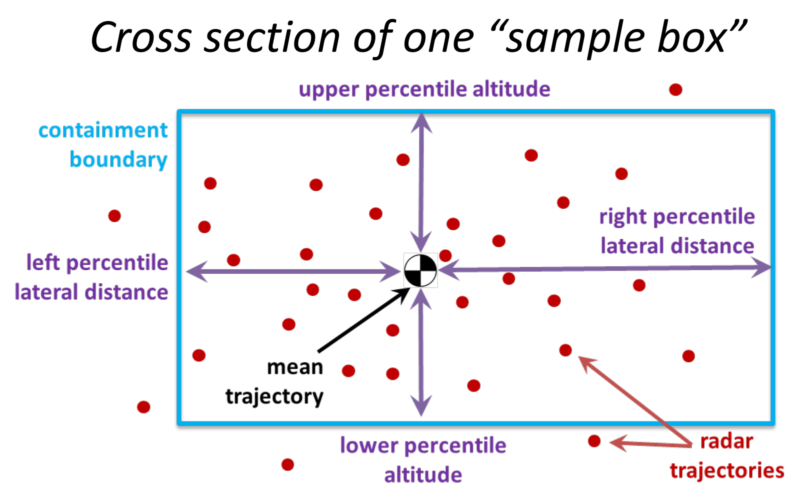
3. **Determine viable integration pathways, estimate feasible throughput, lay out requirements**



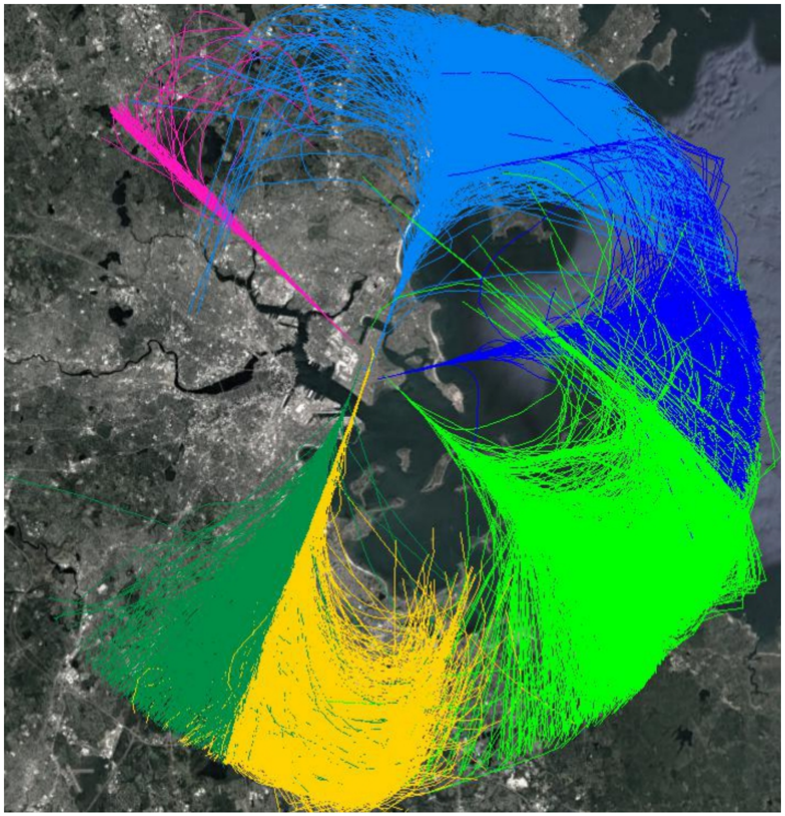
Containment Boundaries

- Defined a "containment boundary" to enclose a specified percentile of radar trajectories
- Boundary defined for trajectories based upon same along-track distance from the runway end

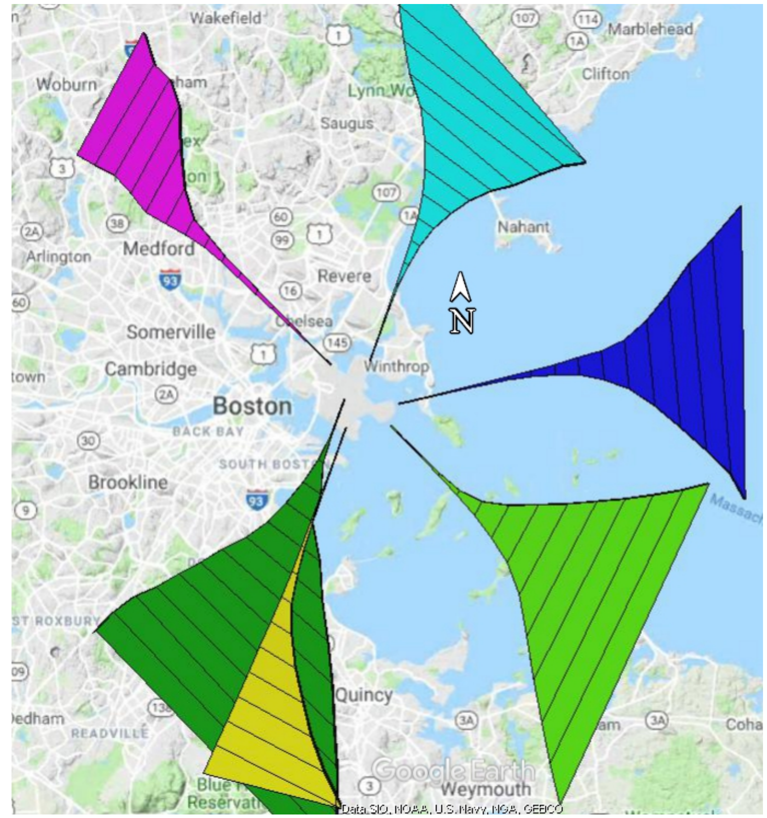




Containment Boundaries

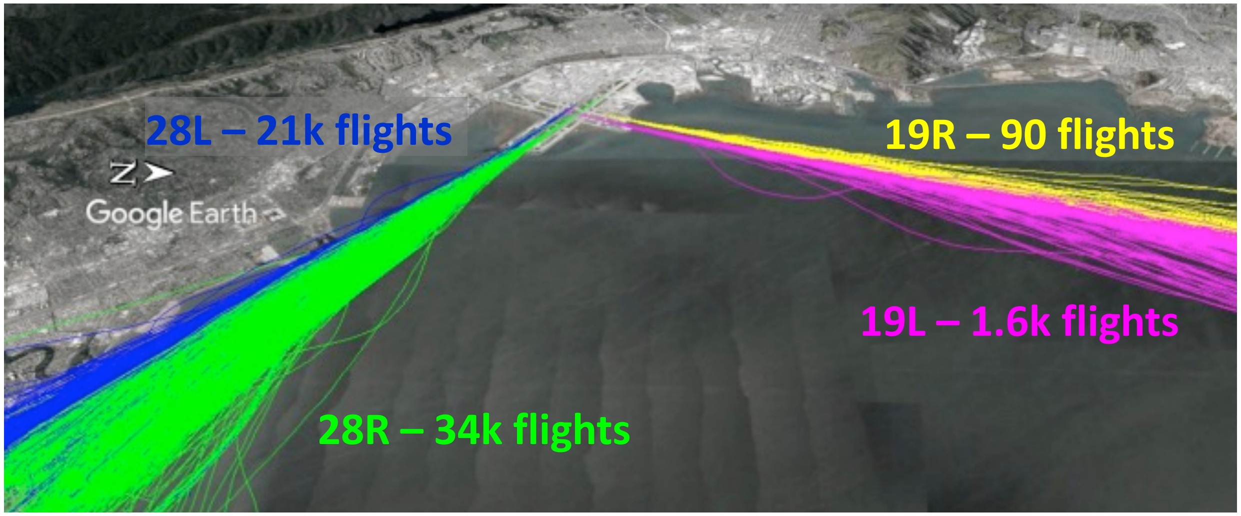


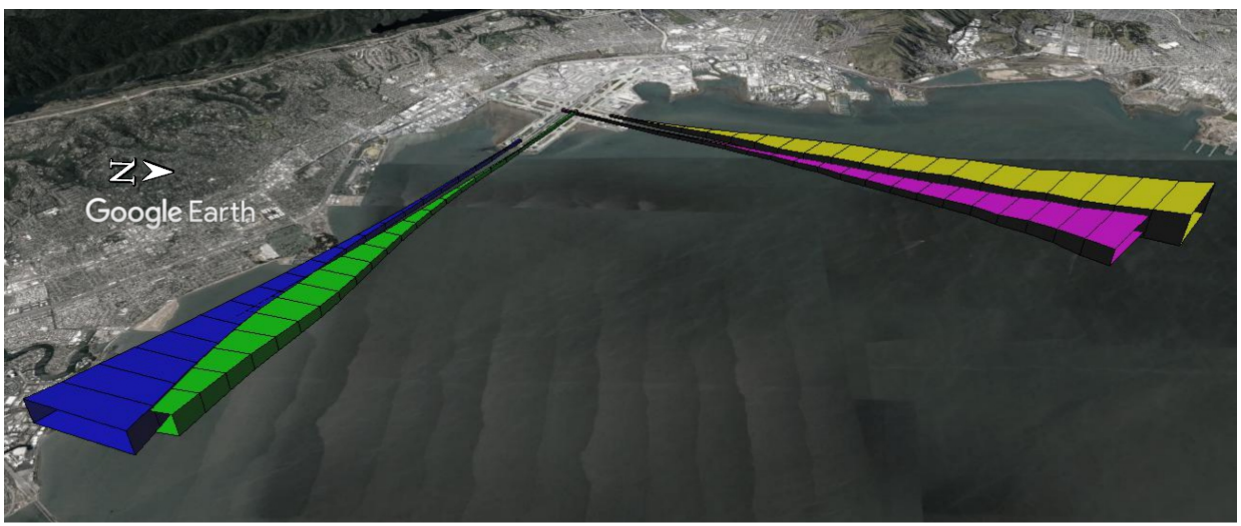
Large transport arrivals to Logan for 180 days in 2015-2016



99.5th percentile containment boundaries

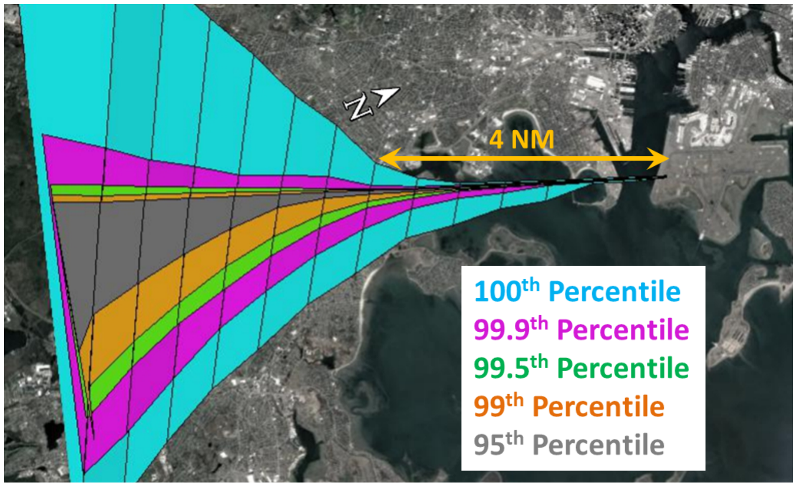
Containment Boundaries



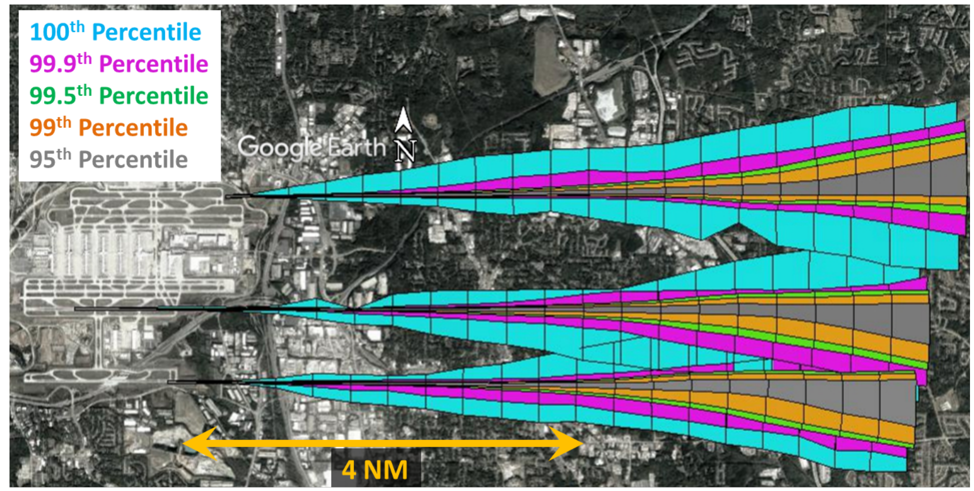


trajectory containment boundaries with 99.5% inclusion

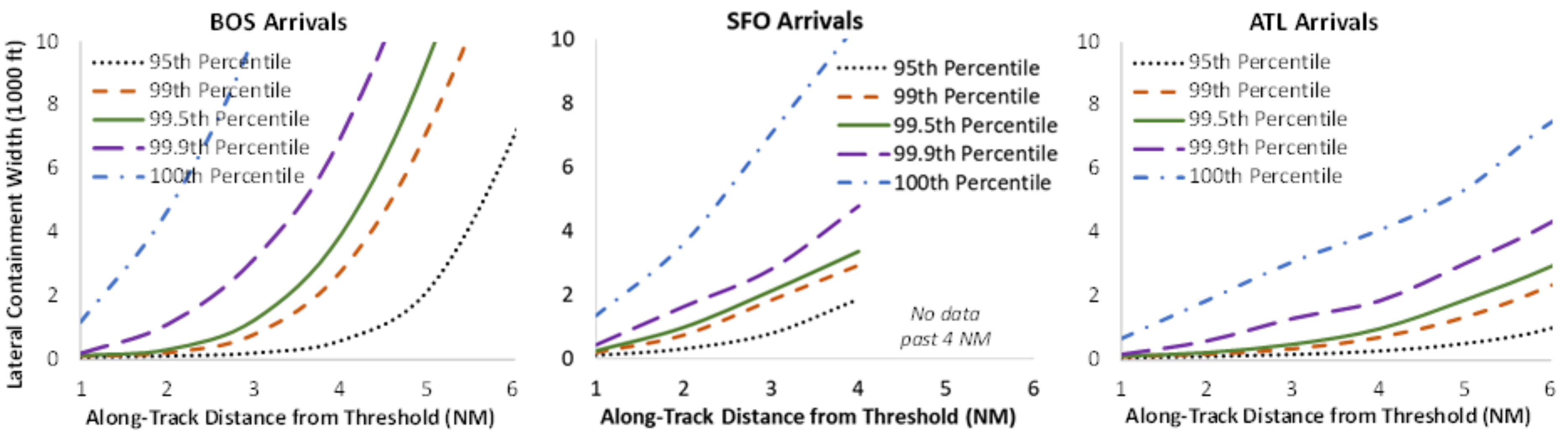
Containment Boundary Variation with Percentile Inclusion and City - Arrivals



Large jet arrivals to runway 4R at Logan



Large jet arrivals in west flow at Atlanta



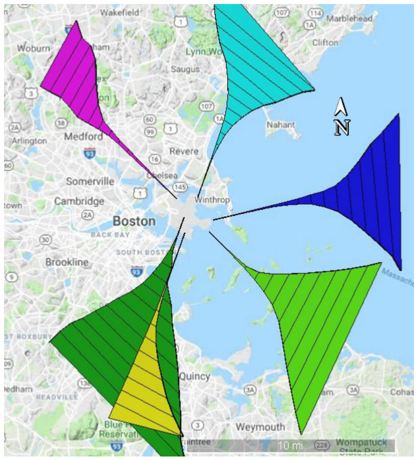
Lateral width of trajectory containment boundaries for arrivals at case study airports

99.5th Percentile Containment Boundaries for 3 Case Study Airports

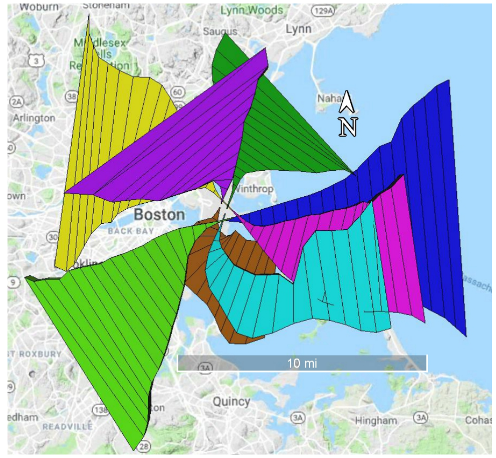
MIT ICAT

Boston

37,000 arrivals

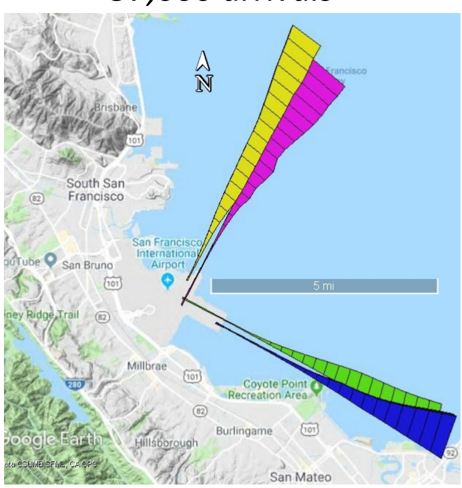


56,000 departures

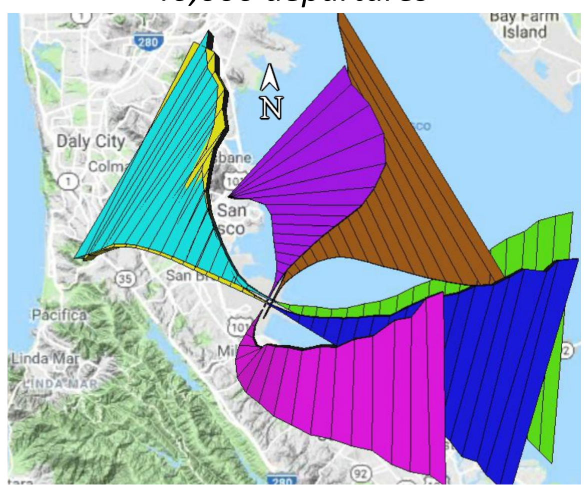


San Francisco

57,000 arrivals

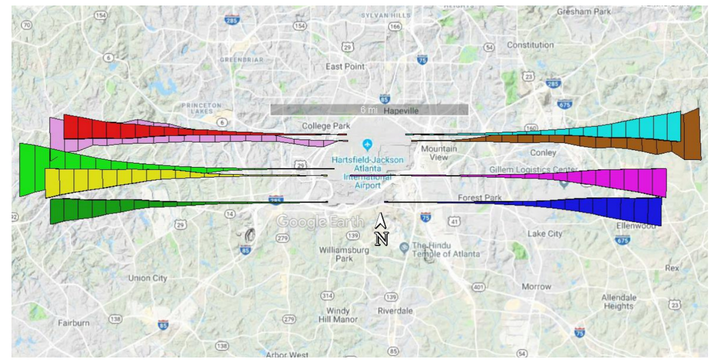


46,000 departures

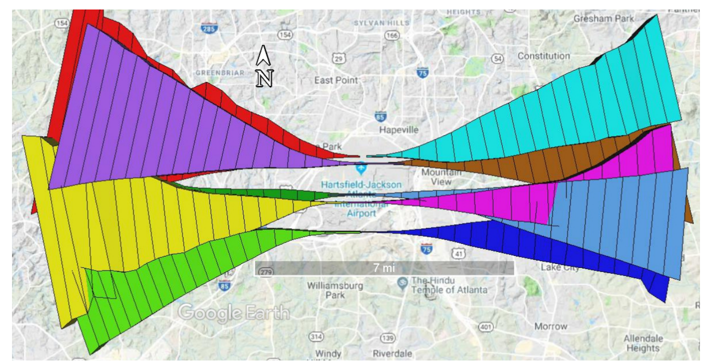


Atlanta

99,000 arrivals



173,000 departures



Examples

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  - **Degraded Breaking Conditions** *(Nicolas Meijers)*
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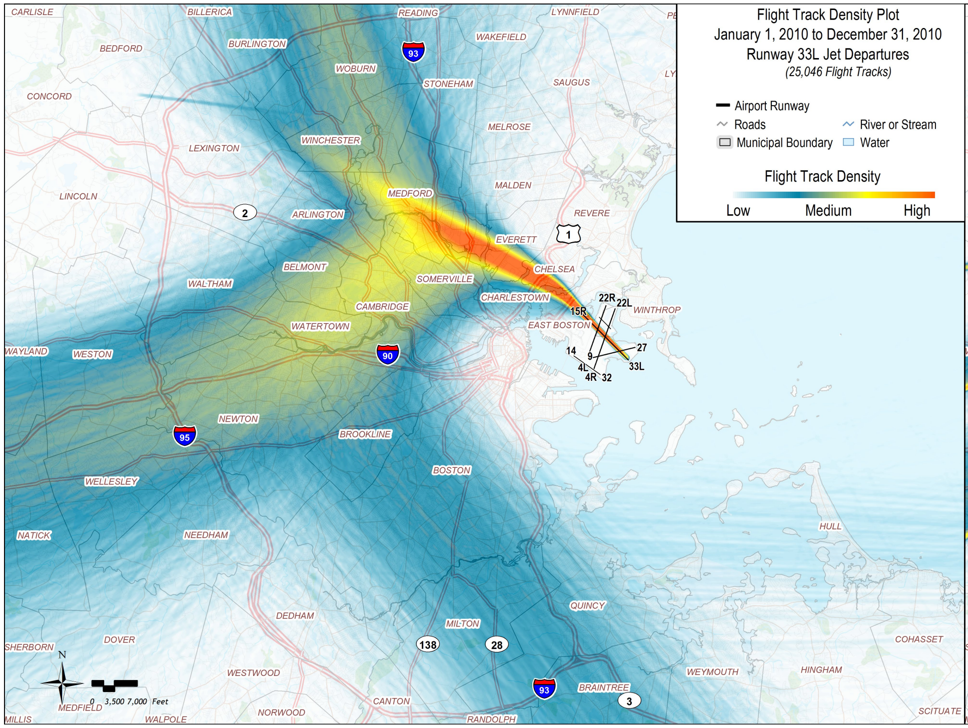
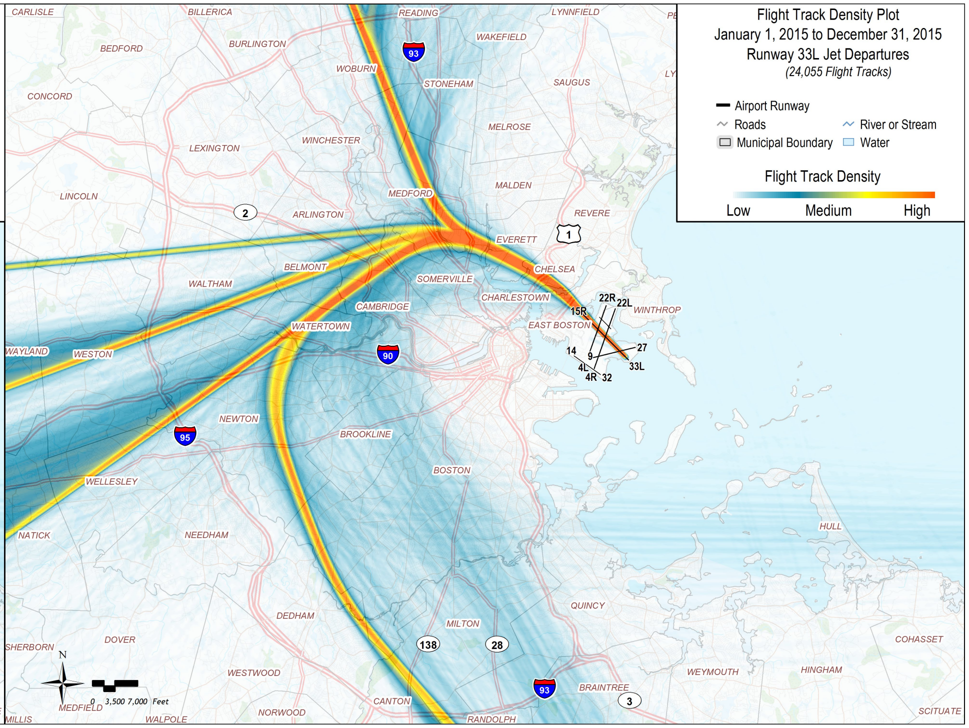
RNAV Track Concentration

2010

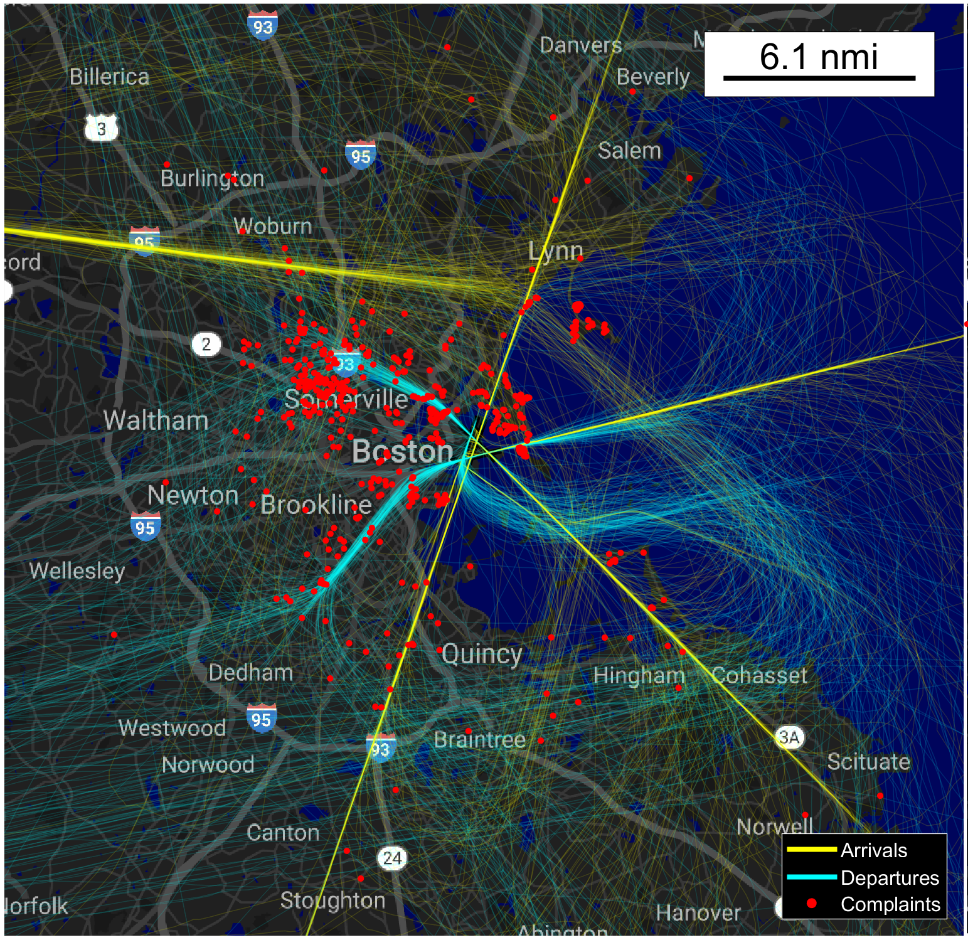


2015

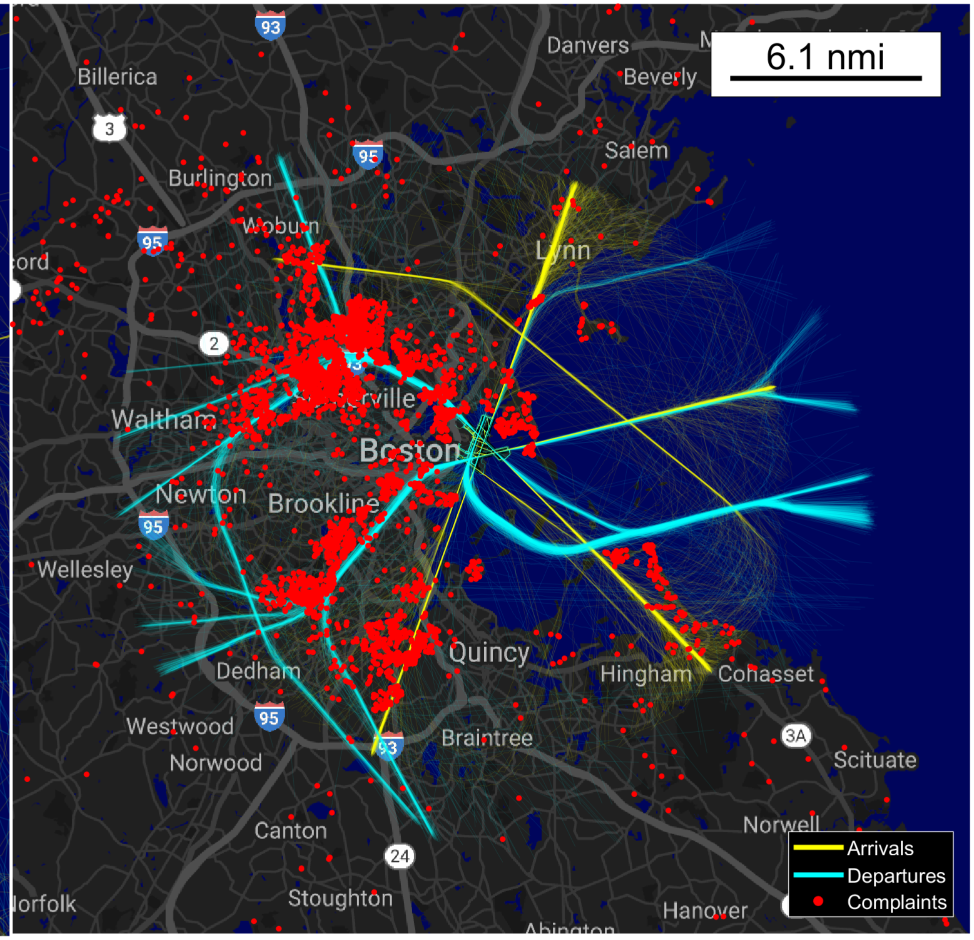


Noise Complaints and RNAV Track Concentration

2010



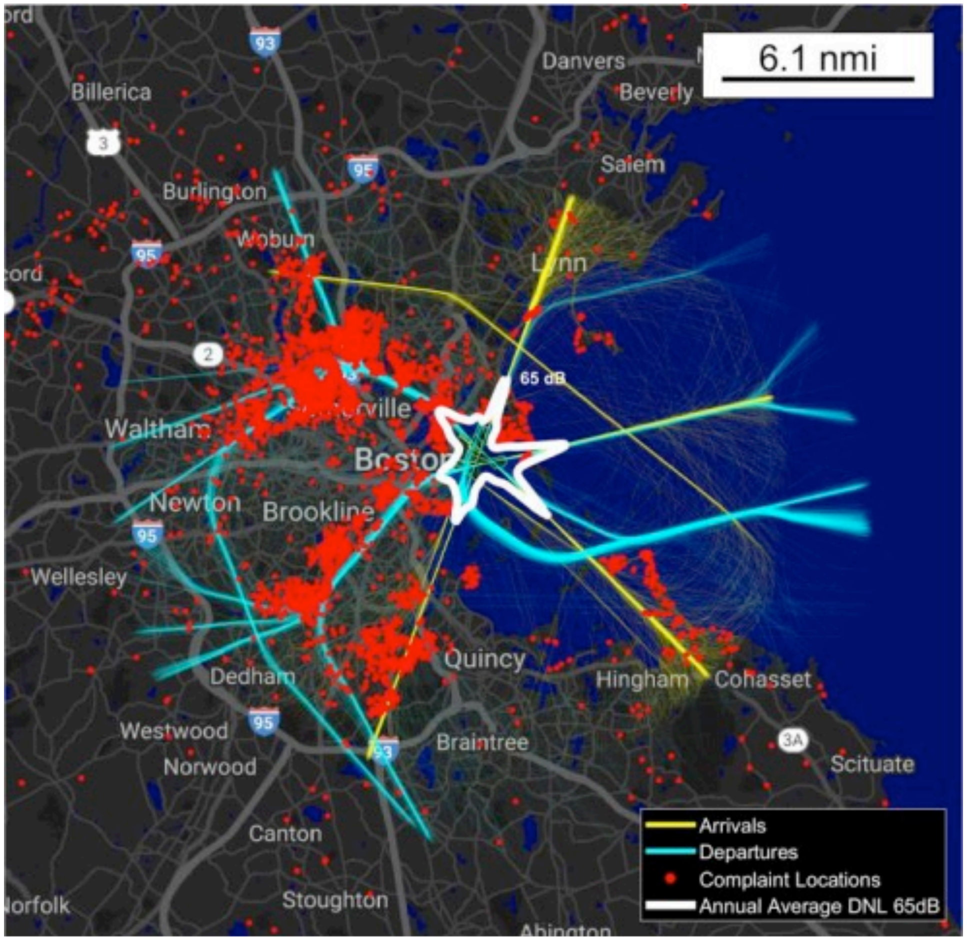
2017



Alternative Metrics to Capture RNAV Concentration Impacts

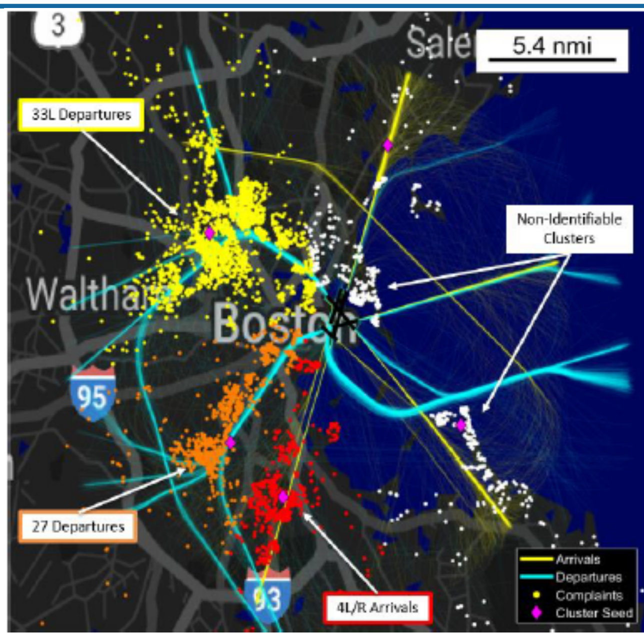
- RNAV concentration issue outside of Annual Average DNL 65dB contour
- Analysis performed by this research team at BOS, MSP, CLT, and LHR indicates that N_{60} on a Peak Day with 50 overflights represents the noise threshold for complaints

2017

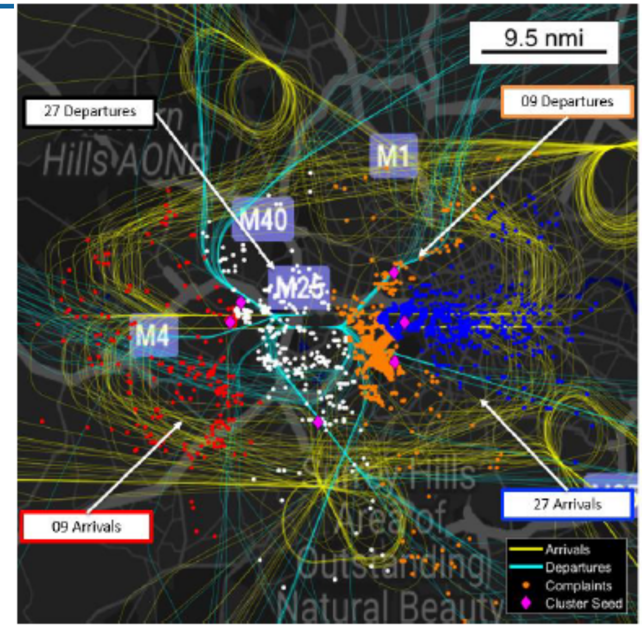


Cluster Analysis to Correlate Complaint Locations with Procedure

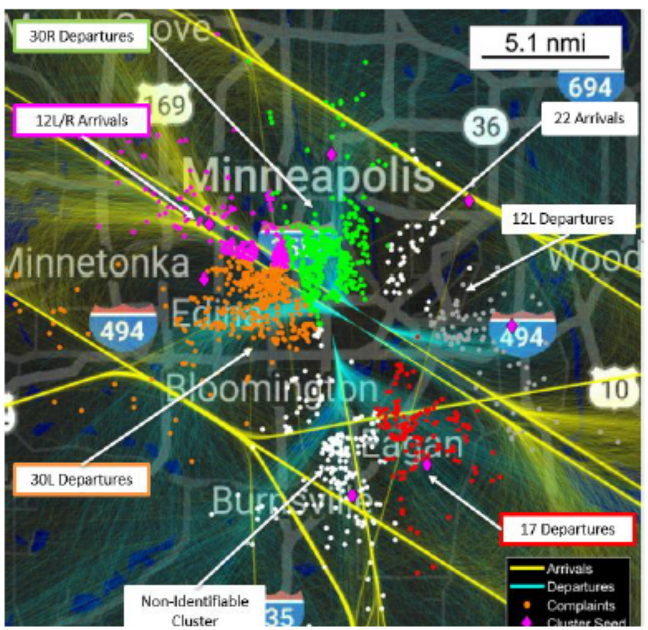
BOS



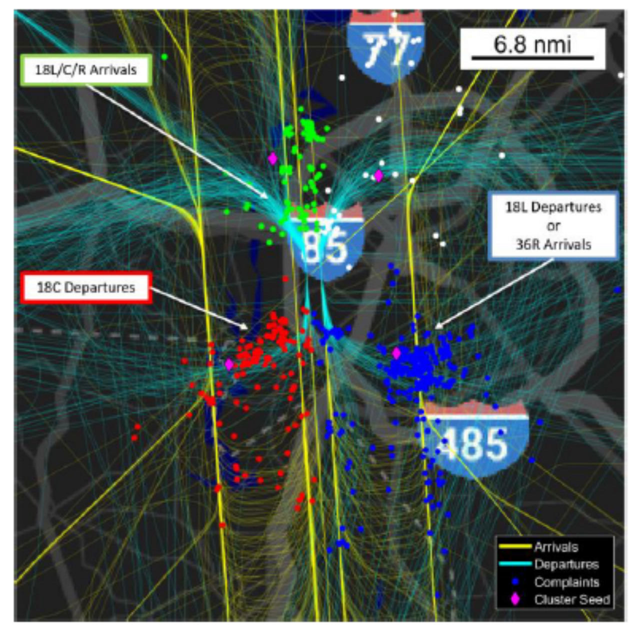
LHR



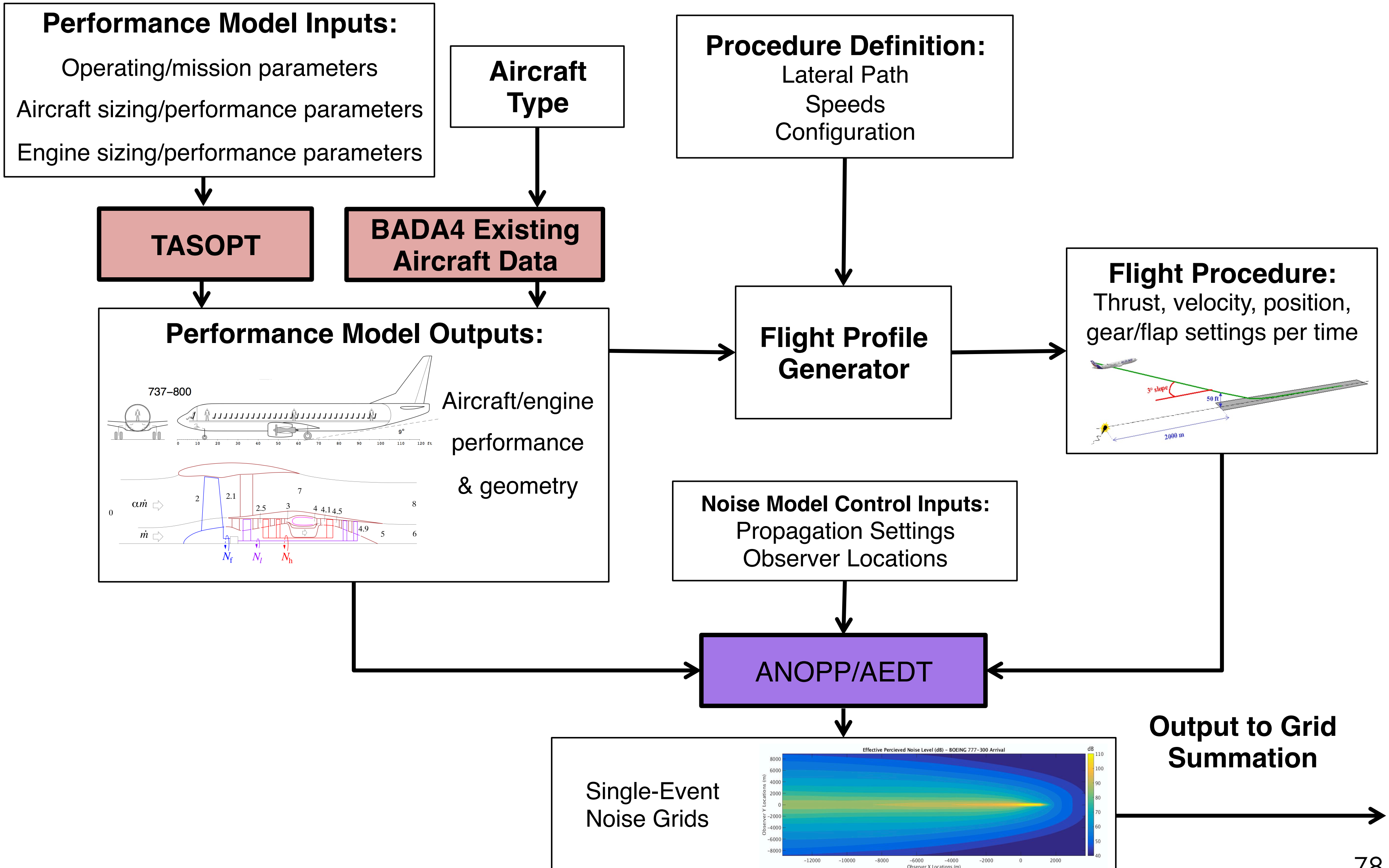
MSP



CLT



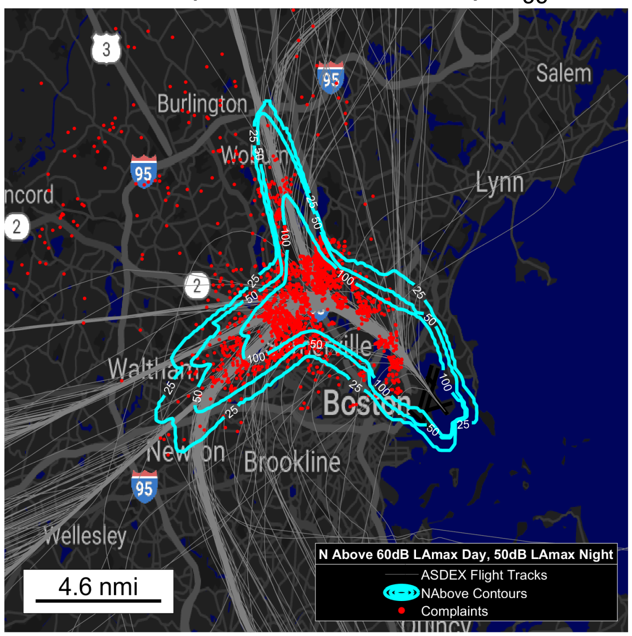
Noise Analysis Framework



BOS N_{60} Count Thresholds

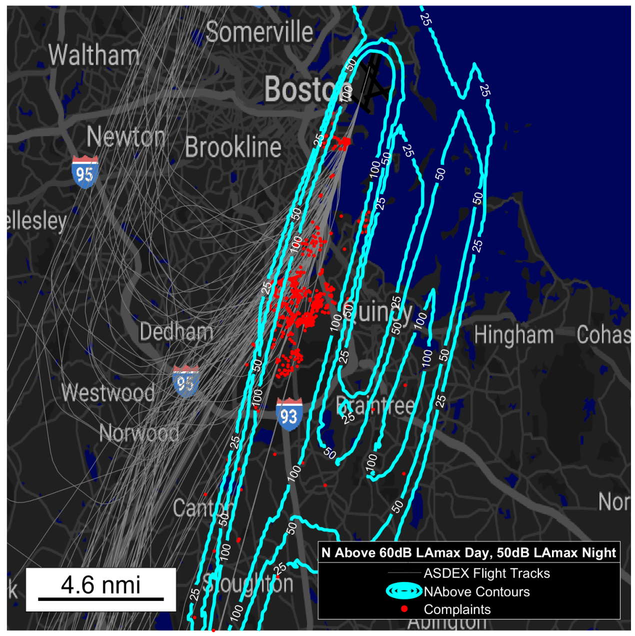
- N_{60} on a peak day with 50 overflights appears to capture complaint threshold in dispersion analysis

33L Departures Peak Day N_{60}



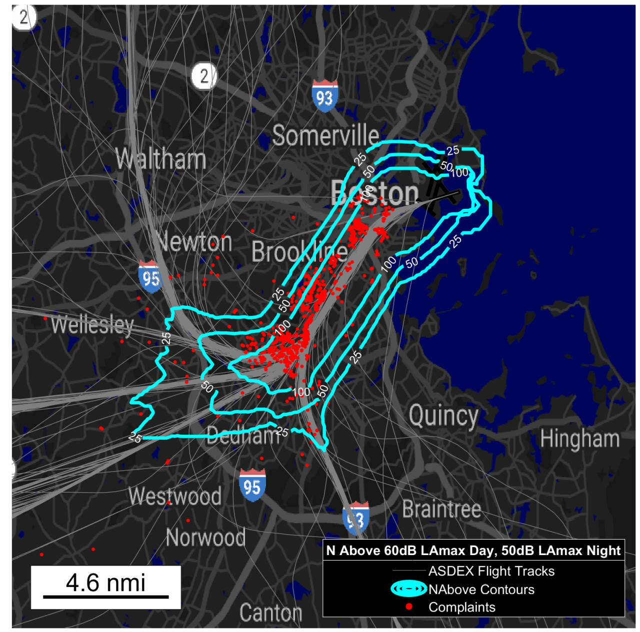
Peak Day N_{60}	Complaints Captured
25x	87.3%
50x	80.9%
100x	59.4%

4L/R Arrivals Peak Day N_{60}



Peak Day N_{60}	Complaints Captured
25x	97.7%
50x	94.7%
100x	81.0%

27 Departures Peak Day N_{60}



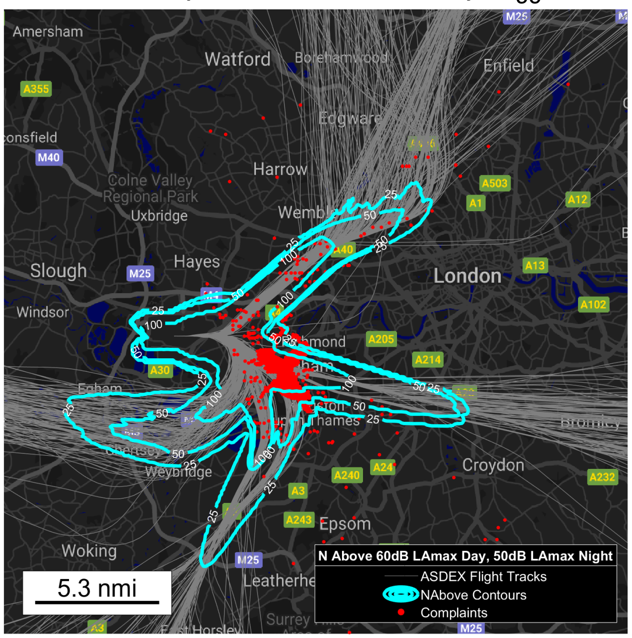
Peak Day N_{60}	Complaints Captured
25x	95.4%
50x	92.1%
100x	78.8%

2017 Data

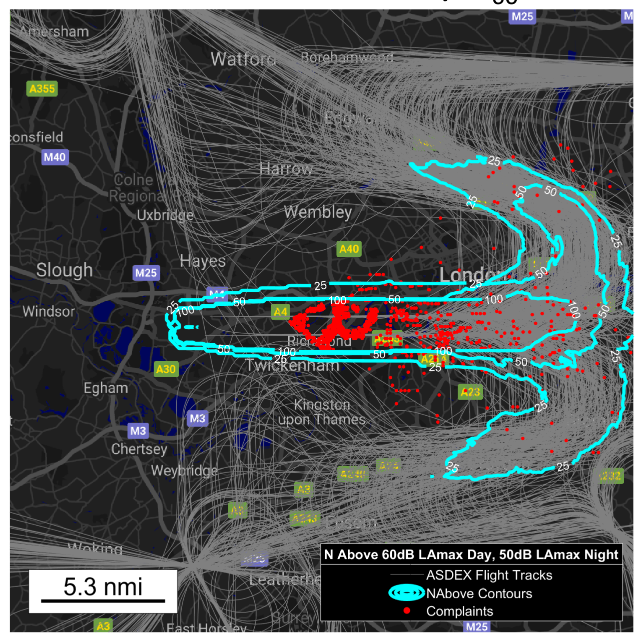
LHR N_{60} Count Thresholds

- N_{60} on a peak day with 50 overflights appears to capture complaint threshold in dispersion analysis

09 Departures Peak Day N_{60}



27 Arrivals Peak Day N_{60}



Peak Day N_{60}	Complaints Captured
25x	91.0%
50x	82.6%
100x	61.4%

Peak Day N_{60}	Complaints Captured
25x	93.2%
50x	84.9%
100x	80.2%

2017 Data

Examples

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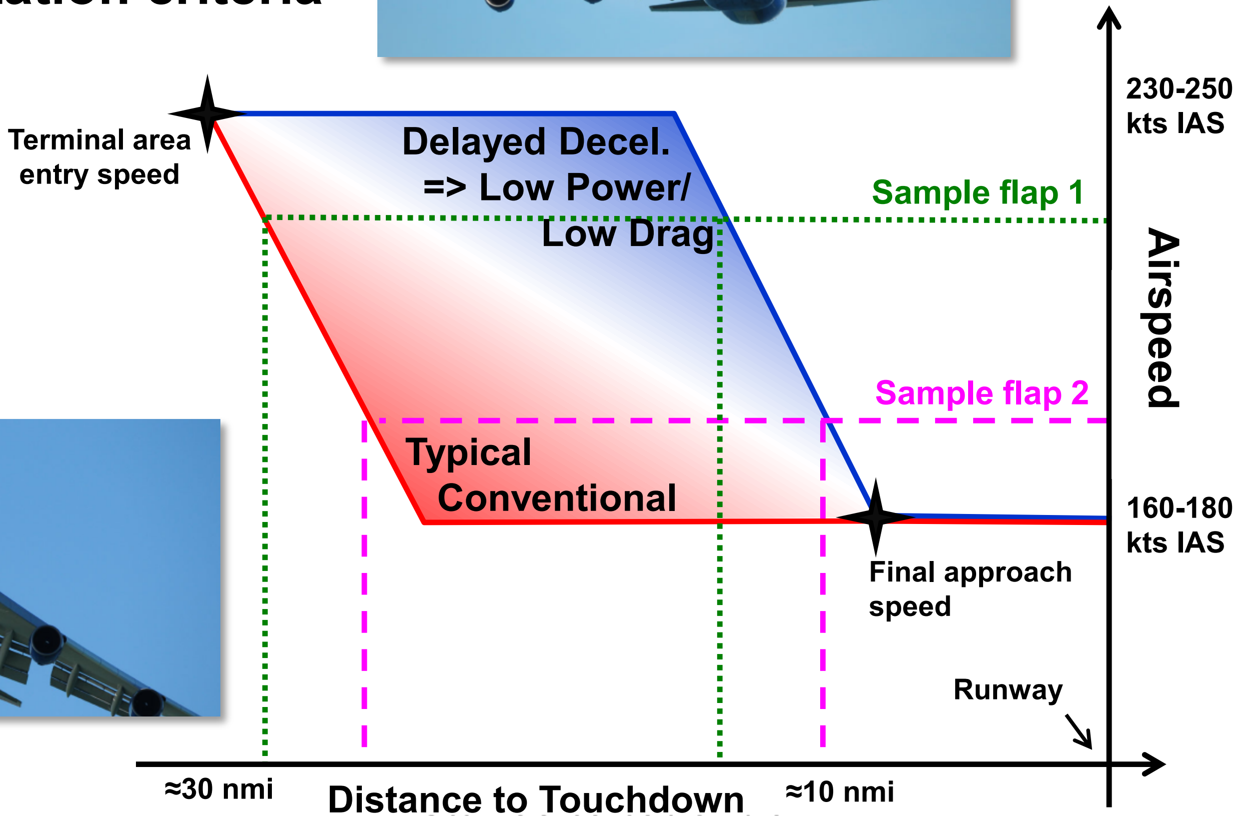
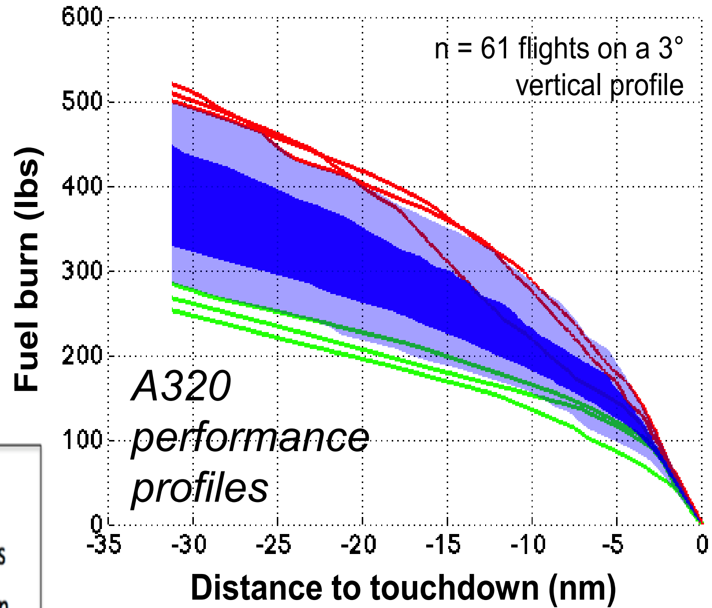
Delayed Deceleration Approach (DDA)

- **Keep aircraft "clean" for longer on approach when appropriate without impacting terminal area entry or final approach stabilization criteria**
  - **Between these speed gates, opportunity for encouraging more efficient approach speed profiles**

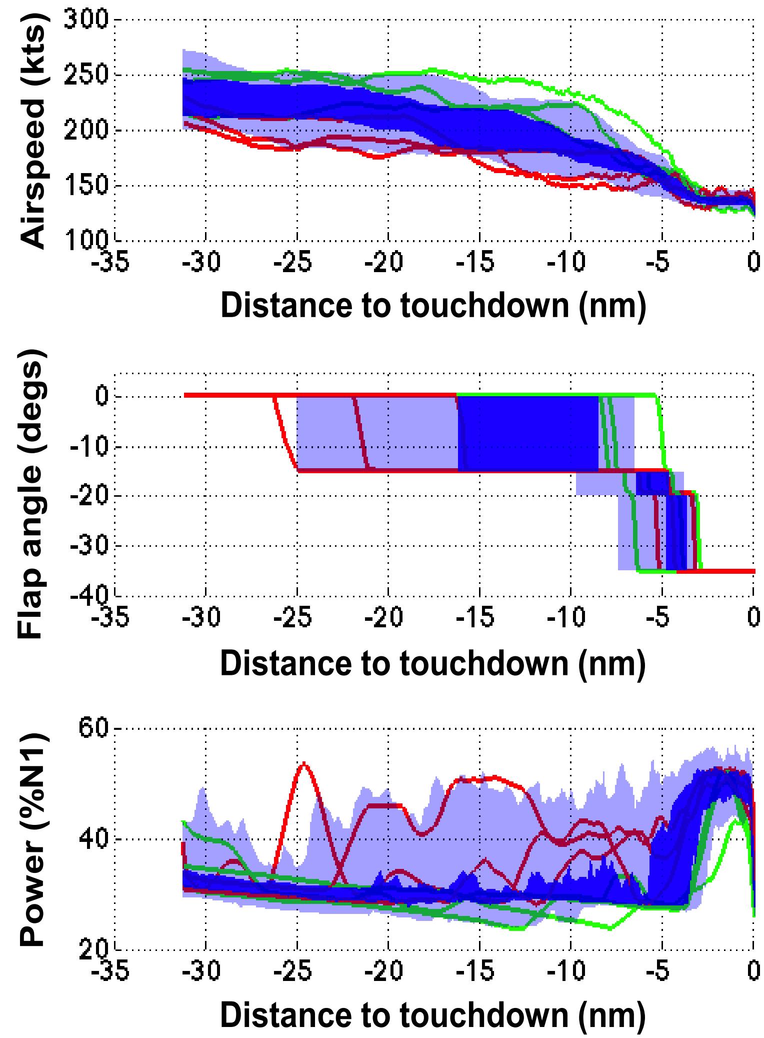


DDA Fuel Benefits Potential

European A320 Flight Data Recorder Analysis
(similar results for B757 & B777)



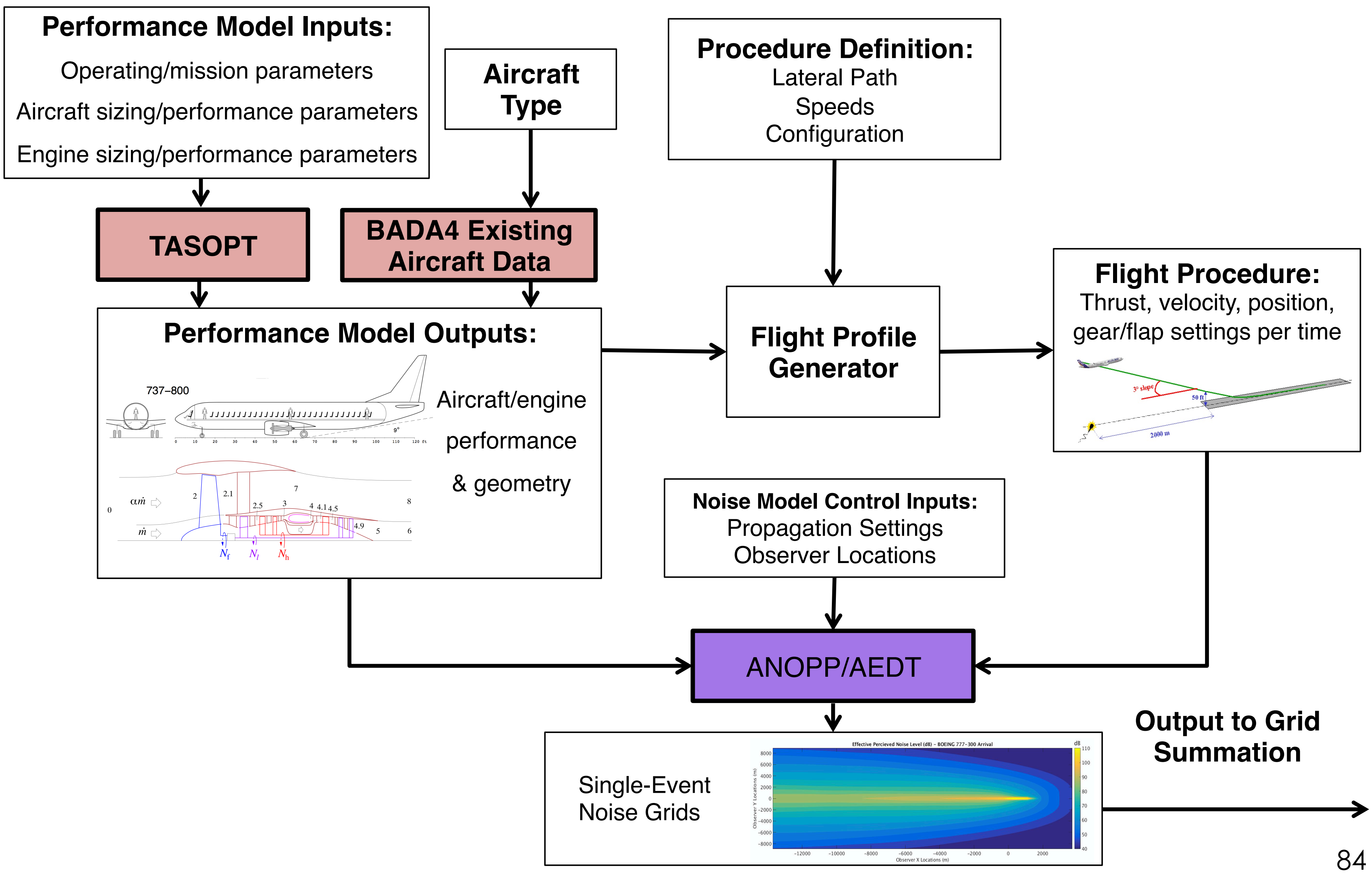
From 5 to 95 % of the flights
From 25 to 75 % of the flights
3 flights with lowest fuel burn
3 flights with highest fuel burn



- **Lowest fuel burn flights (green profiles) associated with delayed deceleration**

30-50% fuel burn reduction potential from DDAs from 10,000 ft to touchdown, similar to Continuous Descent Approach (CDA)

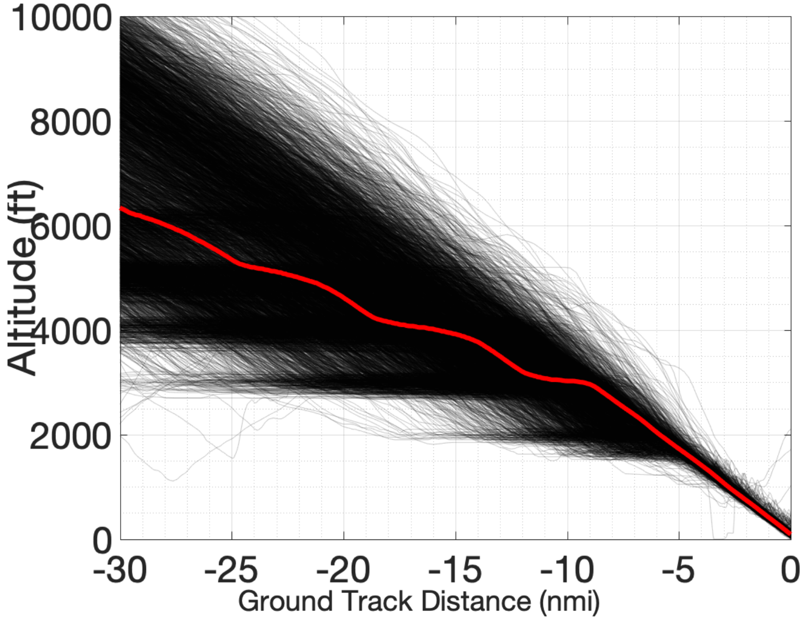
Noise Analysis Framework



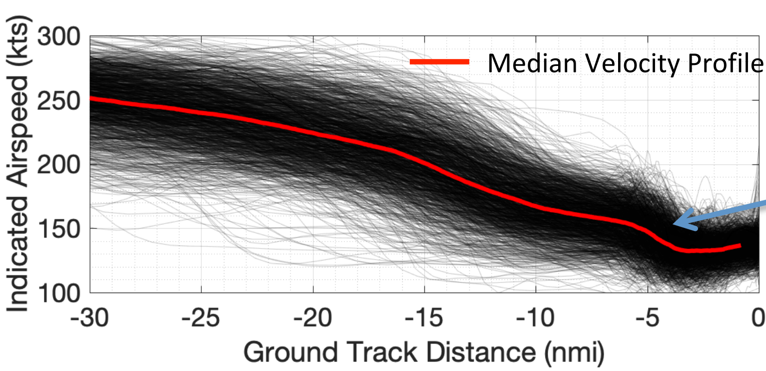
Flight Profile Generation

Example for a B737-800 Approach

Example Approach Radar data in 2017 at BOS, 22L

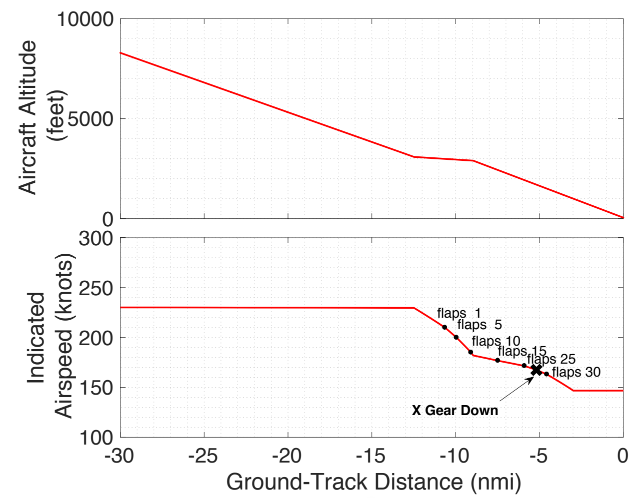


Groundspeed Radar data converted into indicated airspeed, assuming no wind

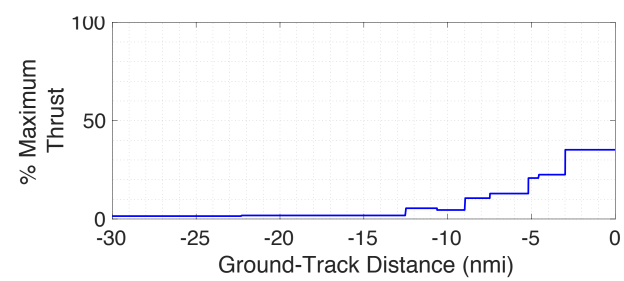


Gear assumed deployed ~6nmi from touchdown based on observed deceleration

- Altitude (3000ft level off in this case only) and Velocity is constrained to the medians of this data
- Flaps assumed deployed within their maximum and minimum speed ranges



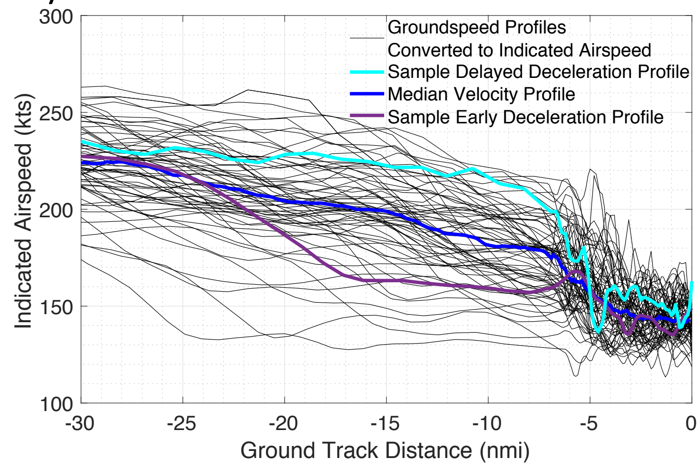
Resulting thrust profile is determined for these profiles from drag data



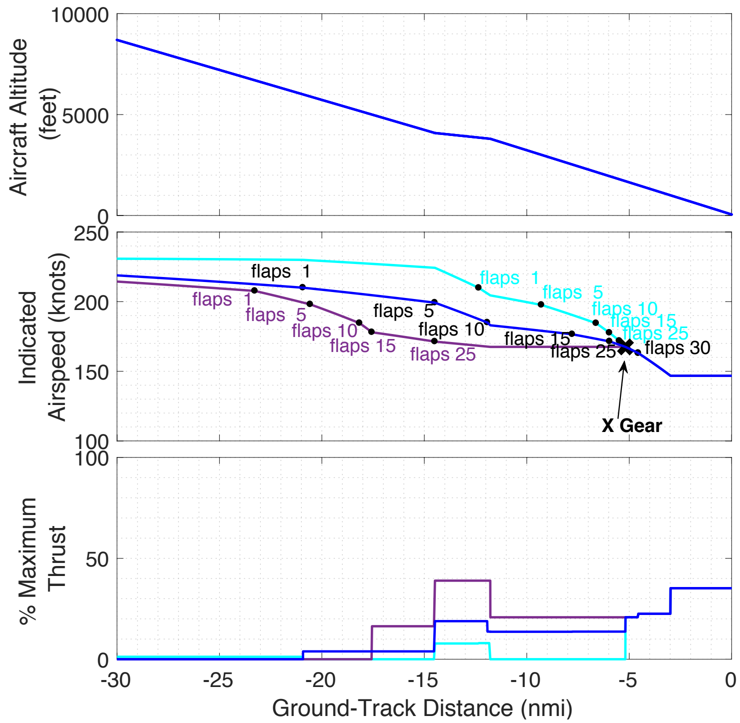
Delayed Deceleration Approaches

MIT ICAT

Velocity Radar Data for B737-800 4000ft Level Offs into 4R

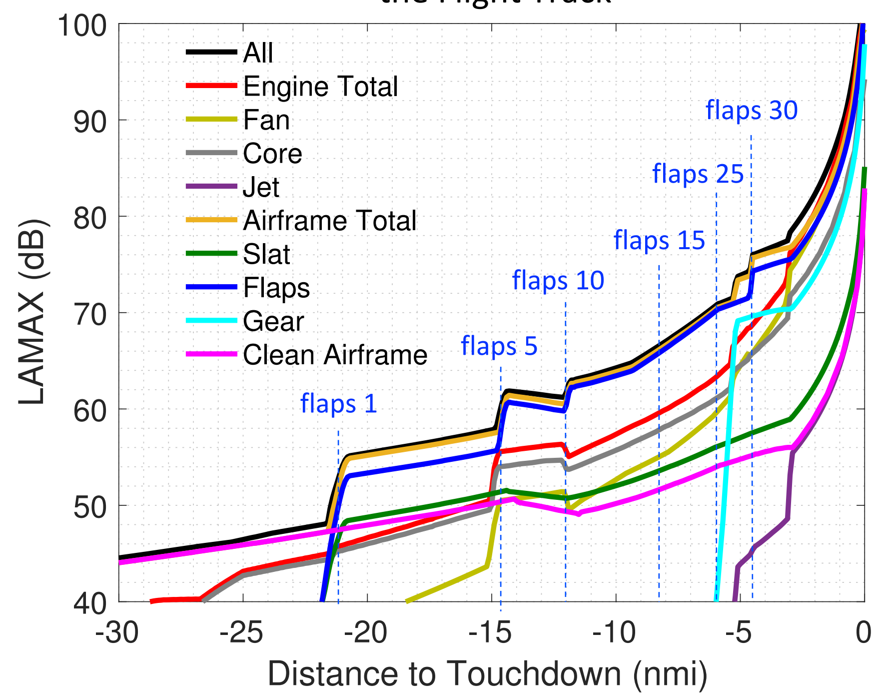


Modeled Profiles



- Reduce noise by delaying extension of flaps
- Potential concerns from ATC and pilots regarding different deceleration rates and managing traffic
- Must decelerate early enough to assure stable approach criteria

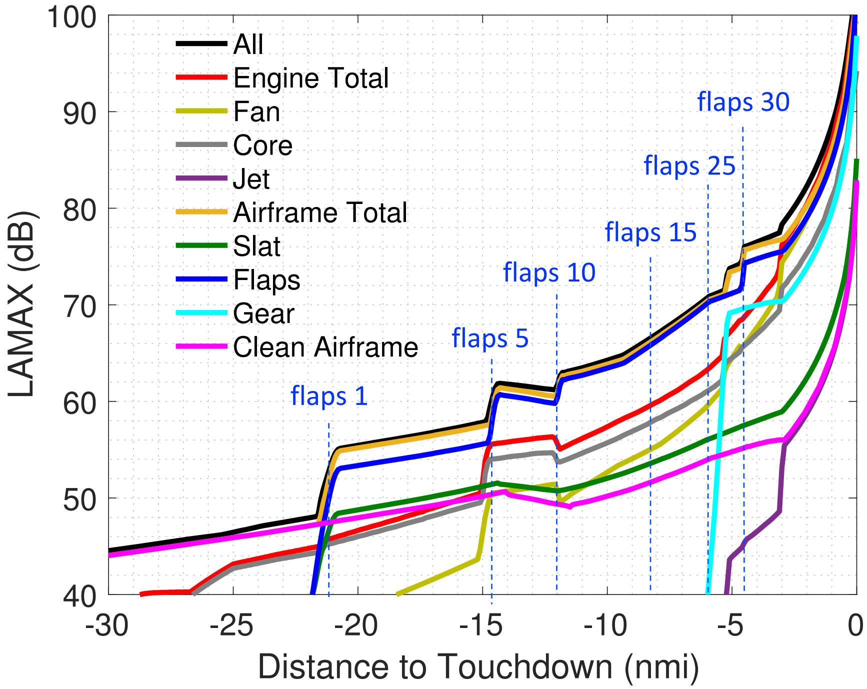
Example Noise Component Breakdown Under the Flight Track



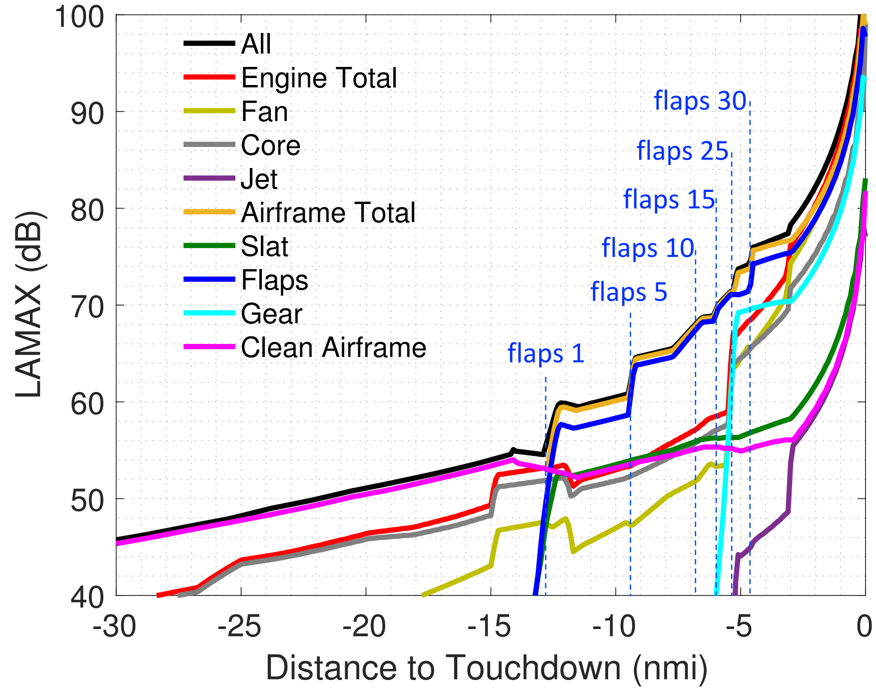
Delayed Deceleration Approaches

Boeing 737-800 ILS approach with 4,000 ft level off
Noise Component Breakdown Under the Flight Track

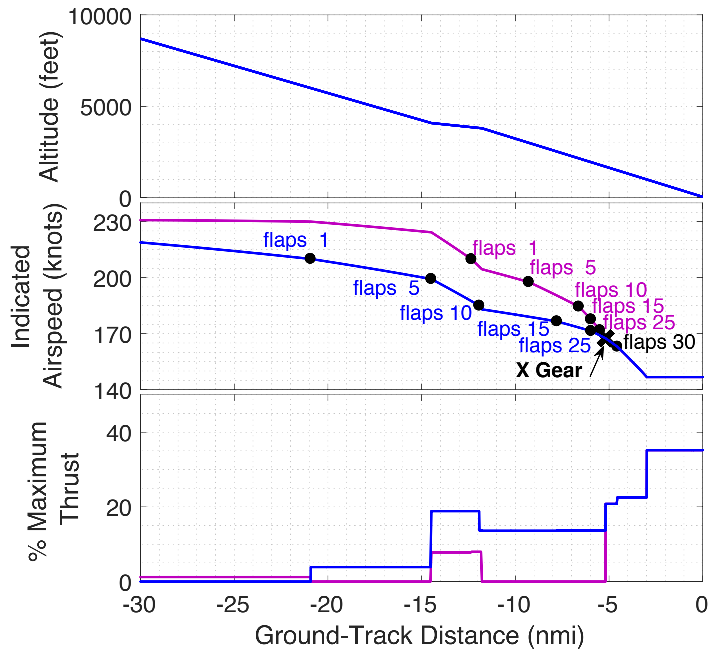
Standard Deceleration from mean velocity seen in radar Data



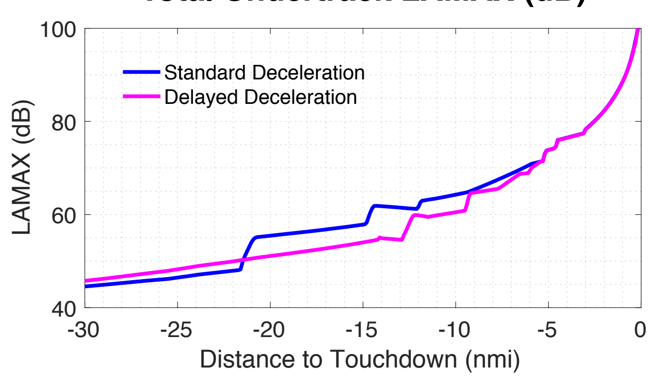
Example Delayed Deceleration



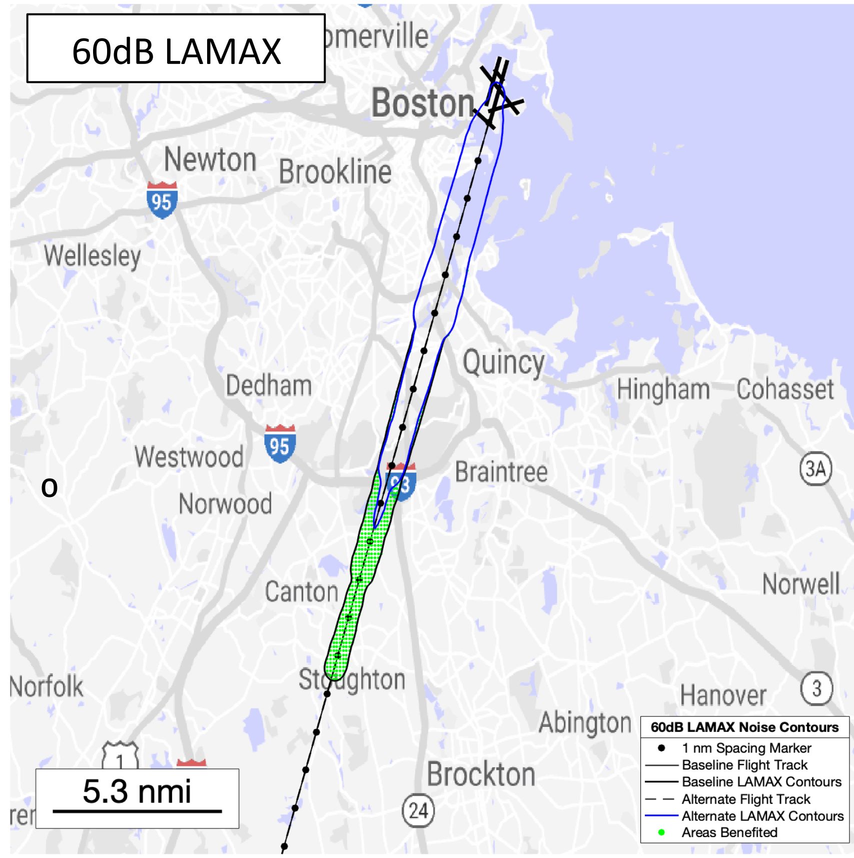
DDA vs Standard Approach
B737-800, 4000 ft Level Off



Total Undertrack LAMAX (dB)



60 dB Contour Comparison



Population Exposure

$L_{A,max}$	60 dB	65 dB	70 dB
Standard	37,621	14,912	4,936
DDA	31,835	13,927	4,784
Difference	5,786	985	152

Preliminary example to evaluate methodology only. Should not be considered representative case.

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Quality of Life Impact of LHR Airport on Surrounding Communities

Quality of Life Attribute Structure

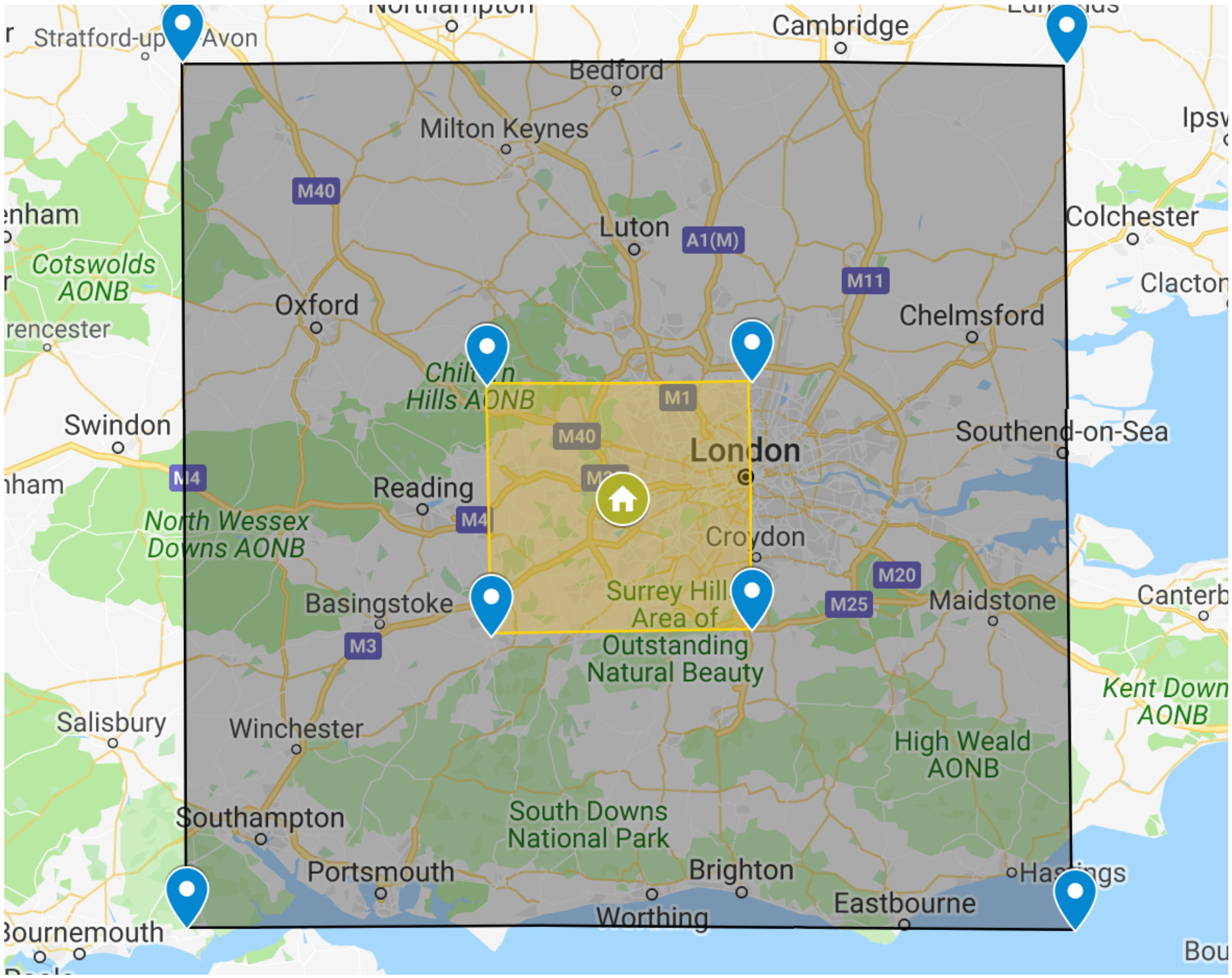
Category	Attribute	Definition
Economic Conditions	Individual Conditions	Individual state of the economy and material living conditions in surrounding communities
	System- level Conditions	Systematic state of the economy
Environmental	Leisure & Social Conditions	Opportunities for participating in non-work-related activities and have interpersonal exchanges
	Environmental Conditions	Indirect health; disaster; environmental services & amenities
	Physical Safety	Risk for physical integrity of human body
	Accessibility & Connectivity	Mobility for individuals and goods; opportunities for interaction
Internal Individual	Health	Covers length of life and assesses mortality and morbidity impacts
	Well-Being/Happiness	Perception of being comfortable, healthy, and happy
	Political Voice & Governance	Perceived involvement in policymaking and decision making
Socio-Demographic	Socio-Demographic	Characteristics of a population

Social Media Analysis

Social Media Analysis is used to provide further insight on the perceptions, sentiments and opinions about London Heathrow in surrounding communities

Twitter Sentiment Analysis

- Analysis for 15 mile and 50 mile collection areas



Twitter Sentiment Analysis

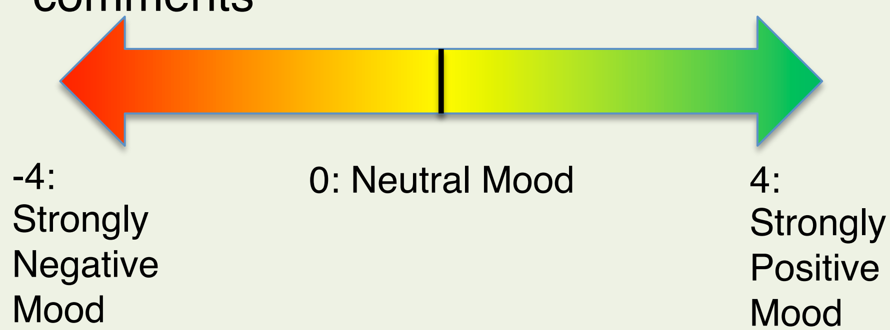
Data

- Twitter data: Geolocated and time-stamped
- Data collected since June 13th, 2018 using the Twitter API
- 13 million tweets collected between June 2018 and January 2019
- Initial collection zone: 15 miles of LHR, extended to 50 miles

Methodology

SentiStrength Machine Leaning Algorithm

- Ranks the sentiment in tweets on a scale from -4 to 4
- SentiStrength used a training dataset of human-classified MySpace posts and comments

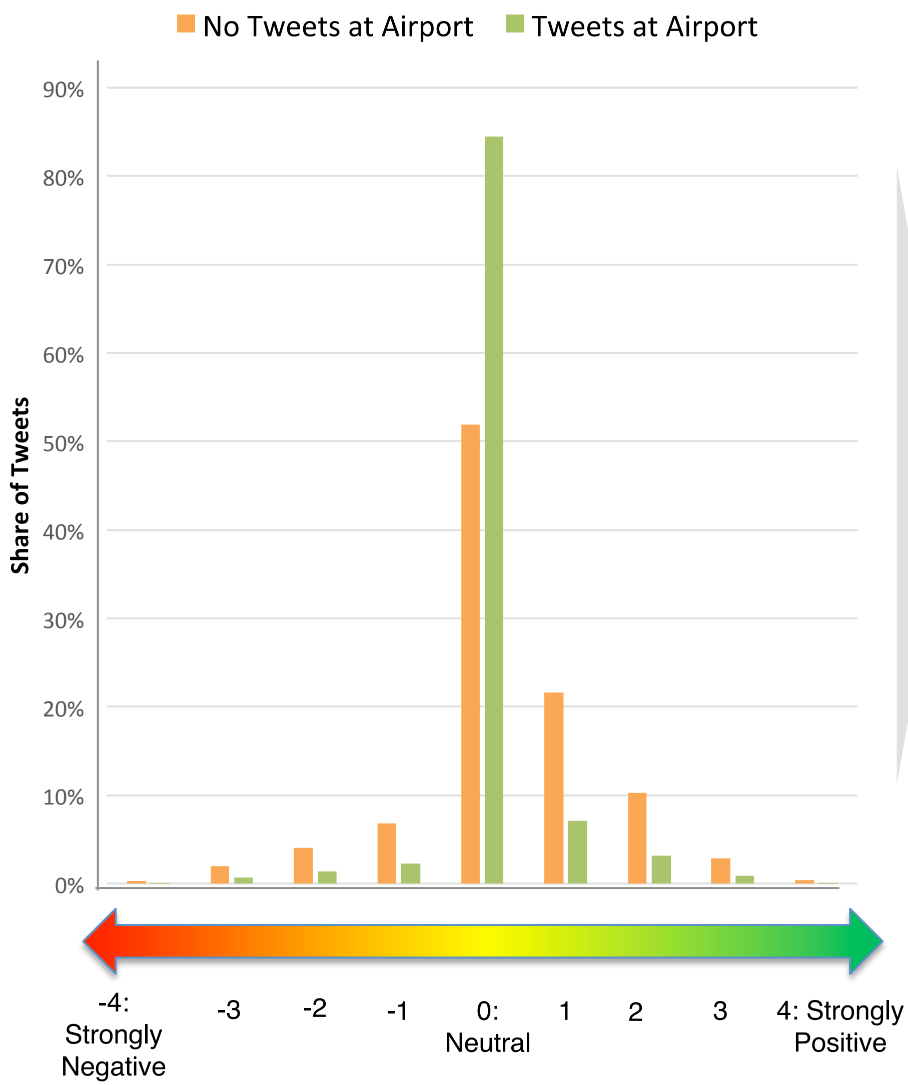


- These tweets were first analyzed as a whole set then using a keyword filter to see general sentiment and sentiment related to aviation + aviation/ noise to extract specific tweets

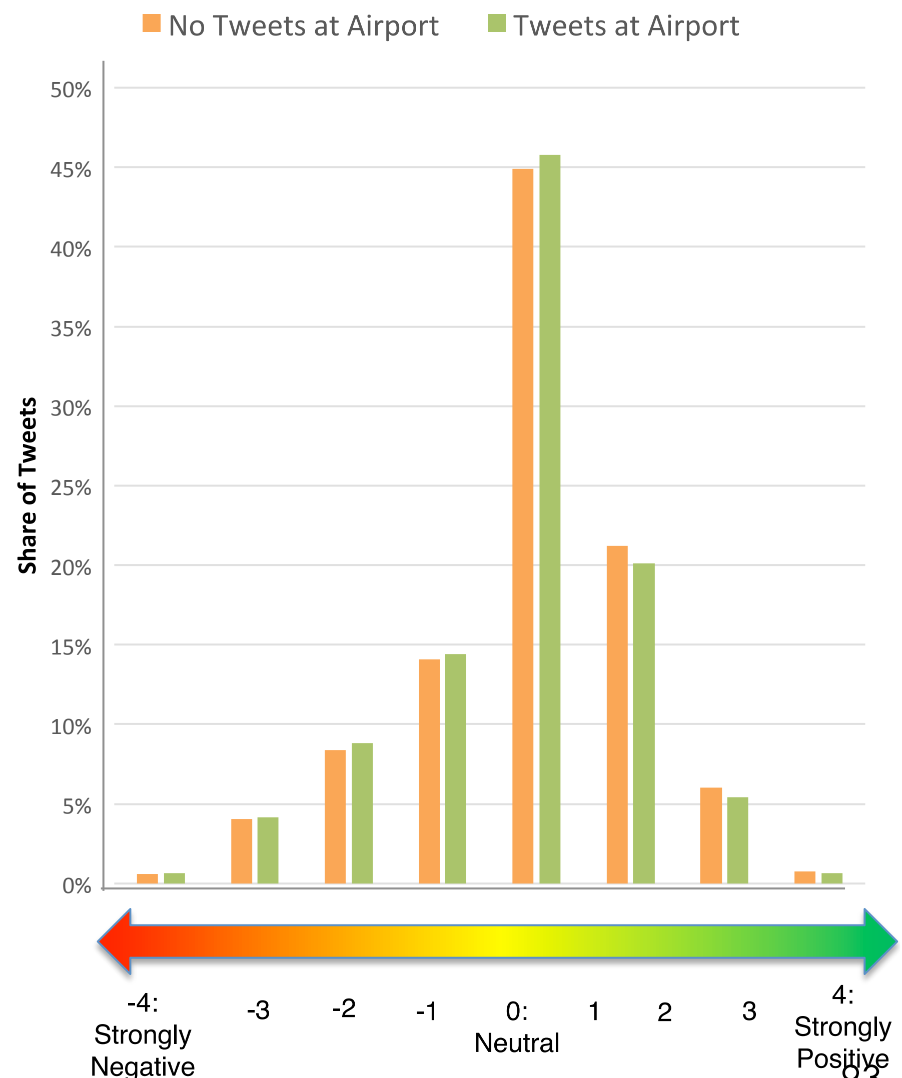
Overall Tweet Sentiment

Distribution of Tweet Sentiments

N= 13,039,129

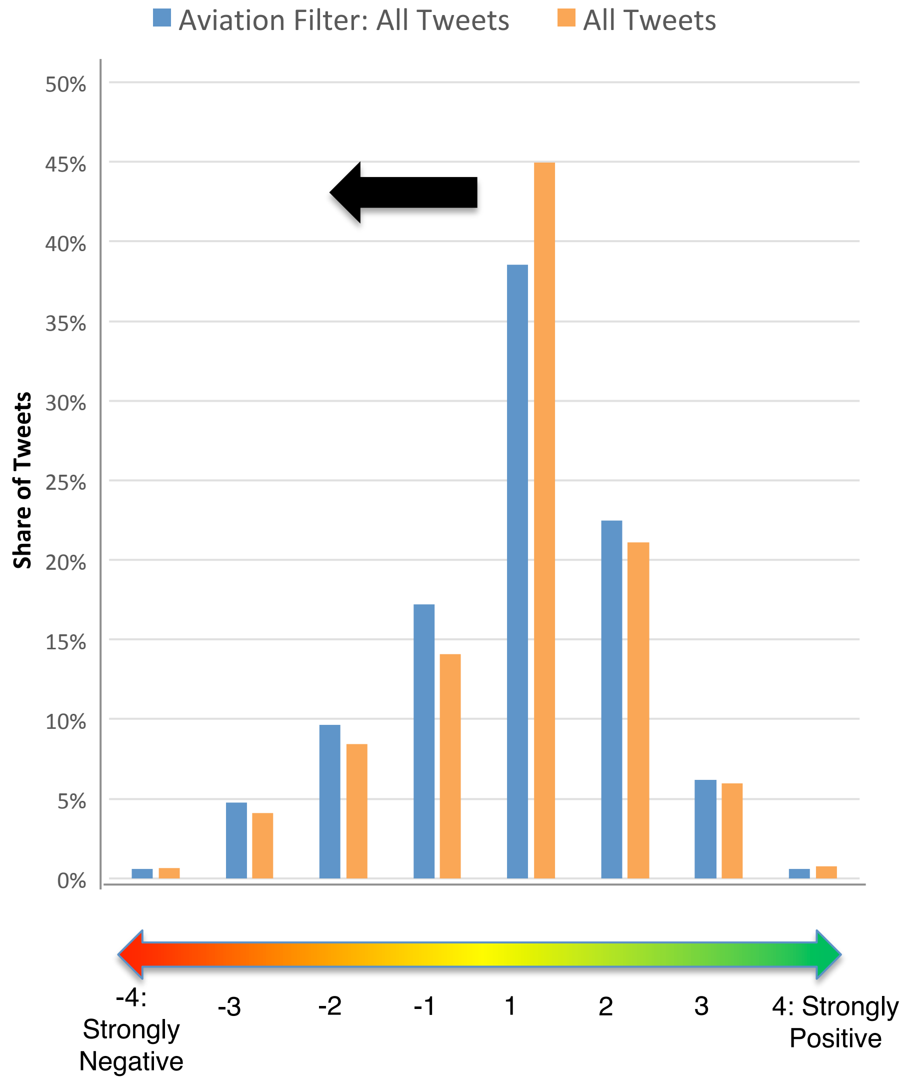


Distribution of Non-Neutral Tweet Sentiments

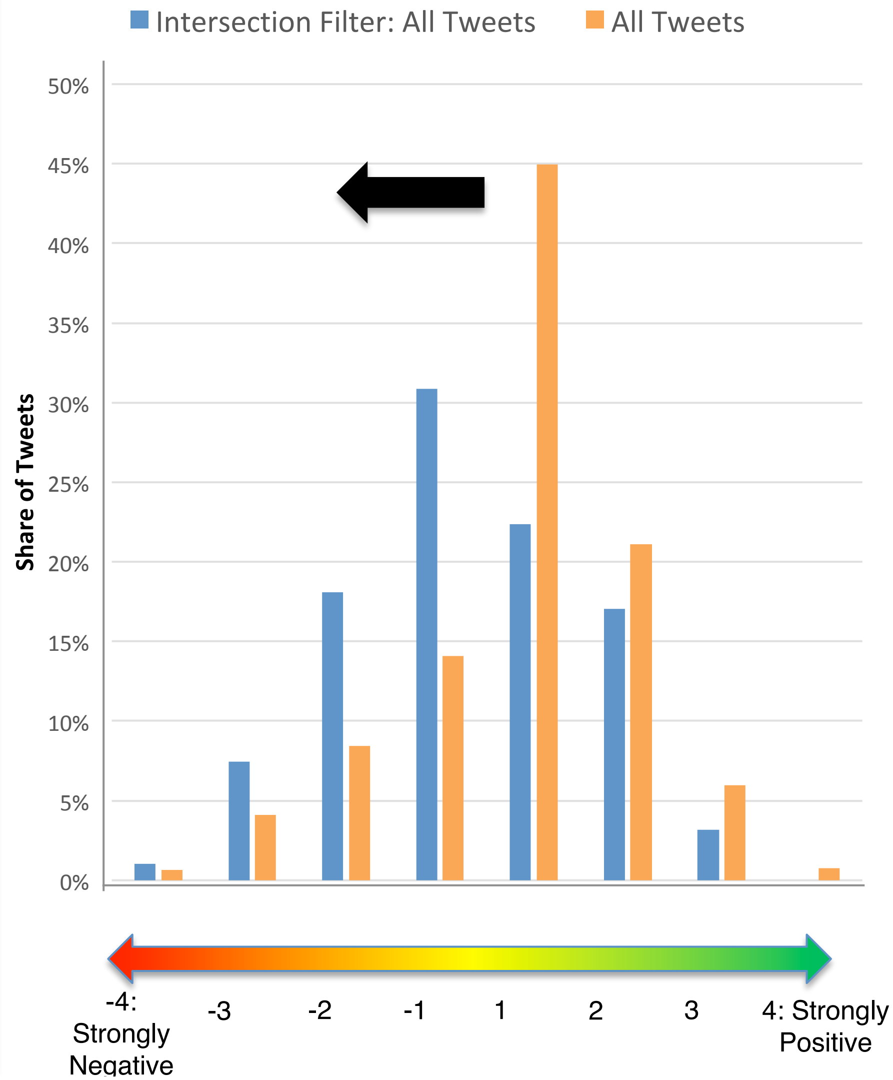


Keyword Specific Tweet Sentiment

Aviation Keywords: *airport* or *LHR* or *Heathrow* or *airplane* or *aeroplane* or *plane* or *wing*



Aviation/Noise Keywords: words (*noise or noisy*) **<u>AND</u>** (*airport or LHR or Heathrow or airplane or aeroplane or plane or wing*)



Word Cloud for Highly Positive (3, 4) Aviation-Related Tweets

Word	Frequency (%)
‘you’	2.47
’following’	1.58
‘thank’	1.05
‘great’	1.03
‘good’	1.02
’please’	0.86
‘appreciated’	0.64
‘london’	0.47
‘heathrow’	0.45
‘airport’	0.42
‘heathrowairport’	0.32
’excited’	0.32
‘today	0.32

Word Cloud

15 miles

Initial Processing:

- Remove non-Latin characters
- Remove weblinks
- Remove profanity
- Remove words shorter than 3 characters
- Remove English stopwords (e.g. able, also, the, and, that)

Word Cloud for Highly Negative (-3, -4) Aviation Tweets

Word	Frequency (%)
'you'	1.43
'following'	0.77
'showing'	0.71
'knowing'	0.70
'airport'	0.65
'your'	0.61
'wing'	0.60
'hate'	0.58
'planet'	0.53
'plane'	0.49
'right'	0.48
'heathrow'	0.46
'heathrowairport'	0.23

Word Cloud

15 miles

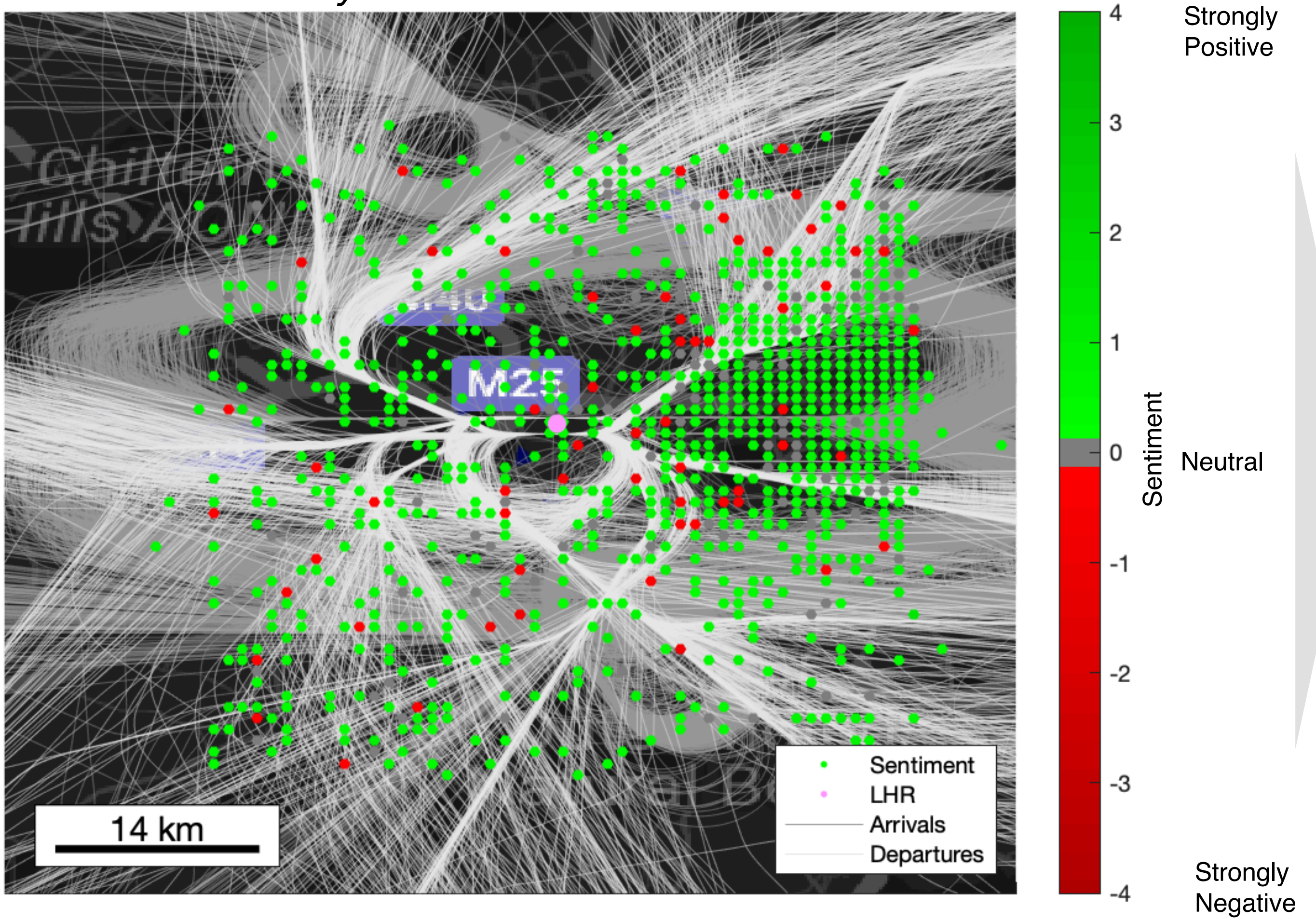
Initial Processing:

- Remove non-Latin characters
- Remove weblinks
- Remove profanity
- Remove words shorter than 3 characters
- Remove English stopwords (e.g. able, also, the, and, that)

Spatial Distribution of Tweet Sentiments and Flight Tracks

Average sentiment of non-neutral tweets
*Only cells with 5 or more tweets are shown; 1km*1km grid*
June 2018-January 2019

15 miles



No statistically significant trend with distance from LHR nor distance to Central London observed

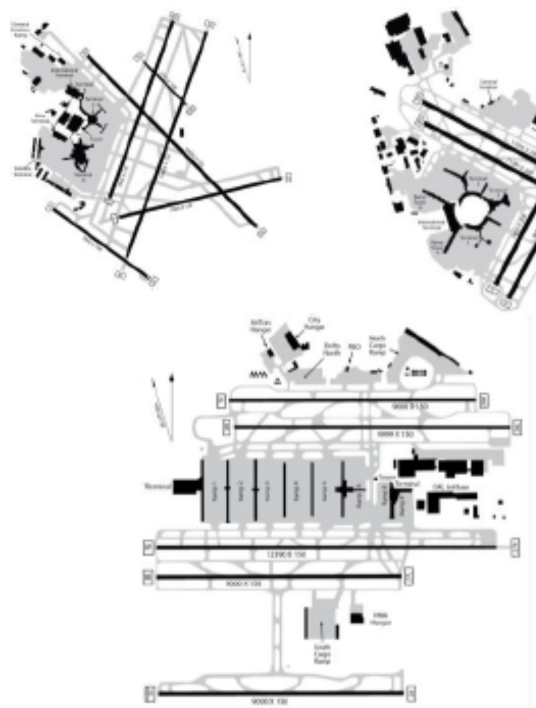
Questions?

Example Positive and Negative Aviation Tweets

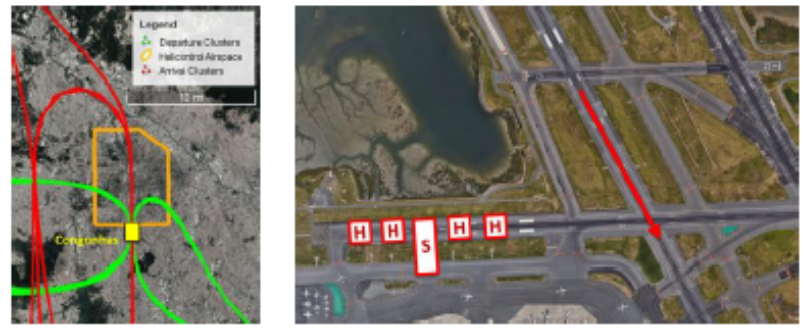
Positive Tweet	Sentiment Score		Negative Tweet	Sentiment Score
Absolutely amazing to see the @rafredarrows fly past @HeathrowAirport!	4		F***** hate living so close to Heathrow airport, planes at night are annoying	-4
Expanding Heathrow Airport will create jobs! It's time for the government to approve it!	4		@Heathrow Why every f**** minute a new noisy smelly plane. What are these noise sewers? You are hurting children. Scum.	-4
Have you been to #London Heathrow Airport??? It's gorgeous and one of the busiest in the world!	3		The thing I hate the most about Heathrow is that they always give the gate information super late. I'm boarding late	-3
Absolutely loving the British Airways Retro Uniforms for 99 Years of BA!! #britishairways #ba #flyba #heathrow	3		@HeathrowAirport complete s*** at T5 transit. One lift and both escalators from T5A departures down to transit are broken	-3

Approach to Evaluate UAM Airport and Airspace Integration

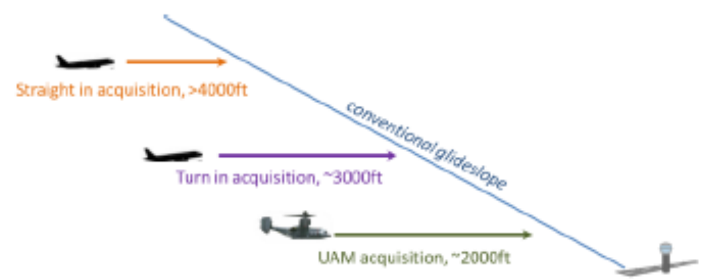
1. **Case studies at Boston, Atlanta, and San Francisco**



2. **Evaluate air traffic control, airfield infrastructure, terminal buildings, and ground access to support UAM**



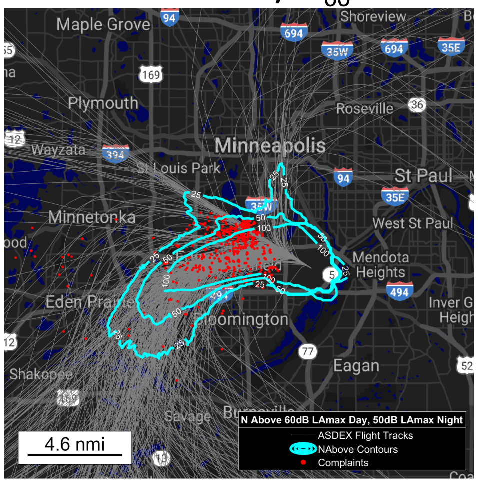
3. **Determine viable integration pathways, estimate feasible throughput, lay out requirements**



MSP N_{60} Count Thresholds

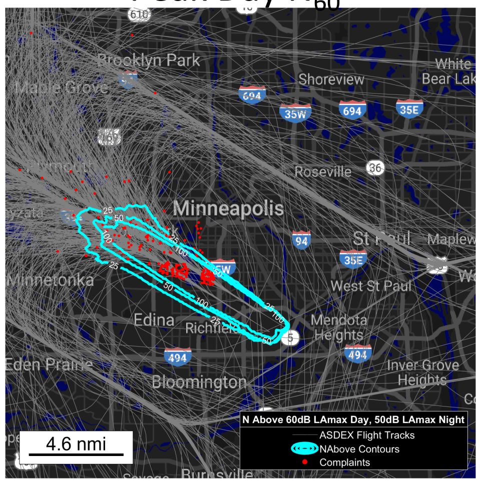
- N_{60} on a peak day with 50 overflights appears to capture complaint threshold in dispersion analysis

30L Departures
Peak Day N_{60}



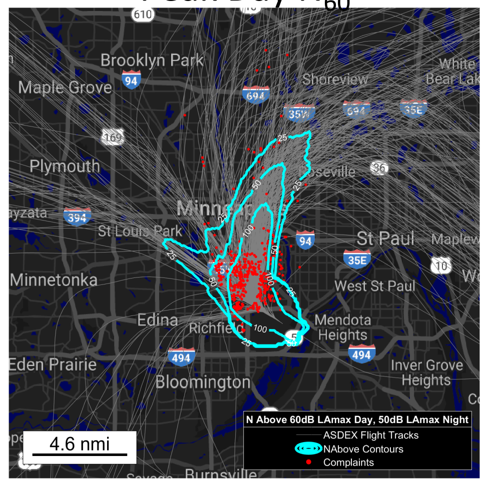
Peak Day N_{60}	Complaints Captured
25x	92.7%
50x	83.1%
100x	55.7%

12L/R Departures
Peak Day N_{60}



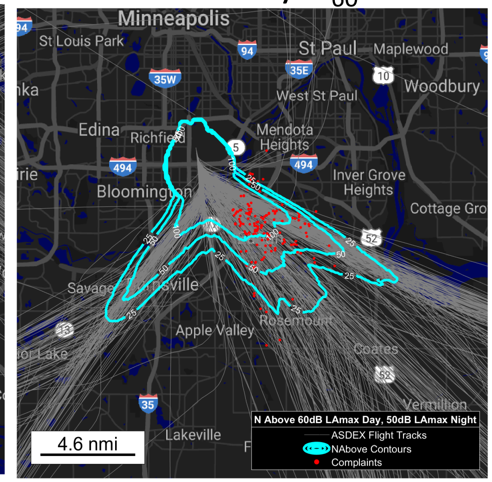
Peak Day N_{60}	Complaints Captured
25x	85.4%
50x	77.6%
100x	70.7%

30R Departures
Peak Day N_{60}



Peak Day N_{60}	Complaints Captured
25x	91.9%
50x	87.2%
100x	69.4%

17 Departures
Peak Day N_{60}



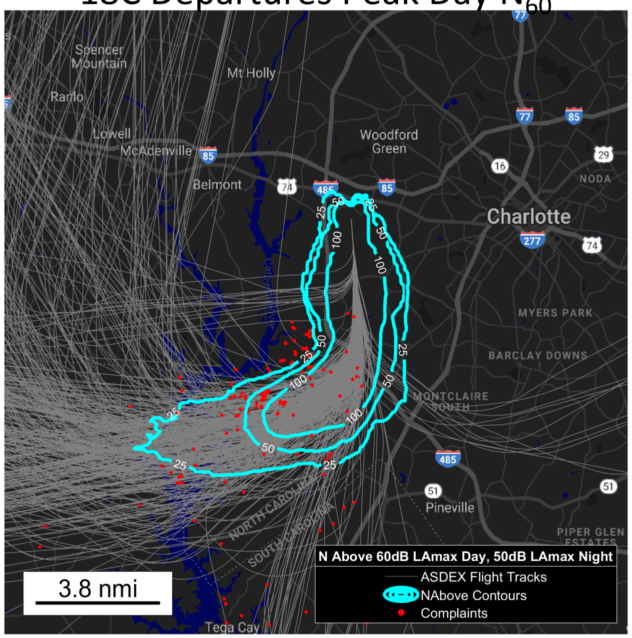
Peak Day N_{60}	Complaints Captured
25x	90.3%
50x	83.2%
100x	53.5%

2017 Data

CLT N_{60} Count Thresholds

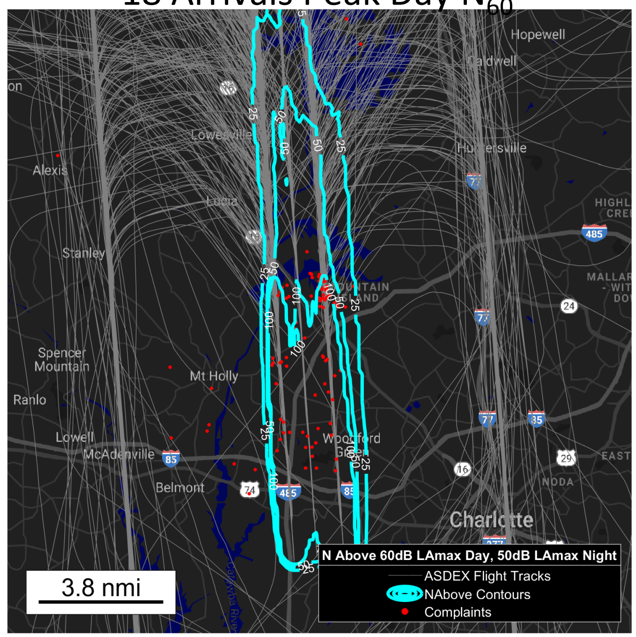
- N_{60} on a peak day with 50 overflights appears to capture complaint threshold in dispersion analysis
- Communities around CLT appear to have increased sensitivity

18C Departures Peak Day N_{60}



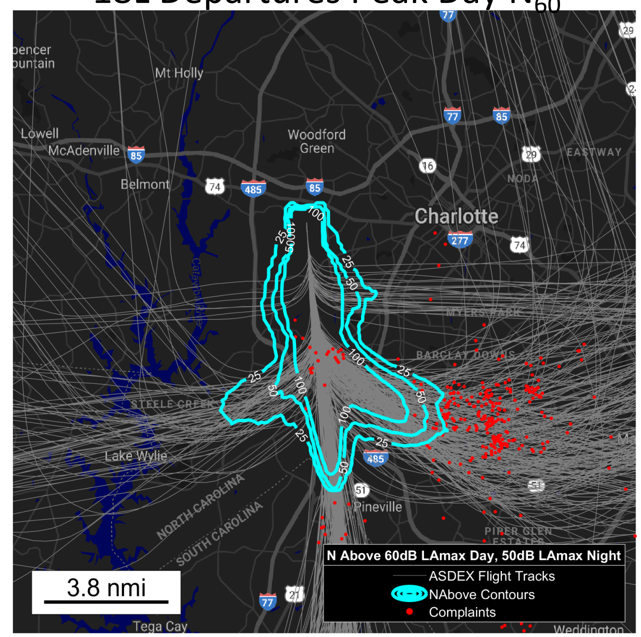
Peak Day N_{60}	Complaints Captured
25x	53.1%
50x	34.0%
100x	13.6%

18 Arrivals Peak Day N_{60}



Peak Day N_{60}	Complaints Captured
25x	83.5%
50x	80.7%
100x	59.6%

18L Departures Peak Day N_{60}



Peak Day N_{60}	Complaints Captured
25x	9.7%
50x	7.1%
100x	6.2%

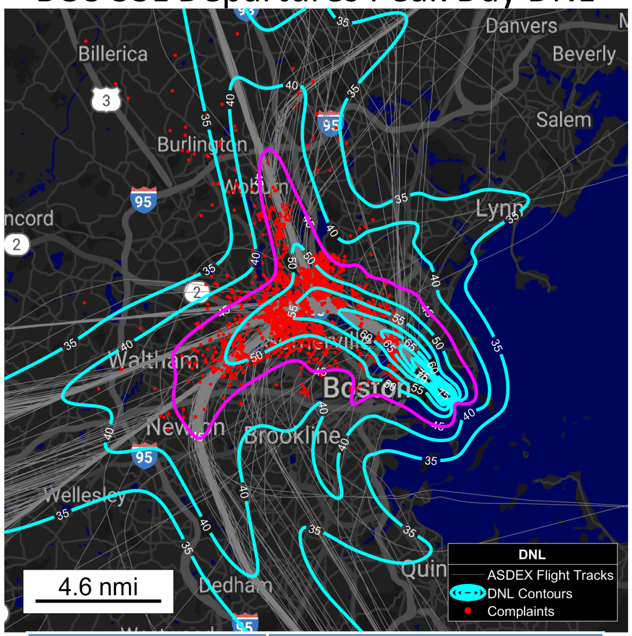
2017 Data

Peak Day DNL

- 45db DNL on a peak day appears to capture complaint threshold in dispersion analysis
- Potentially confusing to explain to stakeholders

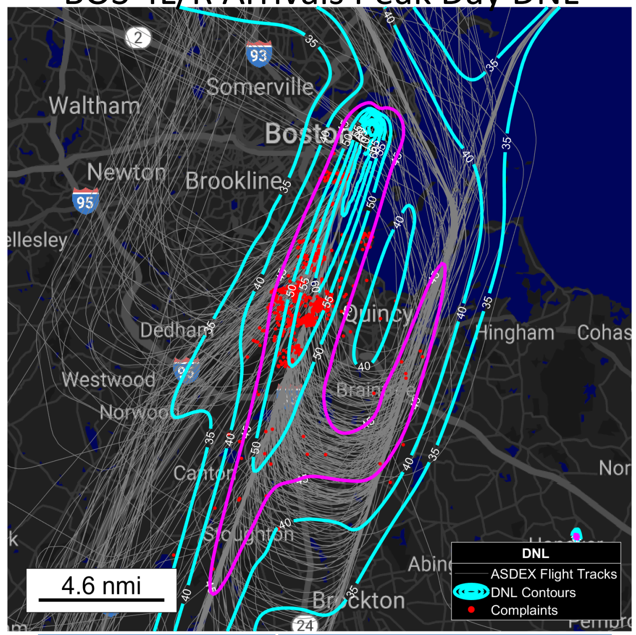
2017 Data

BOS 33L Departures Peak Day DNL



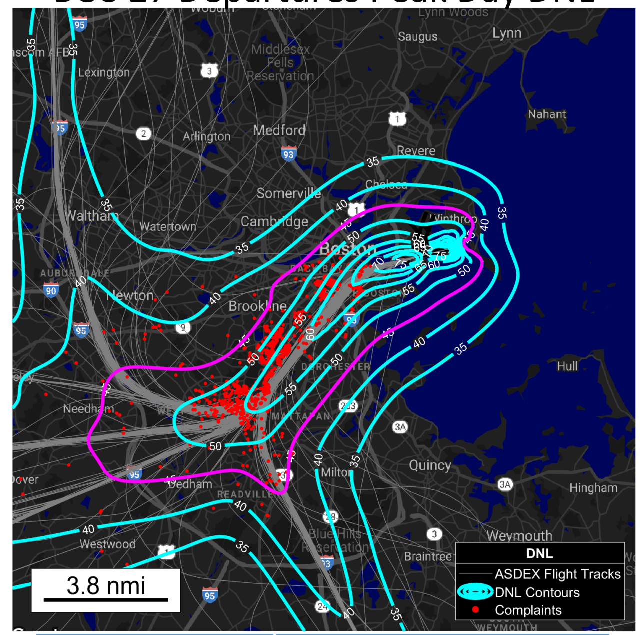
Peak Day DNL	Complaints Captured
35 dB	98.3%
40 dB	96.3%
45 dB	91.4%
50 dB	64.1%
55 dB	20.1%
60 dB	7.2%
65 dB	2.1%

BOS 4L/R Arrivals Peak Day DNL



Peak Day DNL	Complaints Captured
35 dB	99.9%
40 dB	98.7%
45 dB	92.9%
50 dB	73.1%
55 dB	45.1%
60 dB	5.4%
65 dB	0%

BOS 27 Departures Peak Day DNL



Peak Day DNL	Complaints Captured
35 dB	99.8%
40 dB	98.8%
45 dB	95.5%
50 dB	84.9%
55 dB	44.6%
60 dB	4.2%
65 dB	3.0%