MIT International Center for Air Transportation

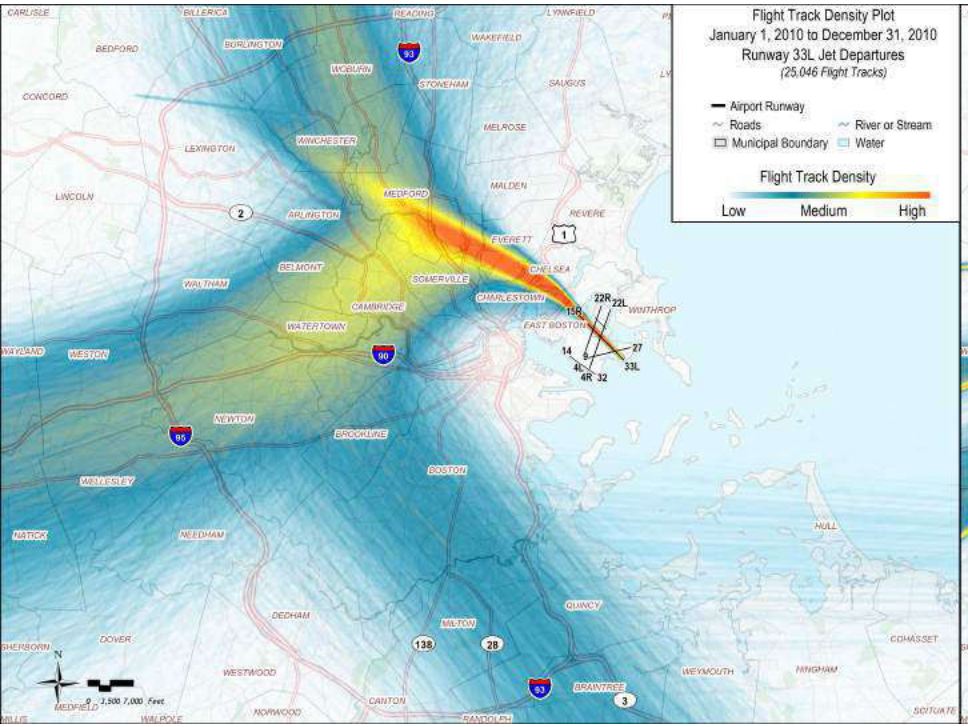
Procedure Design Concepts for Logan Airport Community Noise Reduction

R. John Hansman
rjhans@mit.edu

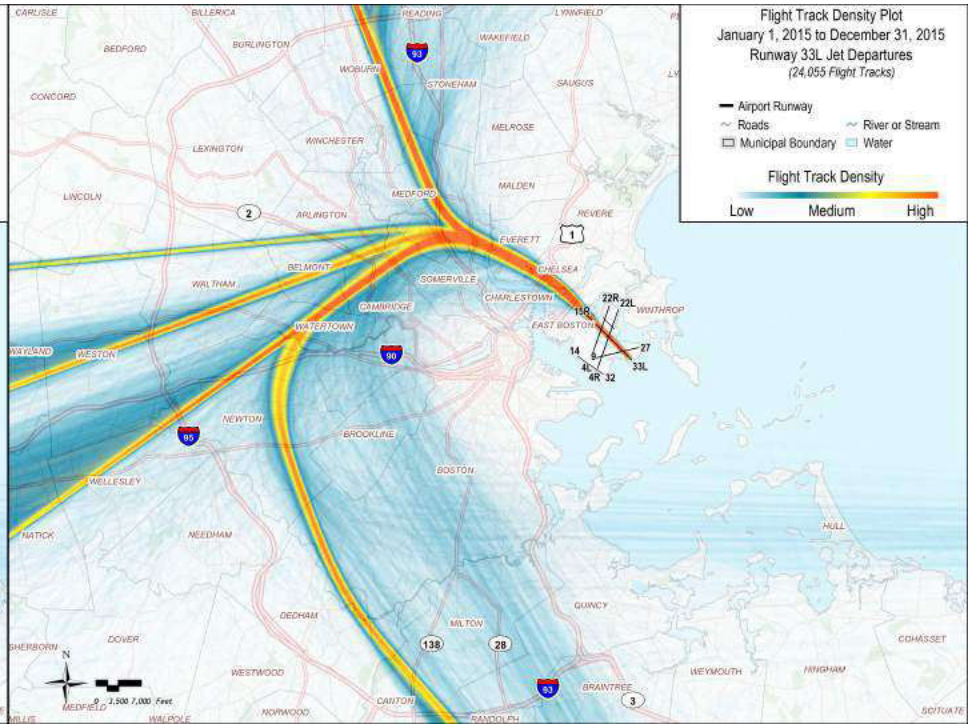
Technical support from MIT ICAT students, HMMH, and Massport

RNAV Track Concentration

2010



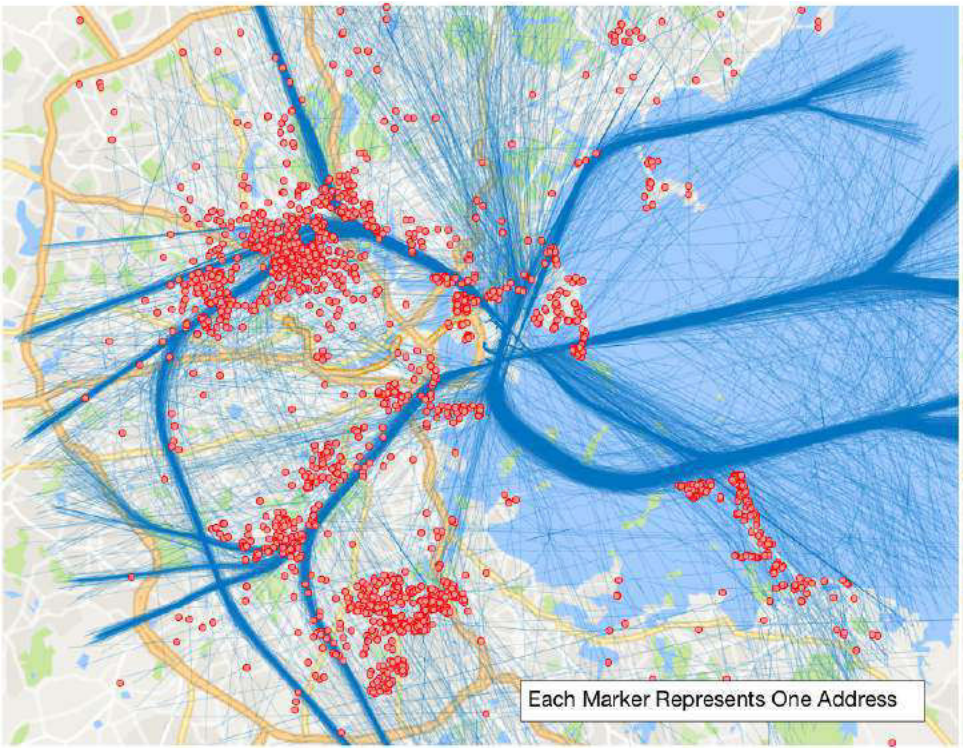
2015



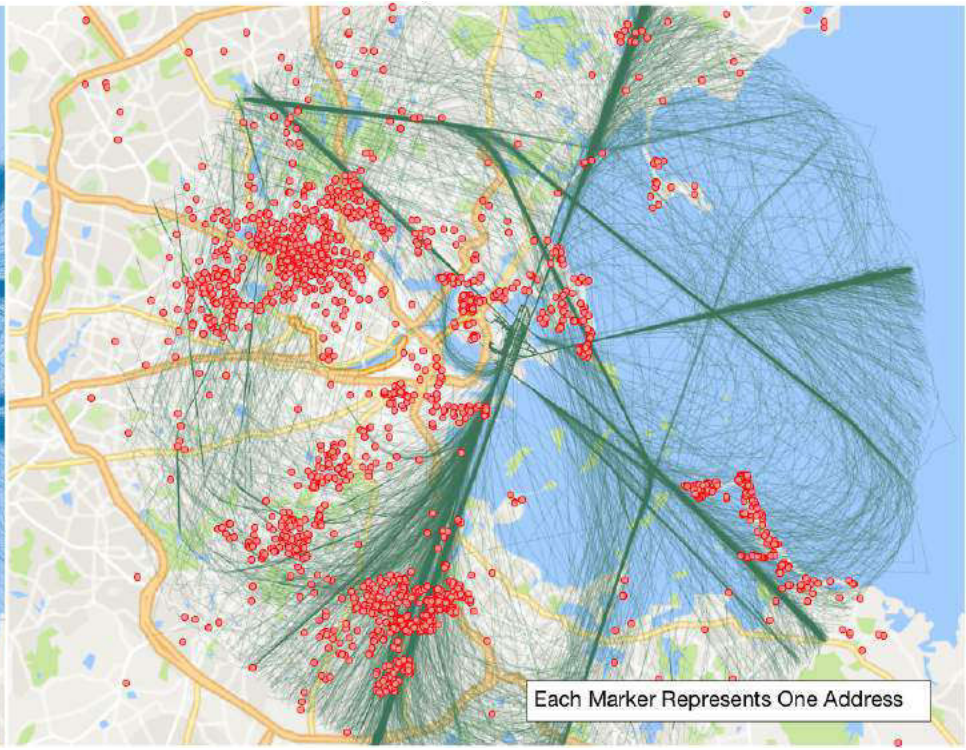
Noise Complaints at BOS: One Dot per Address

Each dot represents an address that registered at least one complaint during period

Departures



Arrivals



Complaint Data: August 2015– July 2016
Track Data: ASDE-X from 12 days of operation, 2015-2016

Technical Approach

- Collect Data and Evaluate Baseline Conditions
  - Pre and Post RNAV
  - Community Input (Meetings and MCAC)
- Identify Candidate Procedure Modifications
  - Block 1
    - Clear noise benefit, no equity issues, limited operational/technical barriers
  - Block 2
    - More complex due to potential operational/technical barriers or equity issues
- Model Noise Impact
  - Standard and Supplemental Metrics
- Evaluate Implementation Barriers
  - Aircraft Performance
  - Navigation and Flight Management (FMS)
  - Flight Crew Workload
  - Safety
  - Procedure Design
  - Air Traffic Control Workload
- Recommend Procedural Modifications to Massport and FAA
- Repeat for Block 2

Outreach (Partial List)

- Community
  - Community Meetings
  - Massport Community Advisory Committee
  - Public Officials
  - ASCENT
- FAA
  - ATO Air Traffic (HQ, TRACON, Tower, Center, Region)
  - AJV Flight Procedures
  - AFS Flight Standards
  - AEE Environment and Energy
- Airlines
  - Technical Pilot Group

Procedures Under Consideration

Block 1

- Departure Mods
  - 33L and 27
    - Reduced speed departures (1-D1)
  - 15R
    - RNAV waypoint relocation (1-D2)
  - 22L/R
    - RNAV waypoint relocation
      - Climb to intercept course (1-D3a)
      - Climb to altitude then direct (1-D3b)
    - Heading-based departure (1-D3c)
- Arrival Mods
  - 33L Low-noise overwater approach procedures
    - Overwater RNAV Instrument Approach Procedure with RNP Overlay (1-A1a)
    - Overwater RNAV Visual Procedure (1-A1b)

Block 2

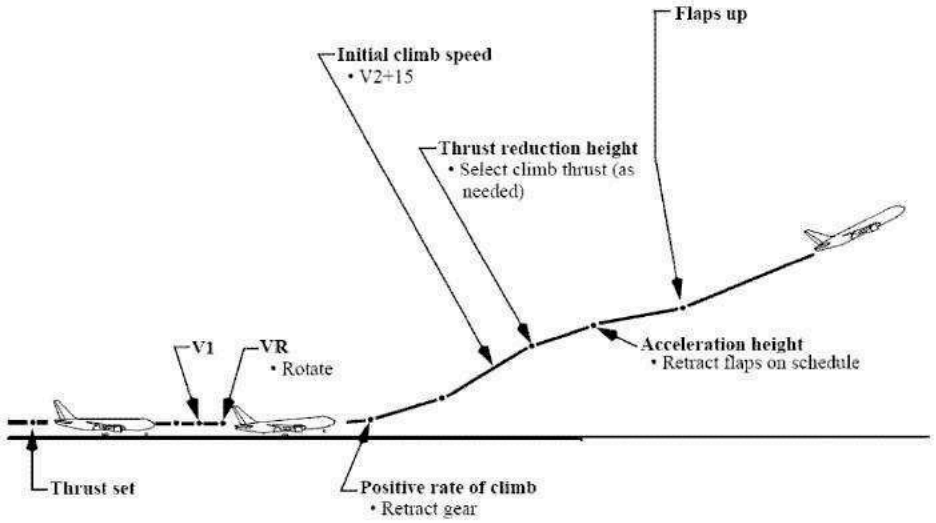
- Departure Mods
  - 33L and 27
    - Introduce dispersion with Open SID or direct-to flexibility on RNAV procedures
- Arrival Mods
  - Low-noise overwater approach procedures
    - 4R
      - RNAV approach to 4R with RNP Overlay
      - RNP approach to 4R
    - 22L
      - RNAV approach to 22L with RNP Overlay

Preliminary/Subject to Change

Block 1: Reduced Speed Departures (1-D1)

Proposed Modification

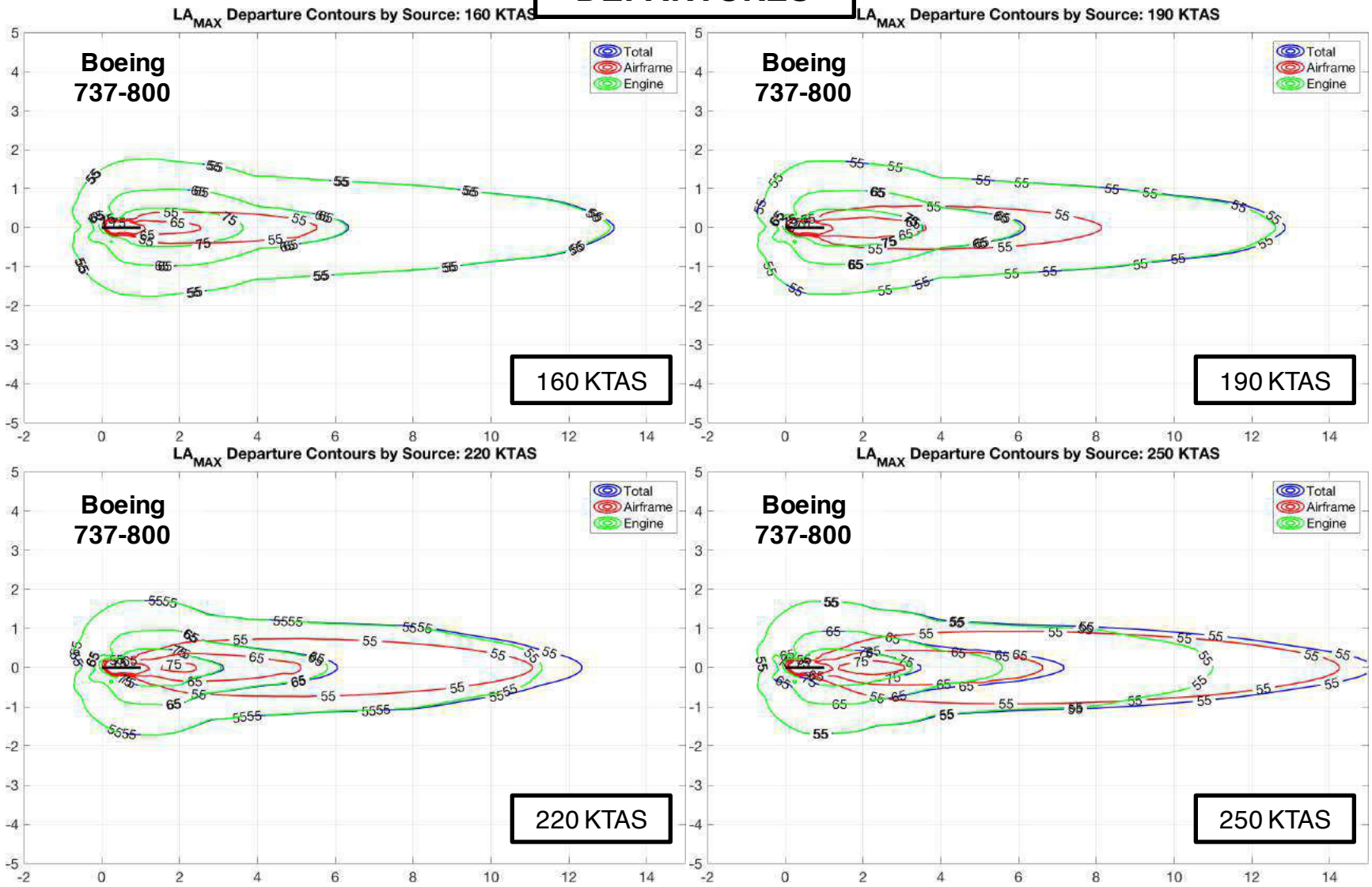
- Standard departure procedures vary by airline
- **Baseline**: Typical profile includes thrust reduction at 1,000' AGL followed by an **acceleration to 250 kt climb speed** and **flap retraction**
- **Proposal:** Thrust reduction at 1,000' AGL followed by an **acceleration to 220 kt climb speed or minimum clean operating speed, whichever is greater** until a TBD altitude (i.e. 6,000' or 10,000')



Simulator Tested for Flyability

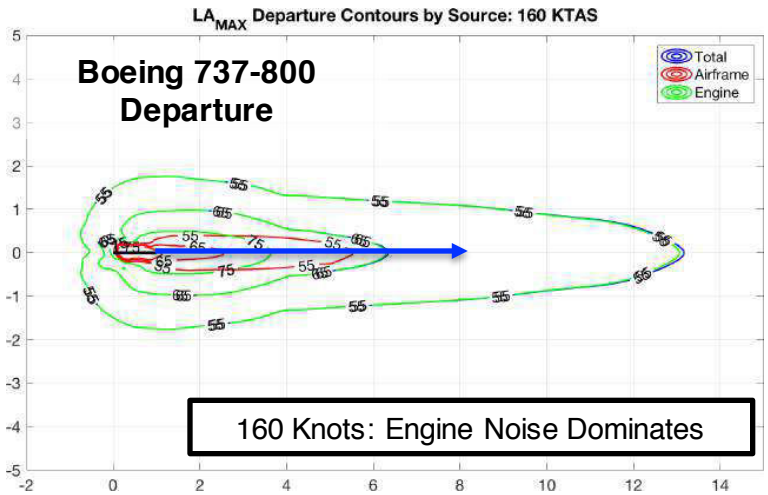
Increasing Speed Increases Airframe Noise

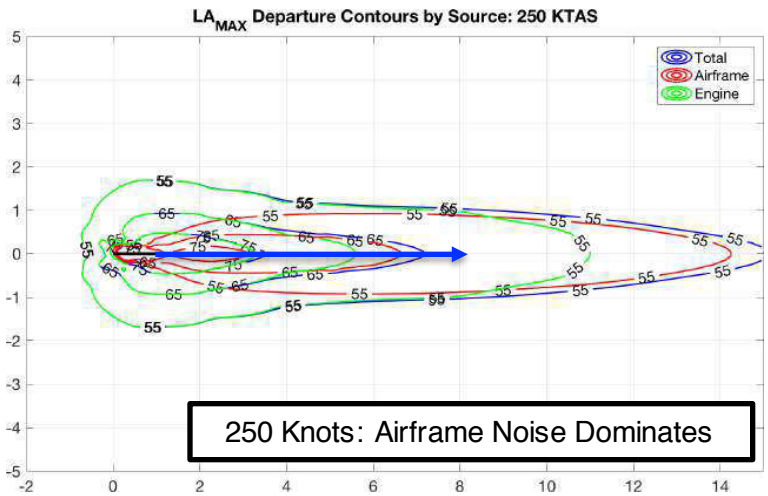
DEPARTURES

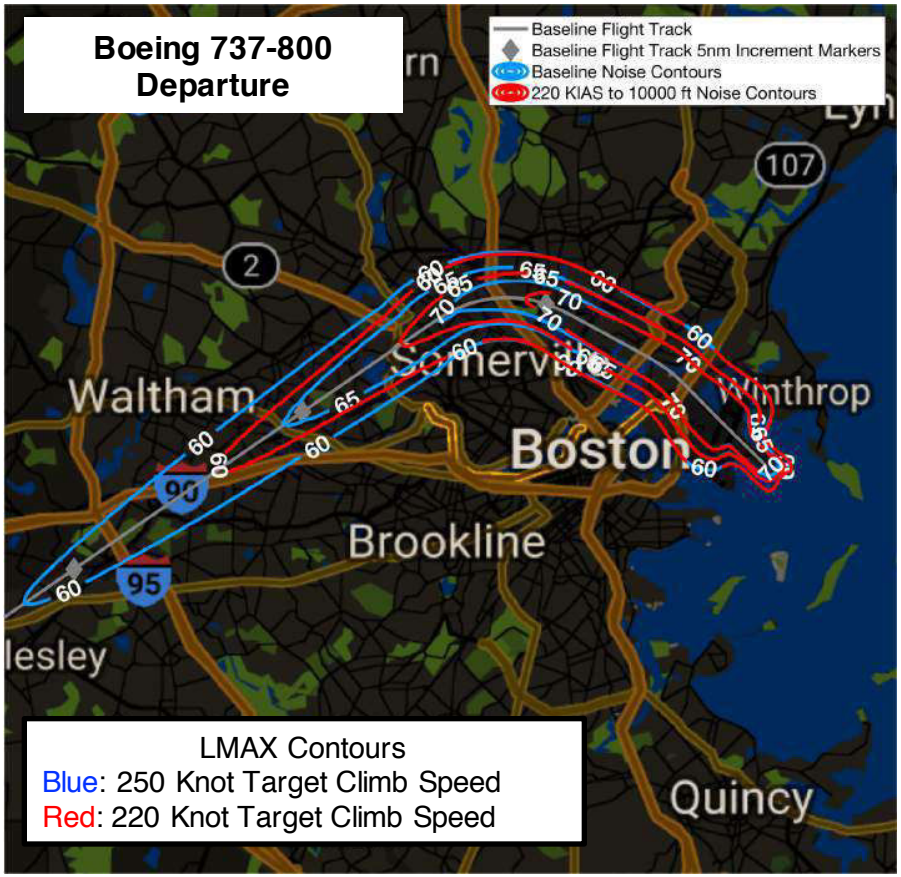


Reduced-Speed Departures

Summary: Limit climb speed on RNAV SID departures to reduce airframe noise contribution (i.e. 220 Knots through 10,000')







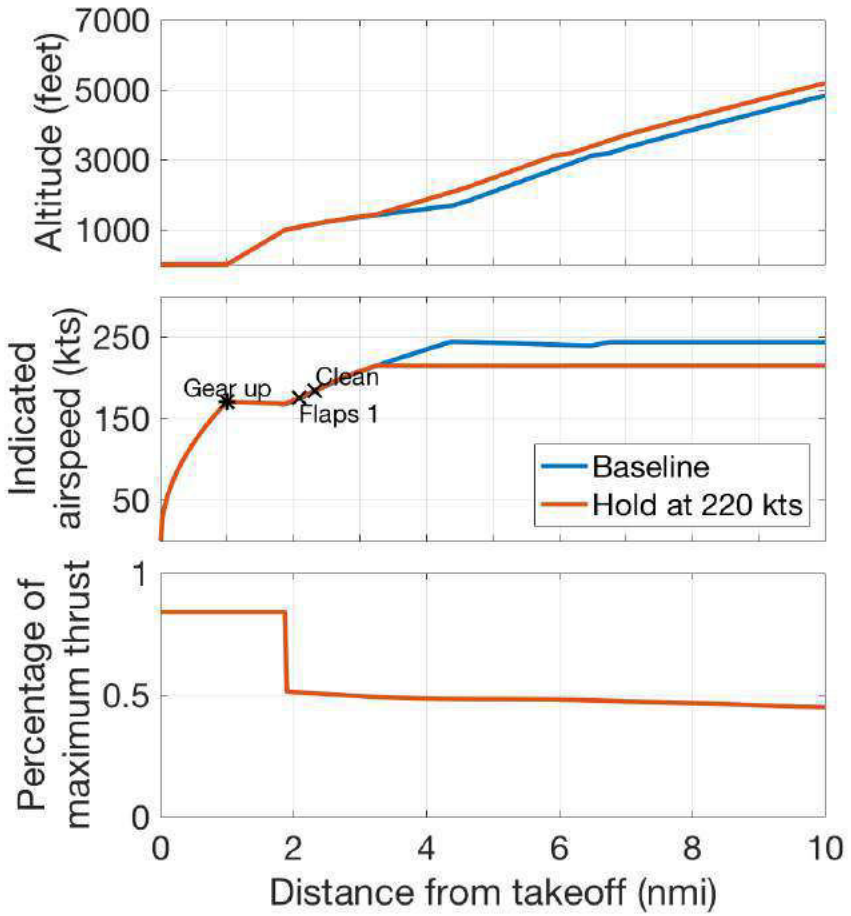
Benefits Mechanism

- Reduced noise along centerline of departure
- Effect observed for most aircraft types (single speed limit for all types)

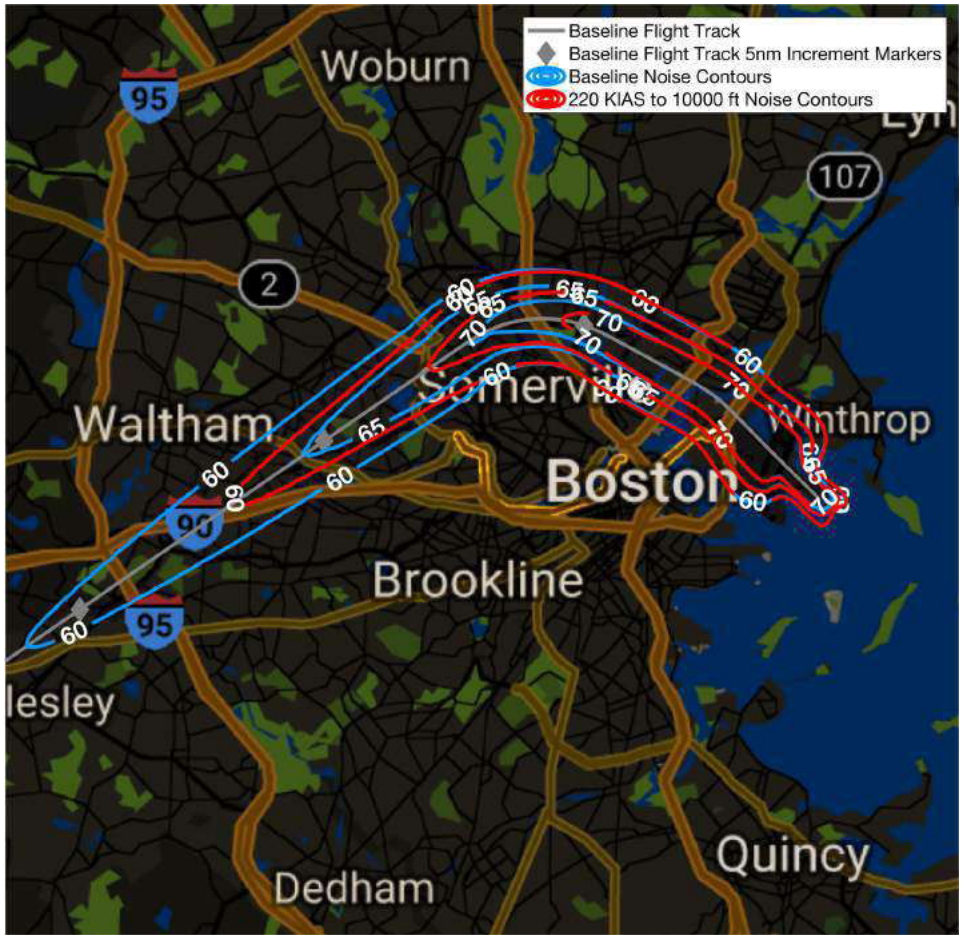
Potential Operational Constraints

- Increased fuel burn
- Increased flight time
- Potential implications for departure throughput

737-800: Delayed Acceleration Climb – 220 knots



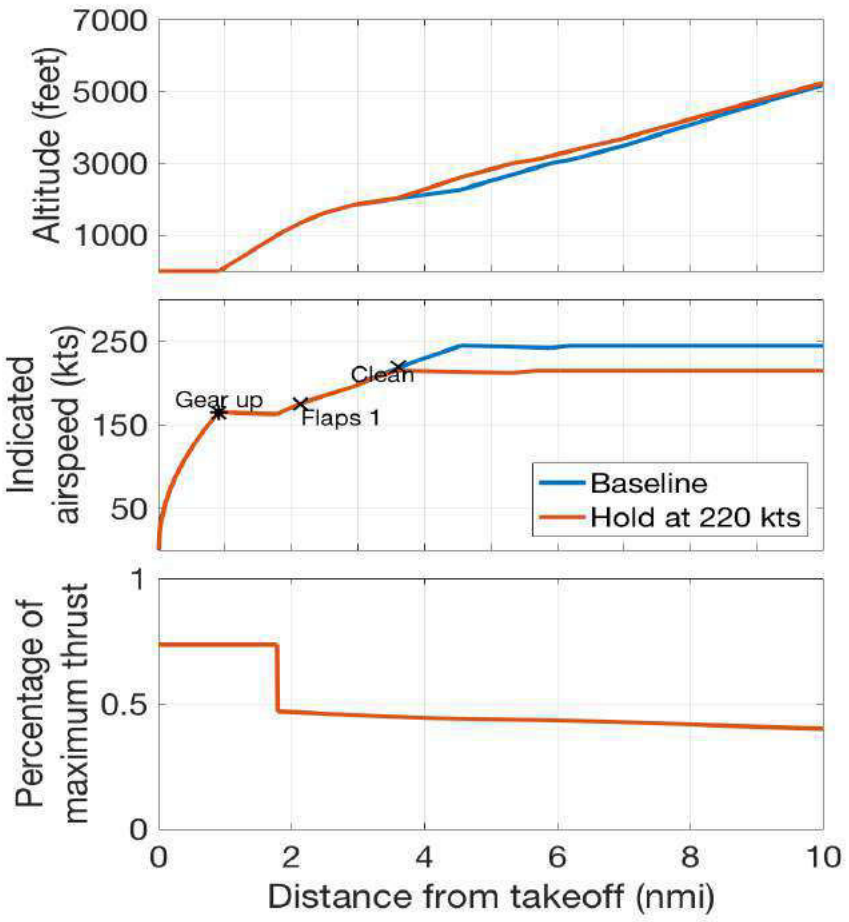
Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	ANOPP
Notes	Runway 33L: Maintain Standard Climb Thrust & 220 KIAS to 10,000'



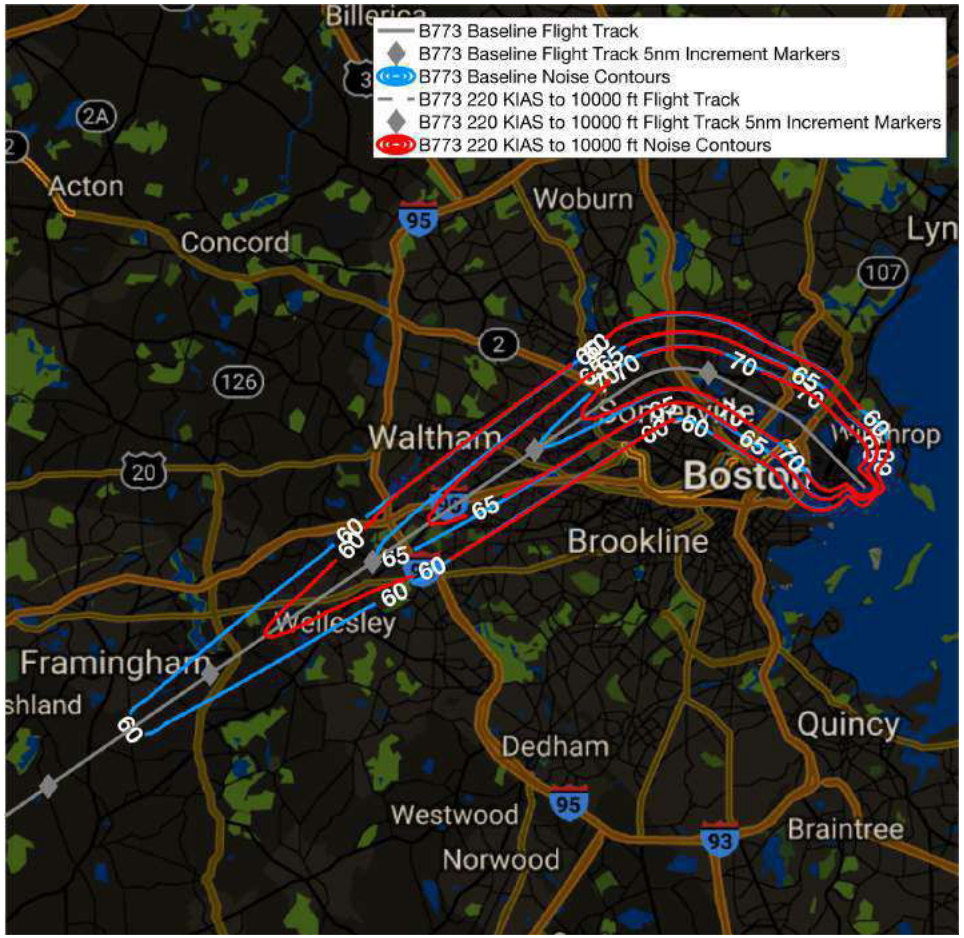
Population Exposure

	60dB	65dB	70dB
Standard Departure	237,952	105,869	38,599
Delayed Acceleration	190,128	75,469	28,239
Reduction	47,824	30,401	10,359

777-300: Delayed Acceleration Climb – 220 knots



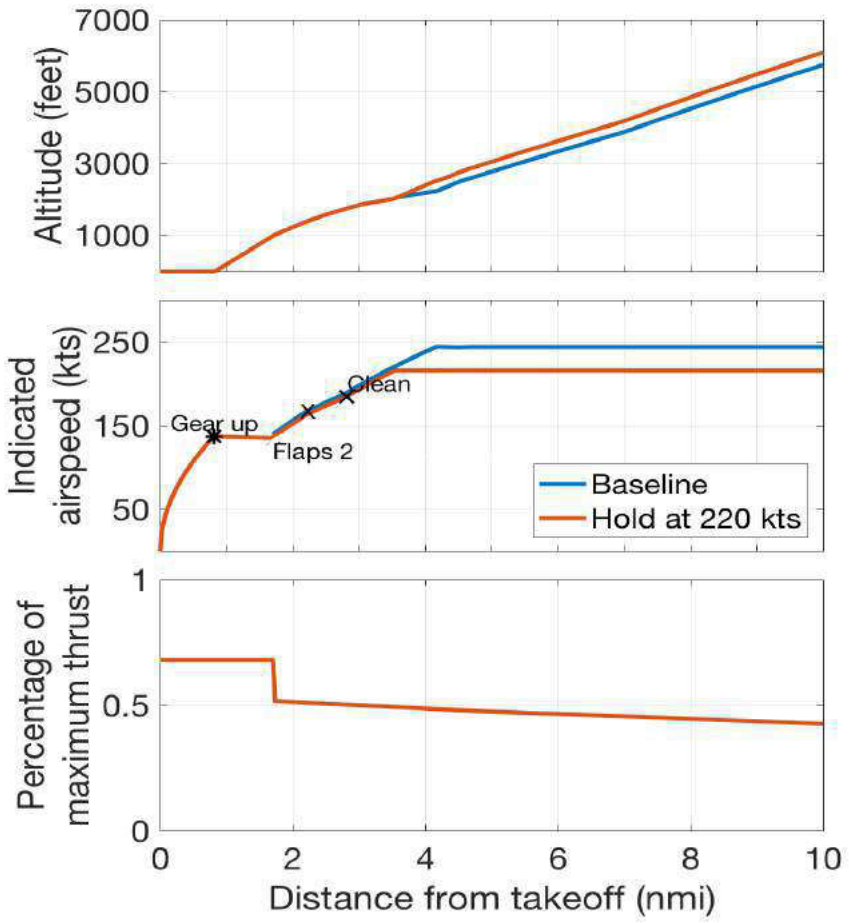
Aircraft	B777-300
Metric	$L_{A,MAX}$
Noise Model	ANOPP
Notes	Runway 33L: Maintain Standard Climb Thrust & 220 KIAS to 10,000'



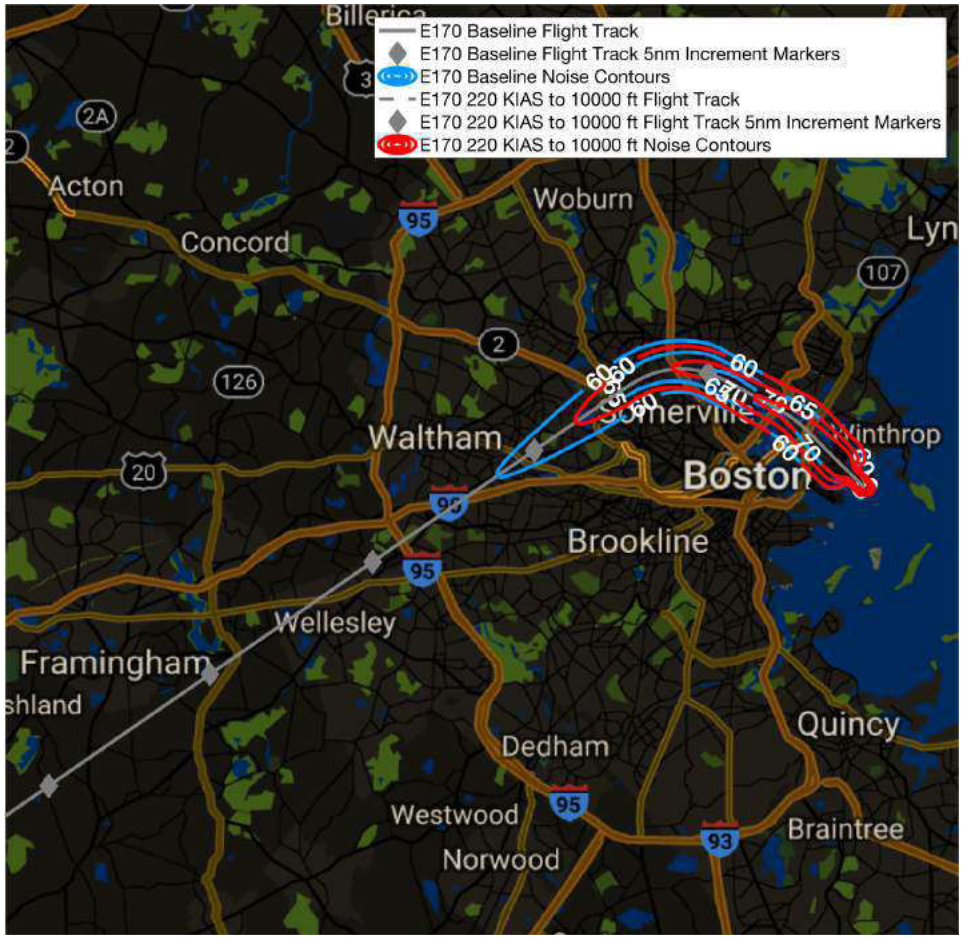
Population Exposure

	60dB	65dB	70dB
Standard Departure	455,746	275,879	118,685
Delayed Acceleration	437,415	262,310	105,182
Reduction	18,331	13,569	13,502

E-170: Delayed Acceleration Climb – 220 knots



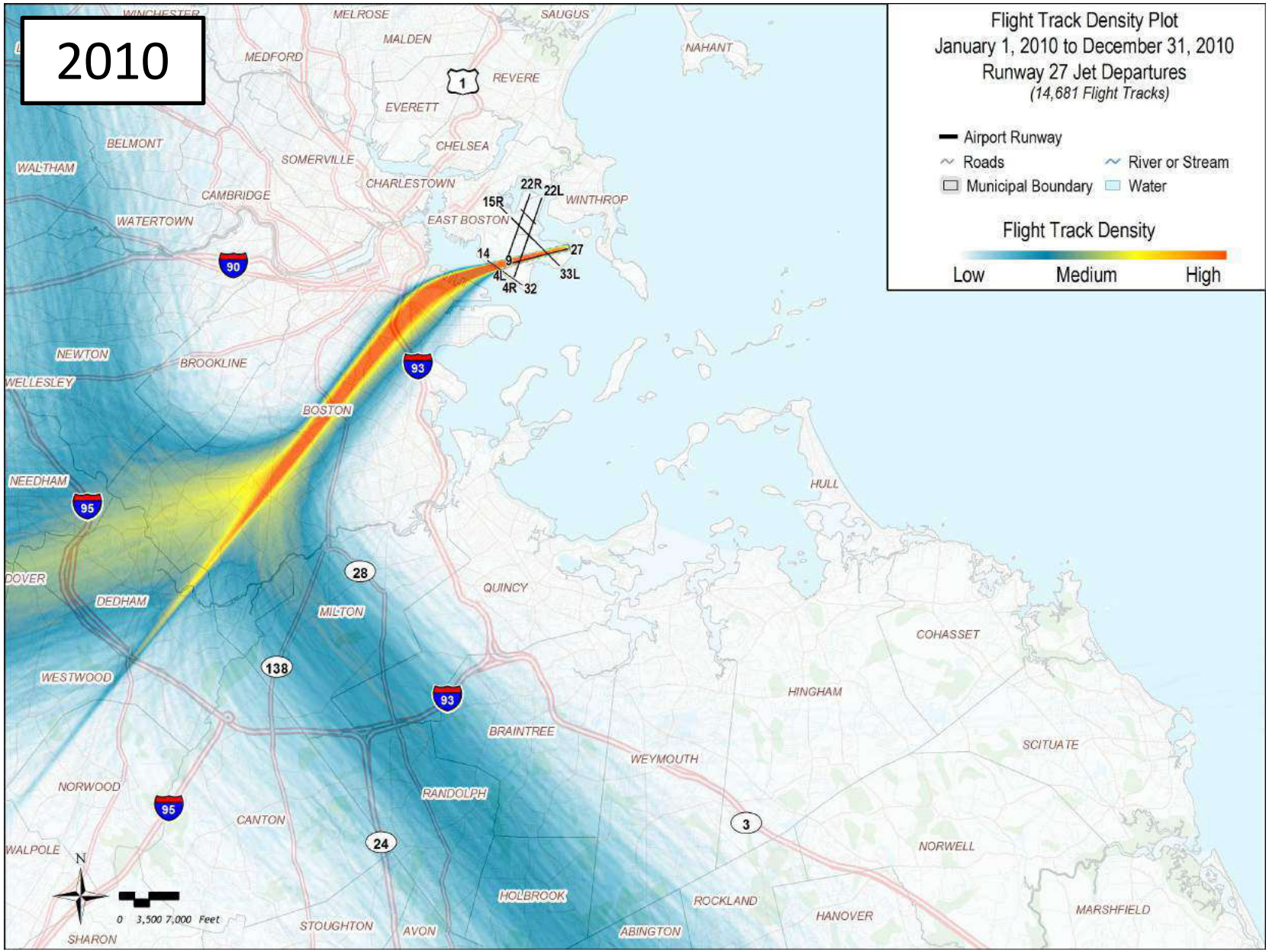
Aircraft	E-170
Metric	$L_{A,MAX}$
Noise Model	ANOPP
Notes	Runway 33L: Maintain Standard Climb Thrust & 220 KIAS to 10,000’



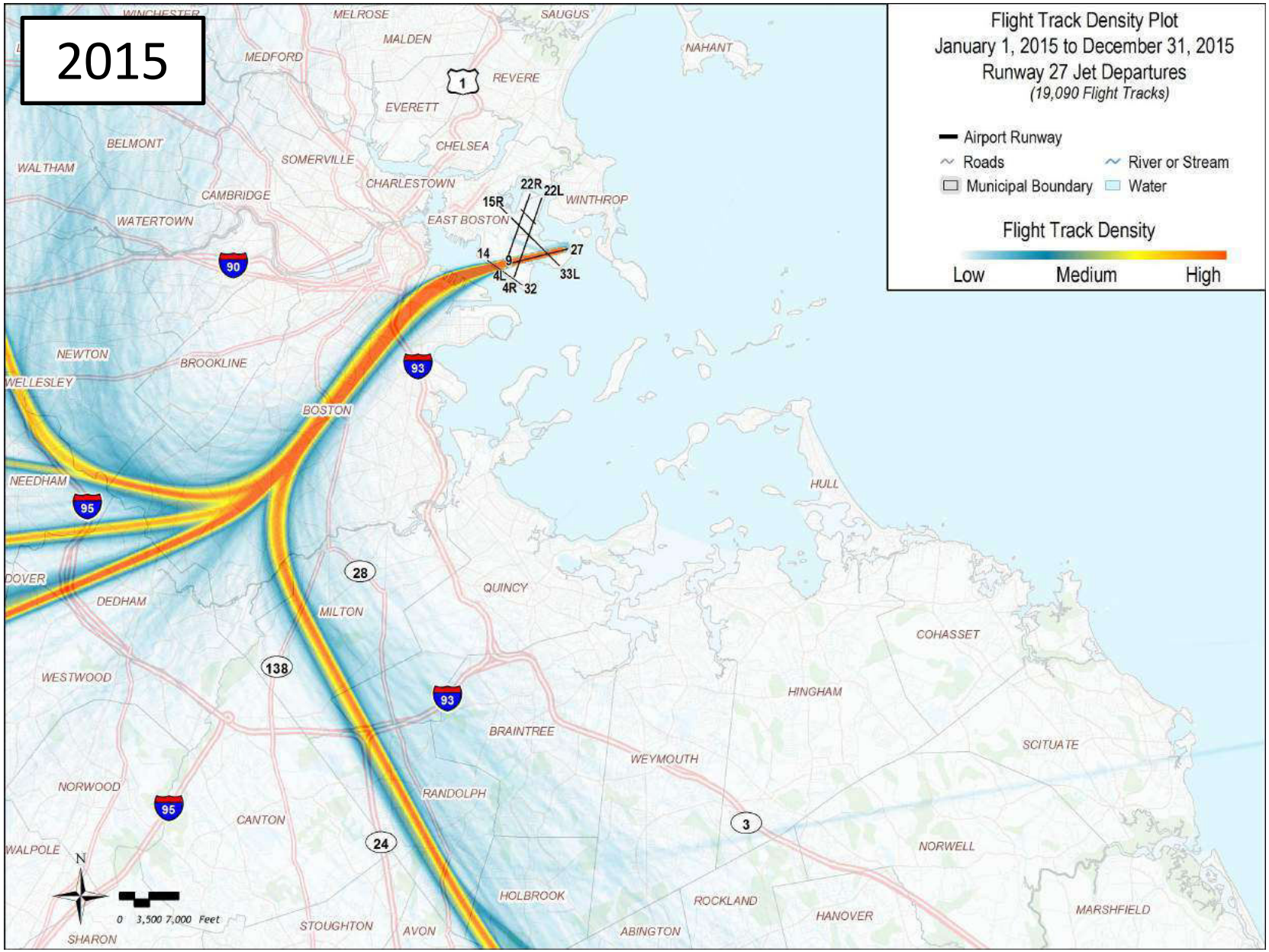
Population Exposure

	60dB	65dB	70dB
Standard Departure	147,222	58,441	10,437
Delayed Acceleration	97,728	33,306	9,298
Reduction	49,493	25,135	1,139

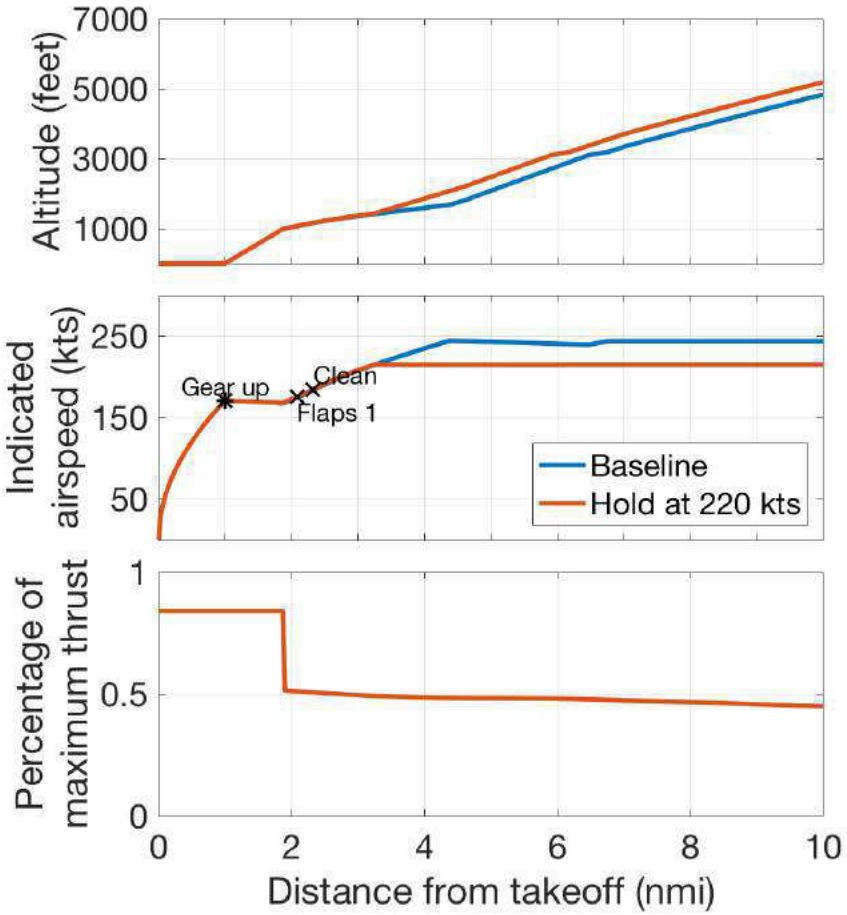
Runway 27 Departures: 2010-2015



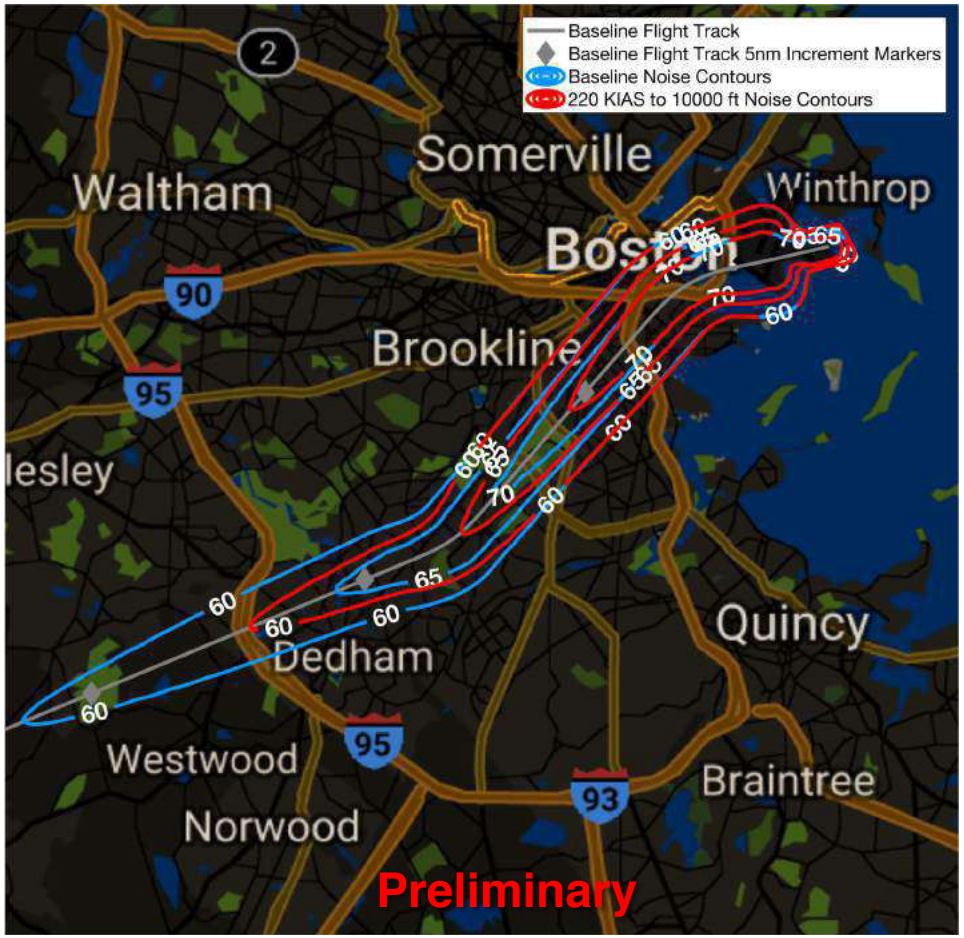
Runway 27 Departures: 2010-2015



Delayed Acceleration Climb – 220 knots



Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	ANOPP
Notes	Runway 27: Maintain Standard Climb Thrust & 220 KIAS to 10,000'



Population Exposure

	60dB	65dB	70dB
Standard Departure	200,576	102,274	37,078
Delayed Acceleration	187,400	76,261	21,066
Difference	13,177	26,014	16,011

Fuel Burn and Time Impact

- Reduced speed climb profiles impact total trip fuel burn and flight time
- Magnitude varies by speed and aircraft type

	B738		E170		B773	
Climb Speed	Fuel Burn Increase (kg)	Time Increase (s)	Fuel Burn Increase (kg)	Time Increase (s)	Fuel Burn Increase (kg)	Time Increase (s)
180 kts	141	121	55	92	674	178
200 kts	54	65	12	43	321	107
220 kts	21	30	4	22	160	52
240 kts	4	8	1	6	32	12

Open Issues

- **Issues**
  - Increased fuel burn and flight time
  - Potential throughput reduction
  - Nonstandard relative to normal operating procedures
- **Pending Analysis**
  - Determining minimum clean operating speed for set of representative aircraft types
  - Historical radar analysis for throughput impact assessment
  - Comparing noise impact of NADP-1 relative to proposed procedure
    - Will recommend NADP-1 adoption if benefits are equivalent

NADP1 vs. 220 Knots to 10,000ft: B737-800 Noise Exposure

Population Exposure (L_{MAX})

	60dB	65dB	70dB
Baseline Departure	234,915	117,504	46,584
NADP-1	230,253	96,202	26,299
Difference	4,662	21,302	20,285

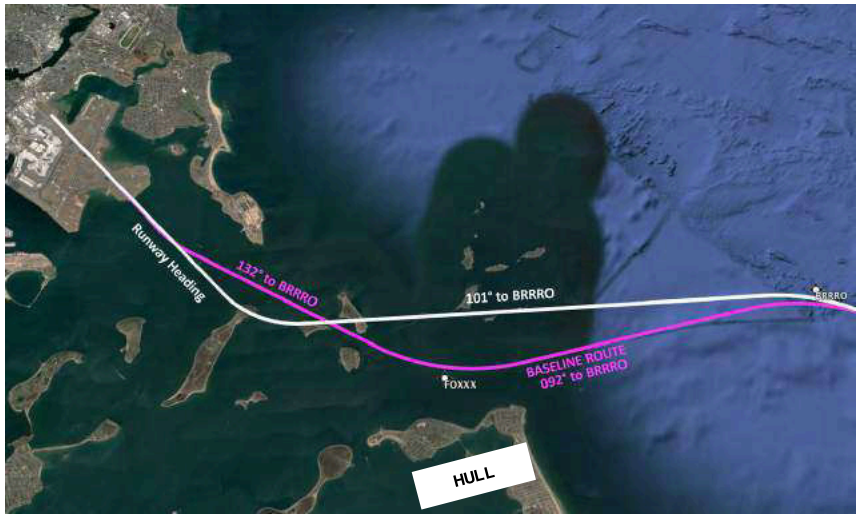
Population Exposure (L_{MAX})

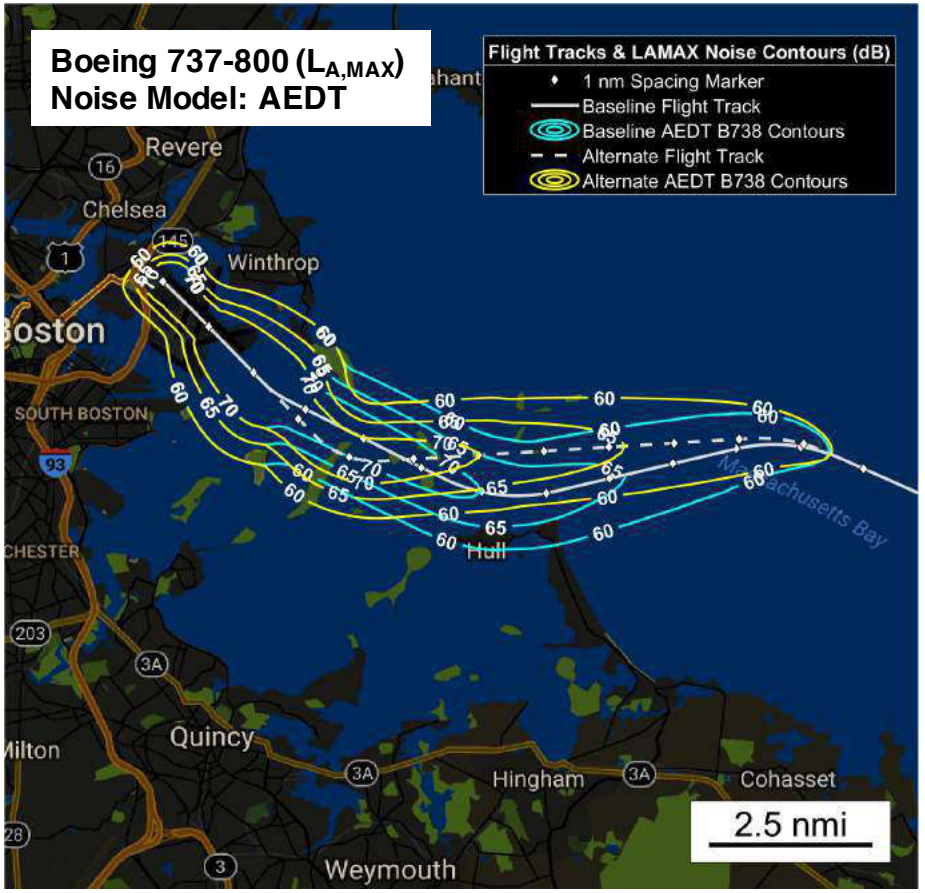
	60dB	65dB	70dB
Baseline Departure	234,915	117,504	46,584
220kt to 10k ft	180,729	74,409	25,634
Difference	54,186	43,095	20,950

Block 1: Runway 15R RNAV Waypoint Relocation (1-D2)

Runway 15R SID Modification

Summary: Relocate initial waypoint on RNAV SID from FOXXX to BRRRO in order to provide noise relief at Hull





Population Exposure

	60dB	65dB	70dB
Baseline RNAV SID	5,372	299	116
Modified Procedure	4,058	288	116
Reduction	1,314	11	0

Benefits Mechanism

- Reduced noise at Hull due to waypoint relocation

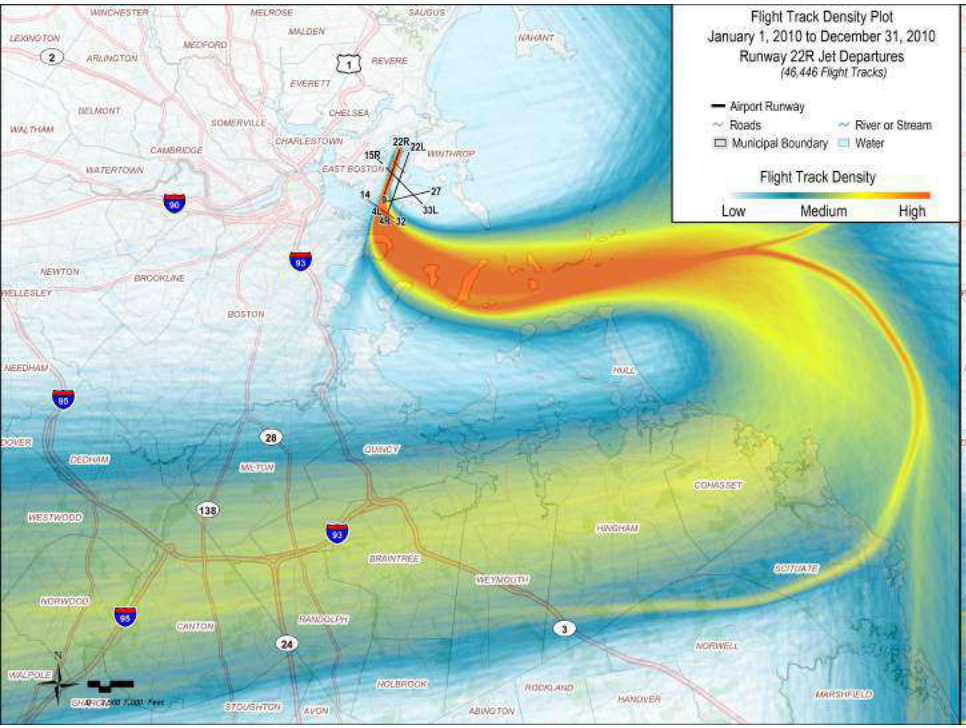
Potential Operational Constraints

- None anticipated

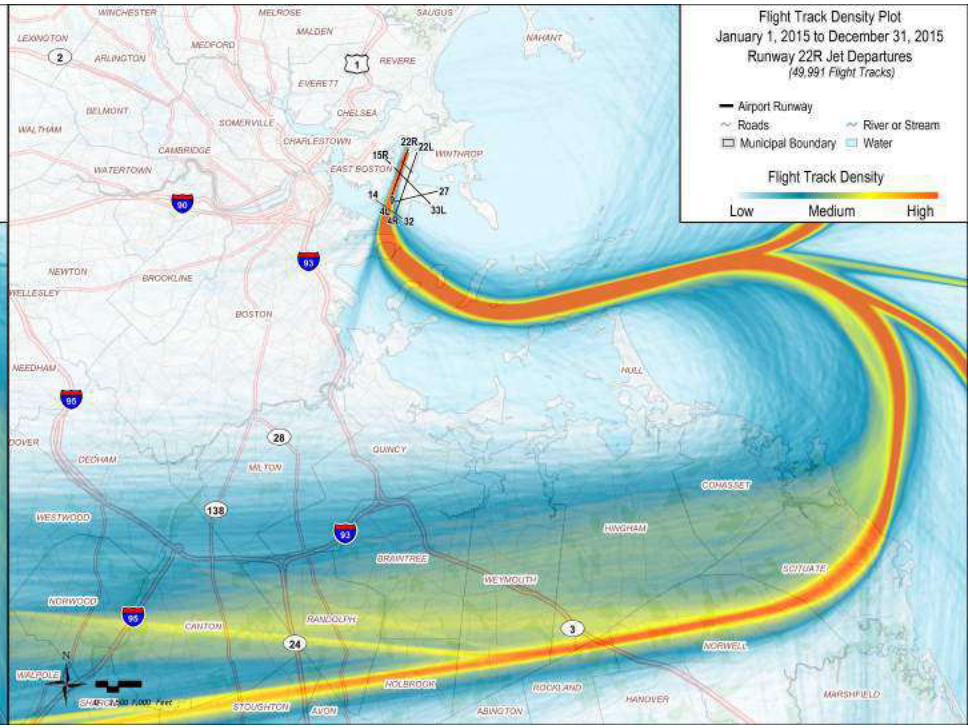
Block 1: Runway 22L/R RNAV SID Modification

Runway 22R Departures: 2010-2015

2010



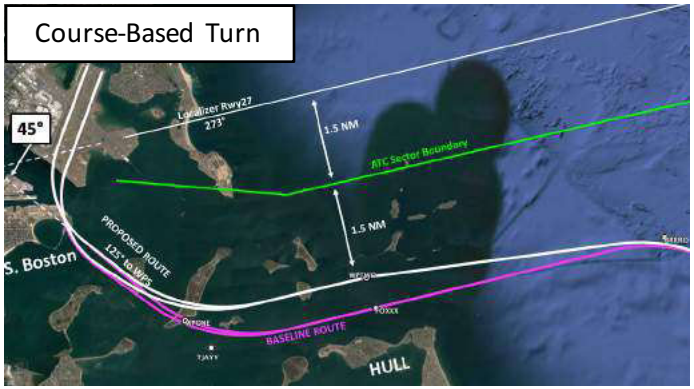
2015



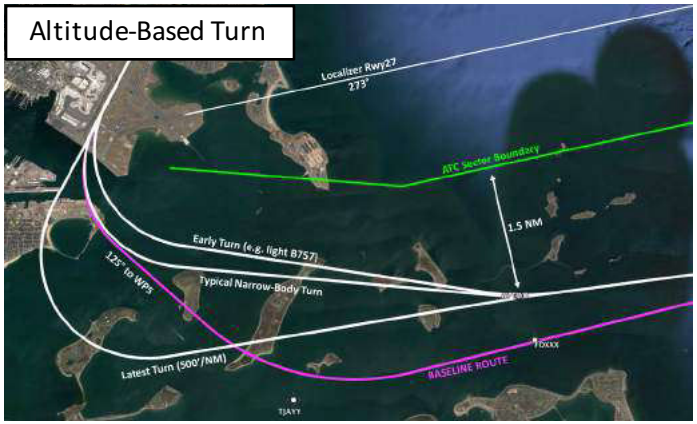
Runway 22L/22R SID Modification Options

Summary: Relocate initial waypoint on RNAV SID from in order to provide noise relief at Hull while initiating post-takeoff turn as early as practical to reduce impact in South Boston

Course-Based Turn



Altitude-Based Turn



Three potential procedure options

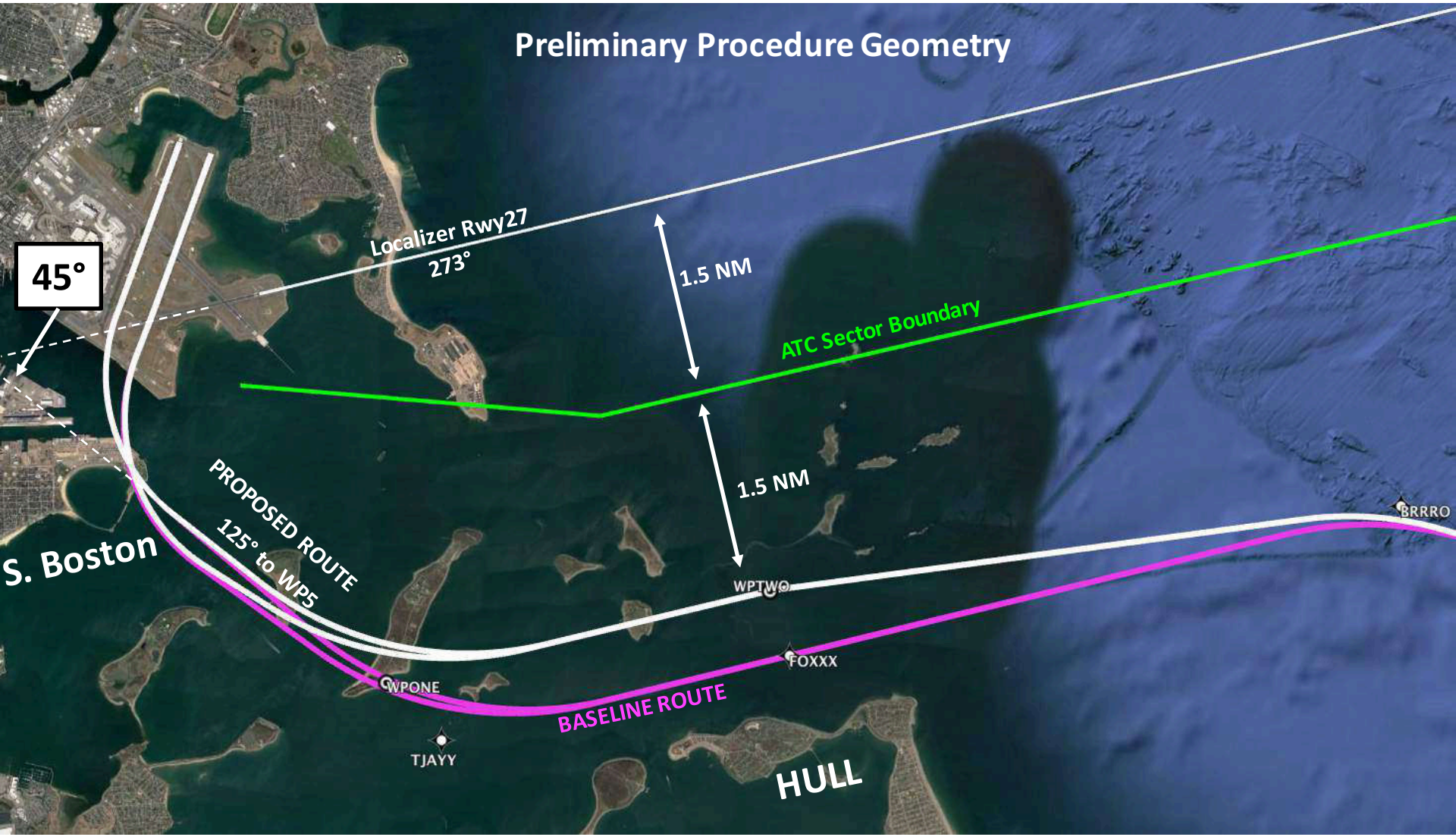
A. Climb on runway heading to intercept an outbound course
B. Climb on runway heading to 500' AGL, then direct to waypoint on SID
C. Historical heading-based departure procedure

Potential Operational Constraints

- Spacing with Runway 27 arrivals
- Compliance with procedure design criteria due to short leg lengths

Baseline Procedure Geometry

Option A - Climb to Intercept Course (1-D3a): Definition



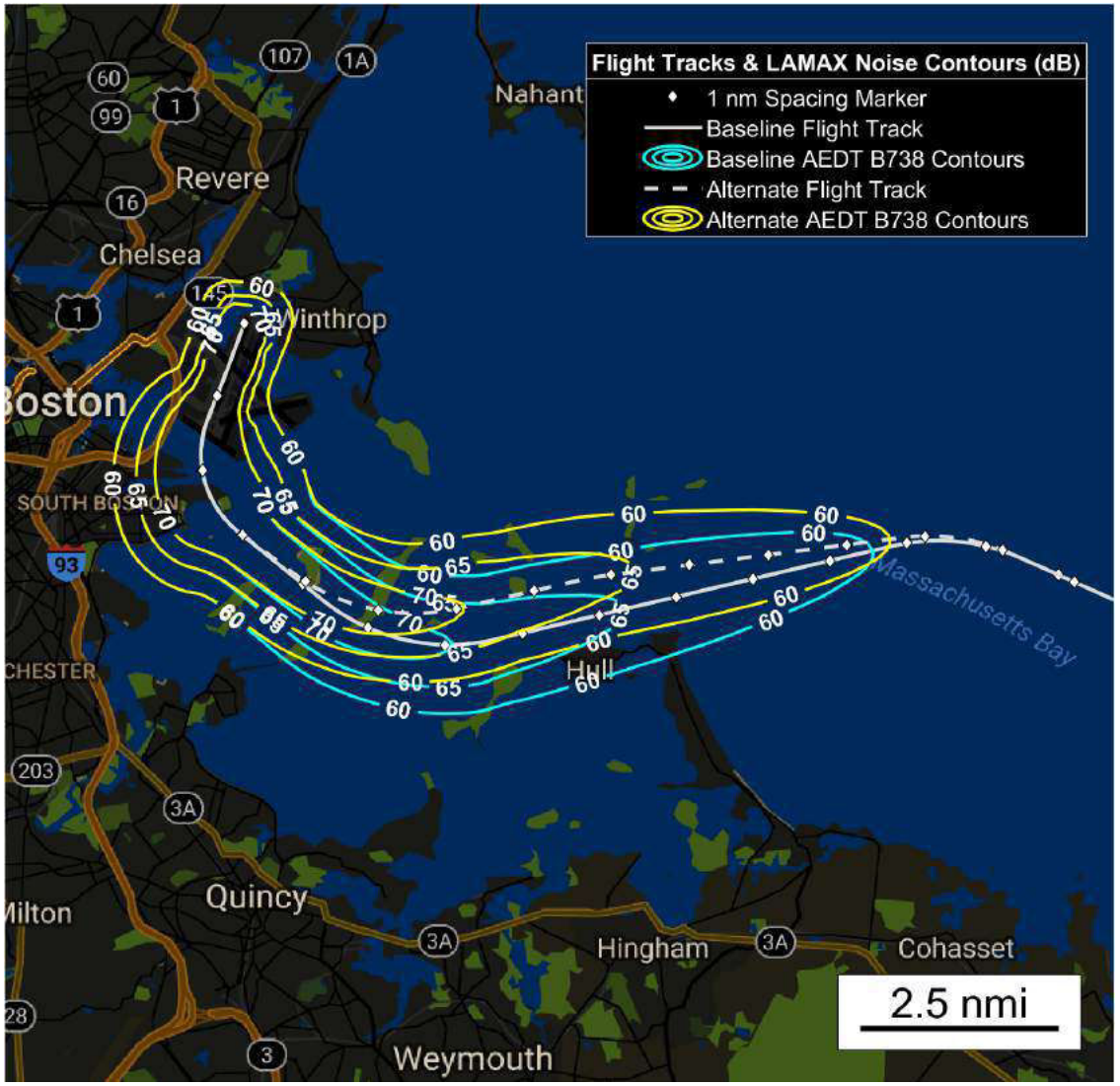
Simulator Tested for Flyability

Option A - Climb to Intercept Course (1-D3a): Noise Impact

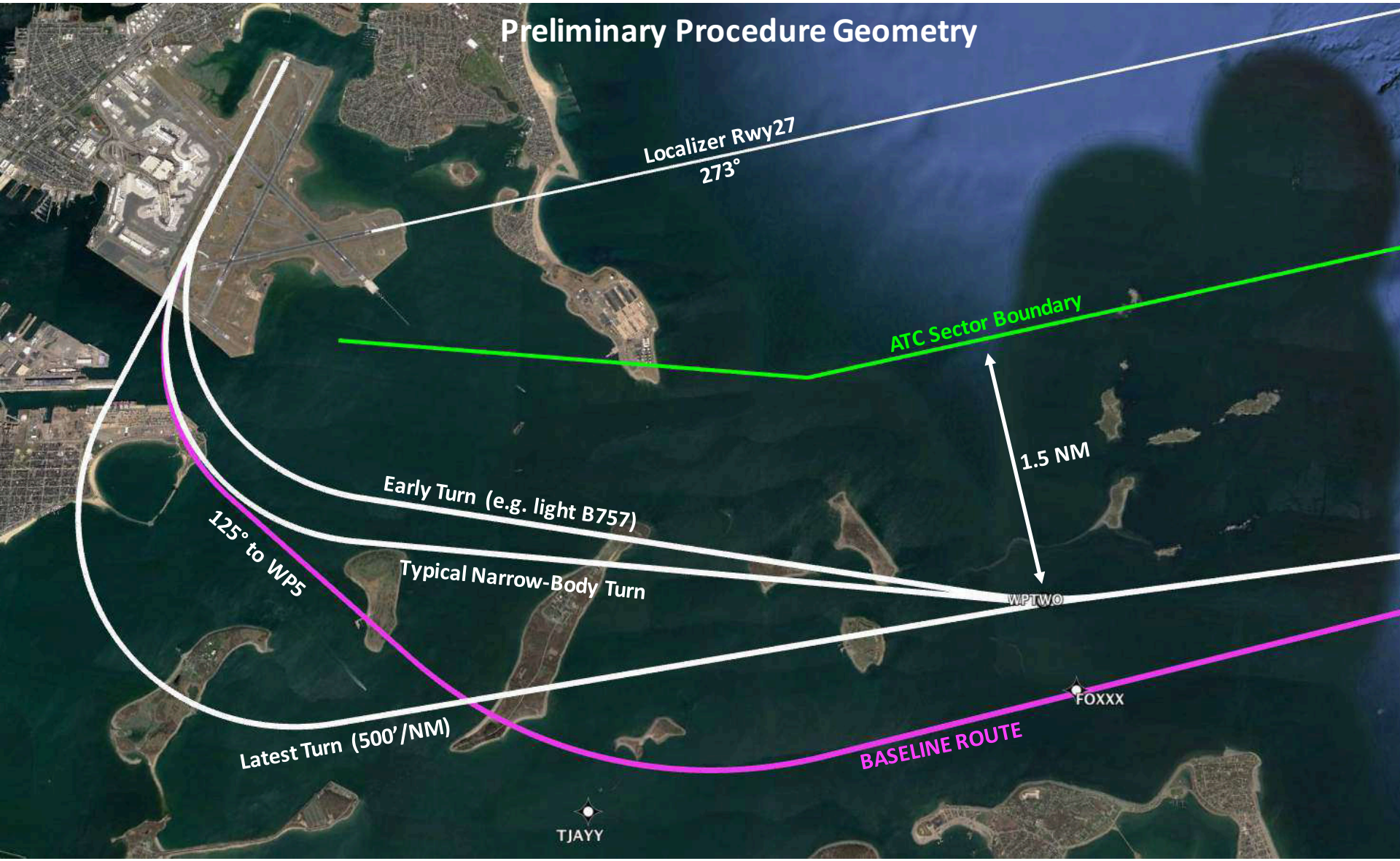
Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Vertical departure profile derived from median or historical radar data

Population Exposure (L_{MAX})

	60dB	65dB	70dB
Baseline RNAV SID	17,761	6,042	1,802
Modified Procedure	16,248	5,992	1,802
Reduction	1,513	50	0



Option B - Climb to Altitude Then Direct (1-D3b): Definition

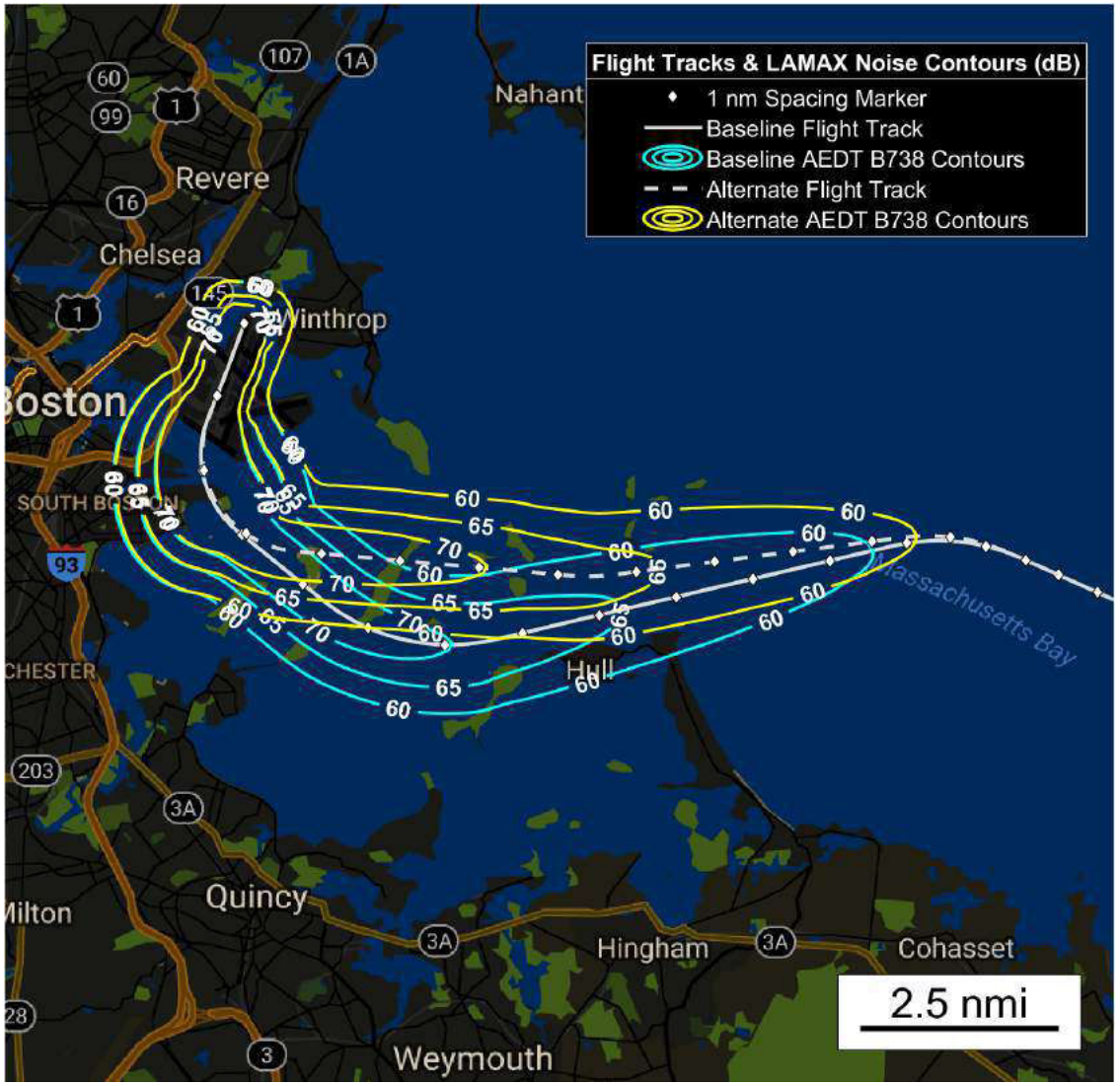


Option B - Climb to Altitude Then Direct (1-D3b): Noise Impact

Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Vertical departure profile derived from median or historical radar data

Population Exposure (L_{MAX})

	60dB	65dB	70dB
Baseline RNAV SID	17,761	6,042	1,802
Modified Procedure	15,445	5,715	1,712
Reduction	2,316	327	90



Option C: Heading-based departure (1-D3c) Definition

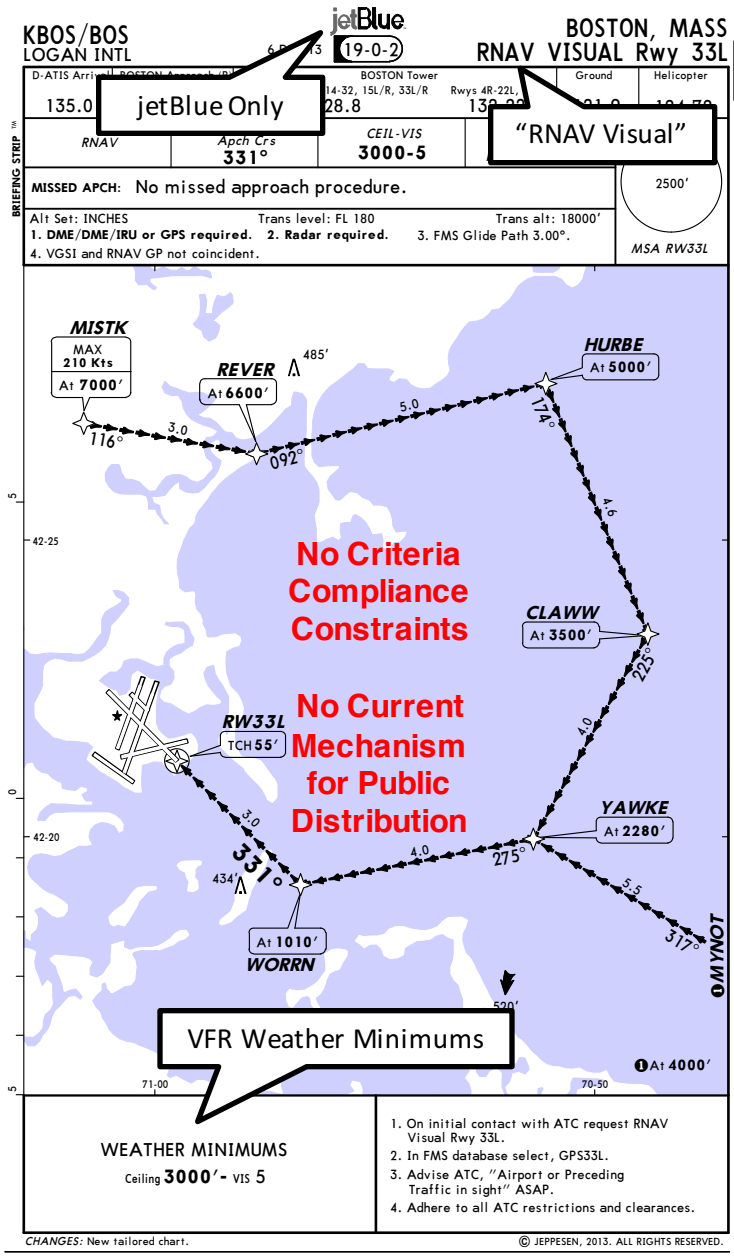
- **Concept**: During periods where runway 27 not in use for arrivals, issue takeoff clearance with heading (followed by vectors or direct-to on course)

Open Issues

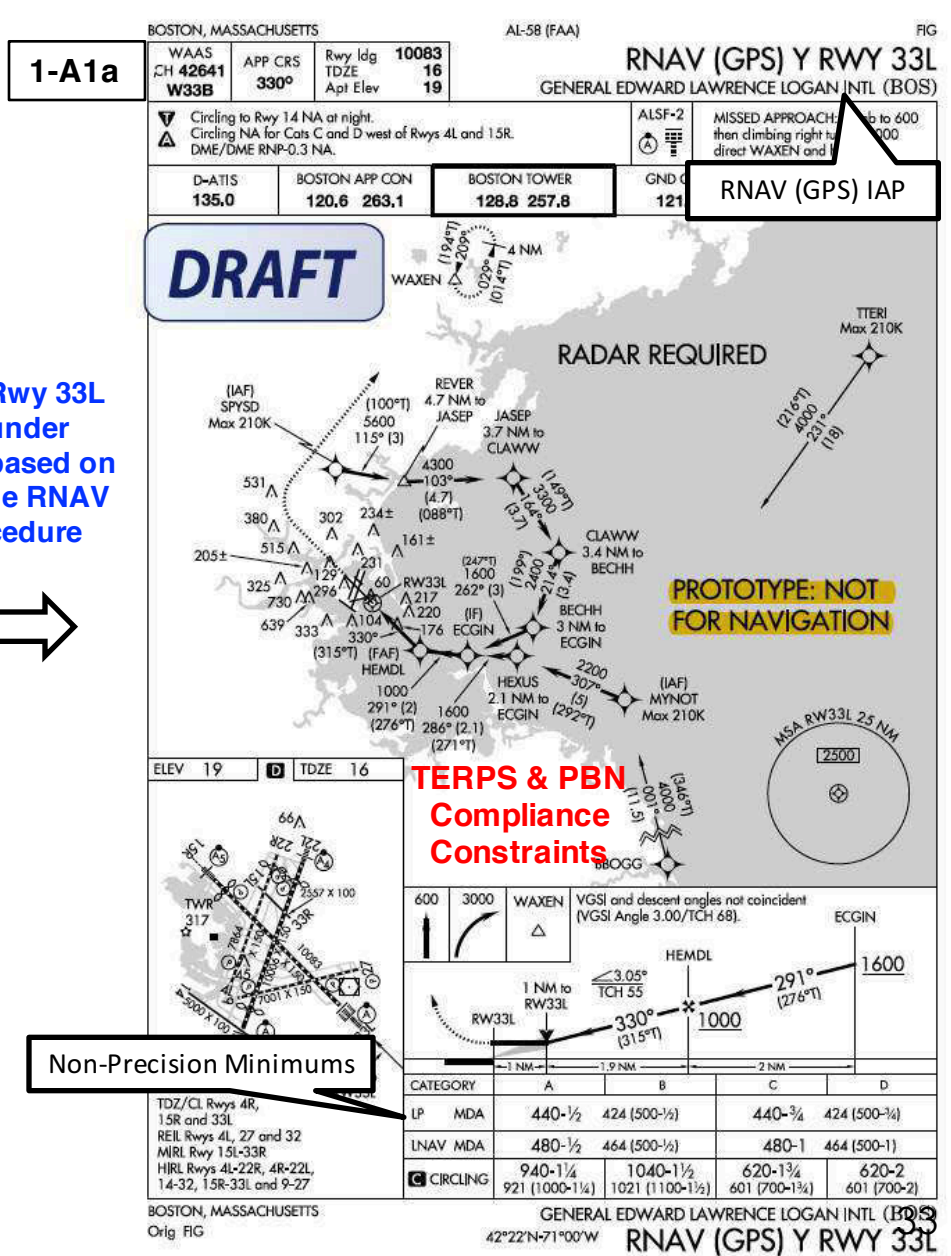
- **Issues**
  - Option A: Climb to intercept course (1-D3a)
    - Waivers required for RNAV SID leg length
  - Option B: Climb to altitude, then direct (1-D3b)
    - Waivers required for RNAV SID turn arc radius
    - Variable track length impacting departure sequencing
  - Option C: Heading-based departure (1-D3c)
    - Only available when Runway 27 arrivals not in use
- **Pending Analysis**
  - Potential TARGETS assessment of criteria compliance
  - Historical runway configuration analysis to determine when procedure would be available

Block 1: RNAV Approach Runway 33L

33L Low-Noise Overwater Approach Procedures

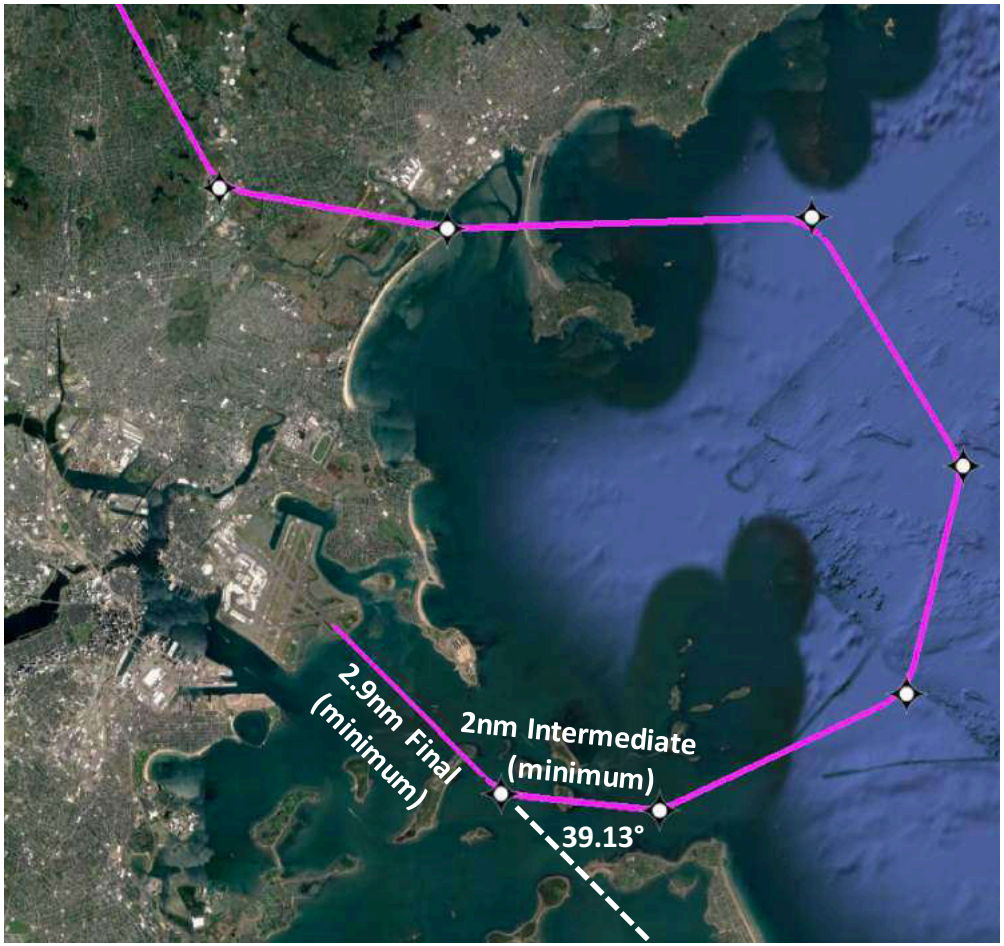


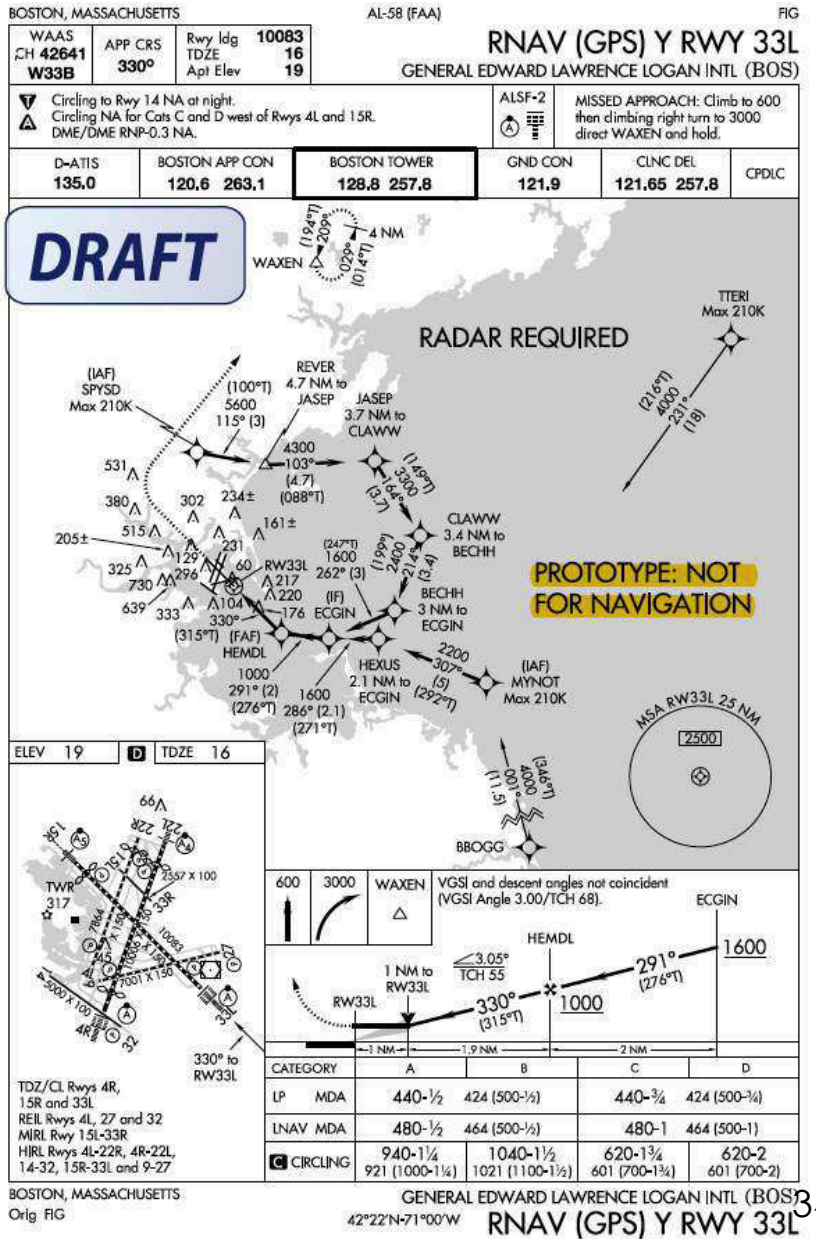
RNAV (GPS) Rwy 33L approach under development based on current JetBlue RNAV special procedure



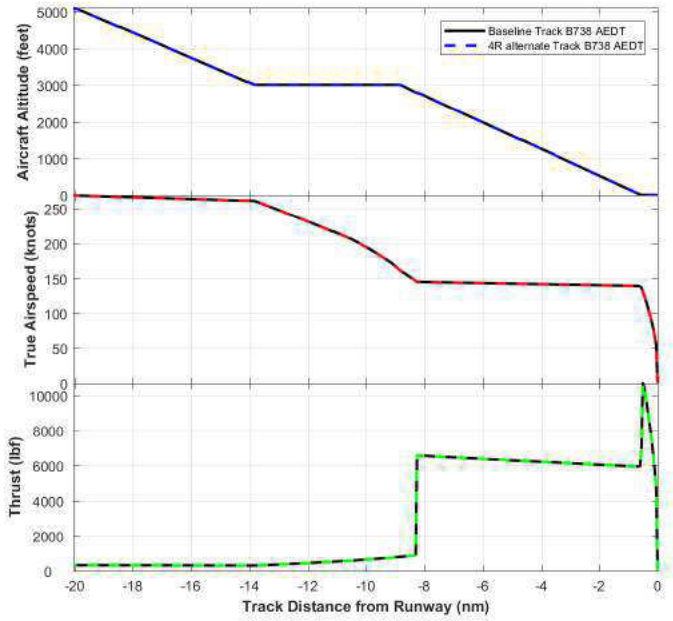
Overwater RNAV Instrument Approach Procedure with RNP Overlay (1-A1a)

- RNAV (GPS) Rwy 33L approach under development based on current JetBlue RNAV special procedure





Overwater RNAV Instrument Approach Procedure with RNP Overlay (1-A1a) – Noise Exposure



Population Exposure (L_{MAX})

	60dB	65dB	70dB
Straight In	2,241	154	0
Modified Procedure	2	0	0
Reduction	2,239	154	0

Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Standard AEDT arrival profile

Open Issues

- **Issues**
  - Option A: Overwater RNAV Instrument Approach Procedure with RNP Overlay
    - Waiver required for final approach intercept angle (39° vs. 30° criteria)
    - Current draft procedure waypoint JASEP increases noise over Nahant
    - Merging and spacing difficulties may only allow use during low demand periods
    - Lack of vertical guidance in procedure may reduce utilization
  - Option B: RNAV Visual Approach Procedure
    - No current mechanism to allow for public distribution
- **Pending Analysis**
  - Potential TARGETS assessment of criteria compliance
  - Identify potential JASEP waypoint alternative

Block 1 Discussion

Block 1 Procedures: Recommendation Status as of 9/22/2017

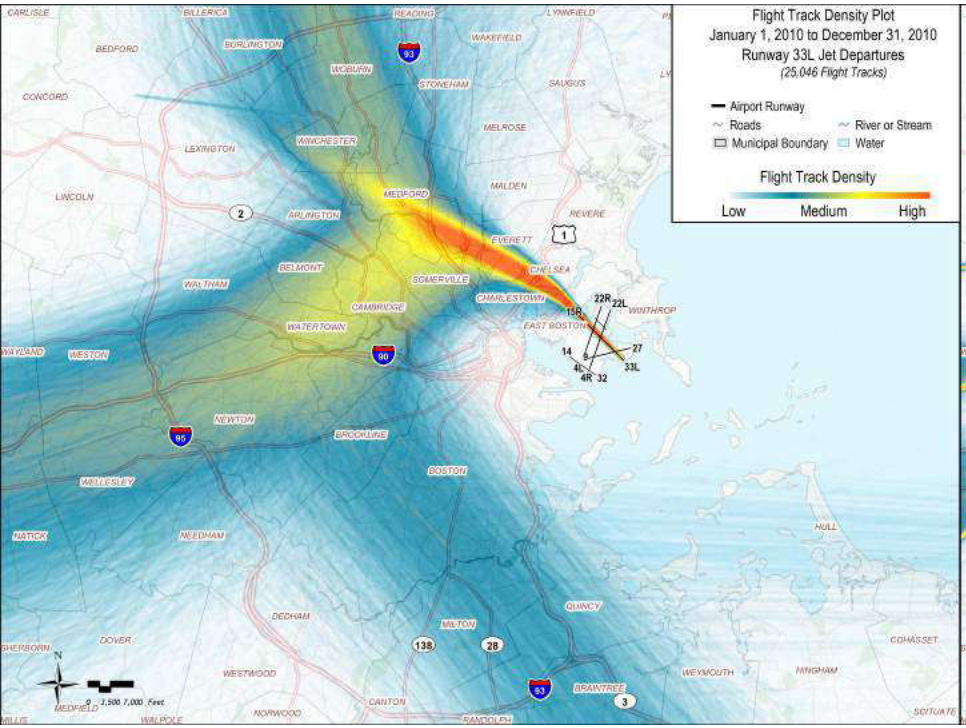
Proc. ID	Procedure	Issues	Pending Analysis
1-D1	Reduced-speed departures (modified to 220 knots or minimum clean maneuvering speed, whichever is higher)	• Increased fuel burn and flight time • Potential throughput reduction • Nonstandard relative to normal operating procedures	• Determining minimum clean operating speed for set of representative aircraft types • Historical radar analysis for throughput impact assessment • Comparing noise impact of NADP-1 relative to proposed procedure
1-D2	Runway 15R RNAV waypoint relocation	• No significant issues	• Potential TARGETS assessment of criteria compliance
1-D3a	Runway 22L/R RNAV waypoint relocation (climb to intercept course)	• Waivers required for leg length criteria	• Potential TARGETS assessment of criteria compliance
1-D3b	Runway 22L/R RNAV waypoint relocation (climb to altitude then direct)	• Waivers required for turn arc criteria • Variable track length impacting departure sequencing	• Potential TARGETS assessment of criteria compliance
1-D3c	Runway 22L/R heading-based departure	• Only available when Runway 27 arrivals not in use	• Historical runway configuration analysis to determine when procedure would be available
1-A1a	Runway 33L overwater RNAV instrument approach procedure with RNP overlay	• Waiver required for final approach intercept angle (39° vs. 30° criteria) • Current draft procedure waypoint JASEP increases noise over Nahant • Merging and spacing difficulties may only allow use during low demand periods • Lack of vertical guidance in procedure may reduce utilization	• Potential TARGETS assessment of criteria compliance • Identify potential JASEP waypoint alternative
1-A1b	Runway 33L overwater RNAV visual procedure	• No current mechanism for public distribution	

Block 2: Runway 33L and 27 Departures – Introduce Dispersion

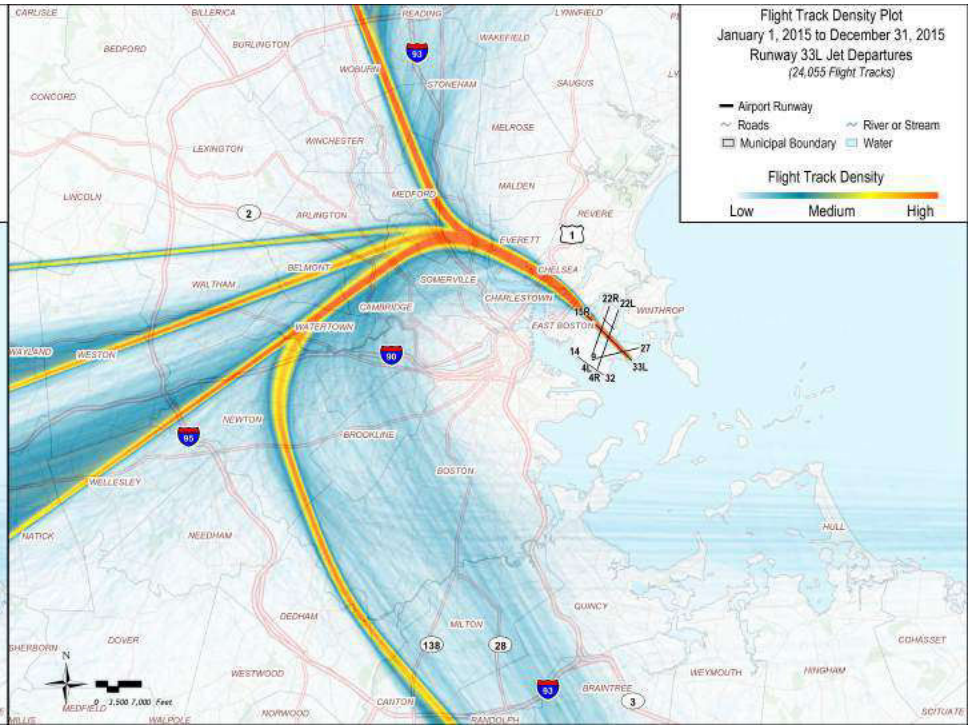
Runway 33L Departures: 2010-2015

Using Open SIDs or Flexible SIDs to Re-introduce Dispersion

2010

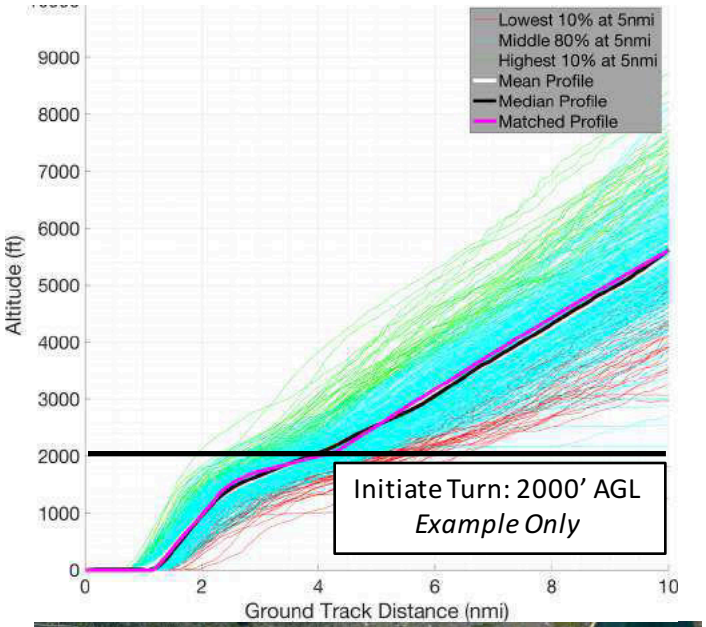


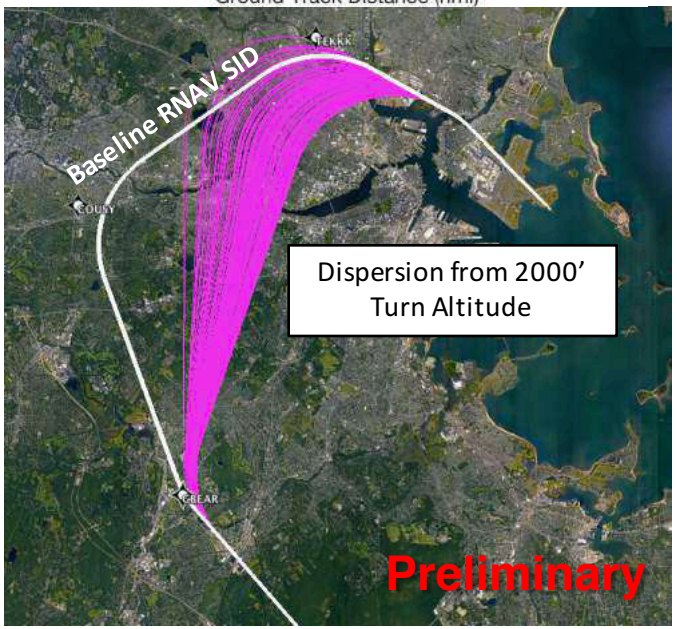
2015



Dispersion Concepts: Open SID or Increased Controller Flexibility

1. Open SIDs are RNAV departure procedures that include ATC radar vector segments.
   - Authorized by FAA in 2015
   - Proven in operation (e.g. CLT, LAX)
2. Dispersion may also be introduced by direct ATC instruction (vector-based or direct-to) based on aircraft altitude or other criteria
   - Allows greater ATC flexibility based on traffic levels and flows
   - Would result in track length reduction with corresponding fuel savings





Federal Aviation Administration

Memorandum

Date: SEP 2 2015

To: Jeff McCarthy, Director, Airspace Services, AJV-1

From: Flight Technologies and Procedures Division, AFS-4

Subject: Criteria for Area Navigation (RNAV) Standard Instrument Departures (SIDs) that contain RADAR Vector Segments (Open SID Design)

Purpose: This memorandum authorizes RNAV SIDs with embedded RADAR vector segments.

Open Issues: Departure Track Dispersion

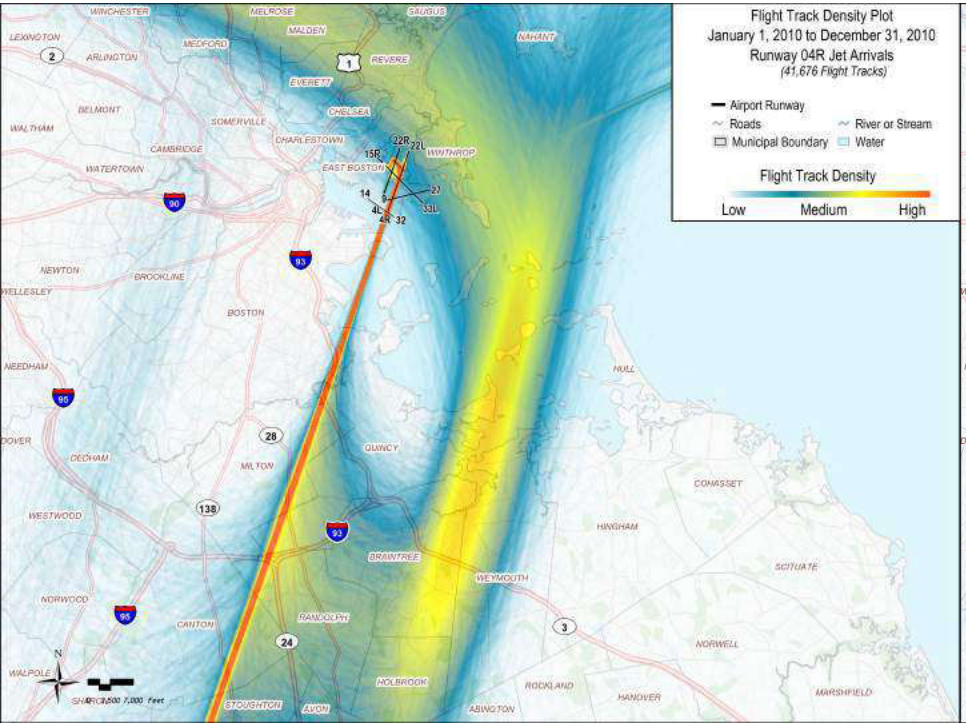
- **Issues**
  - Impact of noise redistribution
- **Pending Analysis**
  - Developing analysis method for dispersed departure tracks under Open SID and Flexible SID options

Block 2: Runway 4R & 22L Arrivals

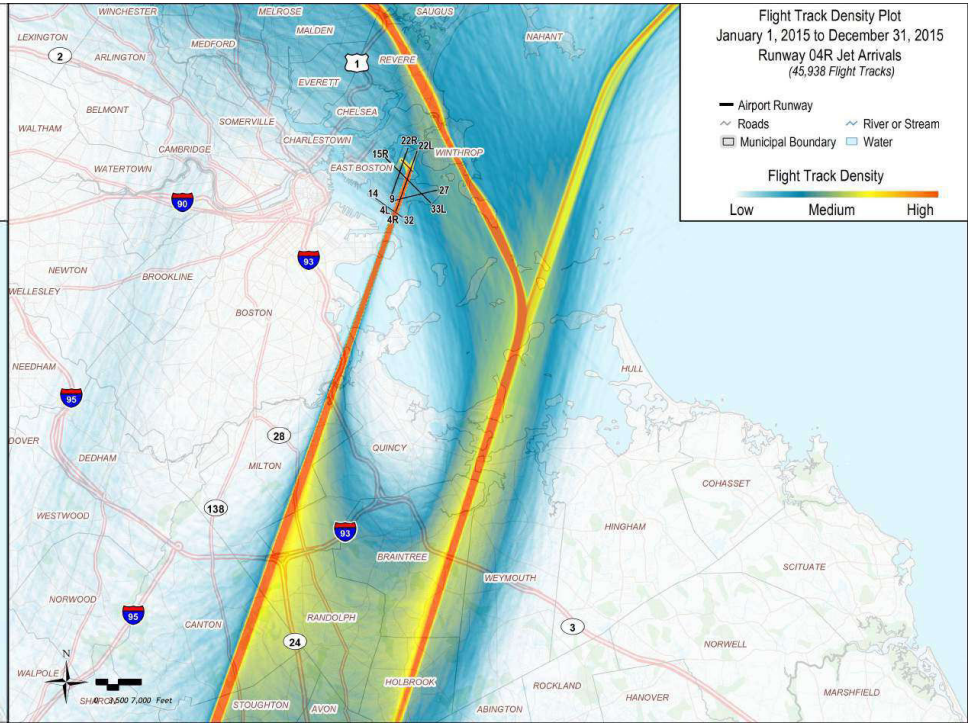
Low-Noise Overwater Approach Procedures

Runway 4R Arrivals: 2010-2015

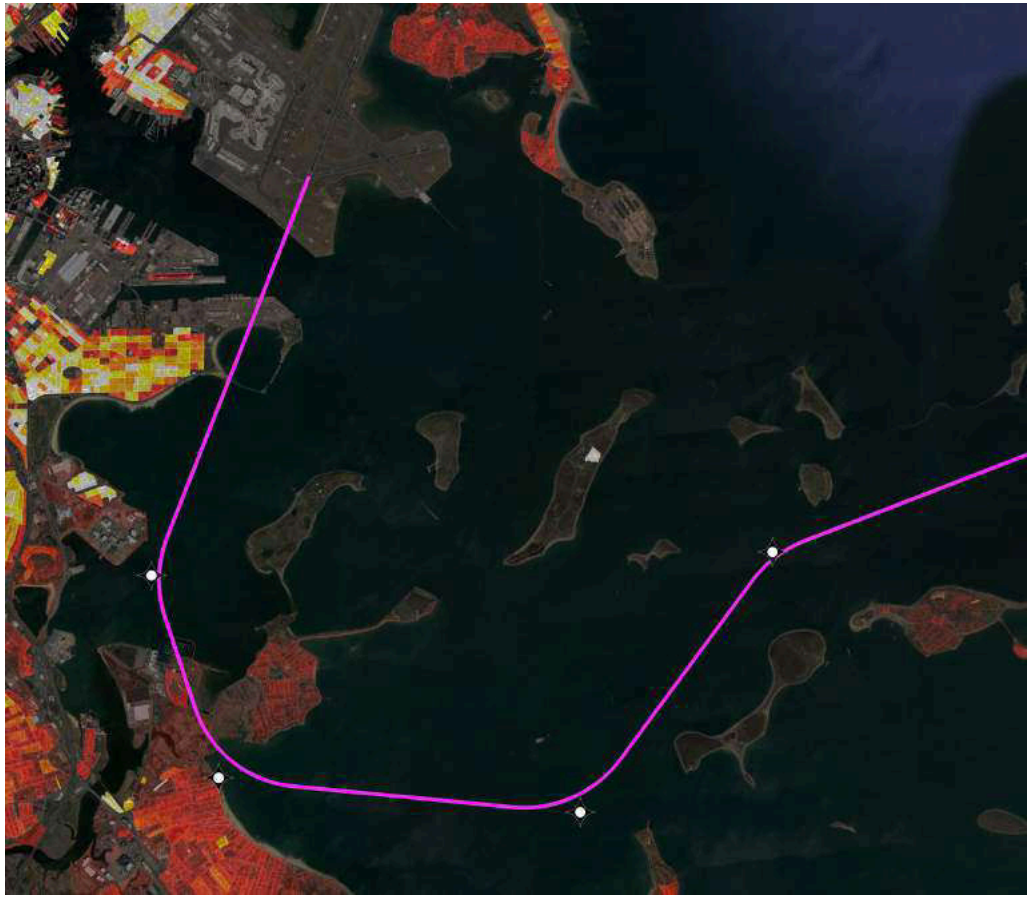
2010

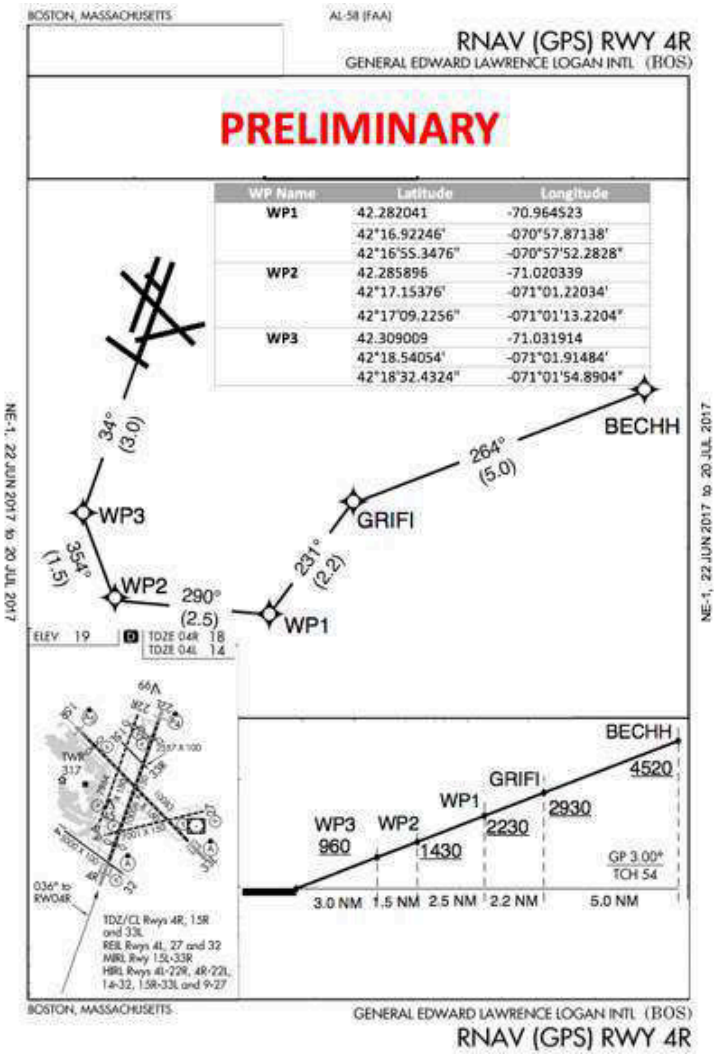


2015



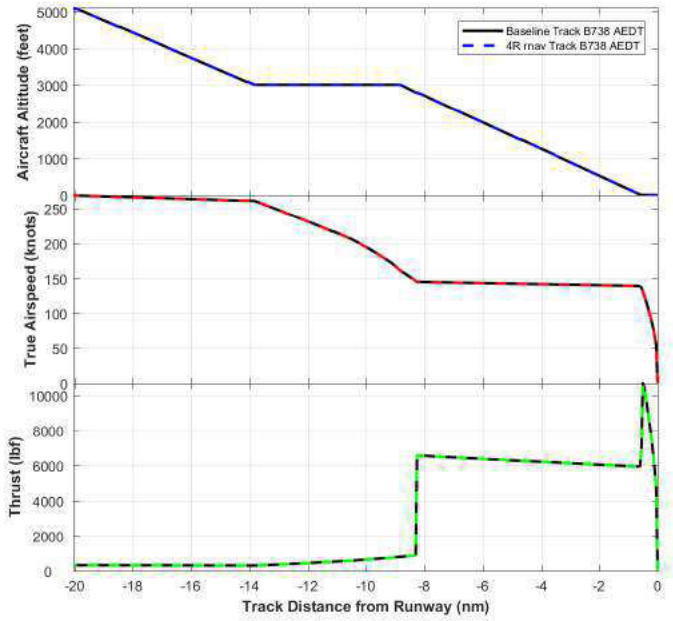
4R Low-Noise Overwater RNAV Approach with RNP Overlay

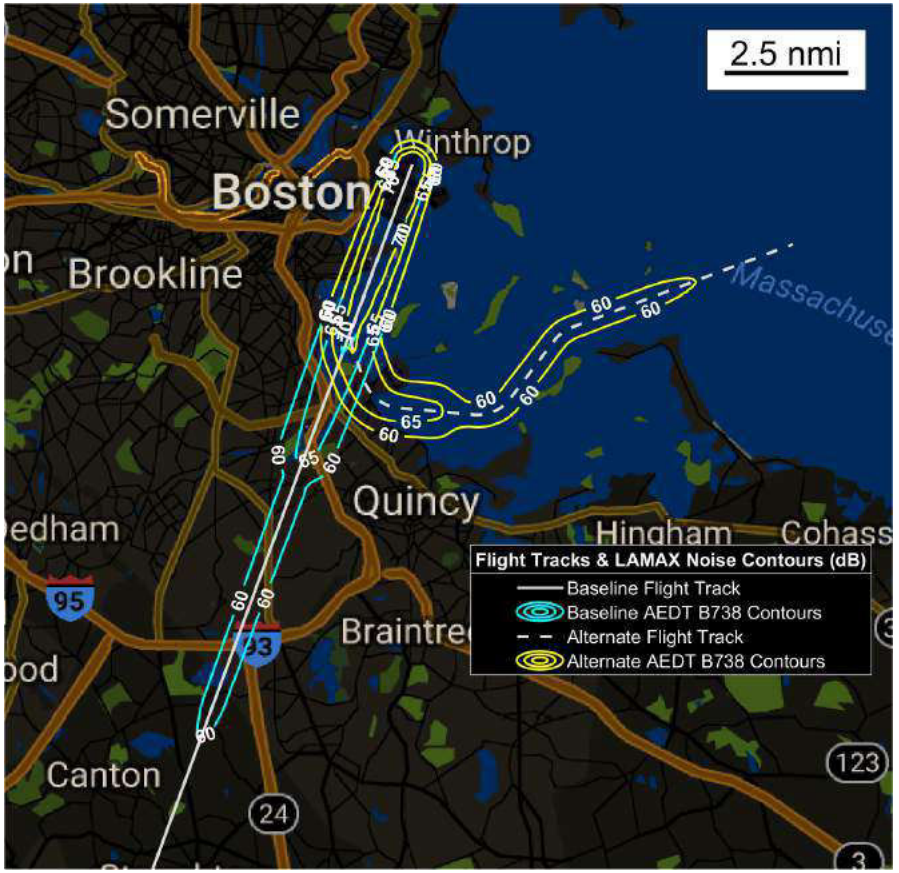




Simulator Tested for Flyability

4R Low-Noise Overwater RNAV Approach with RNP Overlay: Noise Exposure





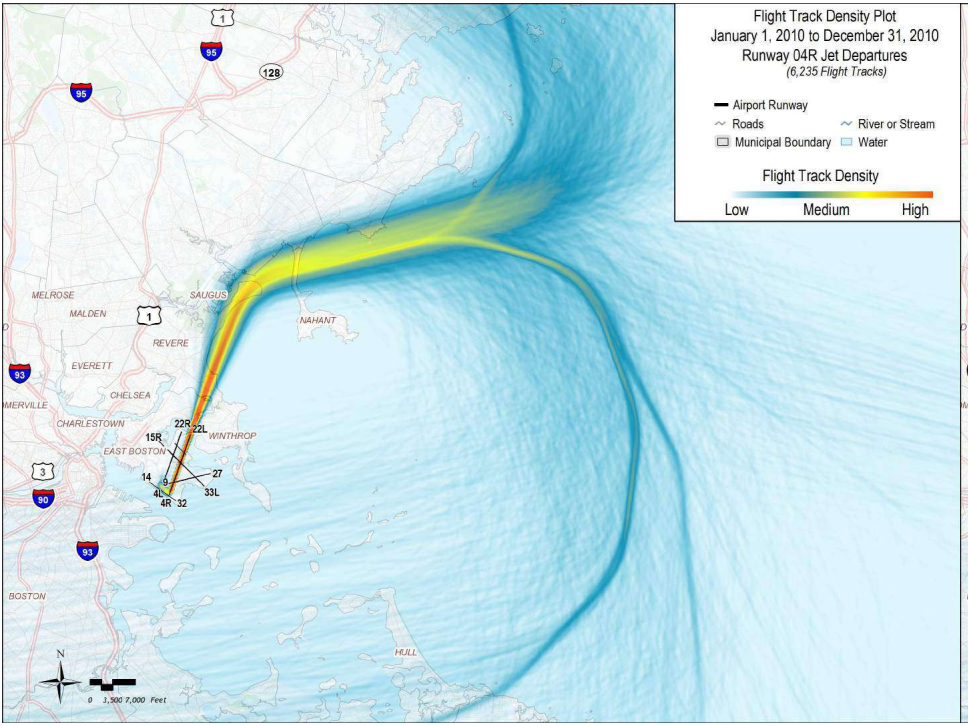
Population Exposure (L_{MAX})

	60dB	65dB	70dB
Straight In	30,239	7,468	530
Modified Procedure	18,283	5,792	529
Reduction	11,956	1,676	1

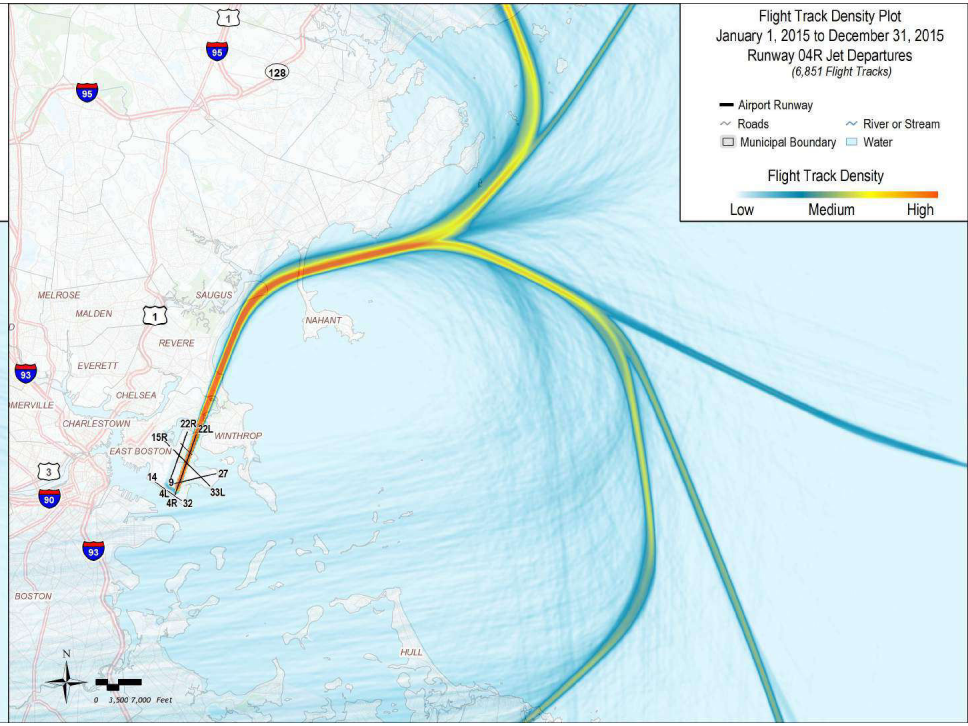
Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Standard AEDT arrival profile

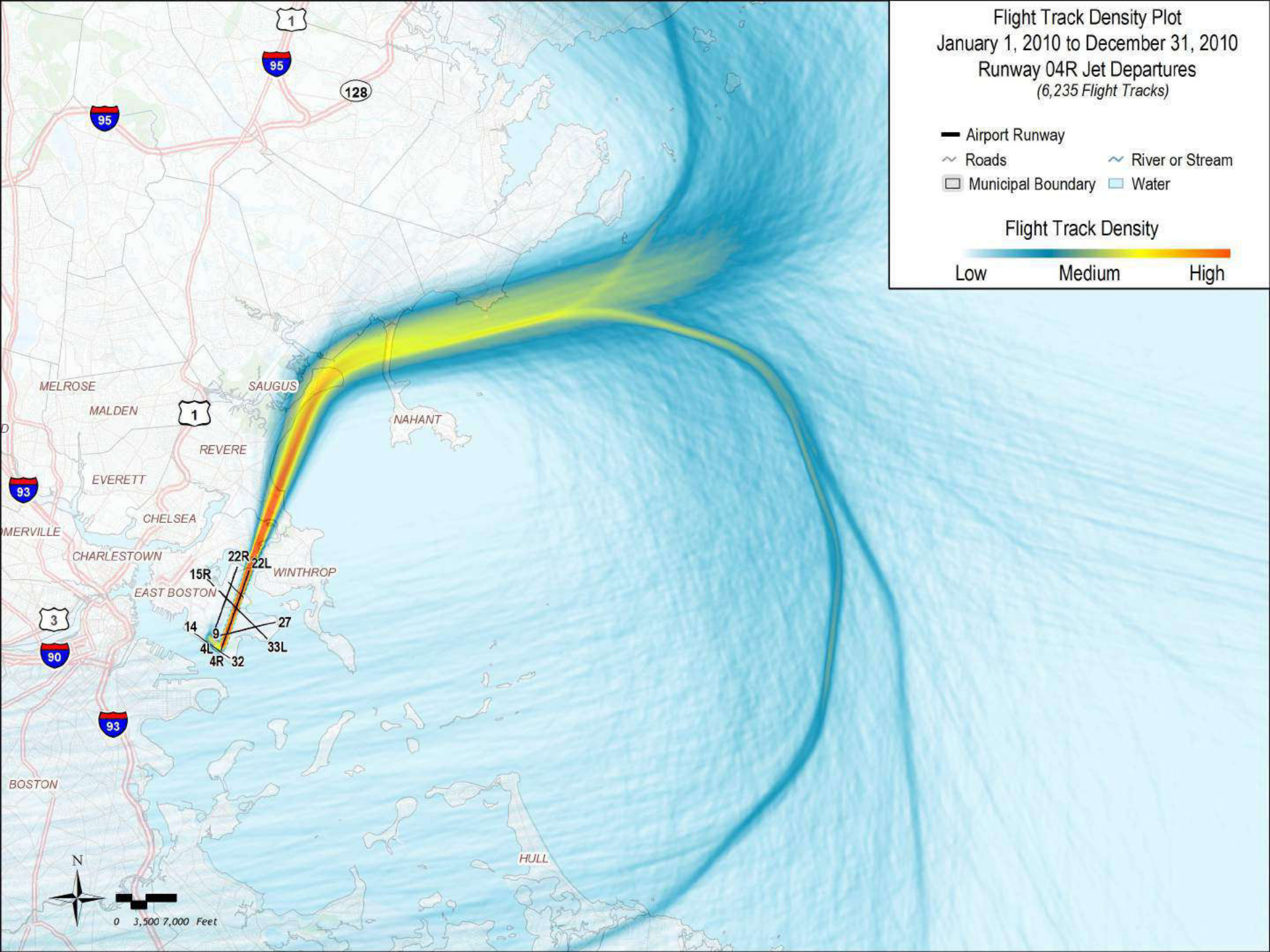
Runway 4R Departures: 2010-2015

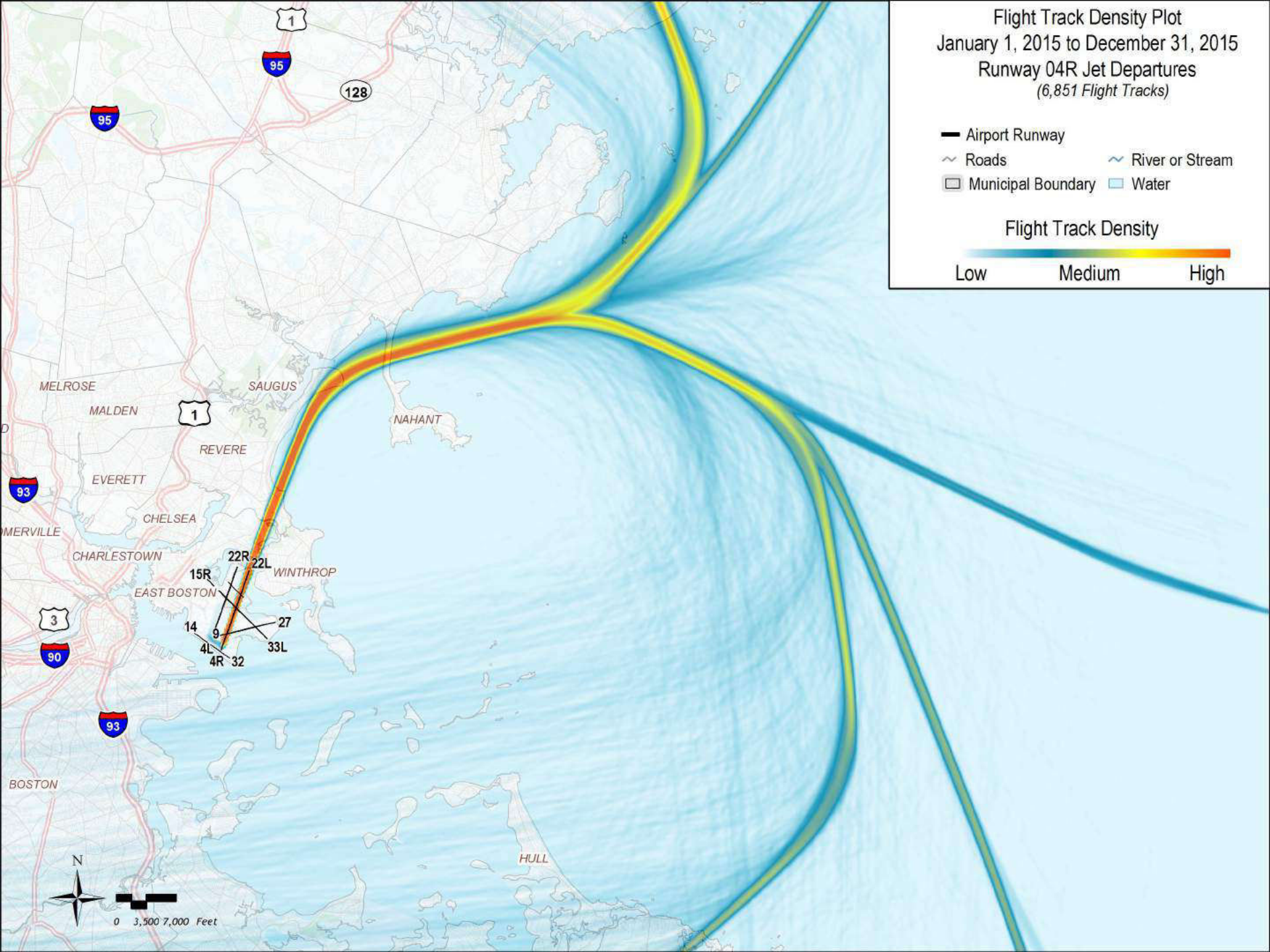
2010

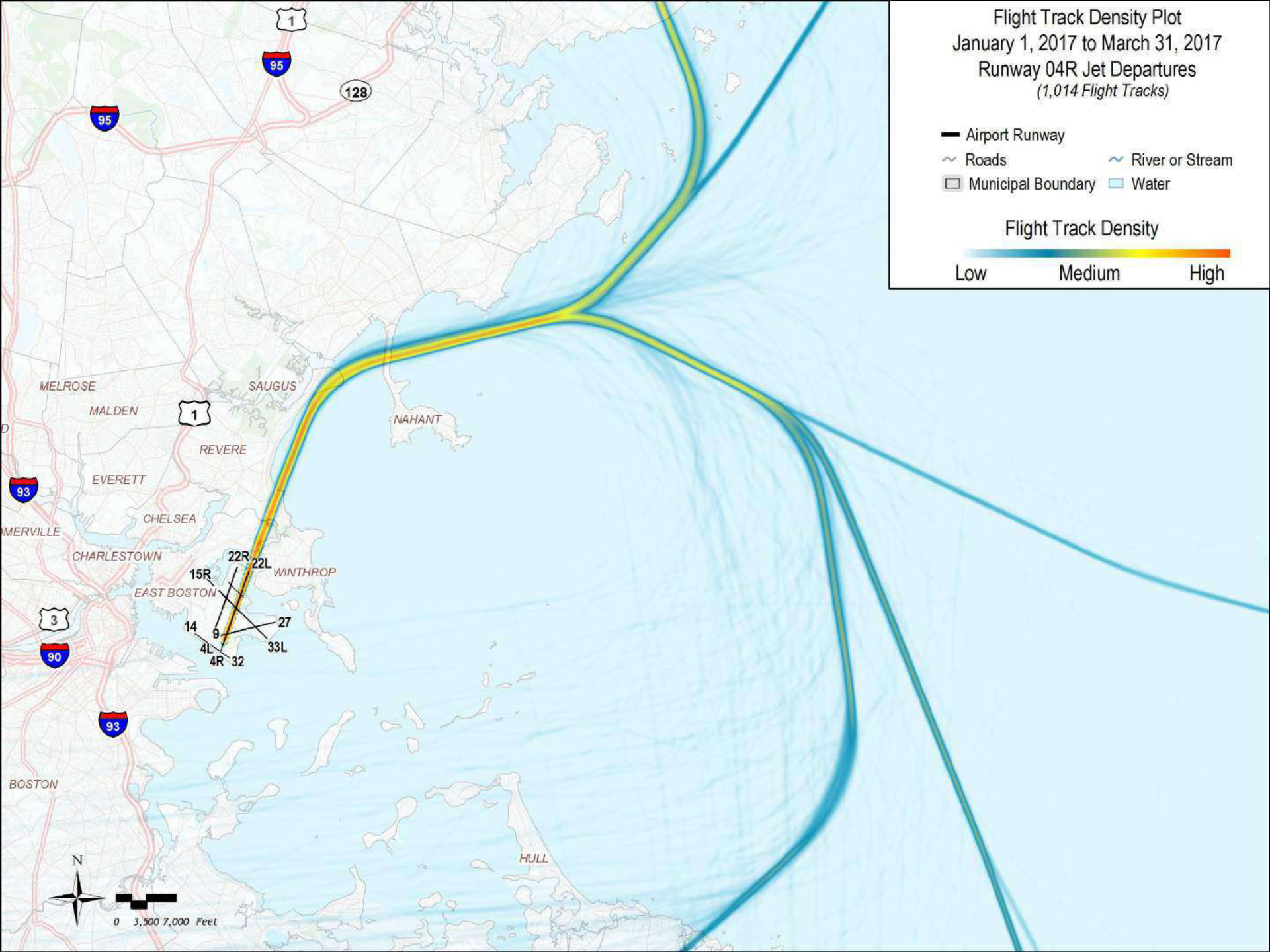


2015



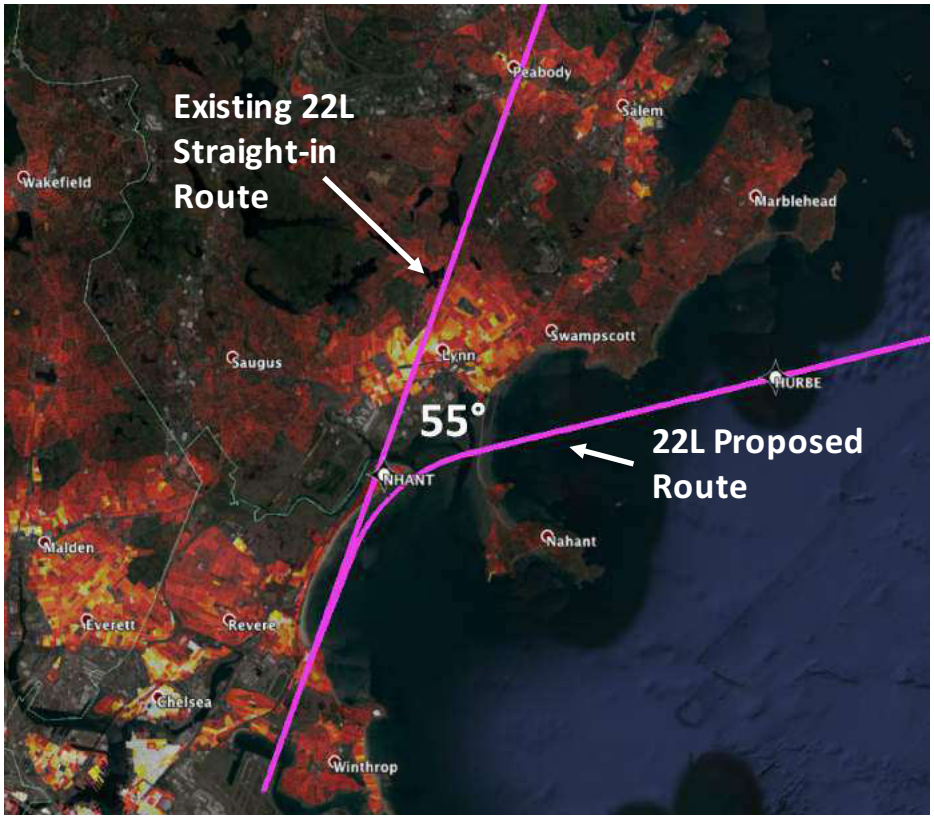

Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 04R Jet Departures
(6,235 Flight Tracks)
Airport Runway
Roads
River or Stream
Municipal Boundary
Water
Flight Track Density
Low
Medium
High
MELROSE
MALDEN
SAUGUS
NAHANT
REVERE
EVERETT
CHELSEA
CHARLESTOWN
WINTHROP
EAST BOSTON
BOSTON
HULL
22R
22L
15R
14
9
27
4L
33L
4R
32
N
0 3,500 7,000 Feet

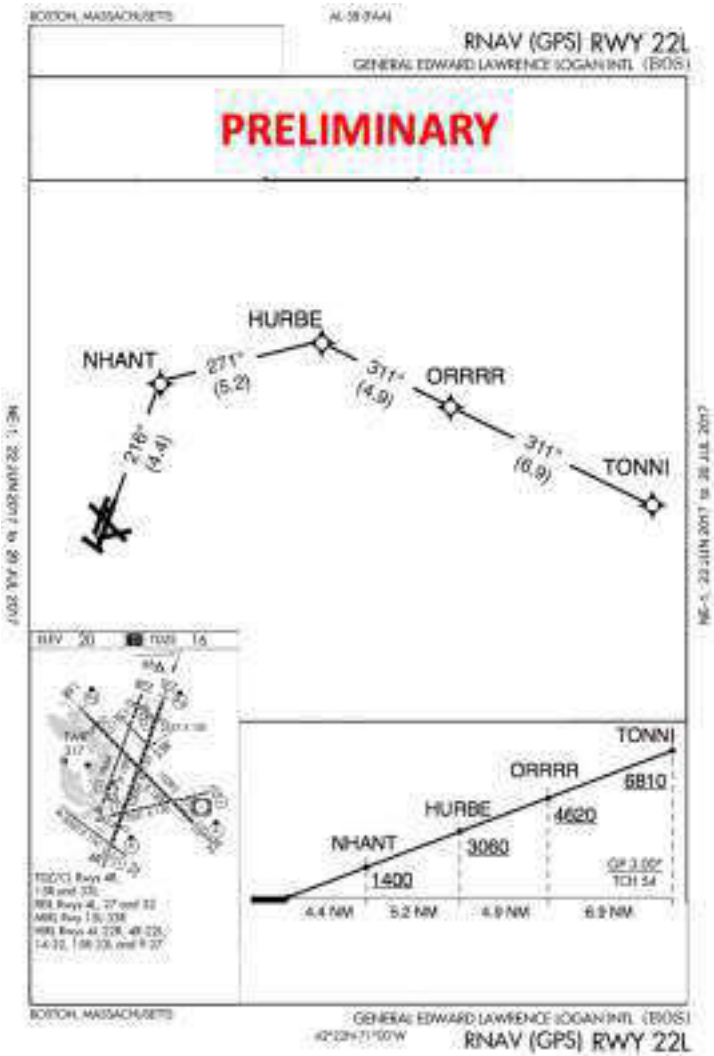

Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 04R Jet Departures
(6,851 Flight Tracks)
Airport Runway
Roads
River or Stream
Municipal Boundary
Water
Flight Track Density
Low
Medium
High
MELROSE
SAUGUS
MALDEN
NAHANT
REVERE
EVERETT
CHELSEA
CHARLESTOWN
WINTHROP
EAST BOSTON
BOSTON
HULL
22R
22L
15R
14
9
27
33L
4L
4R
32
N
0 3,500 7,000 Feet


Flight Track Density Plot
January 1, 2017 to March 31, 2017
Runway 04R Jet Departures
(1,014 Flight Tracks)
Airport Runway
Roads
River or Stream
Municipal Boundary
Water
Flight Track Density
Low
Medium
High
MELROSE
SAUGUS
MALDEN
NAHANT
REVERE
EVERETT
CHELSEA
CHARLESTOWN
WINTHROP
EAST BOSTON
BOSTON
HULL
22R
22L
15R
14
9
27
33L
4L
4R
32
1
95
128
93
90
3
N
0 3,500 7,000 Feet

22L Low-Noise Offset RNAV Approach with RNP Overlay

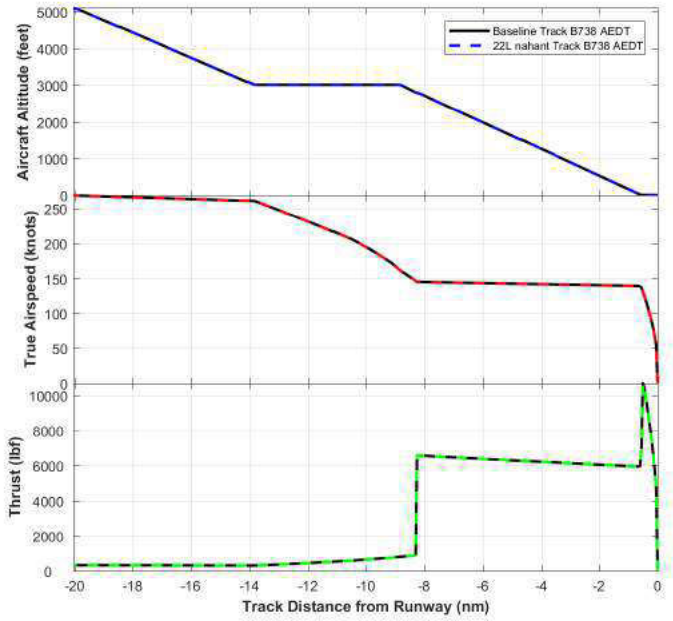
Overlaying arrival corridor on existing 4R RNAV SID for 22L arrivals:





Simulator Tested for Flyability

22L Low-Noise Offset RNAV Approach with RNP Overlay: Noise Exposure

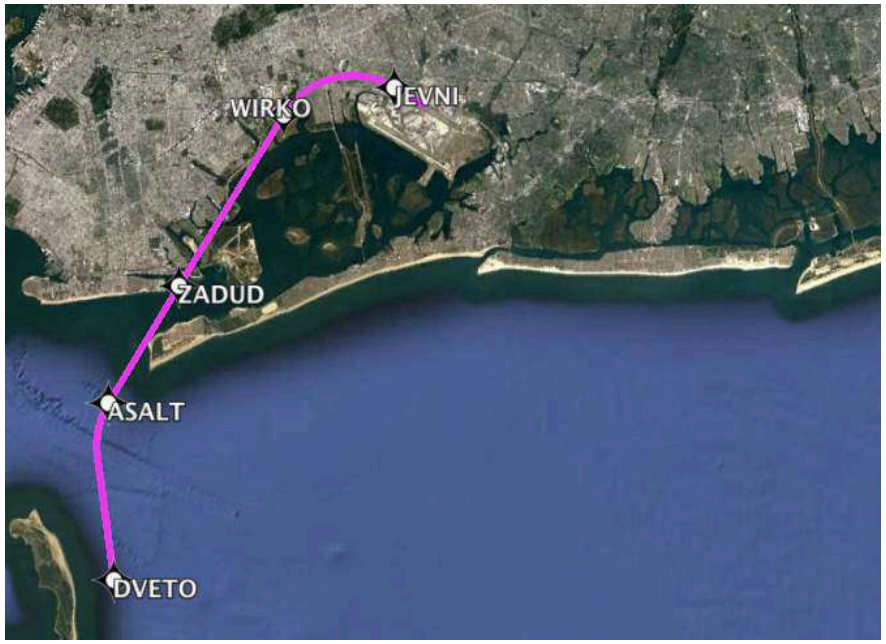


Population Exposure (L_{MAX})

	60dB	65dB	70dB
Straight In	70,469	21,335	6,807
Modified Procedure	28,204	15,566	6,677
Reduction	42,265	5,769	130

Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Standard AEDT arrival profile

Canarsie RNAV (RNP) Special



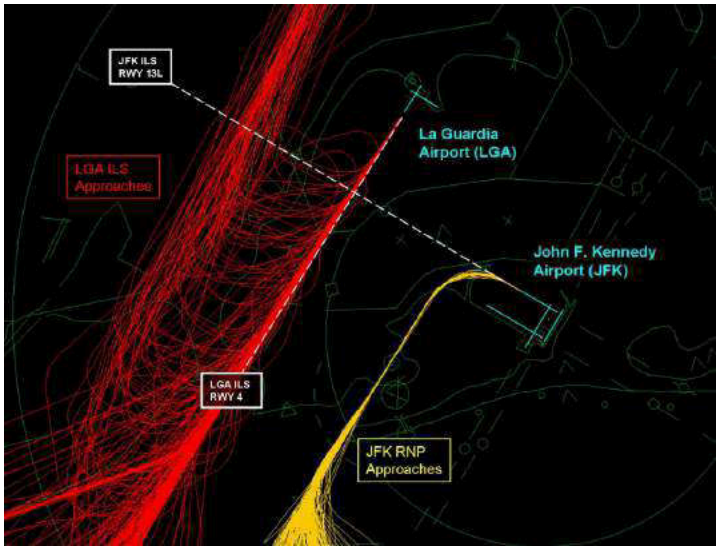
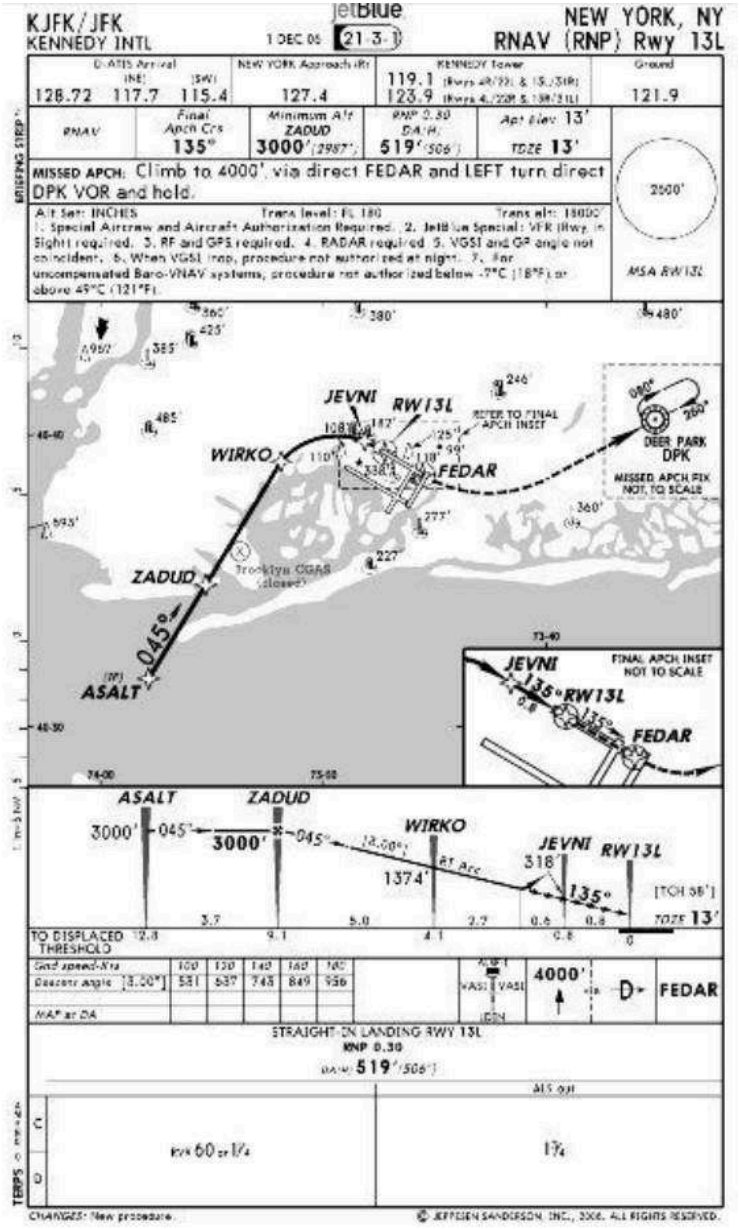
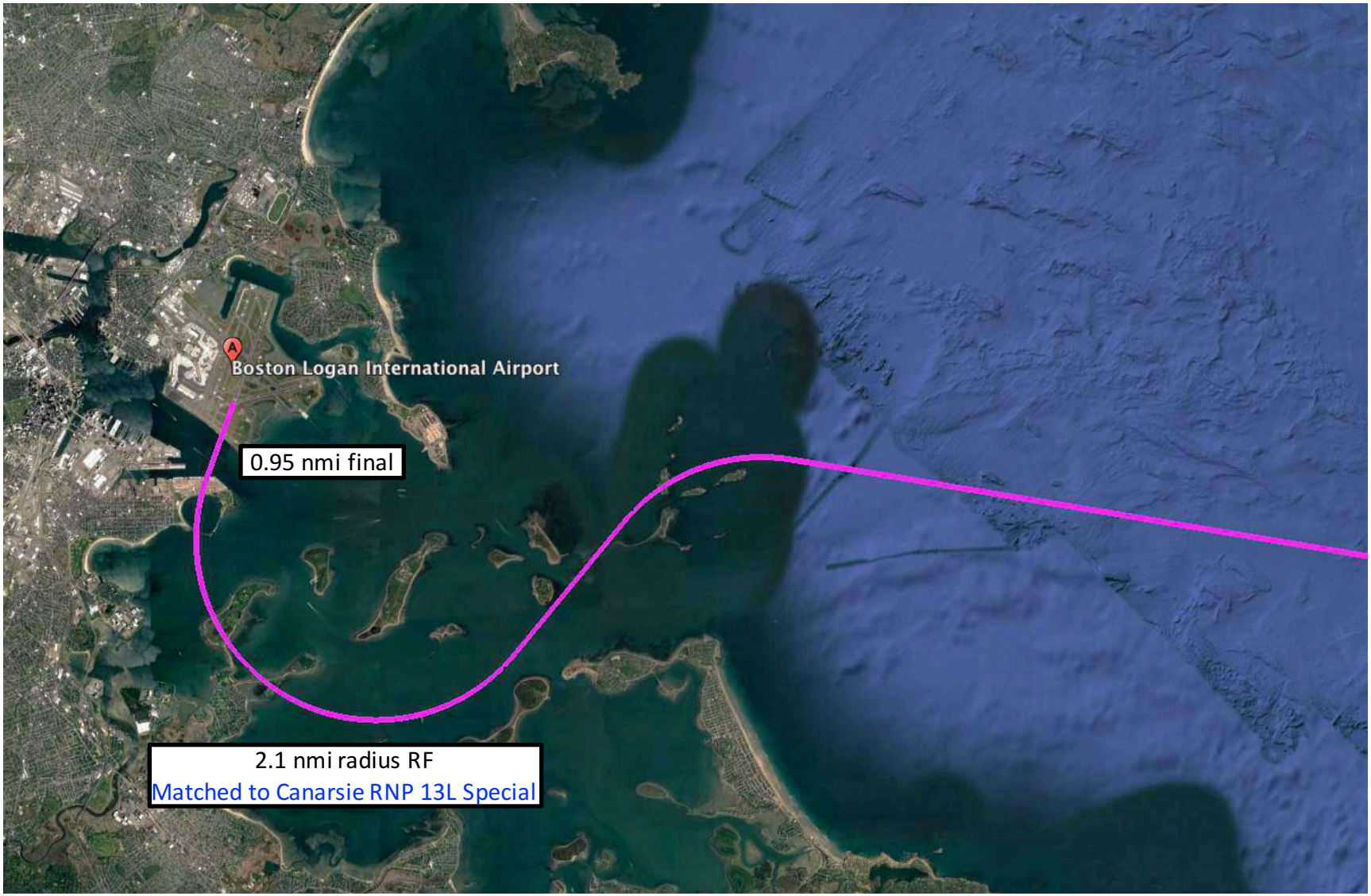


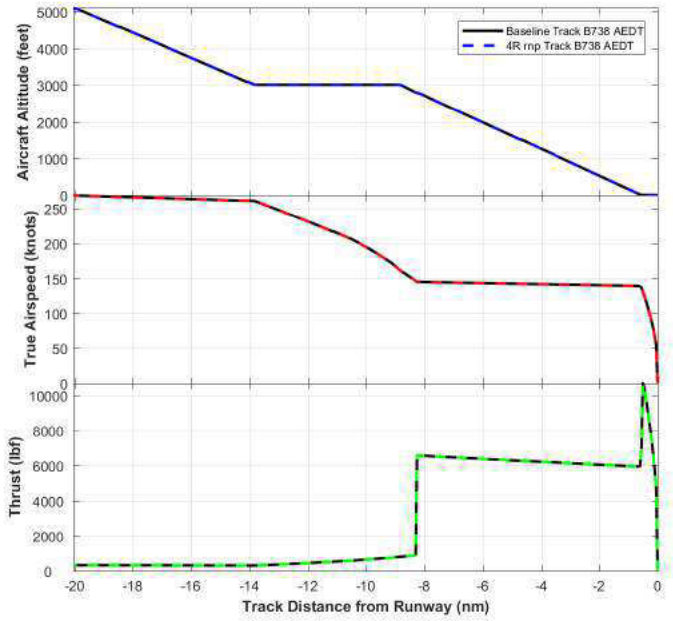
Figure: Honeywell

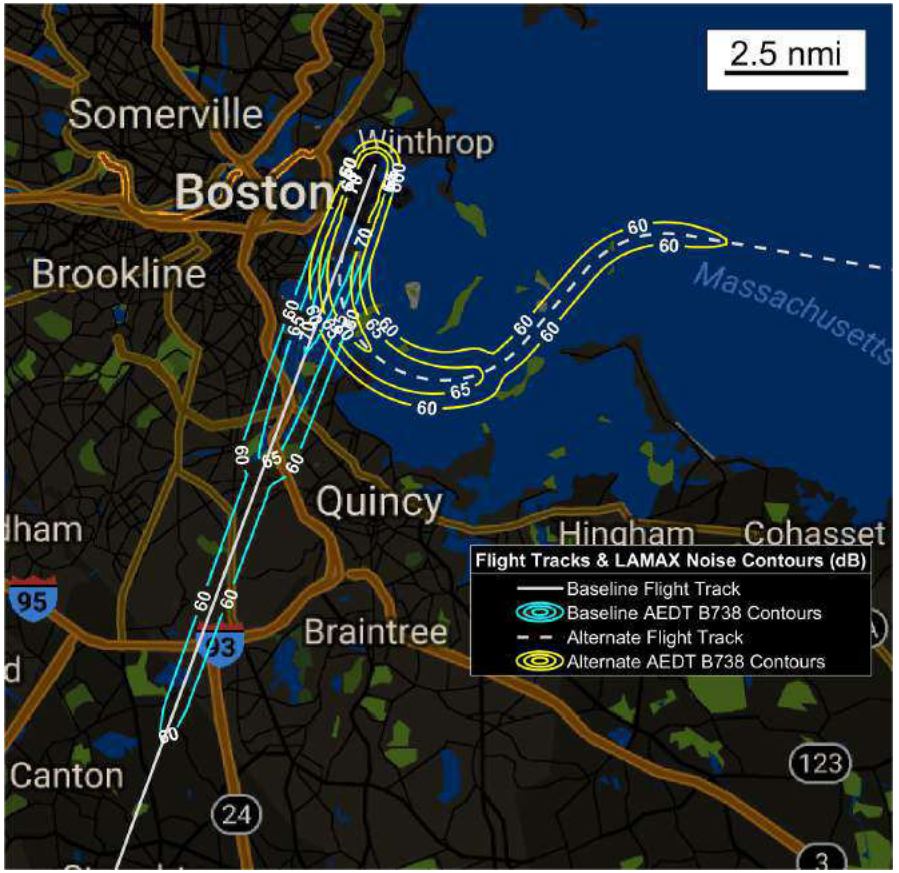


Notional Low-Noise Overwater RNP: BOS Rwy 4R



4R Low-Noise Overwater RNP Approach: Noise Exposure





Population Exposure (L_{MAX})

	60dB	65dB	70dB
Straight In	30,239	7,468	530
Modified Procedure	6,887	2,161	0
Reduction	23,352	5,307	530

Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Standard AEDT arrival profile

Open Issues: Block 2 Low-Noise Overwater Approach Procedures

- **Issues**
  - RNAV Procedures
    - Potential waiver requirements for final approach segment length and intercept angle
    - Merging and spacing difficulties may only allow use during low demand periods
  - RNP Procedures
    - Equipage and training levels prevent use by all operators
- **Pending Analysis**
  - Developing analysis method to evaluate tradeoffs between final approach design criteria and noise reduction potential

Project Schedule/Work Plan Outline

Updated September 28, 2017

Overview of Work Plan	Schedule		Public Engagement
• FAA/ Massport Discussions	Winter – Fall 2016	√	Press Event with Elected Officials, Massport, FAA, MCAC Leadership
• Announcement	Oct 2016	√	
• Consultant Team Organization	Fall 2016	√	Briefings to MCAC Aviation Subcommittee, Executive Committee, and General Meeting
• Historical Flight Comparison\Analysis	Dec to Feb 2016	√	
• Block 1 Procedure Opportunity	Feb 2017	√	Public Hearing, 2/22
– Lower complexity w/ benefits, minimal/no impacts			
– DNL and alternative metrics (e.g. single event above)			
• Block 1 Preliminary Recommendations	Apr-May 2017	√	Briefing to Aviation Subcommittee, 5/5
– Feedback from the Massport CAC			
• Block 1 Detail Analysis/Implementation Barriers	Aug 2017	√	
• Block 2 Procedure Opportunity	Jun 2017	√	Summer 2017 Aviation Subcommittee
– More complex, benefits\negative impacts, noise equity			
– DNL and alternative metrics (e.g. single event above)			
Today			
• Block 2 Preliminary Recommendations	Summer 2018		Fall 2017 Aviation Subcommittee
• FAA Review Process	Ongoing		Fall 2017 MCAC
• Finalize Recommendations	Fall 2018		Winter\Spring 2018 Aviation Subcommittee
• Implementation/Final Report	Fall 2018		

WORK IN PROGRESS SUBJECT TO CHANGE

RNAV MOU Study-Process Next Steps

- Brief Massport CAC Aviation Operations Sub-Committee 9/28
- Finalize Block 1 ideas Fall 2017
  - MIT to make technical feasibility recommendation to FAA and Massport
- Continue work on Block 2 ideas
- Finalize Block 2 ideas by early/mid 2018
  - MIT to make technical feasibility recommendation to FAA and Massport
- Final Report with recommendations to FAA and Massport Summer/Fall 2018
- Seek FAA input and review along the entire study process
- Continue briefing MCAC, seek MCAC review\feedback
- FAA will evaluate final procedure recommendations from Study based on
  - Standard procedure design criteria
  - Safety and efficiency impacts on Logan and the NAS (National Airspace System)
  - NEPA (National Environmental Policy Act) requirements

Preliminary/Subject to Change

Community Suggested Procedures Under Review

Departure Mods

- 27 inclusion
  - Included in Block 1 and 2
- 4R conformance
  - Under review

Arrival Mods

- 4R alternative alignment
  - Under review

Note: Team also reviewed and rejected based on environmental or safety grounds

- Steeper approaches on arrivals
- R4R Arrivals Expressway alignment

Preliminary/Subject to Change

Procedure Concepts Found to Have Limited Benefit and/or Significant Operational Constraints

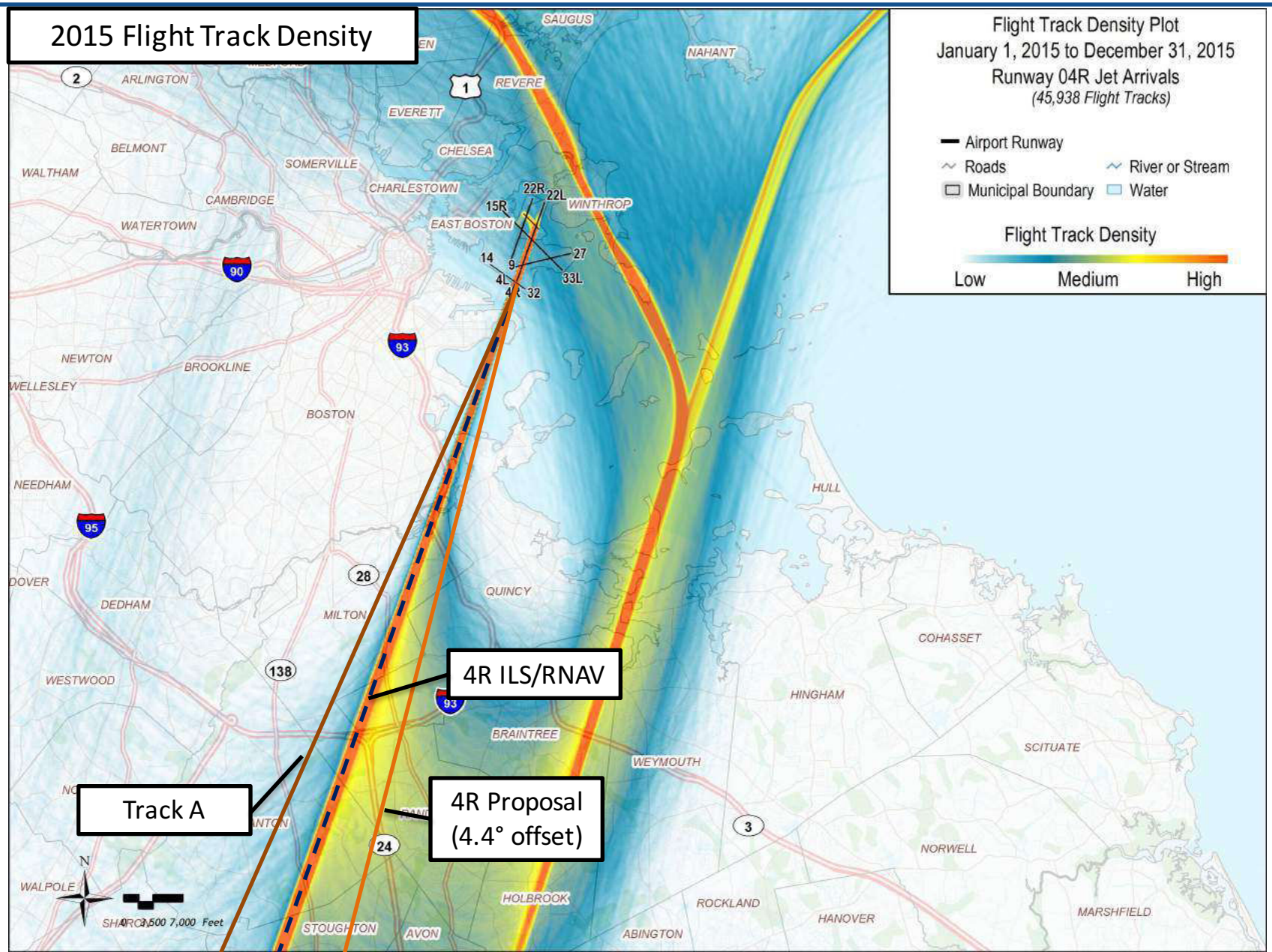
Community Proposed Procedures for 4R

ARRIVALS TO RUNWAY 4R:

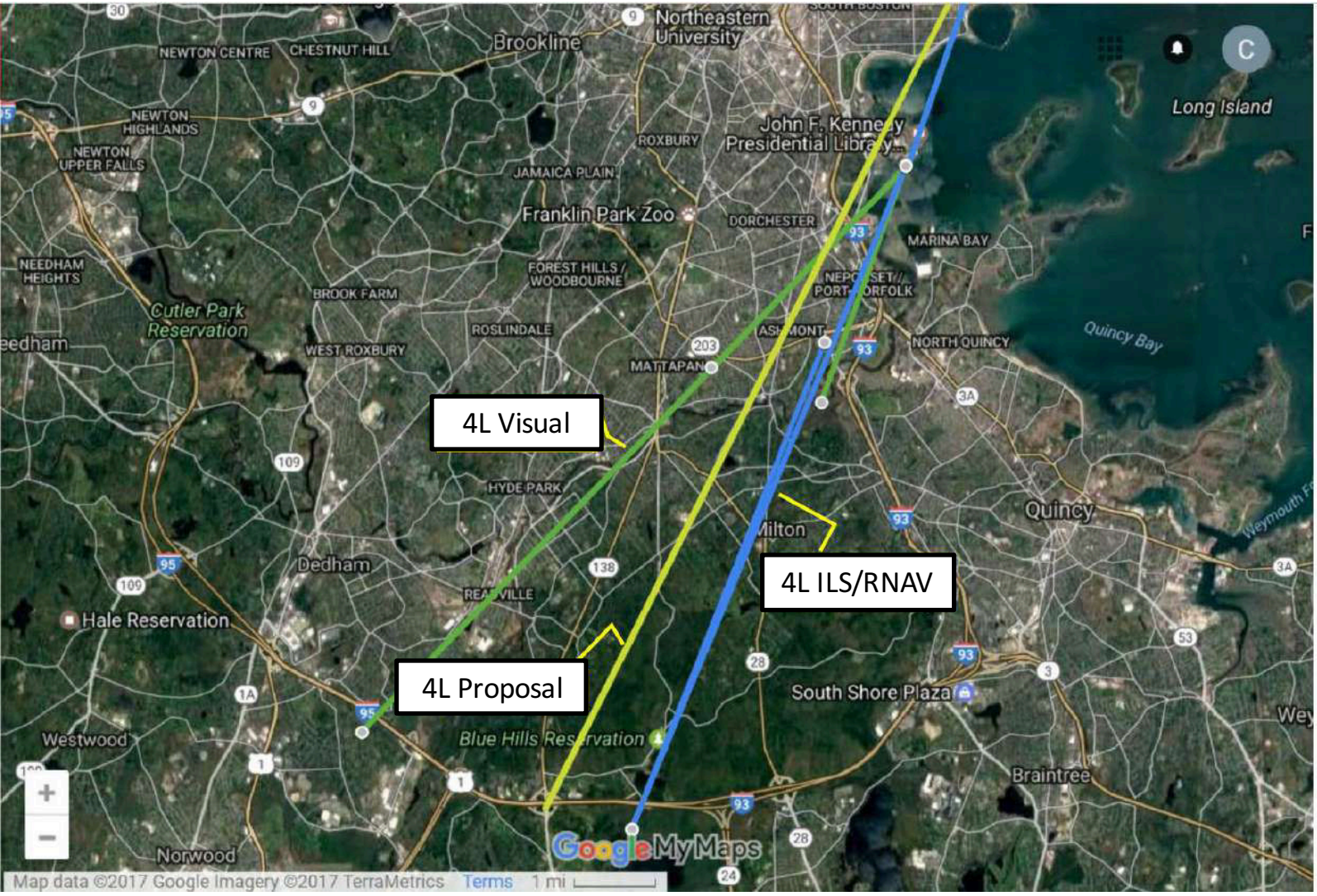
- 4R(ACTUAL);
- 4R(GPS / REPORTED);
- 4R(ALTERNATE)

4

Community Proposed Procedures



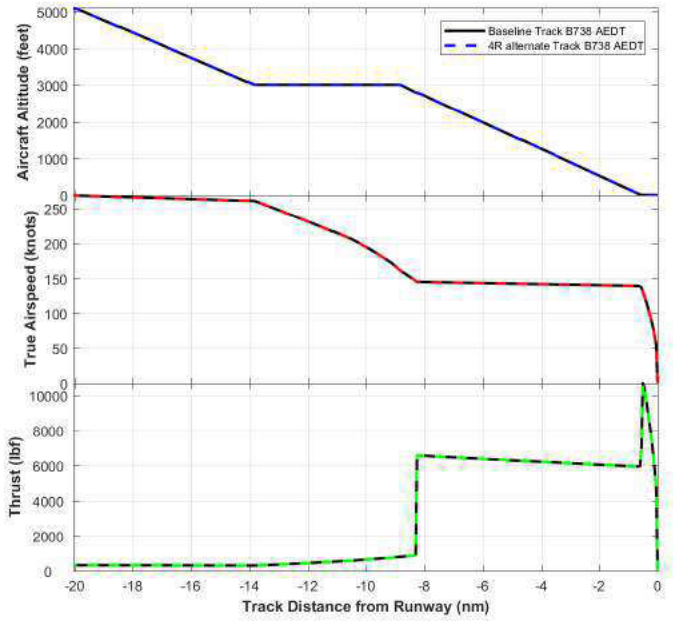
Community Proposed Procedures for 4L

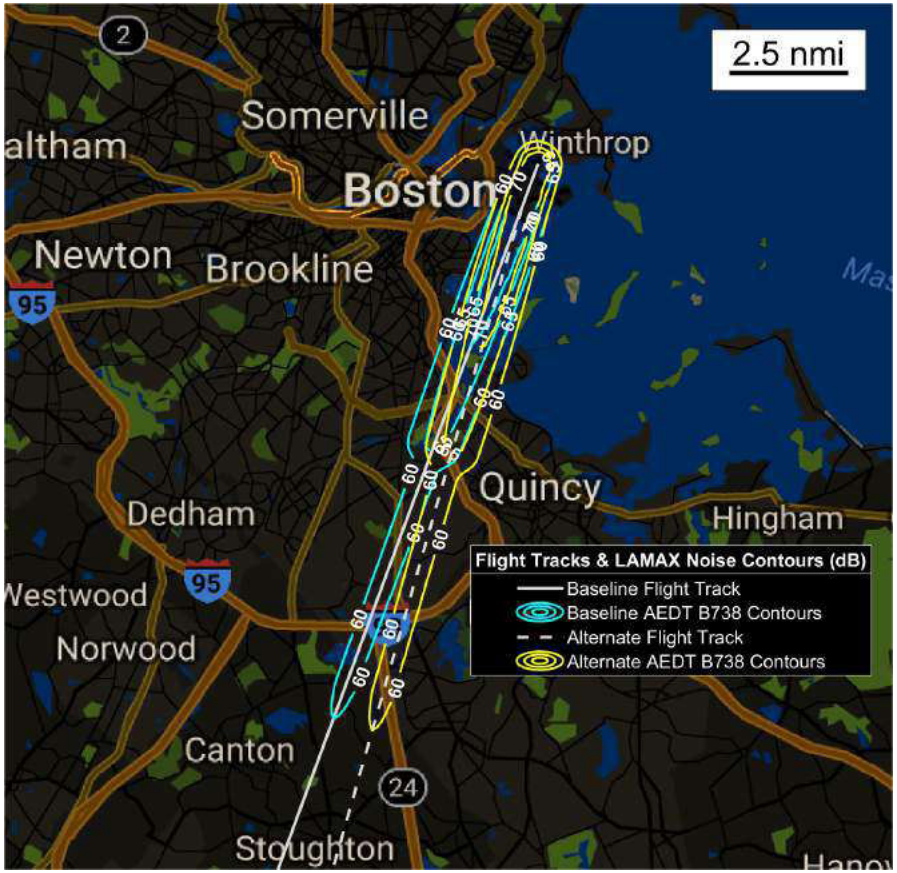


ARRIVALS TO RUNWAY 4L:

- 4L(VISUAL);
- 4L(ALTERNATE);
- 4L(GPS / REPORTED)

4R Community Proposed Procedure: Noise Exposure



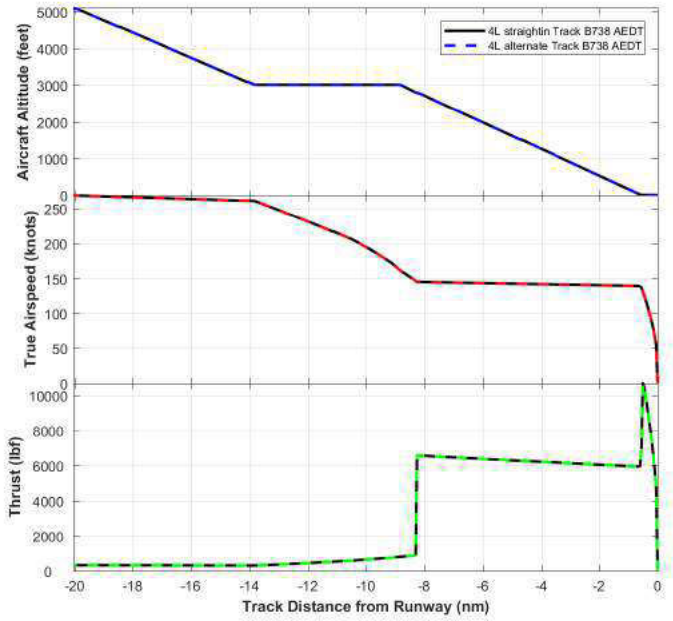


Population Exposure (L_{MAX})

	60dB	65dB	70dB
Straight In	30,239	7,468	530
Modified Procedure	29,424	7,677	0
Reduction	815	-209	530

Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Standard AEDT arrival profile

4L Community Proposed Procedure: Noise Exposure



Population Exposure (L_{MAX})

	60dB	65dB	70dB
Straight In	40,702	19,074	4,500
Modified Procedure	84,483	43,471	11,814
Reduction	-43,781	-24,397	-7,314

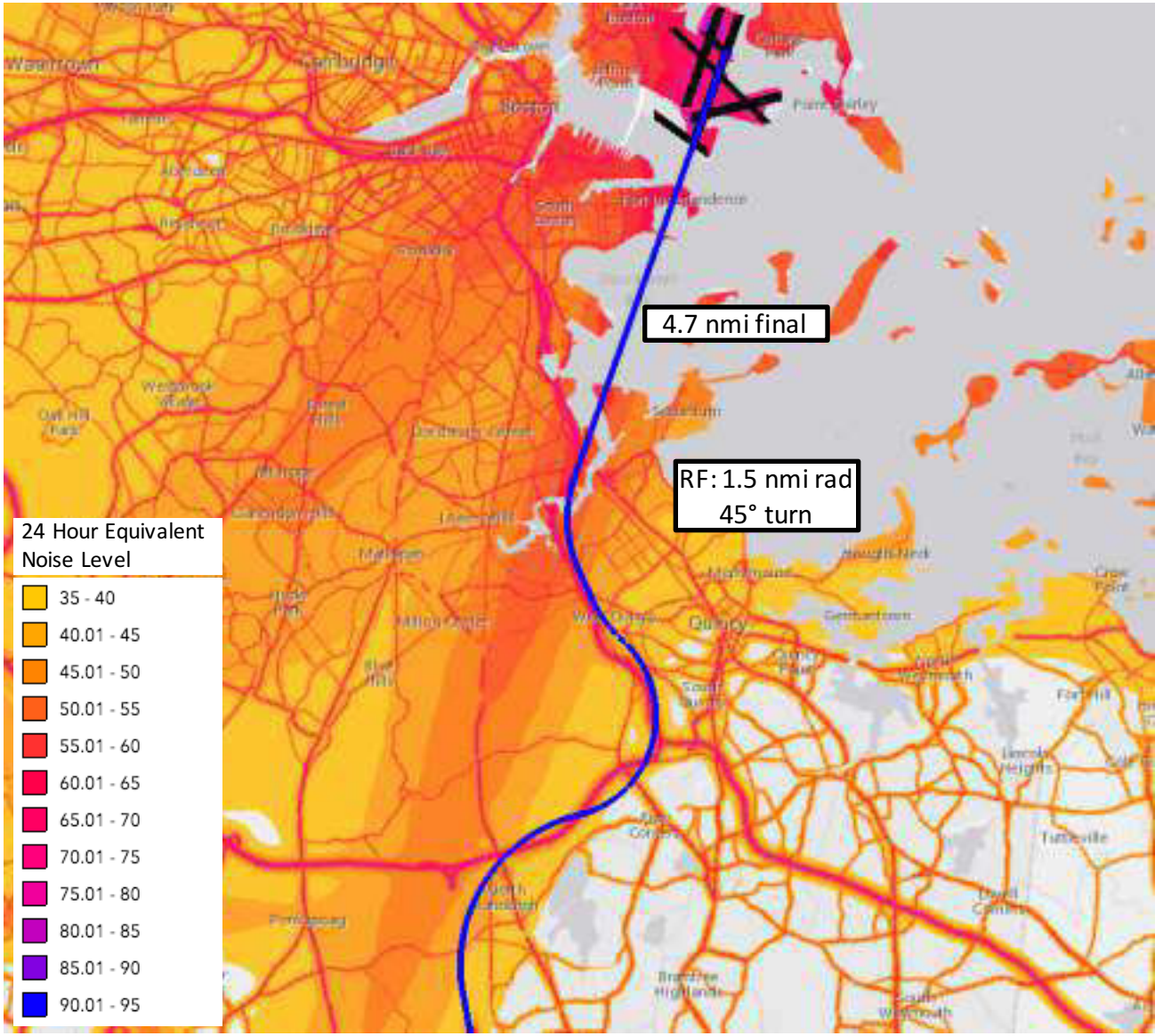
Aircraft	B737-800
Metric	$L_{A,MAX}$
Noise Model	AEDT
Notes	Standard AEDT arrival profile

Community Proposed Procedure: Waypoint Locations

Documents waypoints for the 6 paths.			
Path Name	**south waypoint**	**thru waypoint**	**north waypoint**
4L(VISUAL)	HOCCY	FAMRR	SHYMT
4L(GPS/REPORTED)	LVRON	MTAPN	SHYMT
4L(ALTERNATE)	42.20232, -71.1193		42.31457, -71.04334
4R(GPS/REPORTED)	NABBO	MILTT	42.30905, -71.03176
4R(ACTUAL)	42.20232, -71.1193	42.26238, -71.06286	42.31032, -71.0351
4R(ALTERNATE)*		*CHIKT*	*MILTT(ALTERNATE)*
***Non-FAA Waypoints chosen for the purpose of this study**			
NOTES			
opennav.com	also 4L docs give lat/long		
HOCCY	42.21514, -71.1613		
LVRON	42.19867, -71.09969		
NABBO	42.19518, -71.08699		
FAMRR	42.27672, -71.08147		
MTAPN	42.28098, -71.05566		
MILTT	42.27365, -71.04919		
SHYMT	42.3109, -71.03709		
WITRR	42.2709, -71.0564		
Non-FAA Waypoints chosen for the purpose of this study			
CHMNY	42.26238, -71.06286	4R(ACTUAL)	
CHIKT	42.23226, -71.05562	4R(ALTERNATE)	FOR 5/31/17 PRESENTATION
MILTT(ALTERNATIVE)	42.27362, -71.04035	4R(ALTERNATE)	A/S MTG, BLOCK 1 WORK

Notional 4R Expressway Approach Path

- Concept: move arrival flows over regions of higher ambient noise
  - Highways
  - Industrial areas
- Currently developing prototype arrival profile definitions



Transportation Noise Data Source: Bureau of Transportation Statistics https://www.rita.dot.gov/bts/press_releases/bts015_17

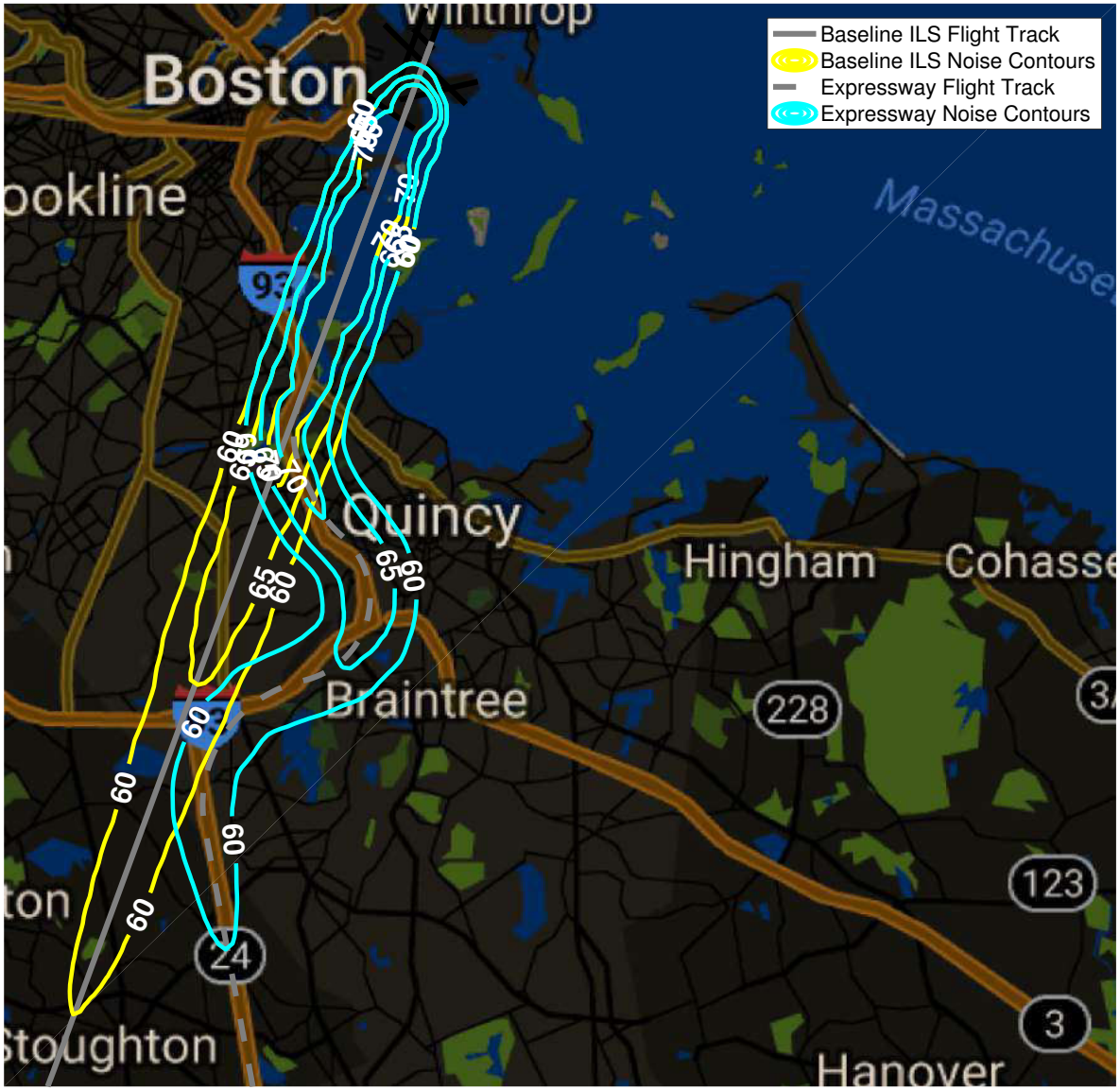
Noise Exposure: 4R Expressway Approach

- 4R Expressway Approach
- Aircraft: B737-800
- Metric: LAMAX
- Noise Model: AEDT

- Potential environmental justice issues

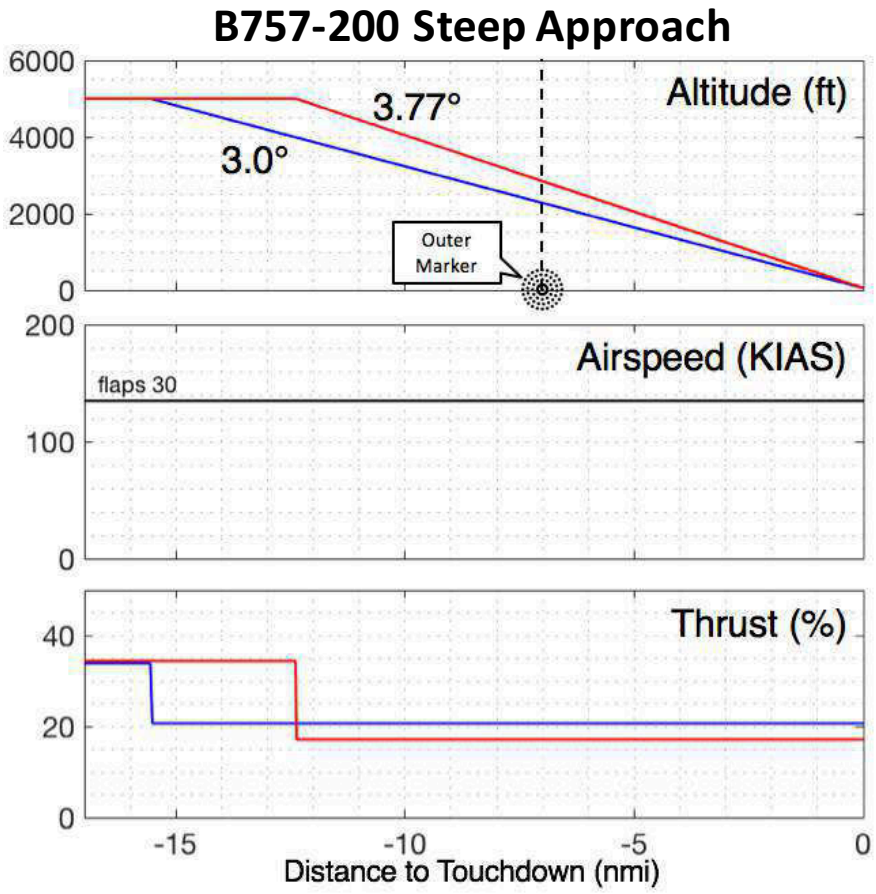
Population Exposure

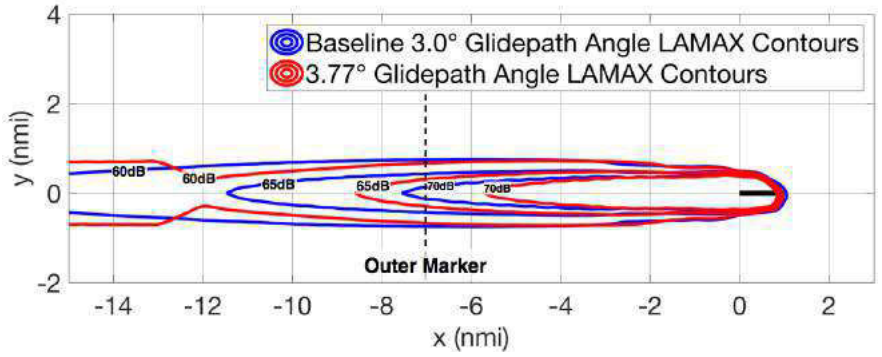
	60dB	65dB	70dB
Baseline	46,039	21,207	5,159
Expressway	66,417	32,879	5,945
Difference	-20,377	-11,672	-786

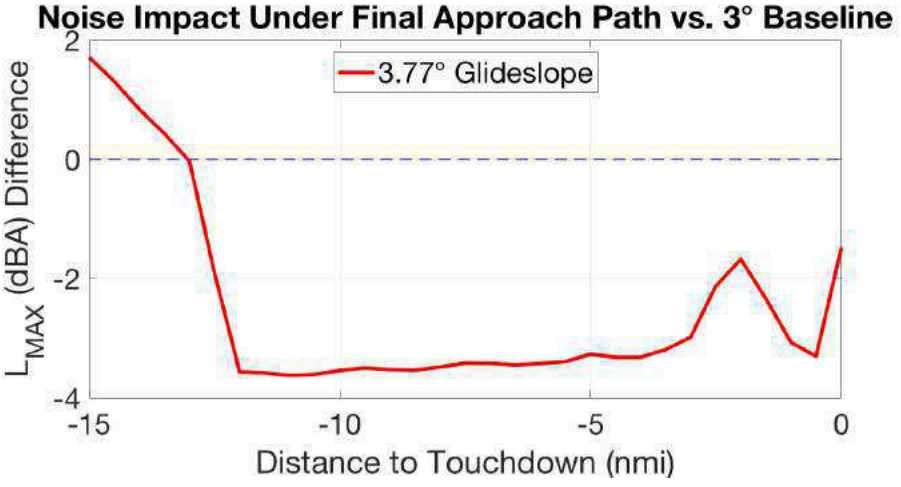


3° and 3.77° Continuous Descent Approach Comparison

- BADA-4 model indicates that steeper glideslopes may be feasible for some aircraft types
- Feedback from operators: Airbus aircraft in planned descent autoflight mode cannot exceed 3.77° glideslope angle

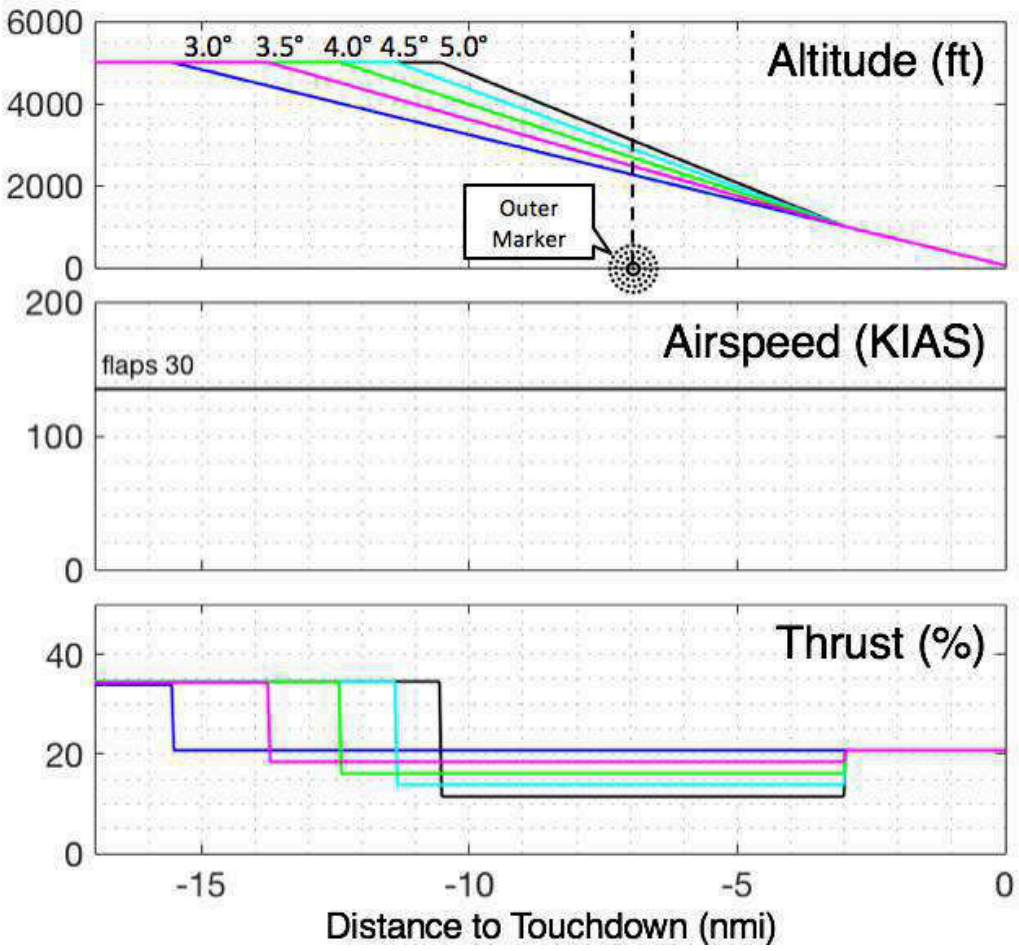


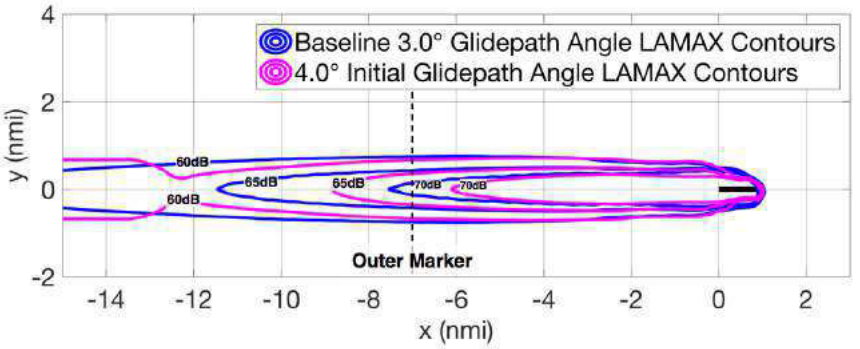


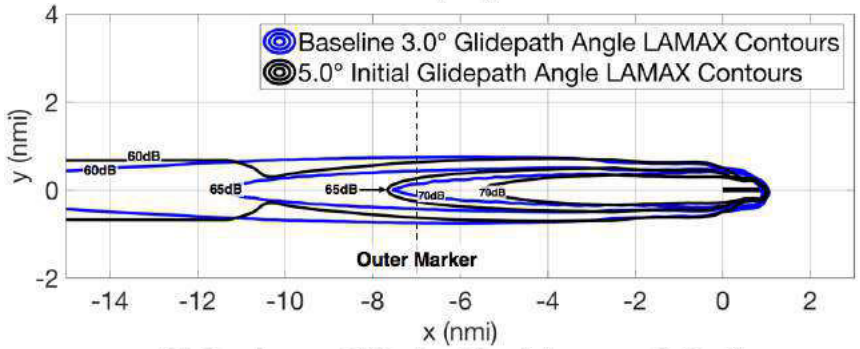


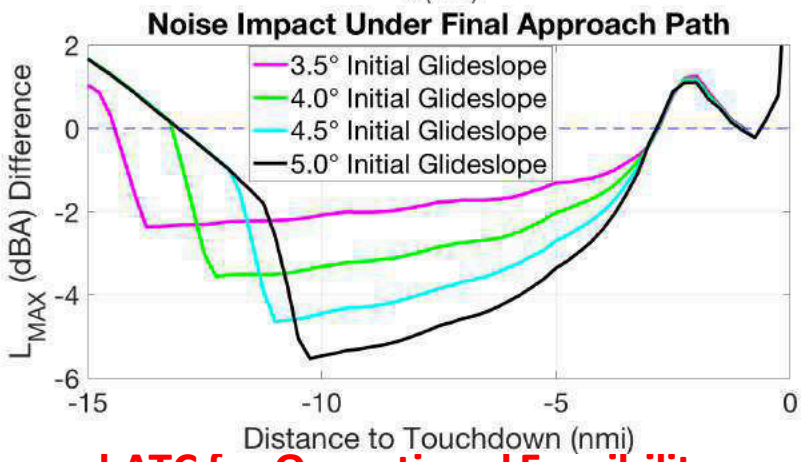
Significant Concerns from Airline Technical Pilots and ATC for Operational Feasibility

Two-Segment Approach Concept









Significant Concerns from Airline Technical Pilots and ATC for Operational Feasibility

Safety Concerns - High-Energy Approaches

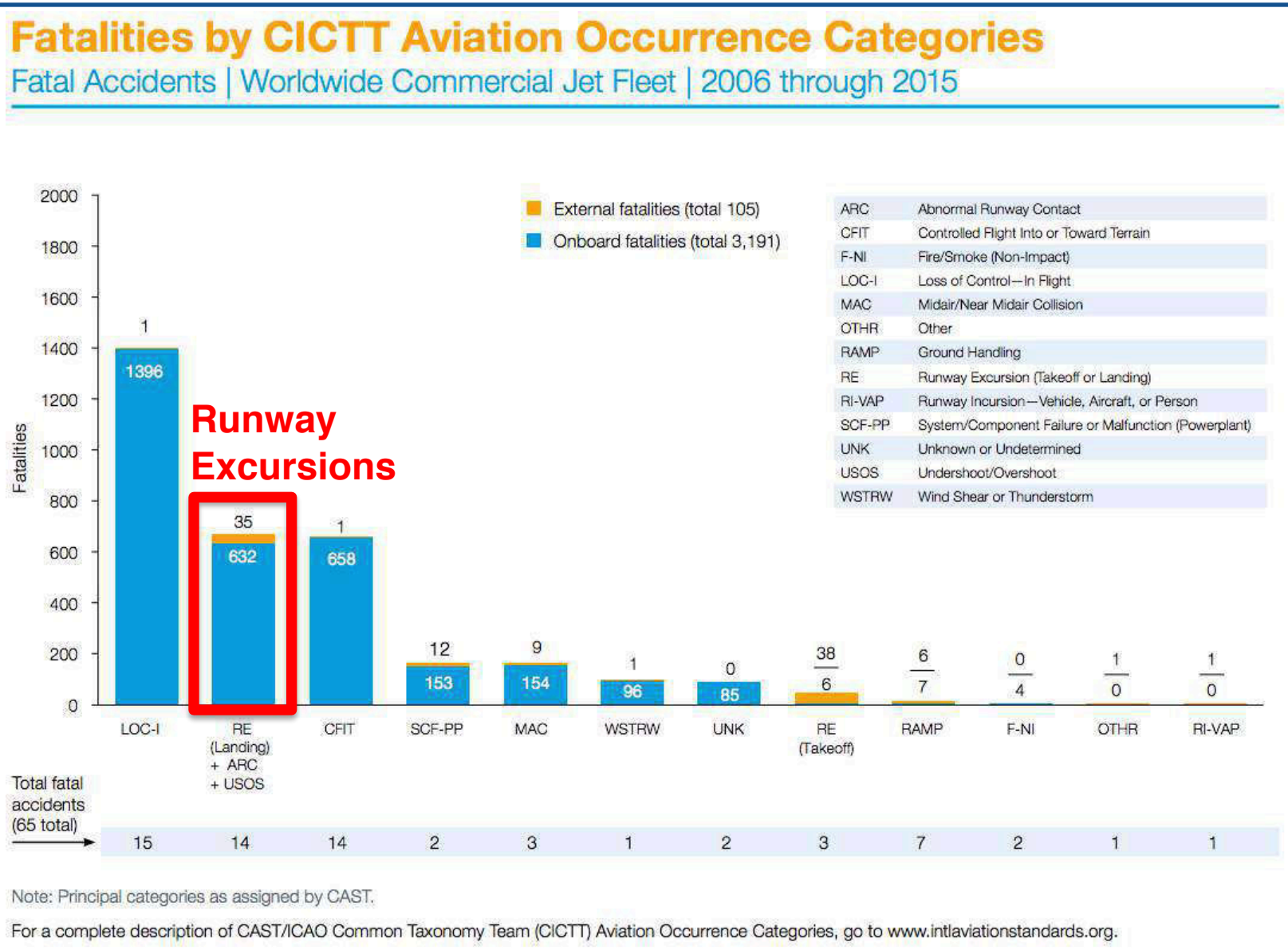
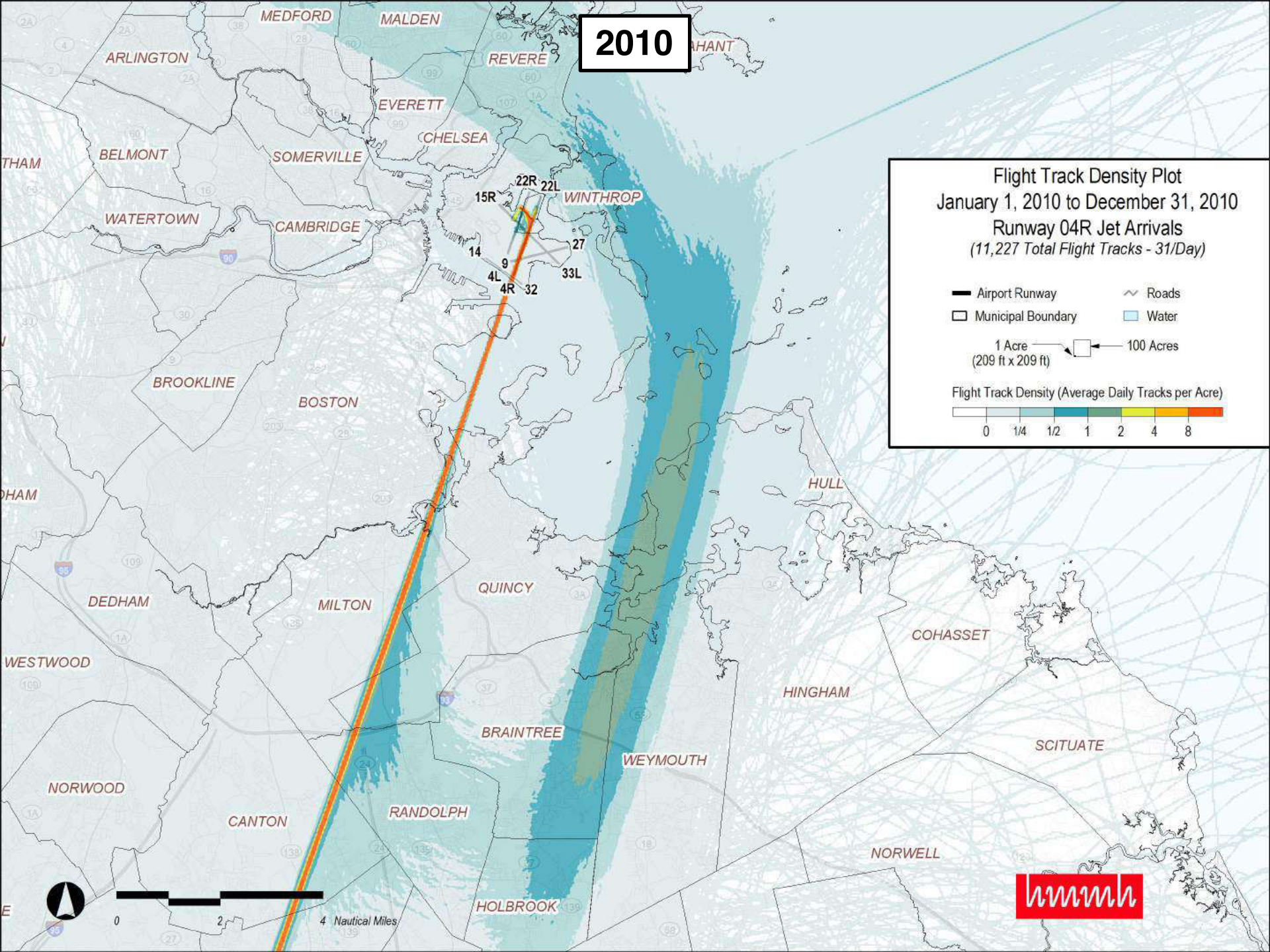
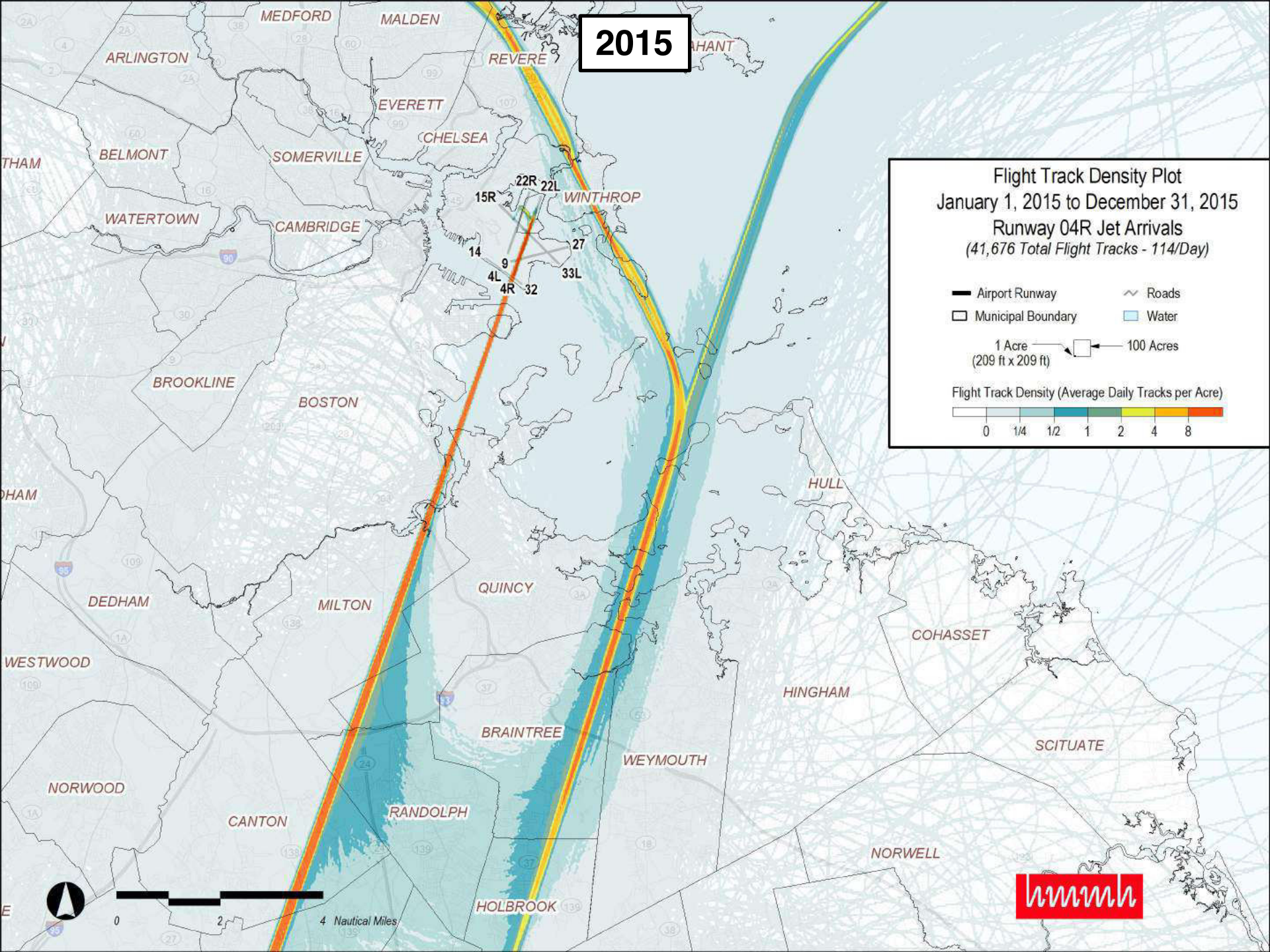
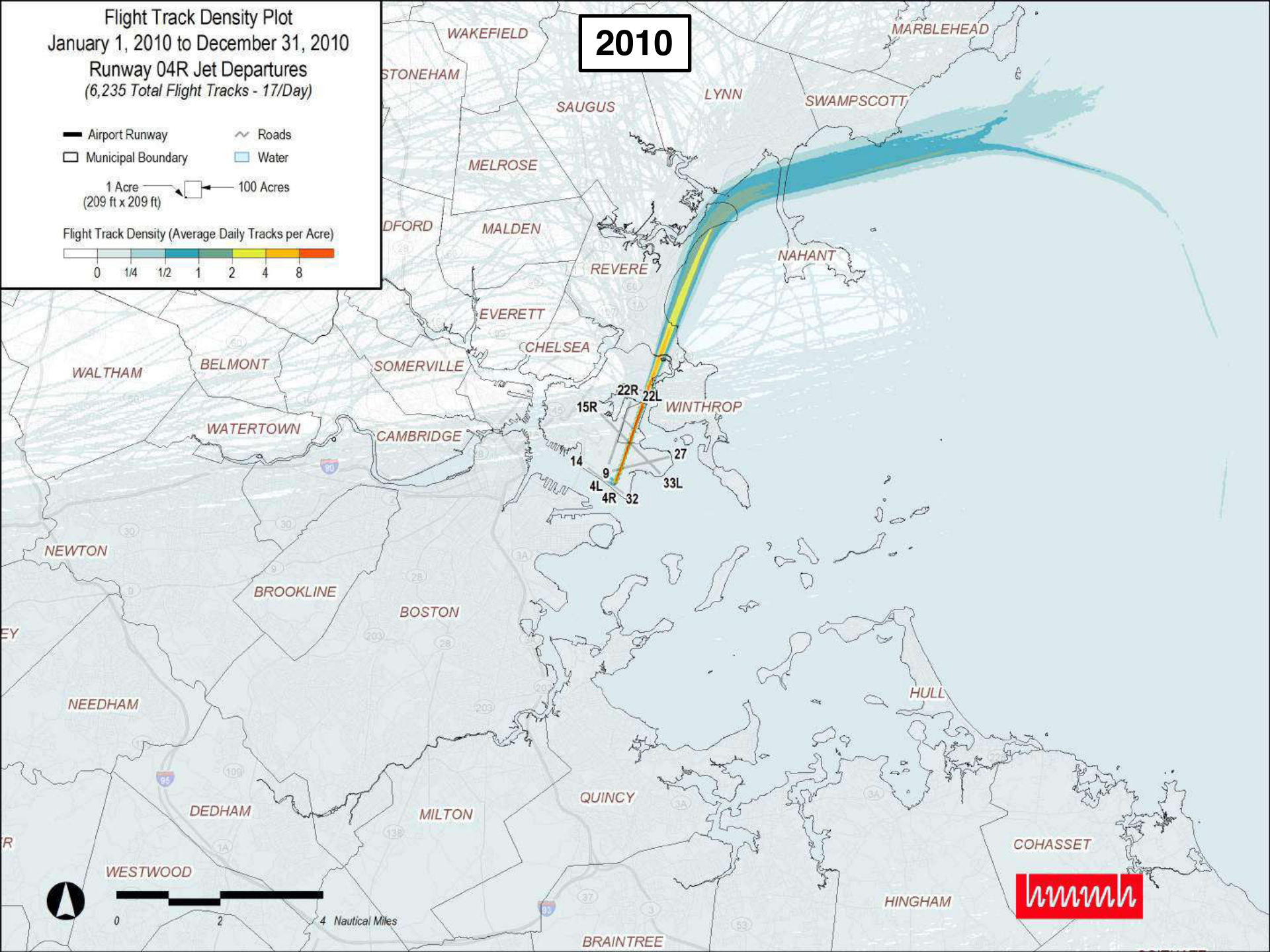


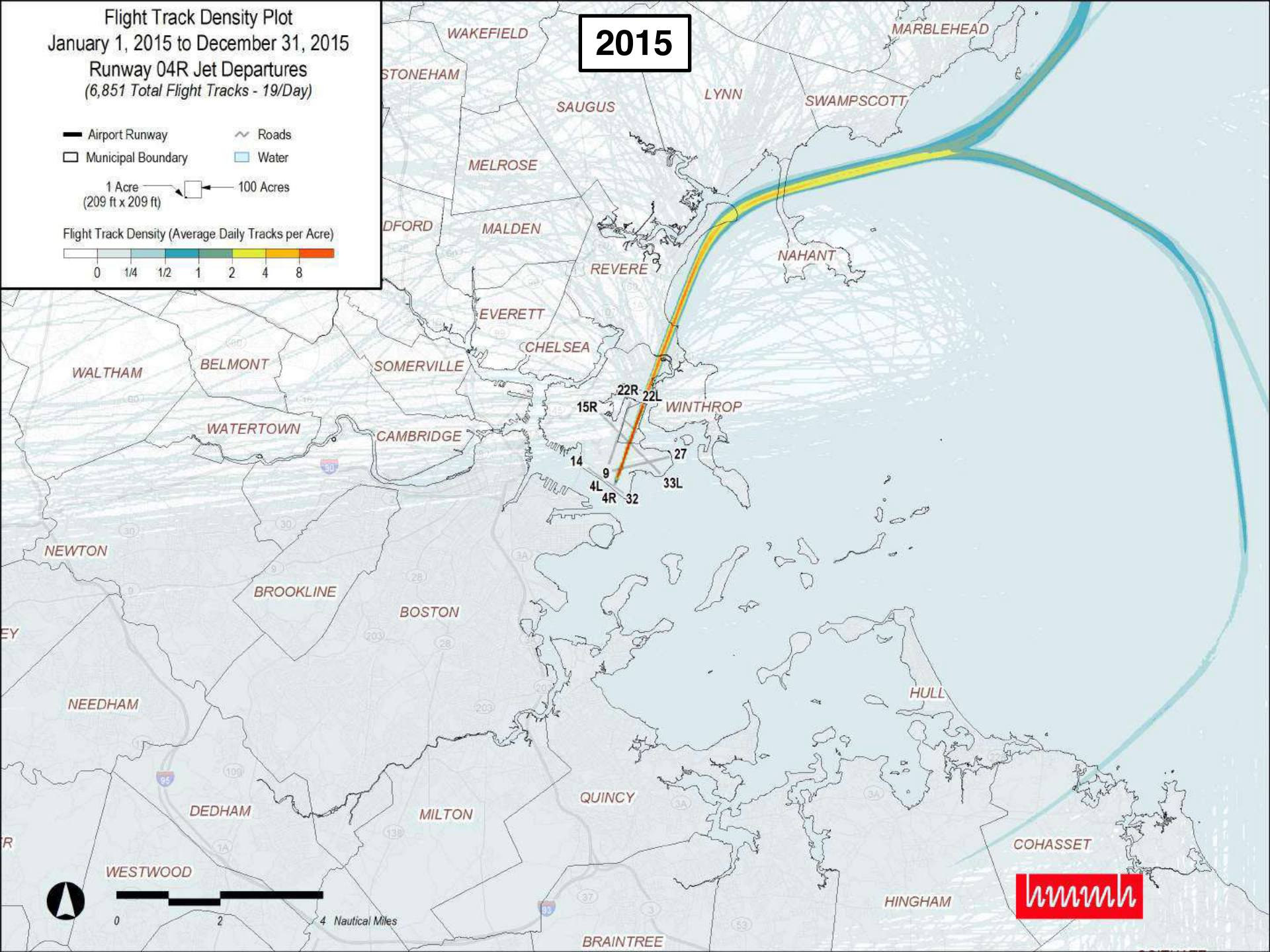
Figure source: The Boeing Company http://www.boeing.com/resources/boeingdotcom/company/about_bca/pdf/statsum.pdf

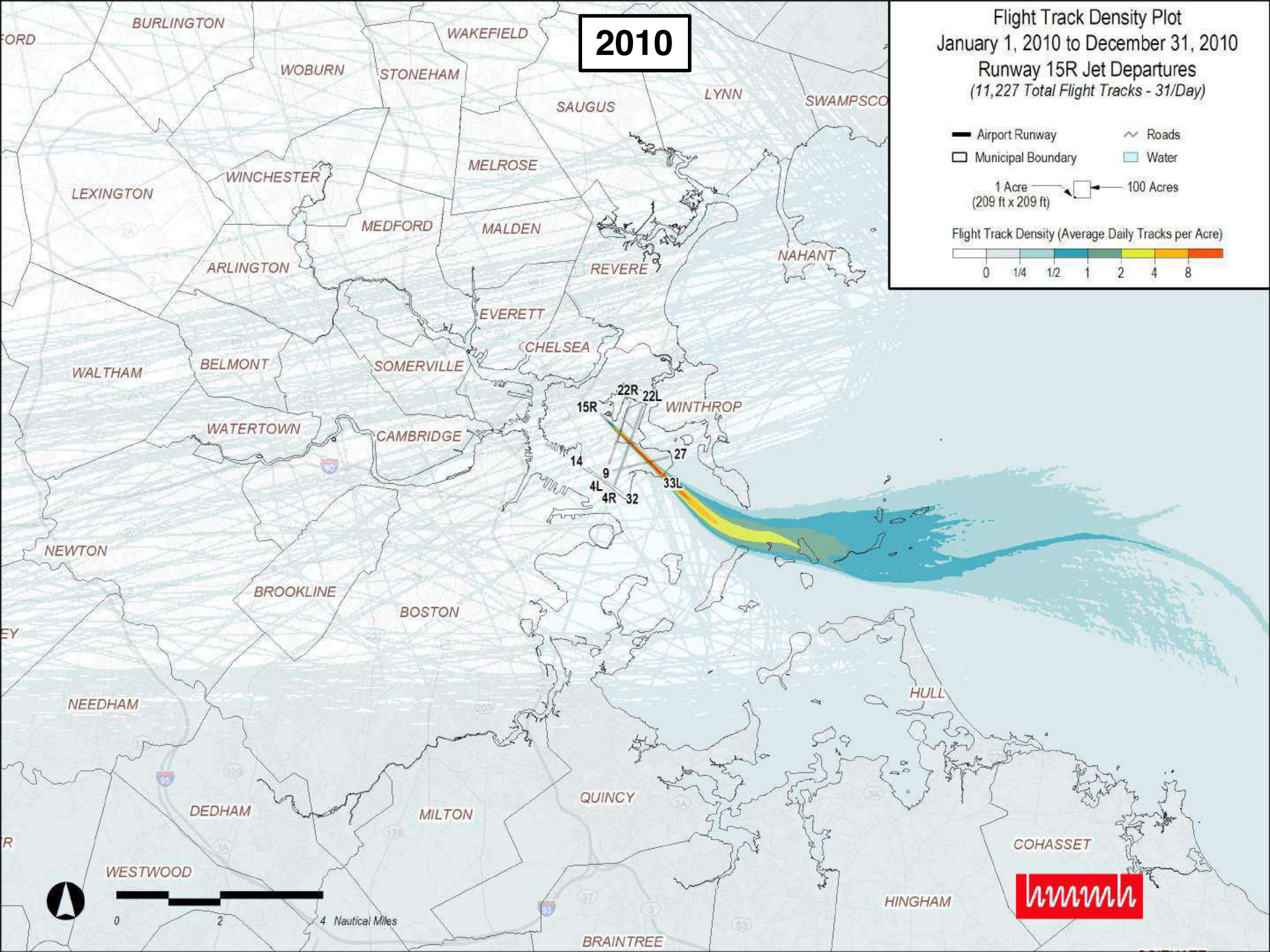
Addendum A: Track Density Plots Presented in Average Daily Flights per Acre

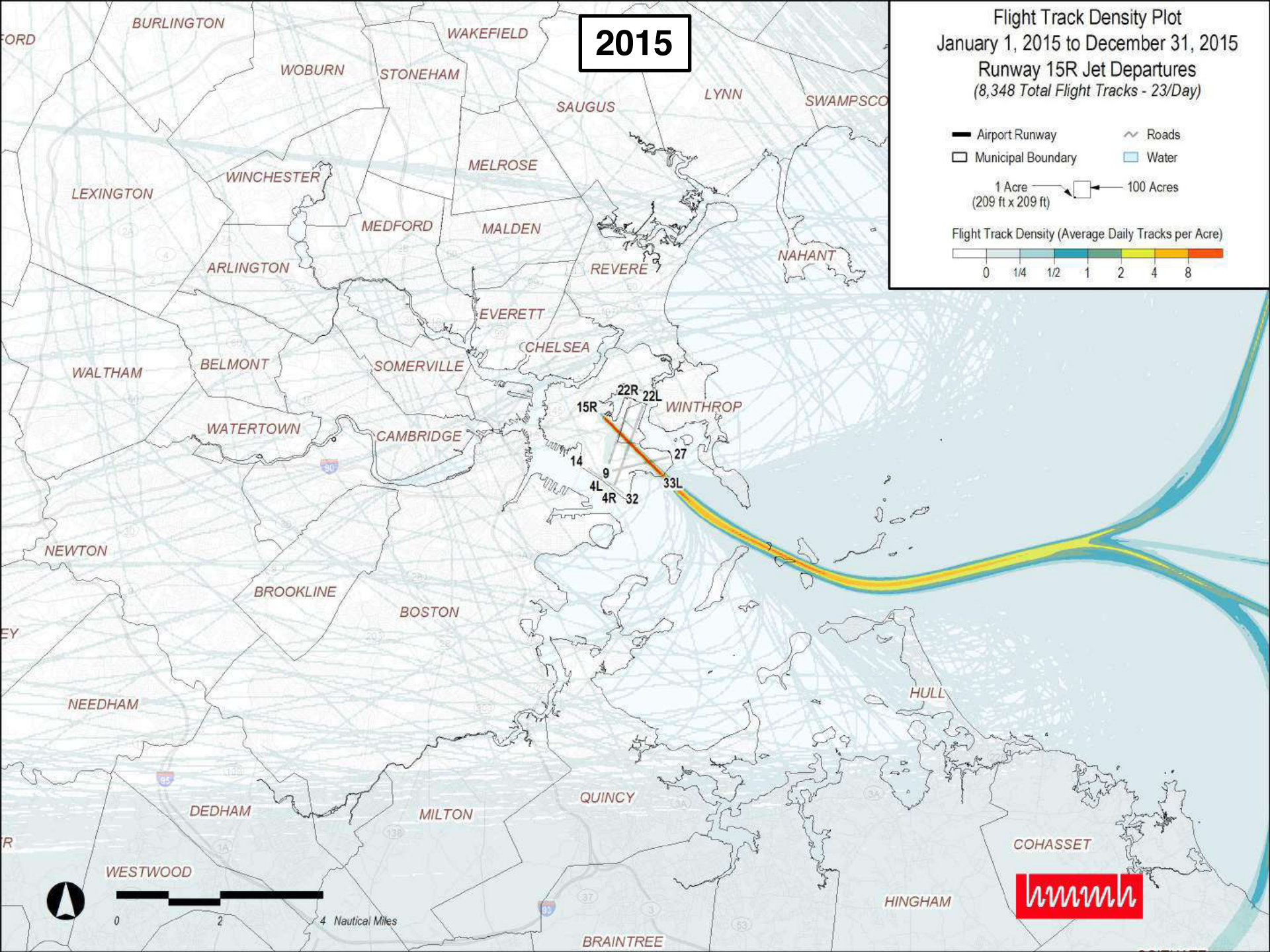

2010
MEDFORD
MALDEN
ARLINGTON
REVERE
EVERETT
CHELSEA
BELMONT
SOMERVILLE
WATERTOWN
CAMBRIDGE
WINTHROP
22R
22L
15R
27
14
9
33L
4L
4R
32
BROOKLINE
BOSTON
HULL
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
WEYMOUTH
SCITUATE
NORWOOD
CANTON
RANDOLPH
NORWELL
HOLBROOK
0
2
4 Nautical Miles
Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 04R Jet Arrivals
(11,227 Total Flight Tracks - 31/Day)
Airport Runway
Roads
Municipal Boundary
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8

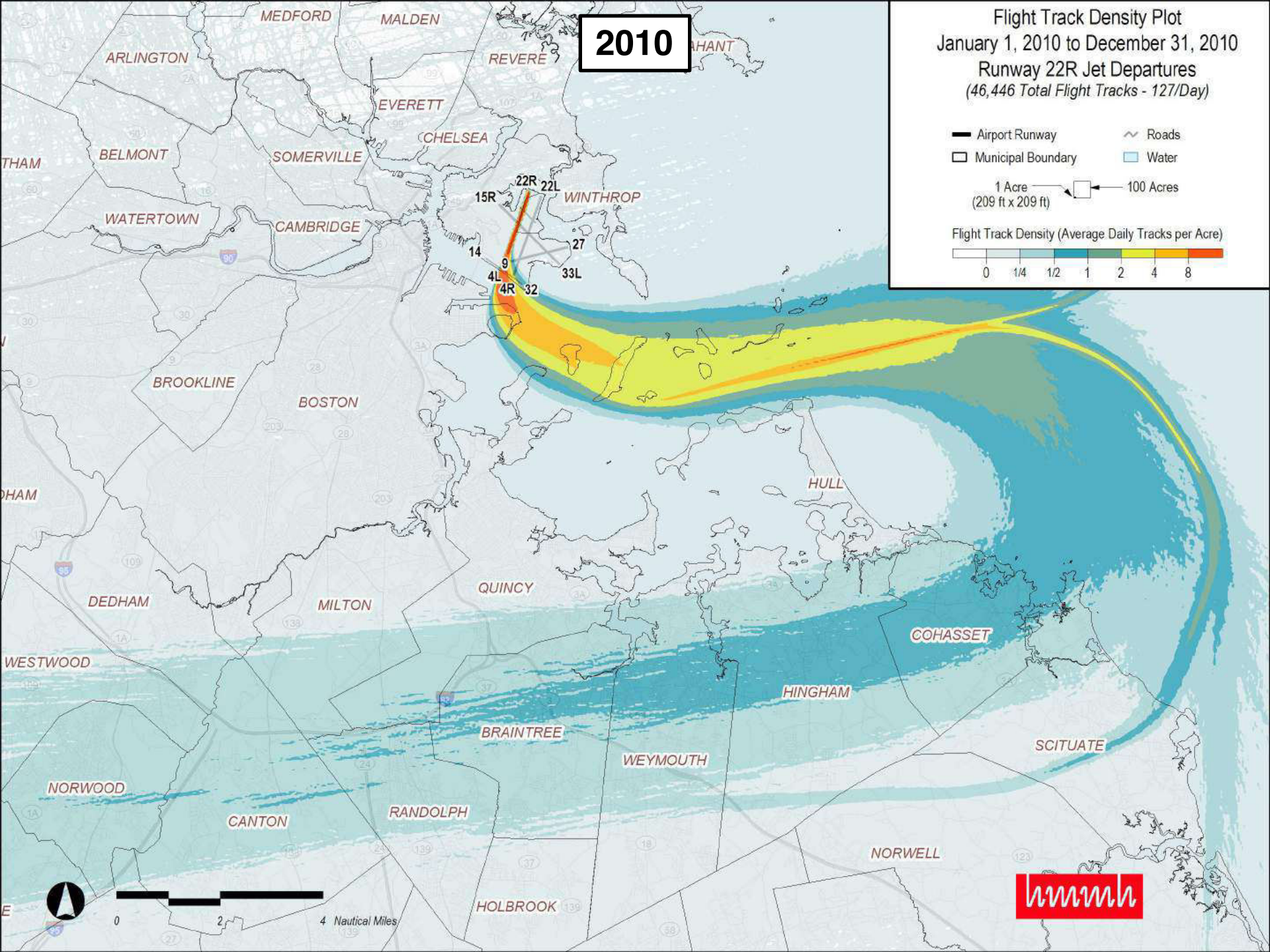

2015
MEDFORD
MALDEN
ARLINGTON
REVERE
EVERETT
CHELSEA
BELMONT
SOMERVILLE
WATERTOWN
CAMBRIDGE
WINTHROP
22R
22L
15R
27
14
9
33L
4L
4R
32
BROOKLINE
BOSTON
HULL
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
WEYMOUTH
SCITUATE
NORWOOD
CANTON
RANDOLPH
NORWELL
HOLBROOK
0
2
4 Nautical Miles
Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 04R Jet Arrivals
(41,676 Total Flight Tracks - 114/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8

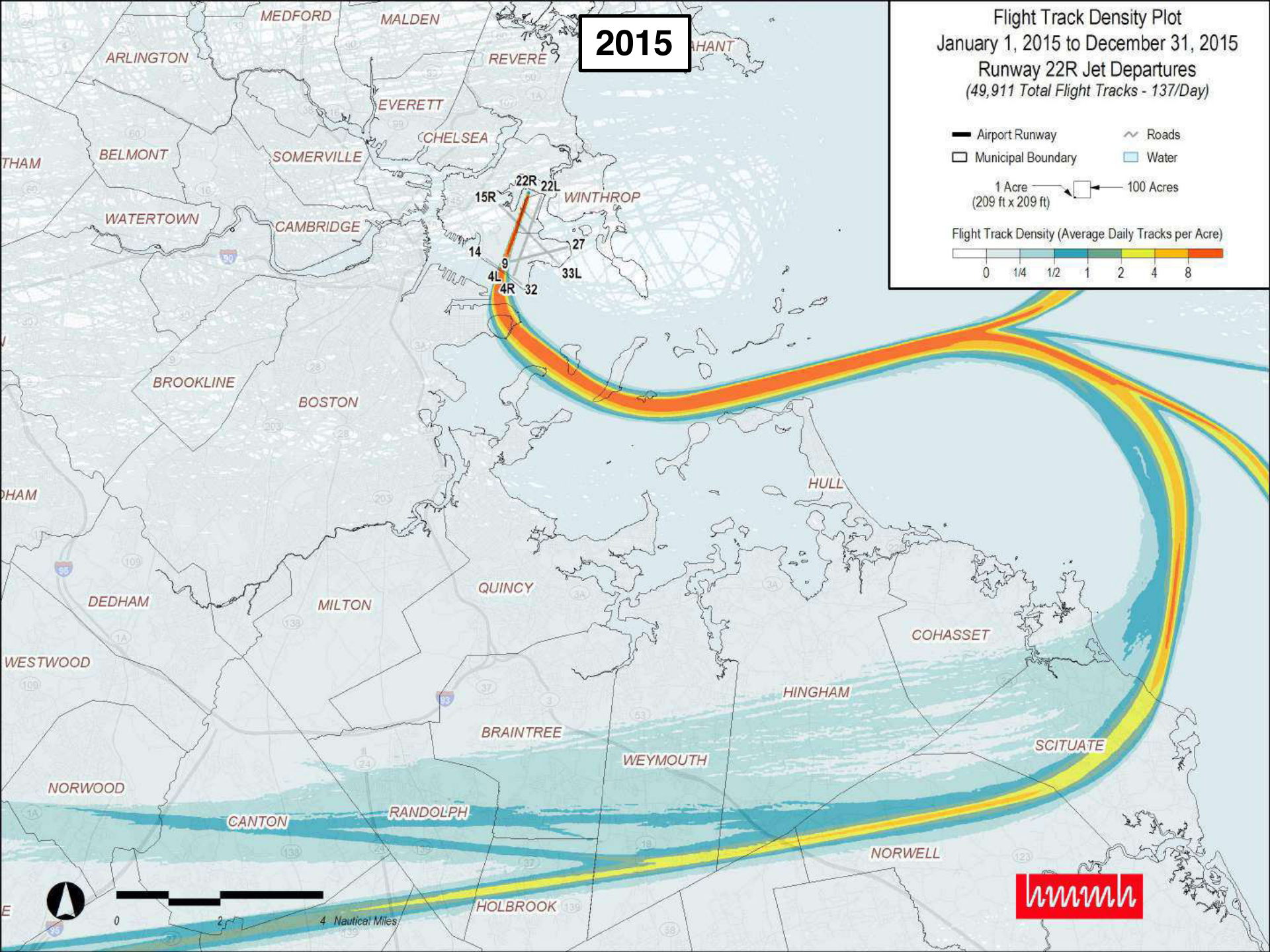

Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 04R Jet Departures
(6,235 Total Flight Tracks - 17/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
2010
WAKEFIELD
STONEHAM
SAUGUS
LYNN
MARBLEHEAD
SWAMPSCOTT
MELROSE
MALDEN
REVERE
NAHANT
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WINTHROP
WATERTOWN
CAMBRIDGE
22R
22L
15R
27
14
9
33L
4L
4R
32
NEWTON
BROOKLINE
BOSTON
NEEDHAM
HULL
DEDHAM
MILTON
QUINCY
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
0
2
4 Nautical Miles

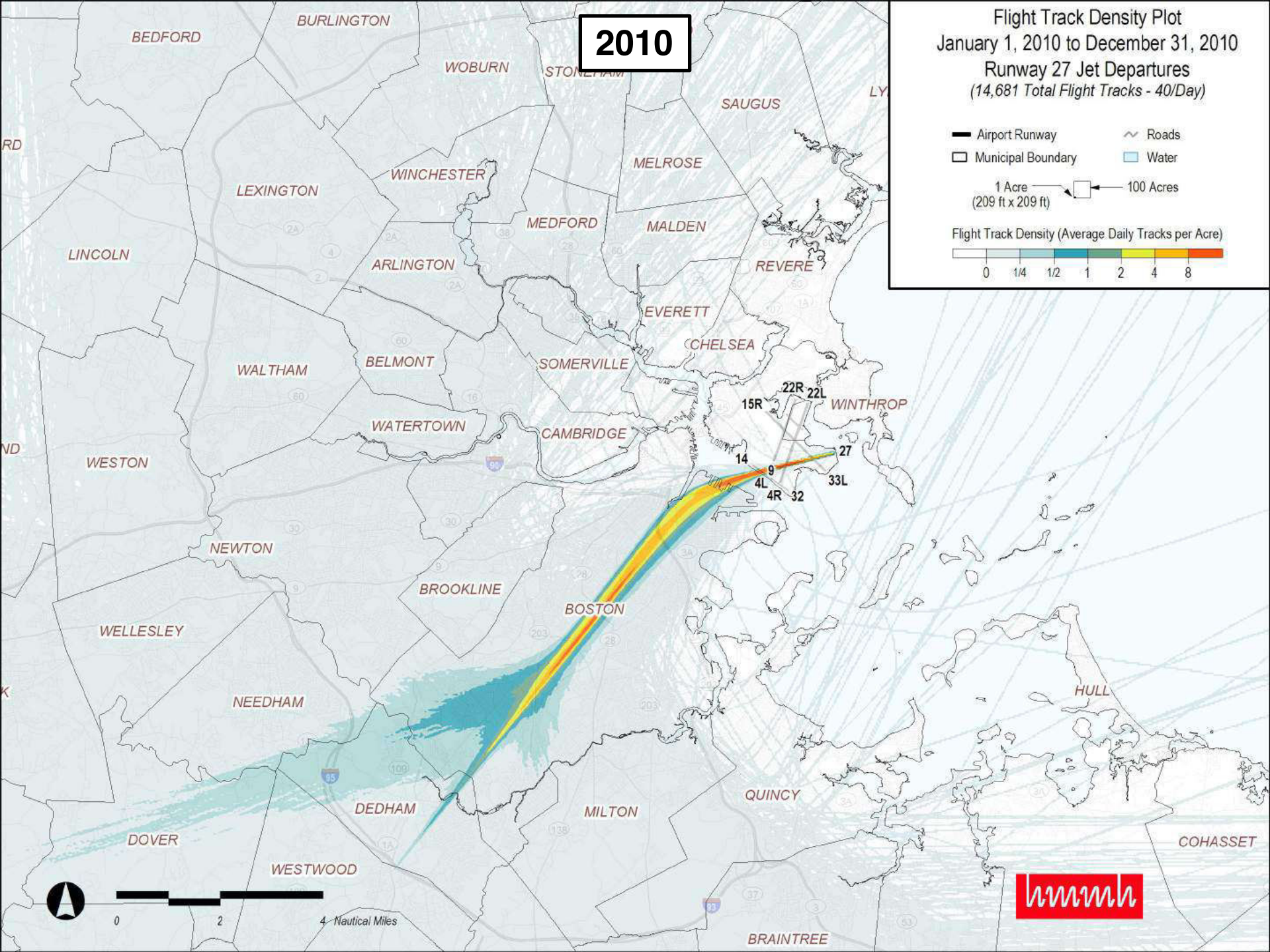

Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 04R Jet Departures
(6,851 Total Flight Tracks - 19/Day)
Airport Runway
Roads
Municipal Boundary
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
2015
WAKEFIELD
STONEHAM
SAUGUS
LYNN
MARBLEHEAD
SWAMPSCOTT
MELROSE
MALDEN
REVERE
NAHANT
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WATERTOWN
CAMBRIDGE
WINTHROP
22R
22L
15R
27
14
9
33L
4L
4R
32
NEWTON
BROOKLINE
BOSTON
NEEDHAM
HULL
DEDHAM
MILTON
QUINCY
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
0
2
4 Nautical Miles

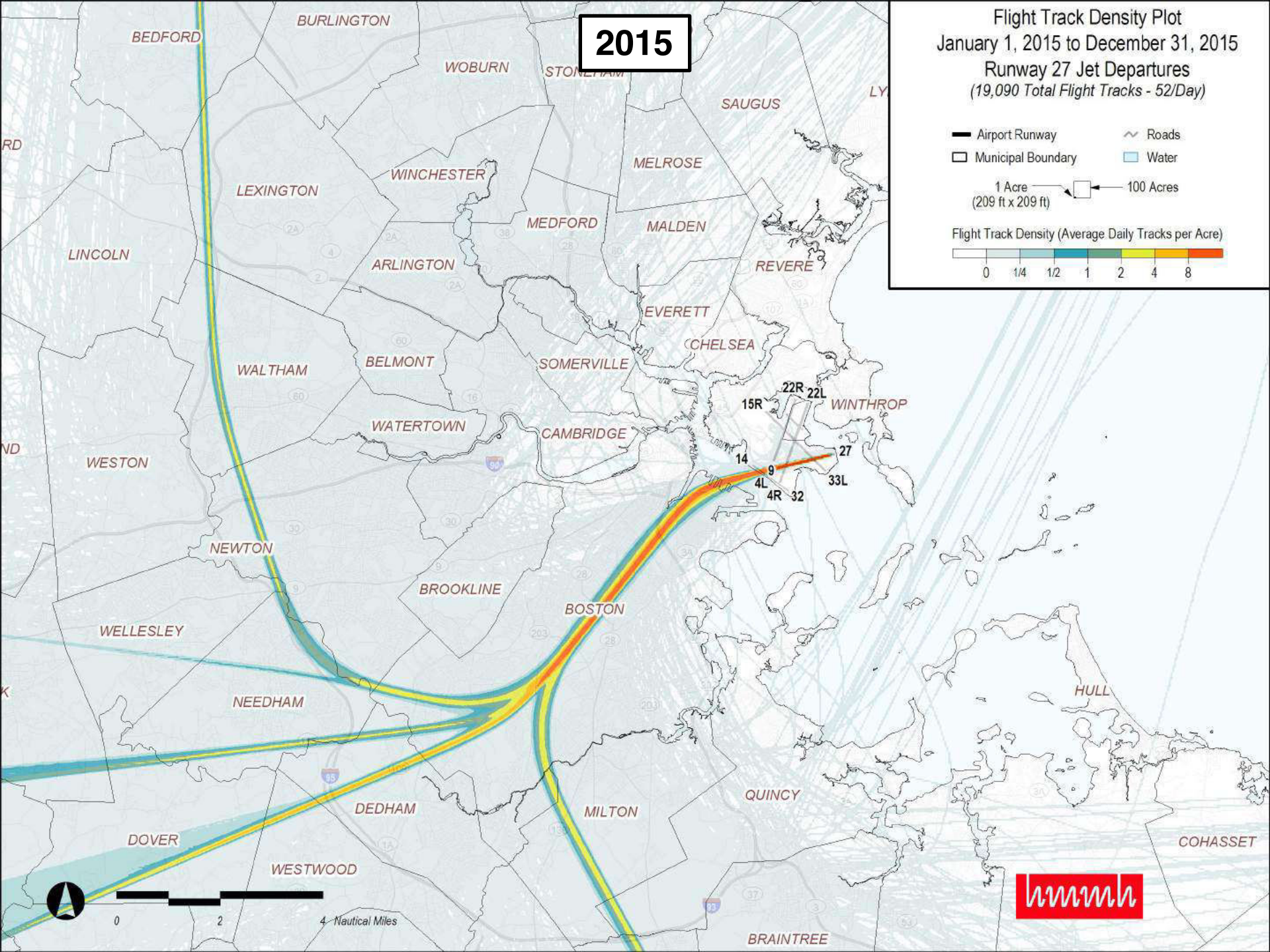

2010
Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 15R Jet Departures
(11,227 Total Flight Tracks - 31/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BURLINGTON
WAKEFIELD
WOBURN
STONEHAM
SAUGUS
LYNN
SWAMPSCO
MELROSE
WINCHESTER
LEXINGTON
MEDFORD
MALDEN
ARLINGTON
REVERE
NAHANT
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WINTHROP
22R
22L
15R
WATERTOWN
CAMBRIDGE
27
14
9
33L
4L
4R
32
NEWTON
BROOKLINE
BOSTON
HULL
NEEDHAM
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
0
2
4 Nautical Miles

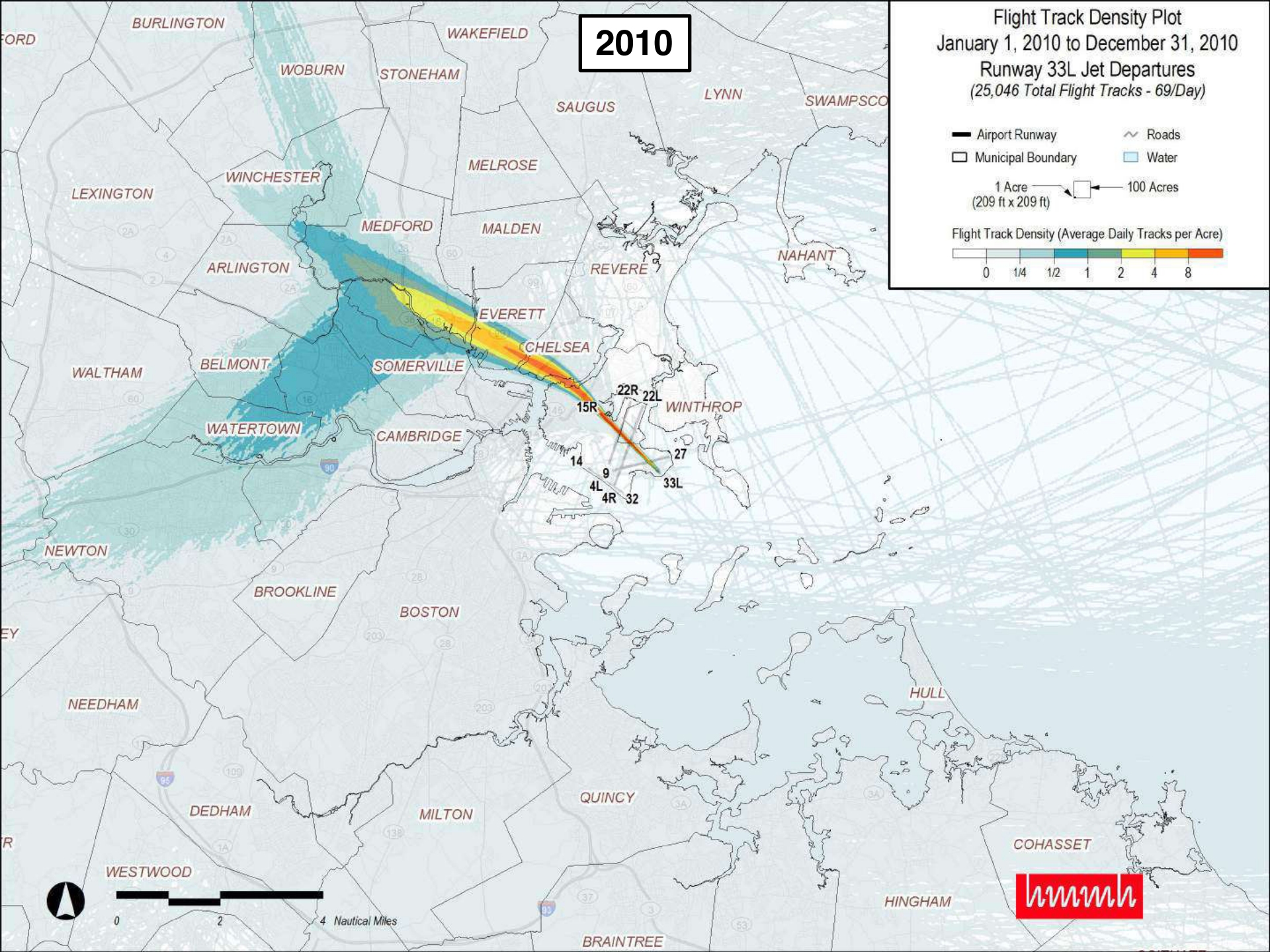

2015
Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 15R Jet Departures
(8,348 Total Flight Tracks - 23/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BURLINGTON
WAKEFIELD
WOBURN
STONEHAM
SAUGUS
LYNN
SWAMPSCO
MELROSE
WINCHESTER
LEXINGTON
MEDFORD
MALDEN
ARLINGTON
REVERE
NAHANT
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WINTHROP
22R
22L
15R
WATERTOWN
CAMBRIDGE
27
14
9
33L
4L
4R
32
NEWTON
BROOKLINE
BOSTON
HULL
NEEDHAM
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
0
2
4 Nautical Miles
BRAINTREE

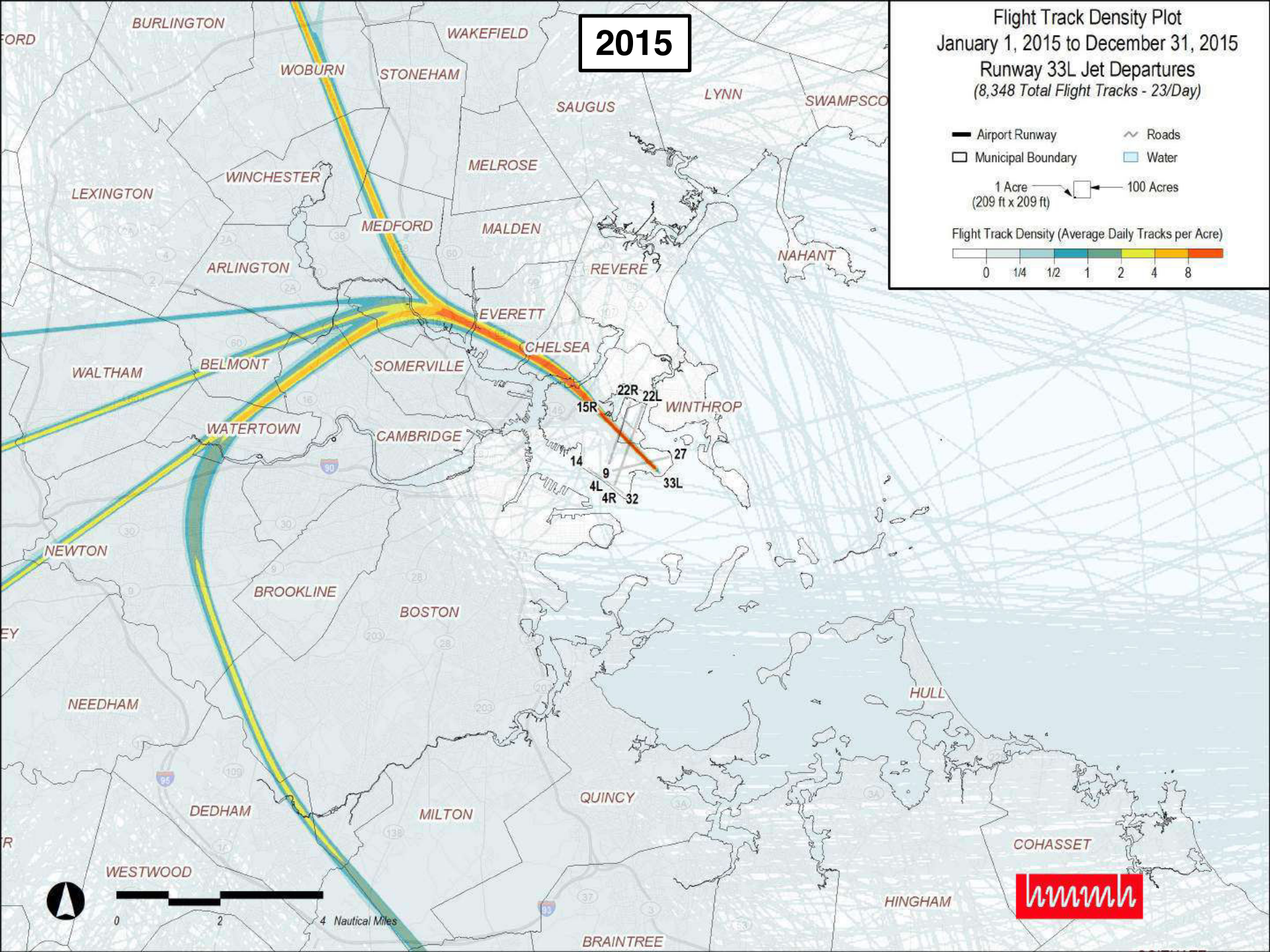

2010
Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 22R Jet Departures
(46,446 Total Flight Tracks - 127/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
MEDFORD
MALDEN
REVERE
ARLINGTON
EVERETT
CHELSEA
BELMONT
SOMERVILLE
WINTHROP
WATERTOWN
CAMBRIDGE
22R
22L
15R
27
14
9
33L
4L
4R
32
BROOKLINE
BOSTON
HULL
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
WEYMOUTH
SCITUATE
NORWOOD
CANTON
RANDOLPH
NORWELL
HOLBROOK
0
2
4 Nautical Miles


2015
Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 22R Jet Departures
(49,911 Total Flight Tracks - 137/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
MEDFORD
MALDEN
REVERE
ARLINGTON
EVERETT
CHELSEA
BELMONT
SOMERVILLE
WATERTOWN
CAMBRIDGE
WINTHROP
22R
22L
15R
14
9
4L
4R
32
27
33L
BROOKLINE
BOSTON
HULL
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
WEYMOUTH
SCITUATE
NORWOOD
CANTON
RANDOLPH
NORWELL
HOLBROOK
0
2
4 Nautical Miles

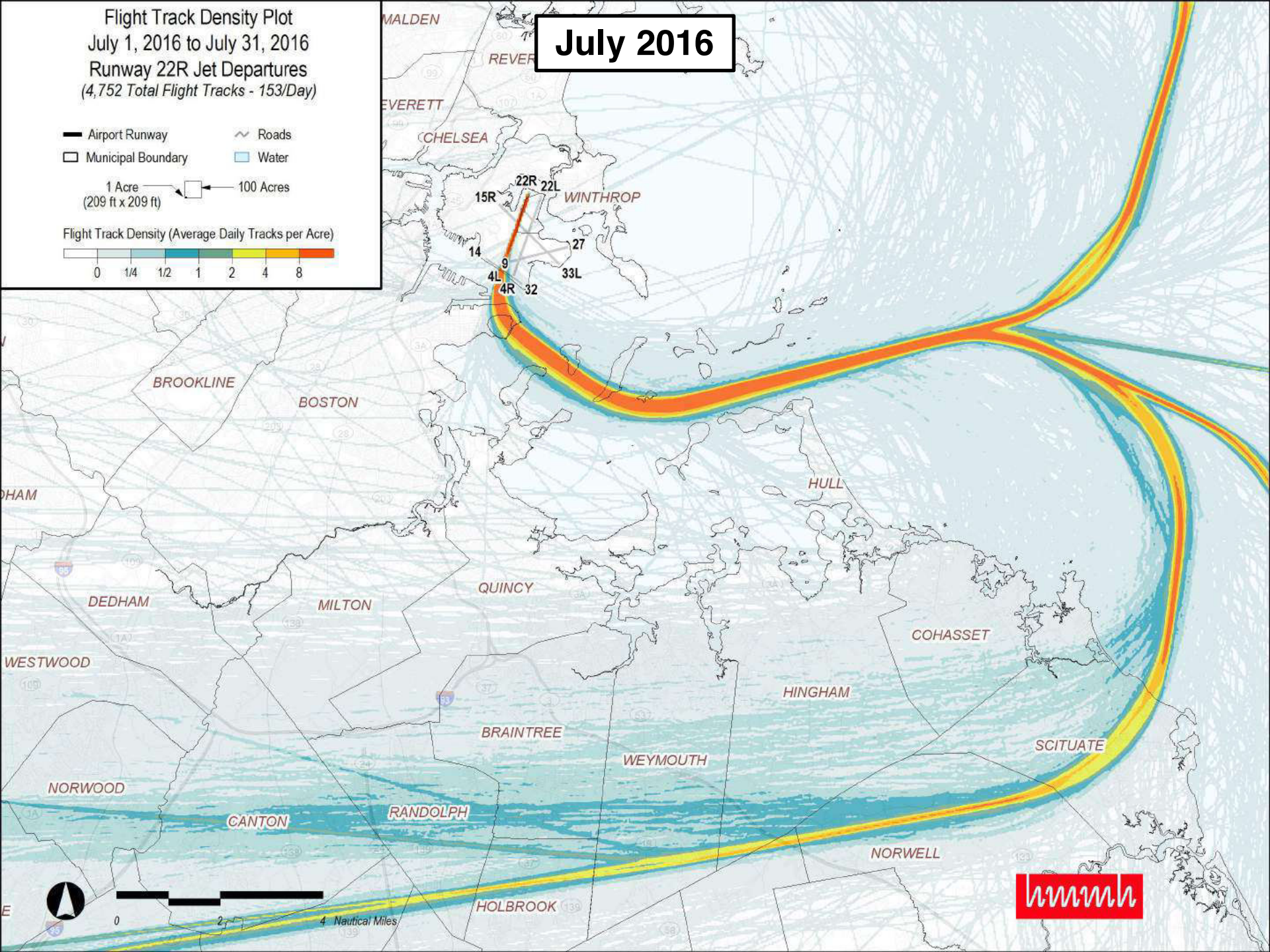

2010
Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 27 Jet Departures
(14,681 Total Flight Tracks - 40/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BEDFORD
BURLINGTON
WOBURN
STONEHAM
SAUGUS
MELROSE
WINCHESTER
LEXINGTON
MEDFORD
MALDEN
LINCOLN
ARLINGTON
REVERE
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WINTHROP
WATERTOWN
CAMBRIDGE
WESTON
NEWTON
BROOKLINE
BOSTON
WELLESLEY
NEEDHAM
DEDHAM
MILTON
QUINCY
HULL
COHASSET
DOVER
WESTWOOD
BRAINTREE
22R
22L
15R
27
14
9
4L
4R
32
33L
0
2
4 Nautical Miles

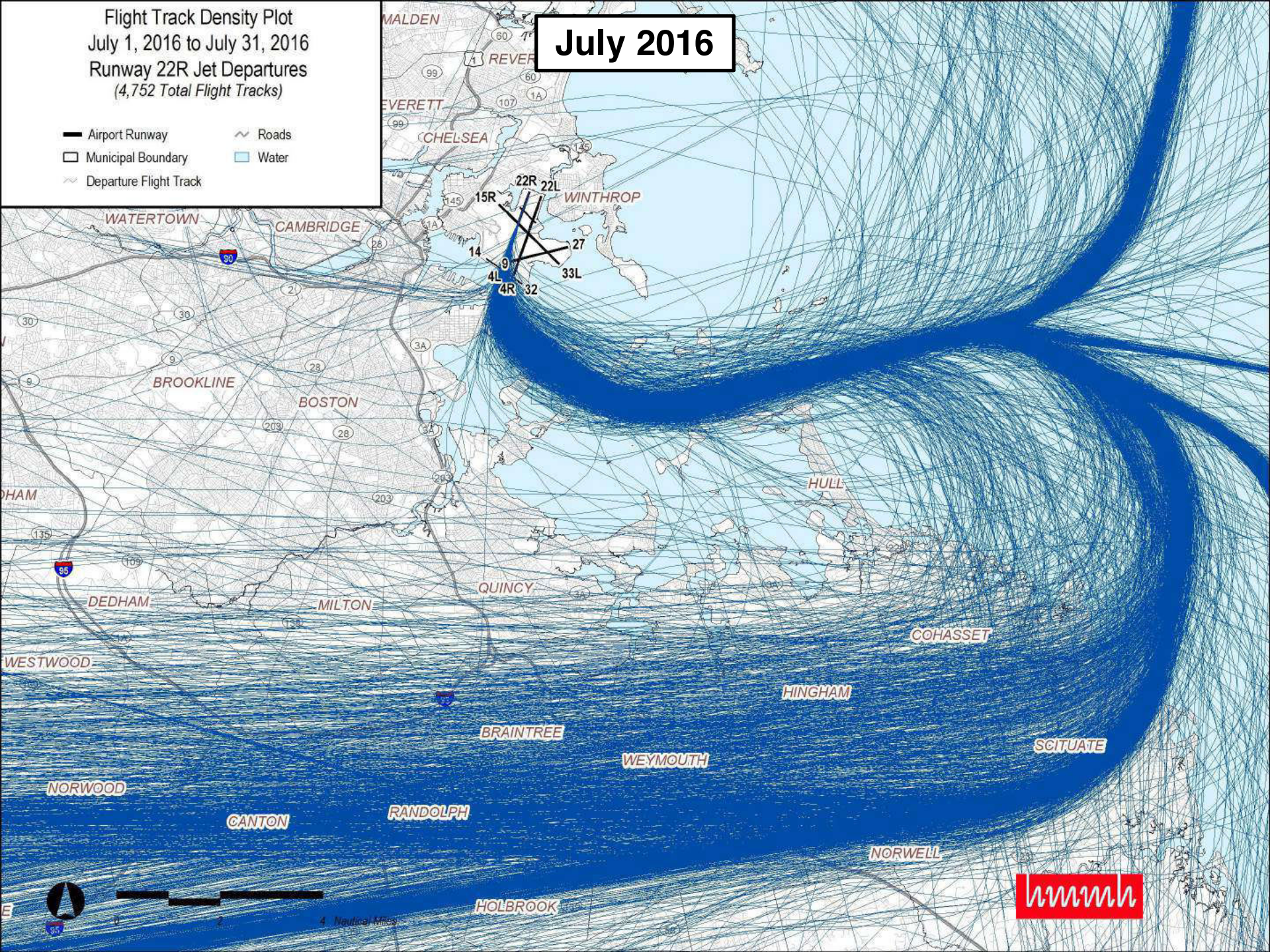

2015
Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 27 Jet Departures
(19,090 Total Flight Tracks - 52/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BEDFORD
BURLINGTON
WOBURN
STONEHAM
SAUGUS
MELROSE
WINCHESTER
LEXINGTON
MEDFORD
MALDEN
LINCOLN
ARLINGTON
REVERE
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WINTHROP
WATERTOWN
CAMBRIDGE
WESTON
NEWTON
BROOKLINE
BOSTON
WELLESLEY
NEEDHAM
HULL
DEDHAM
MILTON
QUINCY
DOVER
WESTWOOD
COHASSET
BRAINTREE
15R
22R
22L
14
9
27
33L
4L
4R
32
0
2
4 Nautical Miles


2010
Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 33L Jet Departures
(25,046 Total Flight Tracks - 69/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BURLINGTON
WAKEFIELD
WOBURN
STONEHAM
SAUGUS
LYNN
SWAMPSCO
WINCHESTER
MELROSE
LEXINGTON
MEDFORD
MALDEN
ARLINGTON
REVERE
NAHANT
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
22R
22L
15R
WINTHROP
WATERTOWN
CAMBRIDGE
27
14
9
33L
4L
4R
32
NEWTON
BROOKLINE
BOSTON
HULL
NEEDHAM
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
0
2
4 Nautical Miles
BRAINTREE

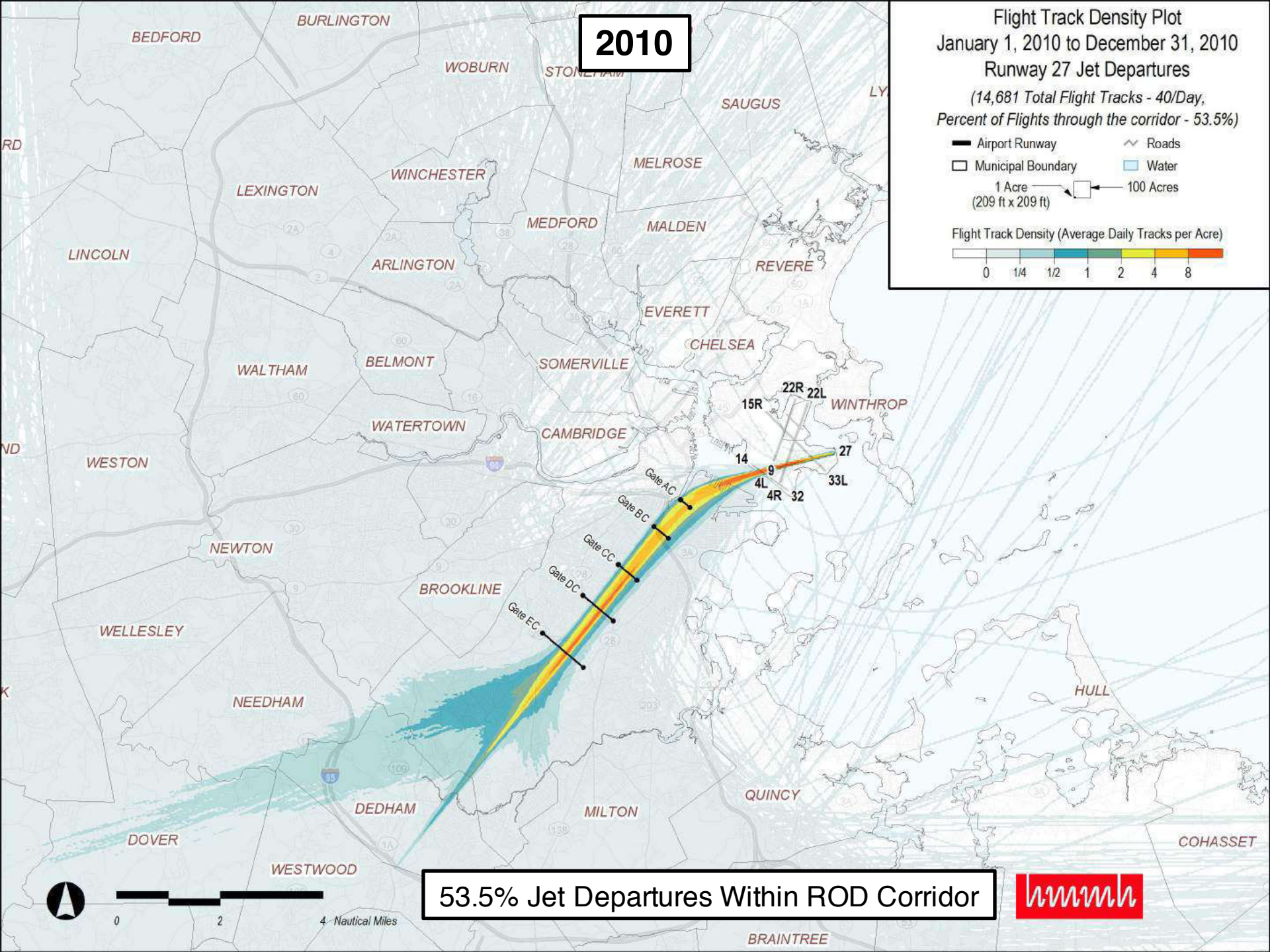

2015
Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 33L Jet Departures
(8,348 Total Flight Tracks - 23/Day)
Airport Runway
Municipal Boundary
Roads
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BURLINGTON
WAKEFIELD
WOBURN
STONEHAM
SAUGUS
LYNN
SWAMPSCO
WINCHESTER
MELROSE
LEXINGTON
MEDFORD
MALDEN
ARLINGTON
REVERE
NAHANT
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
22R
22L
15R
WINTHROP
WATERTOWN
CAMBRIDGE
27
14
9
33L
4L
4R
32
NEWTON
BROOKLINE
BOSTON
HULL
NEEDHAM
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
0
2
4 Nautical Miles
BRAINTREE

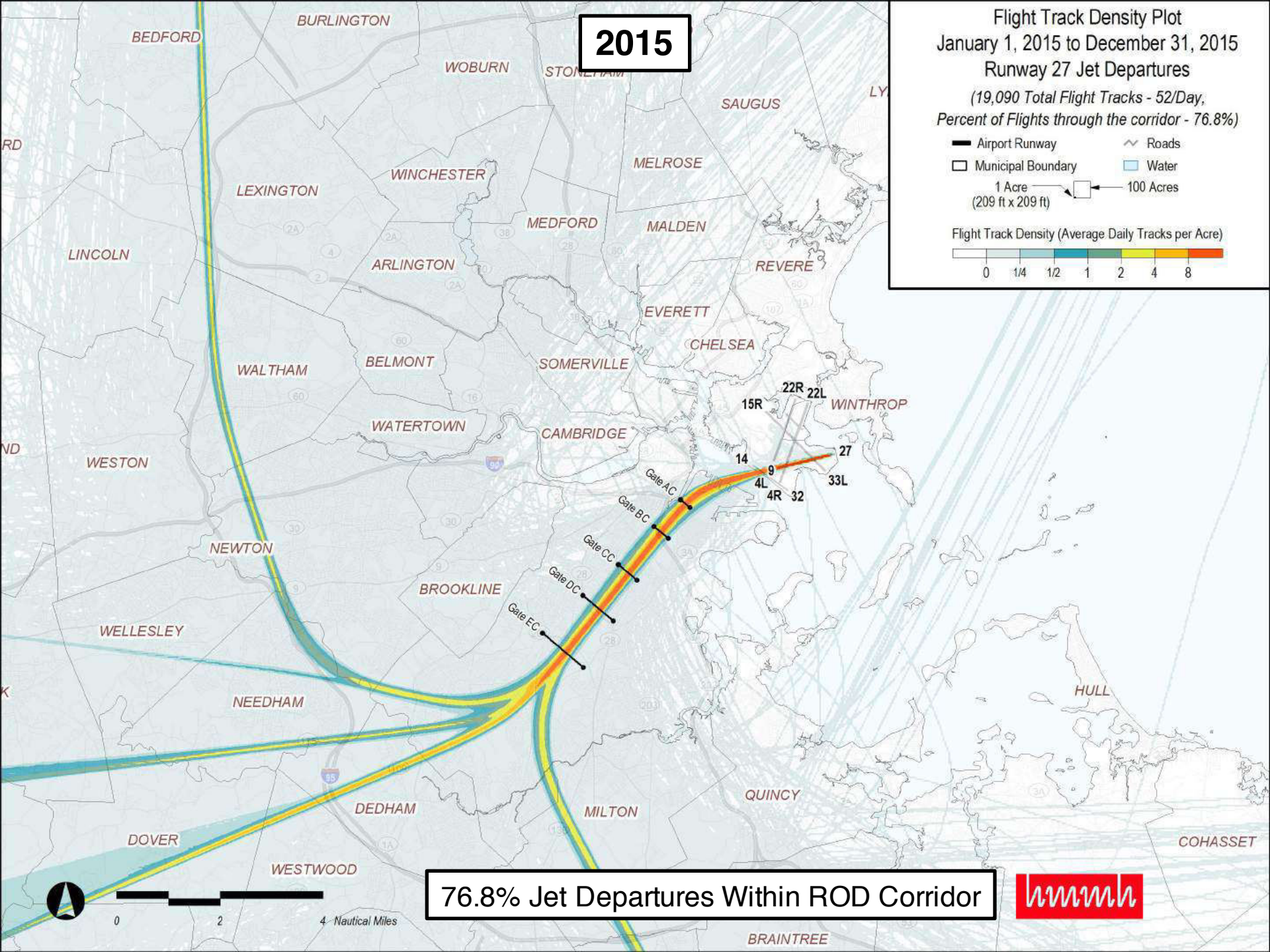
Addendum B: Quantified Track Density vs. Raw Track Plots


Flight Track Density Plot
July 1, 2016 to July 31, 2016
Runway 22R Jet Departures
(4,752 Total Flight Tracks - 153/Day)
Airport Runway
Roads
Municipal Boundary
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
July 2016
MALDEN
REVER
EVERETT
CHELSEA
22R
22L
15R
WINTHROP
14
27
9
33L
4L
4R
32
BROOKLINE
BOSTON
HULL
DEDHAM
MILTON
QUINCY
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
WEYMOUTH
SCITUATE
NORWOOD
CANTON
RANDOLPH
NORWELL
HOLBROOK
0
2
4 Nautical Miles


Flight Track Density Plot
July 1, 2016 to July 31, 2016
Runway 22R Jet Departures
(4,752 Total Flight Tracks)
Airport Runway
Municipal Boundary
Departure Flight Track
Roads
Water
July 2016
MALDEN
REVERE
EVERETT
CHELSEA
WINTHROP
WATERTOWN
CAMBRIDGE
BROOKLINE
BOSTON
HULL
QUINCY
DEDHAM
MILTON
COHASSET
WESTWOOD
HINGHAM
BRAINTREE
WEYMOUTH
SCITUATE
NORWOOD
CANTON
RANDOLPH
NORWELL
HOLBROOK
22R
22L
15R
27
14
9
33L
4L
4R
32
4 Nautical Miles

Addendum C: Runway 27 Flight Tracks with ROD Corridor


2010
Flight Track Density Plot
January 1, 2010 to December 31, 2010
Runway 27 Jet Departures
(14,681 Total Flight Tracks - 40/Day,
Percent of Flights through the corridor - 53.5%)
Airport Runway
Roads
Municipal Boundary
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BEDFORD
BURLINGTON
WOBURN
STONEHAM
SAUGUS
MELROSE
WINCHESTER
LEXINGTON
MEDFORD
MALDEN
LINCOLN
ARLINGTON
REVERE
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WINTHROP
WATERTOWN
CAMBRIDGE
WESTON
NEWTON
BROOKLINE
WELLESLEY
NEEDHAM
DEDHAM
MILTON
QUINCY
HULL
COHASSET
DOVER
WESTWOOD
BRAINTREE
22R
22L
15R
27
14
9
33L
4L
4R
32
Gate AC
Gate BC
Gate CC
Gate DC
Gate EC
0
2
4 Nautical Miles
53.5% Jet Departures Within ROD Corridor


2015
Flight Track Density Plot
January 1, 2015 to December 31, 2015
Runway 27 Jet Departures
(19,090 Total Flight Tracks - 52/Day,
Percent of Flights through the corridor - 76.8%)
Airport Runway
Roads
Municipal Boundary
Water
1 Acre
(209 ft x 209 ft)
100 Acres
Flight Track Density (Average Daily Tracks per Acre)
0
1/4
1/2
1
2
4
8
BEDFORD
BURLINGTON
WOBURN
STONEHAM
SAUGUS
LEXINGTON
WINCHESTER
MELROSE
MEDFORD
MALDEN
LINCOLN
ARLINGTON
REVERE
EVERETT
CHELSEA
WALTHAM
BELMONT
SOMERVILLE
WINTHROP
WATERTOWN
CAMBRIDGE
WESTON
NEWTON
BROOKLINE
WELLESLEY
NEEDHAM
DEDHAM
MILTON
QUINCY
HULL
DOVER
WESTWOOD
COHASSET
BRAINTREE
15R
22R
22L
14
9
27
33L
4L
4R
32
Gate AC
Gate BC
Gate CC
Gate DC
Gate EC
0
2
4 Nautical Miles
76.8% Jet Departures Within ROD Corridor