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Advanced Operational Procedure Design Concepts for Noise Abatement

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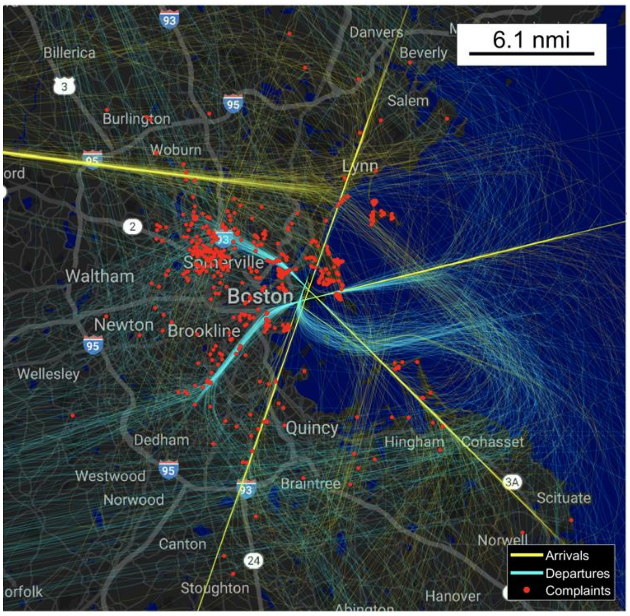
Performance based navigation has led to increased noise complaints due to the concentration of flight tracks. However, performance based navigation allows the opportunity to design advanced operational flight procedures for the purposes of noise abatement. A study of various advanced operational procedure concepts for noise abatement is presented. In this study, a framework is developed and applied for noise analysis of advanced operational procedures. Advanced operational procedures that have been designed for noise abatement include horizontal flight profile modifications, vertical flight profile modifications, and dispersed flight tracks. Metrics used to assess each type of procedure are also discussed.

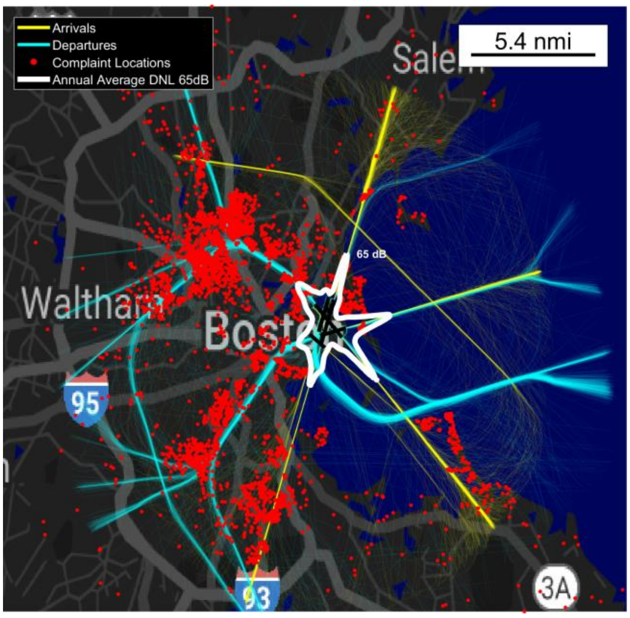
I. INTRODUCTION

Area navigation (RNAV) and Required Navigation Performance (RNP) are performance-based navigation (PBN) techniques which allow for more accurate navigation and have led to an increase of flight track density over many communities. PBN techniques have numerous benefits including allowing for more operational flexibility and precision during arrival and departure procedures. Following the implementation of these techniques and the subsequent concentration of flight paths, there has also been an increase of noise complaints in many communities surrounding airports in the United States. Figure 1 shows the concentration of flight paths following the introduction of RNAV at Boston Logan Airport (BOS). The concentration of flight tracks appears to correlate with an increase in noise complaints beneath those tracks.

The threshold for defining significant noise impact in United States policy is annual average DNL at 65dB [13]. As shown in Figure 1(b), annual average DNL at 65dB only represents 1.2% of the complaint locations at BOS, represented in the white contour. Therefore, metrics which better represent the impact of frequent overflights will be investigated in this study.



(a) 2010



(b) 2017 with annual average DNL 65dB contour

Figure 1. Arrival and Departure Flight Paths and Noise Complaints at BOS in 2010 and 2017

A framework for assessing the noise impacts of proposed advanced operational approach and departure procedures was developed under the Federal Aviation Administration (FAA) ASCENT Program. The framework provides the capability to estimate and compare impacts of current and proposed advanced operational procedures. Flight profile generation, noise modeling, and metrics used for single track and multiple track procedures are discussed. Concepts for noise abatement procedures will then be presented using Boston Logan Airport as an example to illustrate the framework and associated results.

Examples of several procedure types are presented that take advantage of PBN techniques for noise abatement. Horizontal flight profile modifications were examined to assess potential noise benefits afforded by increased horizontal track flexibility from RNAV and RNP on approach. Potential vertical profile changes are enabled by the precisely-defined path lengths for RNP procedures, which may, for example, reduce the need for level off segments traditionally used to handle path length uncertainty. Furthermore, the precision and flexibility of PBN may also provide mechanisms to reduce the concentration of overflights that resulted from increased navigational precision seen after the implementation of RNAV. Dispersed flight track procedures are therefore also examined.

II. Methodology

A. Noise Analysis Tools

The framework to assess the community noise impacts of advanced operational approach and departure procedures is diagramed in Figure 2. It consists of aircraft performance models, flight profile generation models, and aircraft noise models. Aircraft noise is modeled in this framework as a function of the aircraft performance and flight procedure. Single-event noise grids are then output for noise exposure assessments.

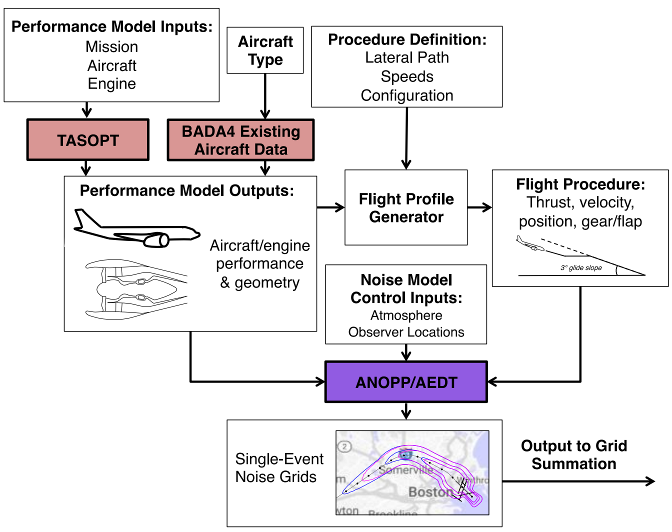


Figure 2. Integrated Aircraft Performance, Flight Procedure, and Noise Analysis Process to Generate High Fidelity Approach and Departure Noise Estimates

Single event flyover noise for a given aircraft and flight procedure is generated via either the Aviation Environmental Design Tool (AEDT) [2] or the NASA Aircraft Noise Prediction Program (ANOPP) [3]. AEDT is the standard tool in the United States for impact assessments of community noise around airports. AEDT utilizes the Noise-Power-Distance (NPD) method to make noise estimates, where community noise is correlated empirically to approach and departure flight test data as functions of aircraft type, thrust, and distance from the aircraft source. This method is fast and reasonably accurate for procedures involving only thrust or lateral track shifts, and only requires the aircraft type from its database and the thrust and position during the flight procedure. However, the NPD curves do not capture the impacts of variations in aerodynamic noise contributions due to flight speed or configuration changes, because the curves are derived for a reference speed of 160 knots and have not been derived for varied speeds and configuration changes.

For procedure modifications that involve speed and configuration changes, the NASA ANOPP model is used. ANOPP is a semi-empirical model that computes aircraft noise at the component level, including noise sources due to the engine (fan, core, and jet) and airframe (trailing edge, flaps, slats, and gear). Throughout the flight procedure, these noise sources vary with the internal engine performance states, such as combustor exit temperature, as well as airframe states such as flap and gear configuration. Thus, these performance states as they vary with the thrust and velocity throughout the flight procedure are required as inputs for the NASA ANOPP model. Engine performance states are calculated using the Transport Aircraft System OPTimization (TASOPT) program [4], which is a physics-based model that jointly sizes and optimizes the airframe, engine, and flight mission of a “tube and wing” transport aircraft. Engine sizing in this program is a work-balance-based, engine component matching formulation that sizes an engine for design conditions and then provides engine state maps for off-design thrusts and flight speeds. The airframe geometry is also sized in this method based on aerodynamic and structural requirements and for existing aircraft can be verified from publicly available aircraft performance and geometry data [5] [6]. TASOPT also enables the sizing and analysis of future or modified aircraft, if desired. ANOPP then provides component level noise estimates based on the thrust, velocity, configuration, position, and altitude changes in a flight profile. Use of these performance and noise tools has been validated against Federal Aviation Administration noise certification data [7].

For procedures mainly involving lateral track adjustments or where changes in noise due to velocity or configuration are not likely to have a substantial noise impact, AEDT is the model used to compute community noise in the framework shown in Figure 2 for its computational speed. For procedures involving speed and configuration changes, ANOPP is used in place of AEDT.

B. Profile Generation

Community noise exposure analysis requires the detailed thrust, velocity, configuration, and altitude profiles of the approach or departure procedure of interest. Both ANOPP and AEDT require a detailed flight profile definition, which is computed by the Flight Profile Generator shown in framework in Figure 2. Based on a given arrival or departure procedure definition, such as a continuous descent or low thrust takeoff, the Flight Profile Generator computes the vertical flight profile, or the required thrust, velocity, and glideslope, with a point mass model that satisfies the weight, drag performance, and configuration speed limitations of a given aircraft. These flight performance characteristics are provided by Eurocontrol's Base of Aircraft Data (BADA 4) [8], a database of aircraft performance parameters from aircraft manufacturers, in this framework.

Given a procedure definition, the vertical profiles of a flight procedure are modeled on a segment-by-segment basis. Given the flight performance characteristics from BADA 4, force-balance is used to determine either: the flight path angle given a thrust and velocity or acceleration constraint, the resulting acceleration or velocity from a flight path angle and thrust constraint, or the resulting thrust from a flight path angle and velocity or acceleration constraint.

An example of profile generation is shown Figure 3, where a departure procedure is defined such that the altitude versus position profile matches the mean altitude profile from a set of Airport Surface Detection Equipment, Model X (ASDEX) radar data. The required thrust that satisfies this altitude profile, as constrained by the aircraft weight, drag, and assumed velocity and configuration changes, is modeled during each segment. Slat and flap changes are assumed deployed or retracted where aircraft are flying within their allowable speed ranges, which are provided by BADA 4 for each configuration, whereas gear deployment or retraction are typically defined by set altitudes.

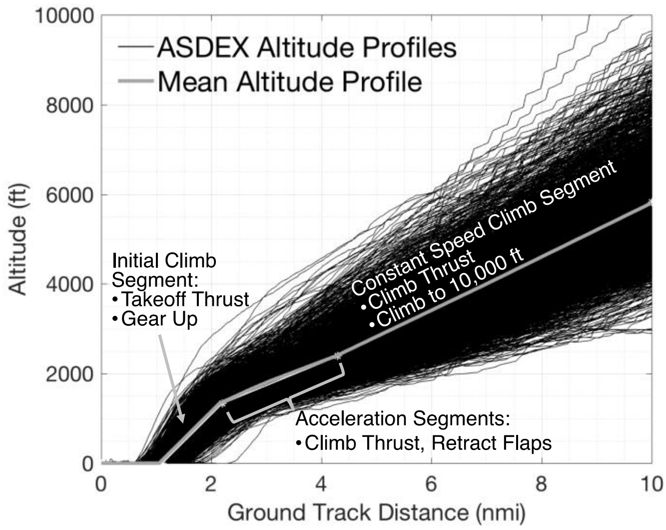


Figure 3. ASDEX Boeing 737-800 Radar Altitude Departure Data Over 20 Days in 2017 from All Runways at BOS

A similar example of profile generation for an approach is shown in Figure 4 and Figure 5, where an approach procedure is defined such that the altitude versus position profile matches the mean altitude profile and the velocity profile is defined to match the median velocity profile both from a set of ASDEX radar data.

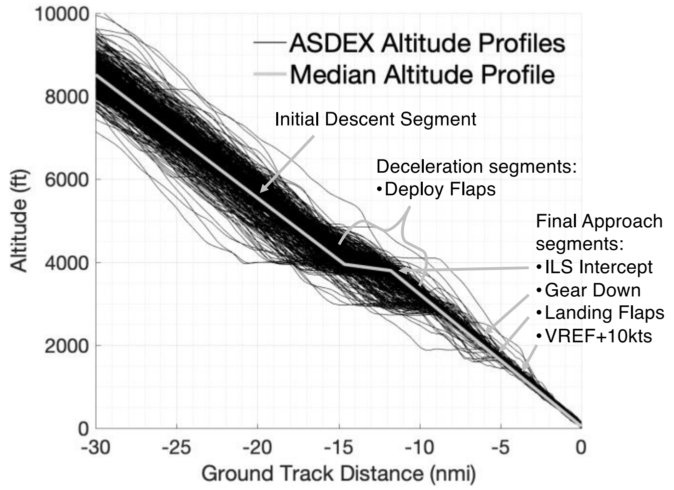


Figure 4. ASDEX Boeing 737-800 Radar Altitude Approach Data into Runway 4R at BOS in 2017

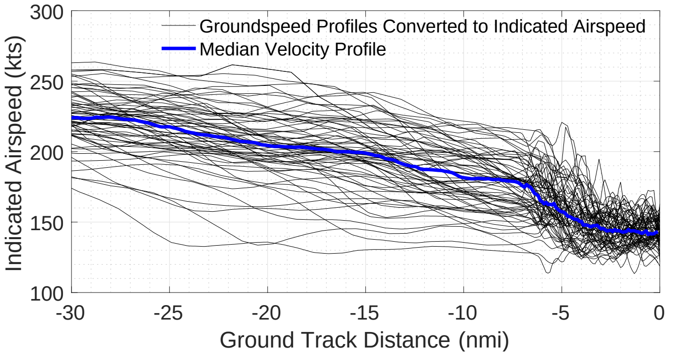


Figure 5. ASDEX Boeing 737-800 Radar Velocity Approach Data into Runway 4R at BOS in 2017

For all approaches and departures, the modeled two-dimensional altitude versus distance profiles are fit to the desired horizontal track to create the entire three-dimensional flight profile.

The horizontal flight path is another aspect of the profile generation. Modifications to the horizontal flight path can allow for noise abatement to specific noise sensitive communities. The criteria for procedure design are given in the US Standard for Terminal Information Procedures (TERPS) [9]. Relevant aspects of approach criteria design include fix-to-fix leg length, required obstacle clearance, final approach segment length and glide path angle [10]. RNP-Authorization Required (RNP-AR) technology allows for horizontal flight path designs that are less restrictive than RNAV flight path designs. RNAV technology allows for navigation between waypoints, while the less restrictive RNP-AR technology also allows for definition of the flight track between waypoints. Figure 6 illustrates some of the procedure design criteria that must be considered for RNAV and RNP procedures, where the RNAV final approach intercept angle must be 15º or less while RNP final approach angles may be as great as 90º.

The total equipage levels are also an important consideration for procedure design and air traffic considerations. Although RNP-AR procedures have advantages in flexibility of design, in the United States

National Air Space, only about 50% of the aircraft fleet are equipped with RNP-AR technology; while greater than 95% of the aircraft fleet are RNAV equipped [11]. Given the high RNAV equipage levels, designing RNAV procedures with RNP-AR overlays was desirable, however in some cases in this study it was necessary to design separate RNP-AR procedures in order to fully meet the desired noise benefits.

In developing horizontal flight tracks, input is first received from the communities. Horizontal flight tracks are then generated based on the community input and then noise analysis and initial feasibility analysis is performed. For the BOS specific procedures shown in section III, the FAA 7100.41A Performance Based Navigation Implementation Process [12] began once the procedure recommendations were given by the communities and MassPort.

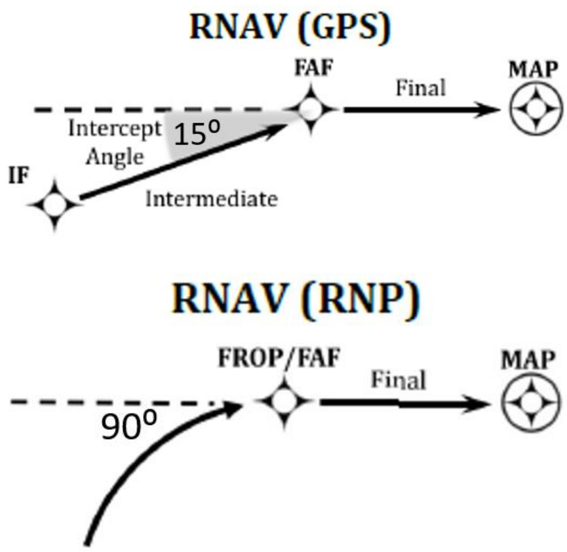


Figure 6. RNAV and RNP Procedure Turn to Final Design Criteria [10]

C. Noise Metrics and Population Data

In order to model community noise impacts, the single event flyover noise grids are coupled with a specific airport geometry and the surrounding population distribution. The grids can be rotated such that the lateral tracks of the associated noise outputs are aligned with the runways and can be summed for noise assessments of multiple flights. Rotated single event noise grids are overlaid with population data obtained from the 2010 Census on a consistent 0.1 nautical mile square grid. Population exposure to the noise due to a specific flight procedure or multiple procedures can then be obtained for the desired metric.

Metrics used in communicating analysis for single overflights include $L_{A,MAX}$ and sound exposure level (SEL). $L_{A,MAX}$ is the A-weighted maximum sound pressure level of an overflight. $L_{A,MAX}$ is fairly simple to understand as the maximum sound level and is frequently used in communicating noise analysis results. SEL accounts for both the duration of an overflight and the maximum sound level of an overflight and is also used in communicating noise analysis results [10].

Integrated exposure metrics considered include day-night average sound level (DNL) and N_x. DNL is a logarithmic value which averages the sound levels over a 24-hour time period. N_x is a count of the number of overflights above a defined $L_{A,MAX}$ threshold in a chosen time period. The chosen representative day significantly impacts the value of an integrated exposure metric. The representative days considered include peak day and annual average day.

Prior aircraft noise exposure analysis indicated that N_{60} on a peak day with 50 overflights is representative of the impact threshold of frequent overflights. This threshold captures at least 80% of complaint locations at BOS, Minneapolis Saint Paul (MSP), London Heathrow (LHR), and one runway at Charlotte Douglas (CLT) airport and is detailed extensively in Reference [14]. The notation N_{60} indicates that an overflight was counted if the $L_{A,MAX}$ exceeded 60 dB during the day or 50dB during the night. Figure 7 through Figure 10 provide examples of the analysis done to correlate noise metrics with the complaint locations data. N_{60} with 50 overflights on a peak day is the noise metric used in the noise impact analysis for dispersed flight tracks in this study.

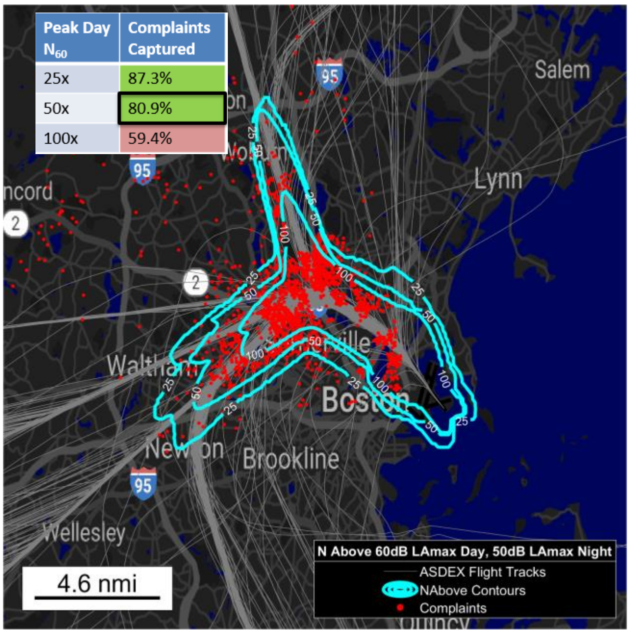


Figure 7. BOS 33L Departures Peak Day N_{60}

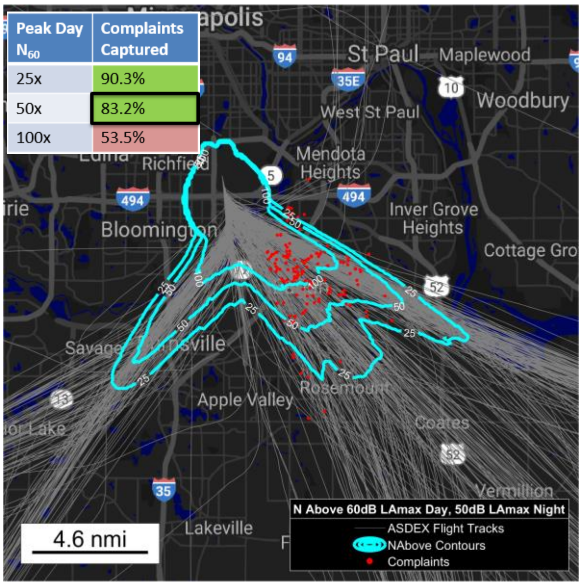


Figure 8. MSP 17 Departures Peak Day N_{60}

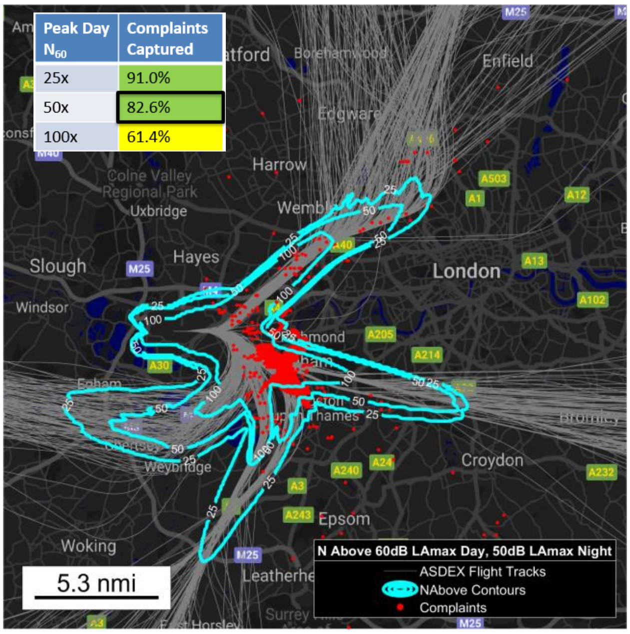


Figure 9. LHR 9R Departures Peak Day N_{60}

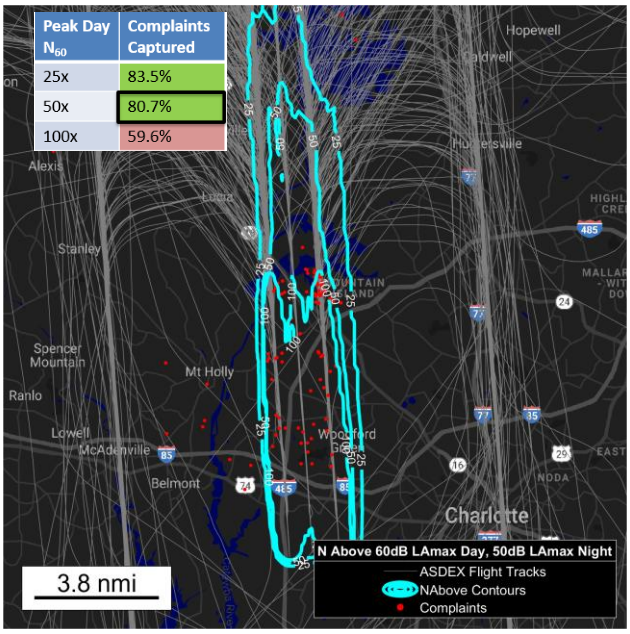


Figure 10. CLT 18L/C/R Arrivals Peak Day N_{60}

Population exposure is also reported to communicate the impact of specific noise contours. On the single event basis, the population exposure to 60dB $L_{A,MAX}$ is reported in the noise analysis. For integrated exposure metrics, the population exposure to N_{60} with 50 overflights on a peak day is reported. If a procedure is analyzed without consideration of a specific city and population data, then the areas of noise contours are compared.

III. Procedure Concepts and Results

Different approaches for noise abatement are considered including changes to horizontal procedure definitions as well as changes to how the aircraft are flown affecting the vertical flight profiles. Specific procedures at BOS will be discussed as examples of possible procedure concepts.

In the figures for single event metrics, the green dots represent population benefited, the red dots represent population disbenefited, and the white circles represent population with no change. Specifically, green dots are the cells in the 0.1nmi by 0.1nmi population grid that were within the impact threshold of 60dB $L_{A,MAX}$ during the day with the existing procedure, and then would no longer be in the impact threshold of 60dB $L_{A,max}$ during the day using the newly designed procedure. The red dots are the cells within the 0.1nmi by 0.1nmi population grid that were originally outside of the impact threshold of 60dB $L_{A,MAX}$ using the existing procedure, then would be inside of the impact threshold of 60dB $L_{A,MAX}$ during the day using the newly designed procedure. The white circles are the cells within the 0.1nmi by 0.1nmi population grid that are within the impact threshold of 60dB $L_{A,MAX}$ during the day using the existing procedure and also when using the newly designed procedure.

A. *Horizontal Flight Profile Modification*

Performance based navigation allows the opportunity for procedures that are designed to avoid overflying noise sensitive communities. An example procedure showing this is presented at BOS. Because BOS is near water, one method of providing noise abatement is overwater RNAV and RNP procedures.

An RNAV approach with an RNP overlay to runway 22L at BOS is shown in Figure 11. The straight-in approach is over large population areas while the PBN approach remains overwater as much as possible. The noise analysis is shown for a Boeing 737-800 since this is one of the most common aircraft in the national airspace. As represented by the green dots in Figure 12, more than 50,000 people, will benefit at the $L_{A,MAX}$ level of 60dB compared to the straight-in approach every time this procedure is used.

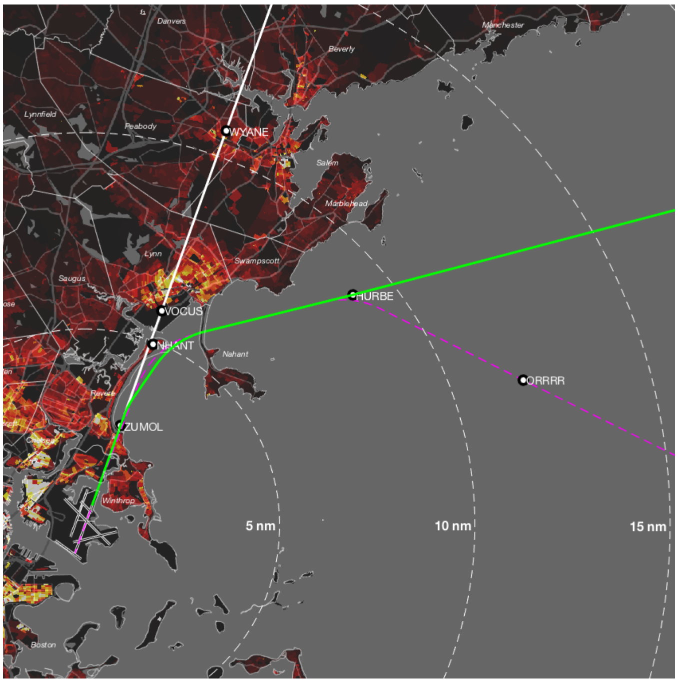


Figure 11. BOS 22L RNAV Approach with RNP Overlay

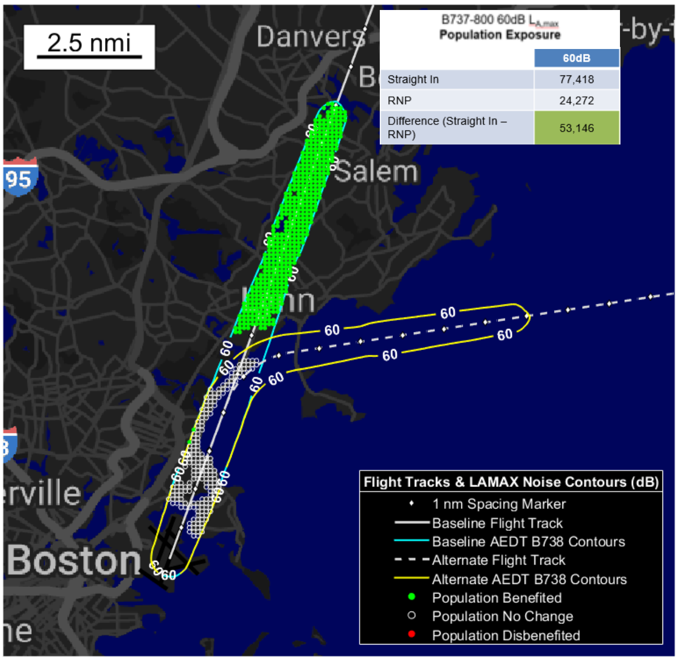


Figure 12. BOS 22L RNAV Approach with RNP Overlay Noise Benefits for Boeing 737-800

An example case where the full benefits of a procedure could not be achieved with RNAV technology, but could be achieved with RNP-AR technology, is the 33L arrival at BOS. The straight-in procedure overflies a peninsula with a noise sensitive community, as shown in Figure 11. The intended purpose of a PBN approach was to avoid overflying the noise sensitive community. However, due to RNAV approach design criteria, the RNAV approach was not able to fully meet the intended purpose and was closer to the noise sensitive community than desired. Therefore, an RNP approach, which allows for more flexibility in approach design, was also designed and does meet the intended noise abatement purposes. The RNP approach is also able to be used simultaneously with the RNAV approach. In Figure 13, the noise sensitive community is noted in red, the straight in approach is shown in yellow, the RNAV approach is shown in green, and the RNP approach is shown in blue.

The noise benefits and the population exposure reduction of the horizontal flight profile modification for a Boeing 737-800 comparing the RNAV procedure and the straight in procedure are shown in Figure 14. Figure 15 shows the noise benefits and the population exposure reduction of a horizontal flight profile modification of a Boeing 737-800 comparing the RNP procedure and the straight in procedure. In Figure 14 and Figure 15, the dots shown in green represent the population that receives a noise benefit at the $L_{A,MAX}$ level of 60dB from the newly designed advanced operational procedure. Consultations with airline operators have indicated that despite a procedure being within TERPS criteria, the airlines may still have concerns about flyability, e.g. regarding the point when the wings are level or regarding the final approach segment length.

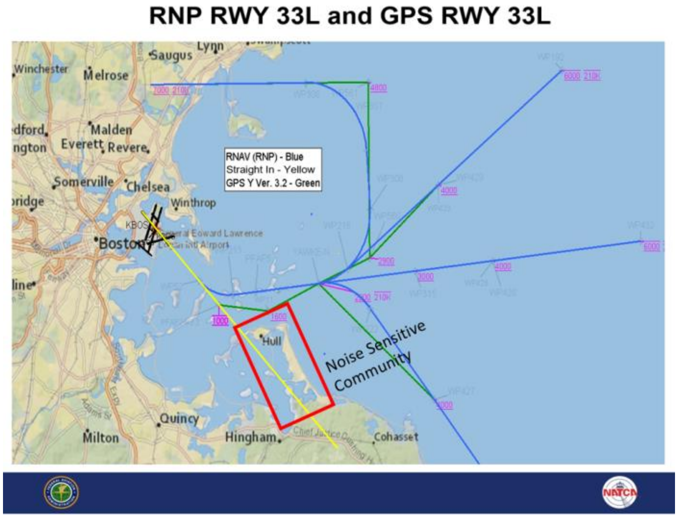


Figure 13. Overwater RNAV and RNP Approach from Ref. [15]

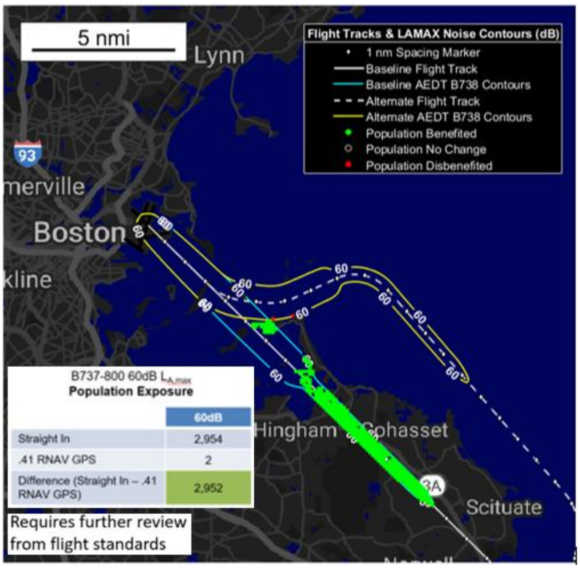


Figure 14. Horizontal Profile Modification RNAV GPS Noise Benefits for Boeing 737-800

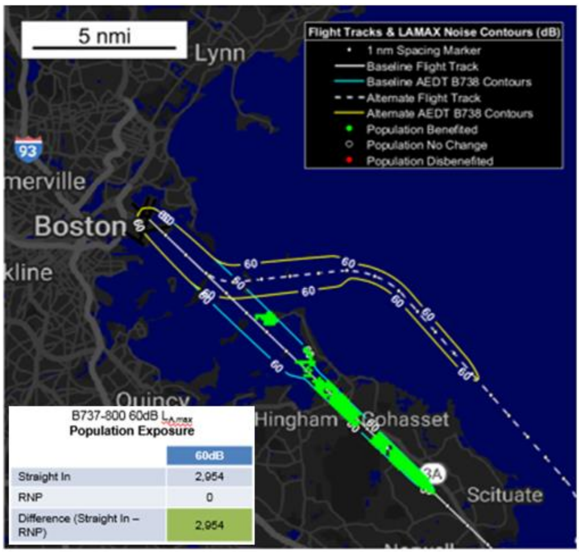


Figure 15. Horizontal Profile Modification RNAV RNP Noise Benefits for Boeing 737-800

The design of both an RNAV GPS procedure and an RNP procedure that are similar is also of note. The RNAV and RNP procedures are designed with similar path lengths and a common initial segment to allow for simultaneous use with minimal Air Traffic Control (ATC) workload. In situations with mixed equipage, air traffic workload would substantially increase without the use of a sequencing tool. Being able to use the RNAV and RNP procedures simultaneously is highly important, since otherwise the default would be to return all aircraft to the straight in approach which would not provide any of the desired noise benefits.

B. *Vertical Flight Profile Modification*

In addition to horizontal flight profile modifications, vertical flight profile modifications present other opportunities for noise reduction. One example vertical flight profile modification is a delayed deceleration approach, shown in *Figure 16*.

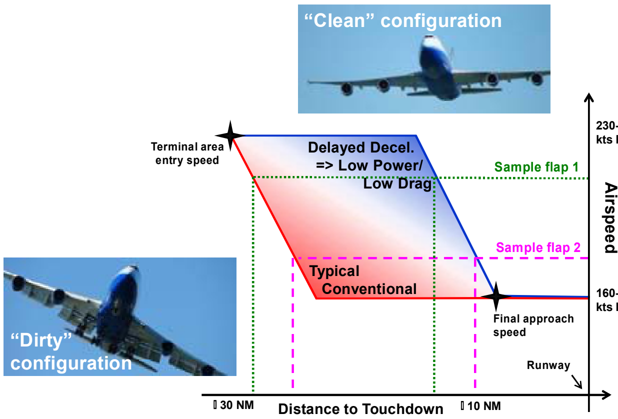


Figure 16. Delayed Deceleration Approach Concept from Ref. [16]

Compared to a standard approach, where aircraft decelerate and deploy flaps and slats early and maintain required thrust through these segments, in delayed deceleration approaches the aircraft maintains the initial approach speed for a longer distance to touchdown and thus delays configuration deployment. Prior analyses have shown that the reduced flight time and thrust during this procedure yields significant reductions in fuel burn [16]. The reduced thrust and delaying of configuration deployment also have the potential for noise reduction.

The noise impacts of this procedure were modeled for a Boeing 737-800 performing a standard ILS approach with a 4000 ft level segment prior to the glideslope intercept, such as the median altitude profile shown in Figure 4. The velocity profile representing a standard deceleration was assumed to be the median velocity profile of Boeing 737-800 aircraft shown in Figure 5. Flaps were assumed deployed once the aircraft decelerated below the maximum slat and flap speeds for each configuration and gear was assumed released at 1,700 ft, which corresponded both to the final approach fix location for Runway 4R at BOS [17] as well as the start of the steep deceleration seen in the velocity profiles at 6 nautical miles to touchdown in Figure 5.

In the delayed deceleration case, the aircraft was assumed to fly at idle thrust and begin the deceleration from the initial approach velocity at the latest point such that it could decelerate to the same speed at the 1,700 ft altitude gear release location as in the standard deceleration approach. Thus, the locations of flap and slat deployment occurred later in the flight profile than in the standard case. A comparison of the profiles and modeled thrust for both the standard and delayed deceleration procedures is shown in Figure 17.

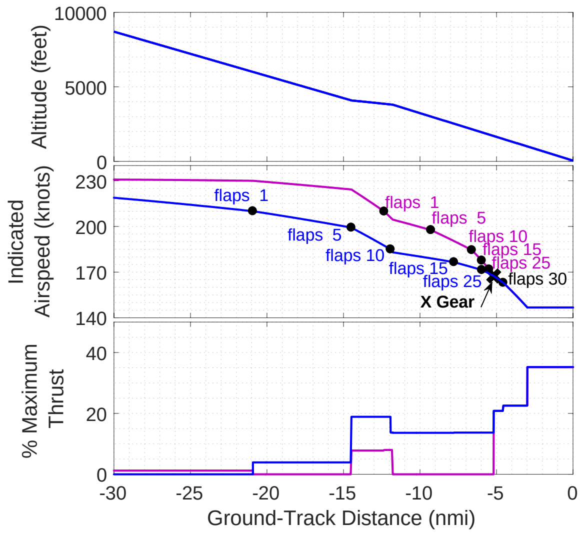


Figure 17. Comparison of Altitude, Velocity, and Thrust Profiles for a Boeing 737-800 Standard Deceleration and Delayed Deceleration Approach

Figure 18 shows the break out of noise modeled with ANOPP of various noise components under the flight track for the ILS approach described above with a standard deceleration. It can be seen that flap deployment contributes significantly to the overall sound level. Figure 19 shows a similar break out of noise but with the delay in the deceleration from the initial approach speed and thus a compressing of the configuration noise to closer to touchdown is apparent. Figure 20 which compares the total noise of these procedures shows a significant noise reduction under the flight track for the delayed deceleration approach compared to the standard.

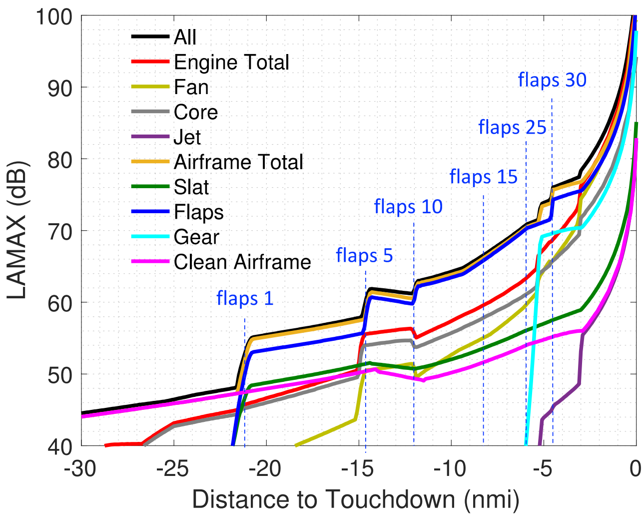


Figure 18. Noise Levels Under the Flight Track for Different Noise Components for a Standard Deceleration, Boeing 737-800 Approach

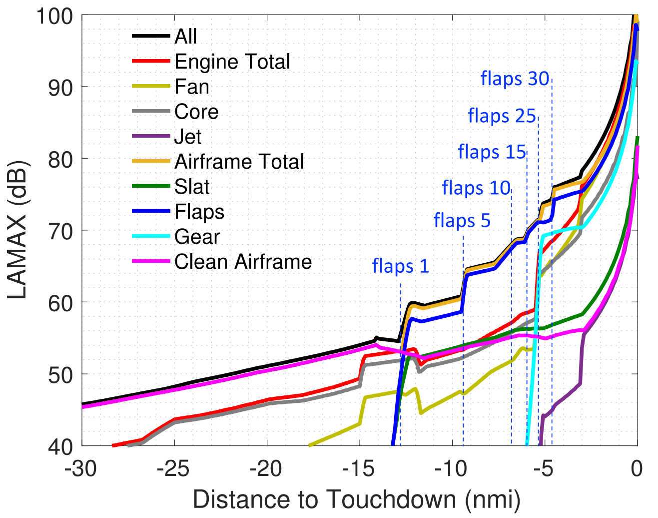


Figure 19. Noise Levels Under the Flight Track for Different Noise Components for a Delayed Deceleration, Boeing 737-800 Approach

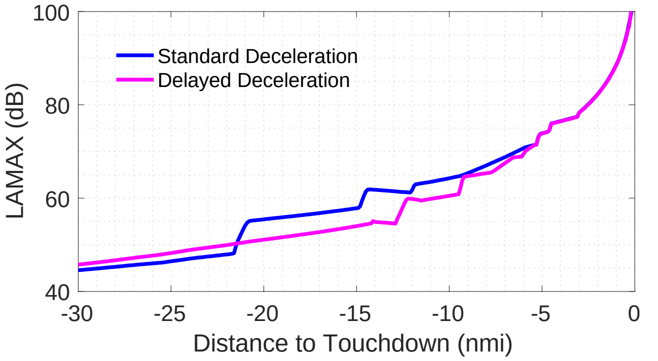


Figure 20. Comparison of Total Noise Levels Under the Flight Track for the Standard and Delayed Deceleration, Boeing 737-800 Approaches

The impacts of this procedure on population exposure are shown in Figure 21, which contains the $L_{A,MAX}$ contours for the standard deceleration, ILS approach compared to the delayed deceleration approach for the Boeing 737-800 on approach to Runway 4R at BOS. The dots shown in green represent the population that receives a noise benefit at the $L_{A,MAX}$ level of 60dB from the delayed deceleration approach. A 4 nautical mile retraction in the 60 dB $L_{A,MAX}$ contour can be seen for the delayed deceleration approach due to the delay in flap deployment. Population exposure at each of the 60 dB, 65 dB, and 70 dB $L_{A,MAX}$ noise levels for the delayed deceleration approach compared to the standard deceleration approach are shown in Table 1. Most of the population exposure reduction occurs at the 60 dB $L_{A,MAX}$ levels due to the delay in deployment of the first flap setting, though reductions are also seen at higher noise levels.

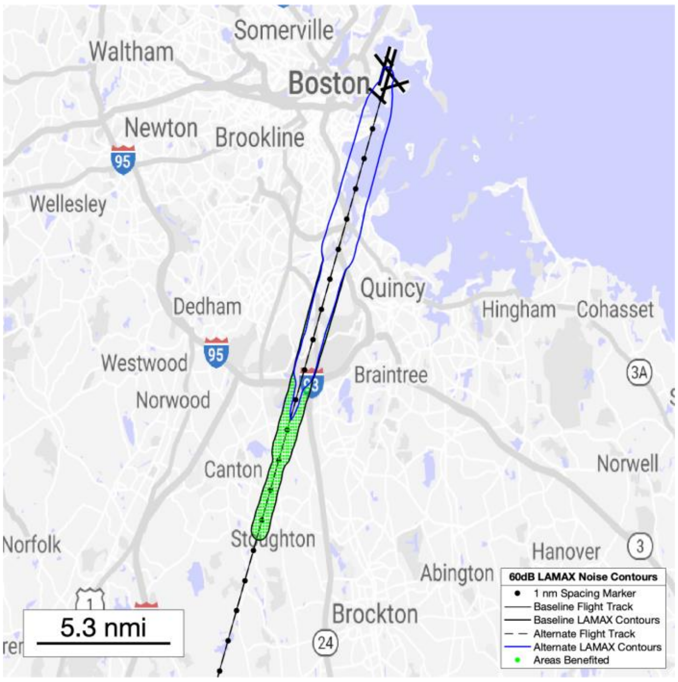


Figure 21. $L_{A,MAX}$ Contours For Boeing 737-800 Performing an ILS Approach with a 4000ft Level Segment Compared to a Delayed Deceleration Approach into BOS Runway 4R

Table 1. Population Exposure for Boeing 737-800 Performing an ILS Approach with a 4000ft Level Segment Compared a Delayed Deceleration Approach into BOS Runway 4R

	$L_{A,MAX}$ Level (dB)	60	65	70
Population Exposure	Standard Deceleration	37,621	14,912	4,936
	Delayed Deceleration	31,835	13,927	4,784
	Decrease	5,786	985	152

These results indicate a potential noise benefit for delaying configuration. Such procedures have many operational implications, as they would require careful assessments about the proper deceleration rates for different aircraft and wind conditions, as well as may lead to increases in air traffic controller workload.

C. Dispersed Flight Tracks

In many cases, the idea of returning to dispersed flight tracks similar to pre-RNAV conditions is politically attractive. However, the community noise impacts are complex due to redistribution issues, and also implementation of dispersion may be difficult for technical reasons. Thus, tools were developed for communities to understand the potential noise redistribution impacts.

In this study, the several dispersion concepts were considered including dispersion on arrivals and departures. Dispersion on arrivals was shown to have limited noise benefits due to the final intercept angle restriction on RNAV approach procedures. Altitude-based dispersion on departures and divergent heading dispersion on departures will be explained and discussed as examples of dispersion.

1) Methodology and Results Communication

The dispersion was modeled by looking at historical data for the flight tracks on the peak day of use for runway 33L at Boston. The radar data for the peak day flight tracks are represented as white lines in Figure 22 and Figure 24. The fleet mix and the transition waypoints of the aircraft are maintained in the modeling to match the peak day of runway 33L usage at Boston in 2017. In the dispersed flight track modeling, the aircraft were sent to the transition waypoints and/or assigned divergent headings based on the determined destination from the radar track analysis.

The aircraft types are also analyzed from the radar data and then sorted into representative aircraft categories. The representative aircraft categories are B773 representing twin aisle jets, B752, A320, B738, MD88 representing older jets, E170 representing large regional jets, and E145 representing small regional jets. This sorting is further described in references [18][19]. The vertical flight profiles are generated for each representative aircraft category as described in Section II.B.

The noise analysis is communicated by showing the population exposure to the impact threshold of N_{60} on a peak day with 50 overflights, as well as by communicating the change in N_{60} on a peak day. In Figure 23 and Figure 25 the warm-colored dots represent cells in the 0.1nmi by 0.1nmi population grid that receive an increase in the count of N_{60} overflights, and the cool-colored dots represent the cells in the population grid that receive a decrease in the count of N_{60} overflights.

2) Analysis

For procedures such as the 33L departures at BOS that have a change in heading to the desired final track, one way to introduce dispersion is altitude-based dispersion. In the dispersion modeling, the aircraft flight tracks are routed direct to the transition waypoint once reaching the chosen altitude of 3000ft. Because of the natural variability in aircraft climb rates, an example of which is shown in Figure 3, aircraft would reach the defined altitude at varying points along the ground and therefore be sent to the transition waypoint at different points thus introducing dispersion. The flight tracks for BOS 33L departures altitude-based dispersion at 3000ft are shown as magenta lines in Figure 22.

The noise analysis for the altitude-based dispersion at 3000ft for 33L departures at BOS is shown Figure 23. The people under the current RNAV tracks generally receive a decrease in N_{60} overflights after the implementation of dispersion; however dispersion would also lead to an increase in N_{60} overflights for people under the newly dispersed flight tracks. The overall number of people exposed to the impact threshold of N_{60} with 50 overflights on a peak day would increase due to dispersed flight tracks over population dense areas in this dispersion concept.

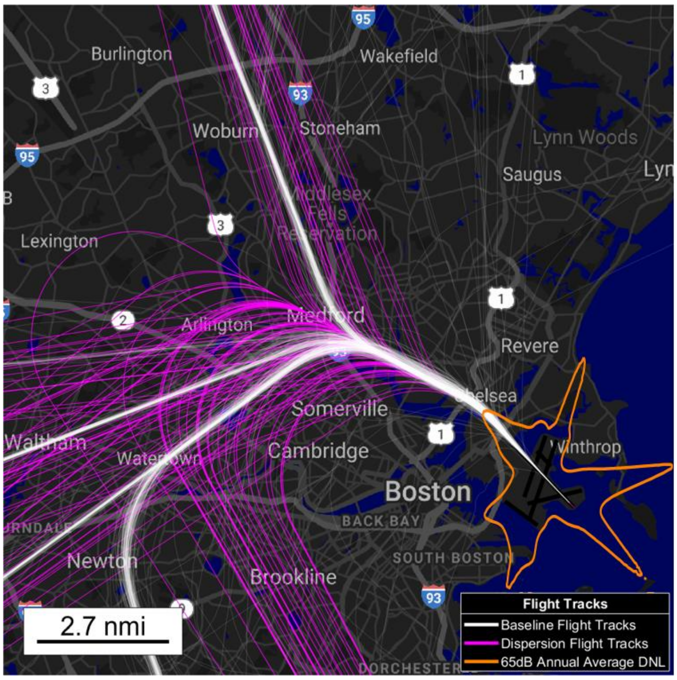


Figure 22. BOS 33L Departures Altitude-Based Dispersion at 3000ft Flight Tracks

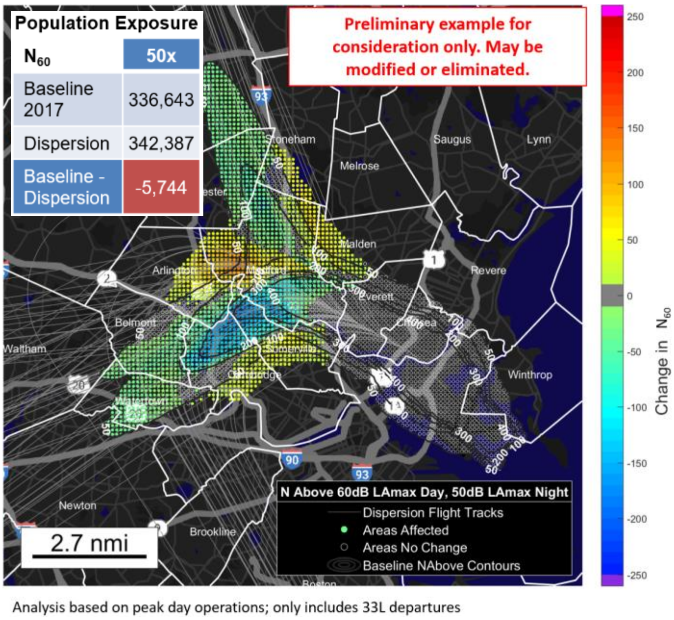


Figure 23. BOS 33L Departures Altitude-Based Dispersion at 3000ft Example Noise Analysis

Another approach would be to do programmed divergent headings of 15º or greater depending on the trajectory. Air traffic controllers expressed concern about path length variability with dispersion and not knowing which aircraft would follow thus making maintaining separation requirements difficult. Air traffic controllers also suggested that divergent headings could be assigned by the tower who does know which aircraft will follow. 15º or greater divergent headings could be assigned based on the aircraft destination and the divergent headings would also help to maintain separation requirements. In the divergent heading dispersion modeling, the aircraft are sent to the transition waypoint upon reaching 3000ft altitude, however the divergent headings help to maintain the separation requirements. The flight track modeling for 33L departures divergent heading dispersion is shown in Figure 24 where the dispersion flight tracks are shown as magenta lines.

The noise analysis for divergent heading dispersion on 33L departures at BOS is shown in Figure 25. The population grid cells under the current RNAV tracks generally receive a reduction in number of N_{60} overflights, as great as a reduction of 200 overflights; however the people under the divergent heading tracks are newly exposed to N_{60} overflights. In this example of divergent heading dispersion the overall population expose to the impact threshold of N_{60} on a peak day with 50 overflights decreases because the divergent heading tracks are over areas of lower population density.

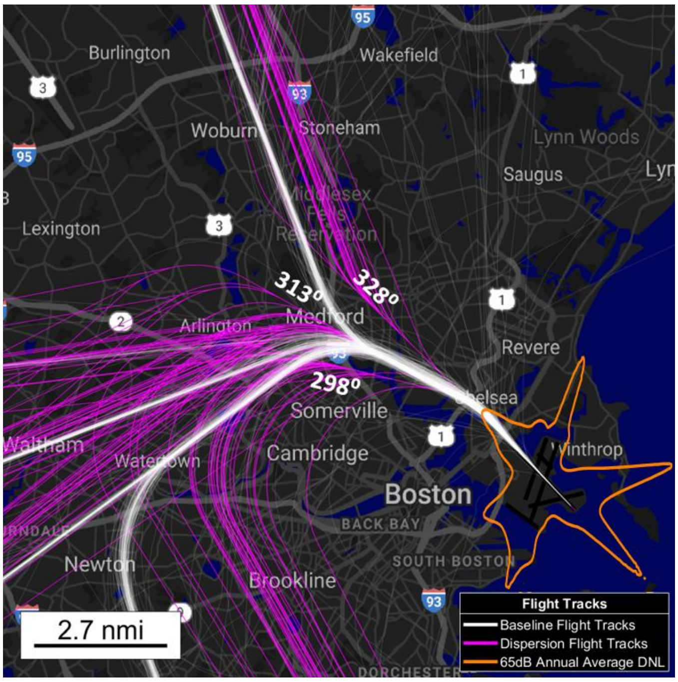
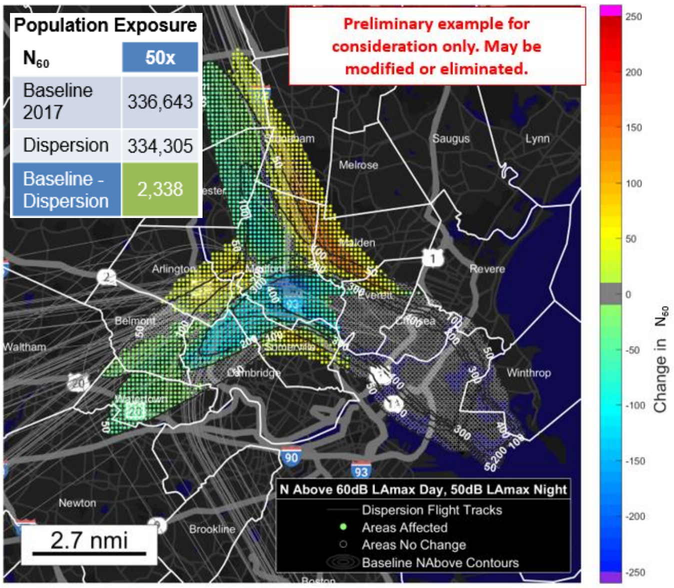


Figure 24. BOS 33L Departures Divergent Heading Dispersion Flight Tracks



Analysis based on peak day operations; only includes 33L departures

Figure 25. BOS 33L Departures Divergent Heading Dispersion Example Noise Analysis

While the technical team can provide the analysis for the aggregate population impact, the communities will need a negotiation process for deciding whether or not to pursue dispersion concepts. These tools are developed to allow communities to understand the procedures and to support the negotiation process. The dispersion analysis is communicated to the stakeholders visually by showing changes in the number of overflights if dispersion was implemented compared to the 2017 peak day. The analysis is also communicated to the stakeholders quantitatively by providing the population exposure to the impact threshold of 50 overflights at the N_{60} level.

IV. Conclusion

Methods to assess potential modifications to current departure and approach procedures were developed. Noise concerns by several communities around airports such as Boston Logan Airport (BOS) were taken into consideration when assessing potential modifications to operational procedures. These noise concerns present an opportunity to search how to modify existing procedures to reduce noise impacts on communities. However, it is key to clearly communicate expected impacts of procedure modifications to all communities. A framework was developed to allow for noise analysis of advanced operational procedures. Single event noise metrics such as $L_{A,MAX}$ and SEL were used for noise impact assessments of single-track procedure modifications. N_{60} with 50 overflights on a peak day was used as an integrated exposure metric for the noise impact assessment of multiple flight track modifications rather than the standard noise metric of annual average DNL 65dB. Potential noise reductions were then analyzed for the following modifications in operational procedures: Horizontal Flight Profile Modification (ex. shown for 22L and 33L at BOS), Vertical Flight Profile Modification (ex. shown for 4R at BOS), and Dispersed Flight Tracks (ex. altitude-based dispersion and divergent heading dispersion).

As shown in this paper, several possible noise-reducing modifications could be implemented but discussion with key stakeholders (e.g. communities, air traffic controllers, FAA, pilots, etc) is key to understanding if the modifications are flyable and acceptable to all parties. With increasing concern about noise in communities surrounding airports, some of the methodologies developed through this research and described in this paper could be utilized to reduce noise levels over communities.

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