U.S. Department
of Transportation
Federal Aviation
Administration

Enhanced Noise Abatement Climb Final Report

Continuous Lower Energy, Emissions and Noise (CLEEN) Program

Submitted by General Electric

DOT/FAA/AEE/2014-05

The Continuous Lower Energy, Emissions and Noise (CLEEN) Program is a Federal Aviation Administration NextGen effort to accelerate development of environmentally promising aircraft technologies and sustainable alternative fuels. The CLEEN Program is managed by the FAA's Office of Environment and Energy.

The report presented herein is the final report deliverable submitted by General Electric for a project conducted under the CLEEN Program to develop FMS (Flight Management System) algorithms to enhance noise abatement climb procedures. This project was conducted under FAA other transaction agreement (OTA) DTFAWA-10-C-00046. This is report is report number DOT/FAA/AEE/2014-05 by the FAA's Office of Environment and Energy.

CLEEN
Enhanced Noise Abatement Climb Procedure
Benefits Analysis

Prepared by:

GE Aviation Systems LLC
3290 Patterson Avenue, SE, Grand Rapids, MI 49512-1991, USA

Table of Contents

Table of Figures

1 Summary

An enhanced procedure for climb noise abatement utilizing both an altitude- and location-based method to reduce noise surrounding airports while maximizing climb thrust was analyzed. Increased climb thrust allows an aircraft to reach cruise altitude earlier resulting in decreased fuel usage due to operation at higher altitudes. Several general takeoff/climb trajectories using various altitude and location noise reduction methods are compared from both a fuel and noise perspective.

Overall, the analysis found that using more advanced noise abatement departure procedures resulted in an average fuel savings of ~60 pounds per flight while having little to no negative effects on the noise profile for the majority of the test scenarios.

2 Introduction

Noise levels surrounding airports present a unique problem for both the communities surrounding the airport and the airline operators. The communities would like to see a reduction in noise while the airline operators want to climb out more quickly to take advantage of greater efficiencies realized at higher altitudes. Current methods for reducing noise employ an altitude-based scheme where the thrust is changed from takeoff to a reduced climb setting once the aircraft climbs above a predetermined altitude. The throttles are then returned to the normal climb thrust setting once the aircraft climbs above a second, higher predetermined altitude. This method helps to reduce noise, but tends to penalize both light and heavy aircraft. The lighter aircraft potentially must reduce thrust earlier than necessary and heavy aircraft may keep the thrust reduced longer than necessary. In 2008, GE and Boeing partnered together to pursue an alternate noise reduction method using location as the driving factor for reducing thrust. This method improves on the altitude-based method by having all aircraft reduce thrust once the noise abatement area is reached regardless of altitude. Figure 1 shows the benefit realized by utilizing this method.

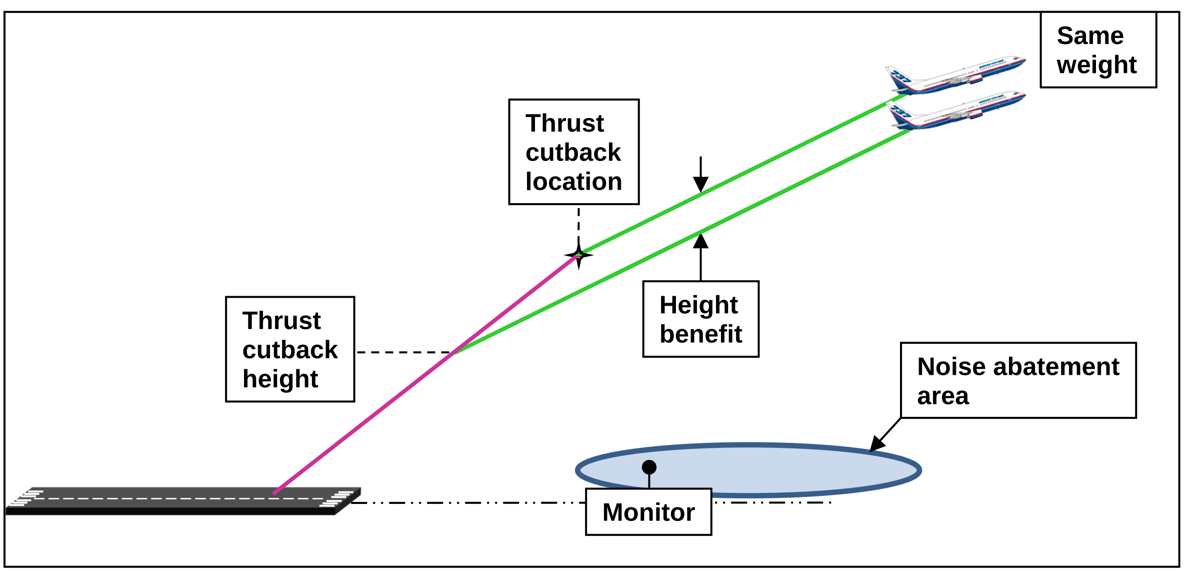

Figure 1 – Benefit of Location-Based Noise Abatement

However, the location-based thrust reduction method also has the shortcoming of the thrust potentially being reduced longer than necessary due to the aircraft having climbed significantly high above the noise abatement area. The method implemented for the CLEEN program incorporates both the altitude- and location-based methods into an integrated scheme where thrust is only reduced when necessary based on distance from the noise area both horizontally and vertically. These noise areas can be customized for particular airports and do not need to impact current departure routes. The intersection between an airlines planned departure and the specified noise area(s) serves as the criteria for noise abatement thrust settings.

3 Enhancements

3.1 Noise Abatement Locations and Altitudes

While methods for using either a set of altitudes or locations to determine thrust reduction and restore points have been explored previously, combining the two methods together to the least constraining factor produces a flexible solution that helps to both reduce noise and maximize climb performance resulting in decreased cruise fuel usage. Figure 2 illustrates how the application of altitude- and location-based thrust reduction affects several vertical flight profiles.

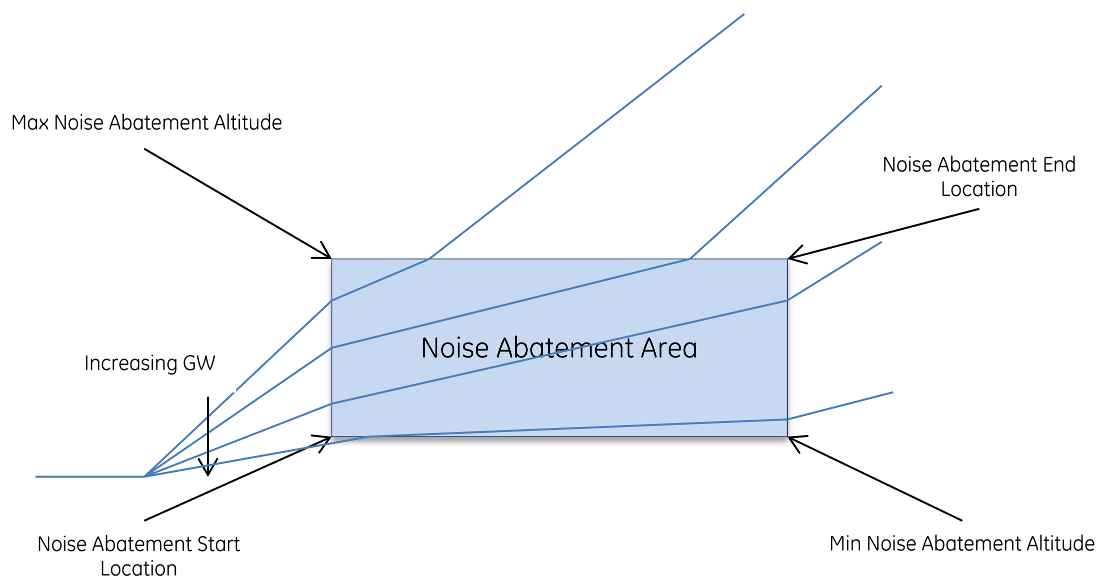

Figure 2 – Altitude- and Location-Based Quiet Climb

As seen in Figure 2, thrust is reduced from takeoff to a derated climb setting once both the minimum noise abatement altitude and the noise abatement start location are reached. A reduced thrust setting is maintained until either the maximum noise abatement altitude or the noise abatement end location is reached.

3.2 Required Noise Factor

In addition to specifying the start and end noise abatement locations, the 2008 demo included the ability to choose between a FAST or SLOW setting for applying normal climb thrust. The FAST (discrete) setting would reduce thrust immediately upon sequencing the noise start location, then reapply the normal climb setting upon exiting the noise area. The SLOW (ramped) setting would immediately reduce thrust upon entering the noise area with a subsequent linear ramping applied halfway through the noise area with normal climb thrust being achieved upon exiting the noise area. For CLEEN, this slewing method was retained. For the purposes of this analysis, all test scenarios were run with the FAST slewing method.

4 Interfaces

4.1 MCDU Pages

The TAKEOFF REF 2/2 page is where most of the noise abatement information is currently located. The display chosen for the 2008 demo was retained for CLEEN (Figure 3). The page displays either the noise altitude values (for altitude-only specified noise abatement) or the noise start and end location identifiers. The altitudes used for the noise- and altitude-based scenarios are located in the loadable performance defaults database.

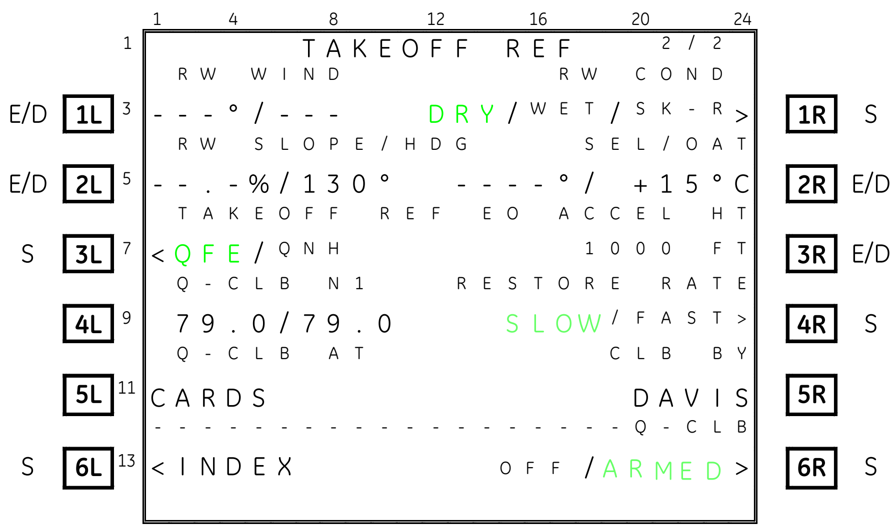

Figure 3 - MCDU

4.2 EFIS Display

Similar to the 2008 demo, the beginning (Q-CLB) and end (CLB) of the noise abatement procedure will be displayed on the path (Figure 4). However, the locations are based on improved takeoff predictions with the combination of the altitude and location criteria determining their placement.

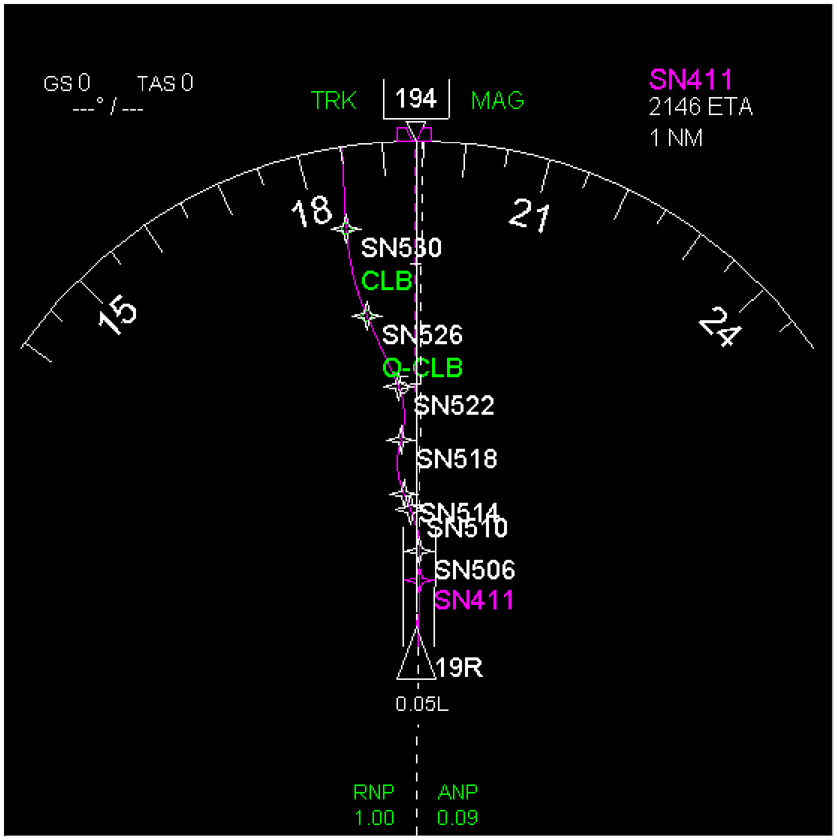

Figure 4 – EFIS Display

For most normal operations, the start location is the displayed Q-CLB point while the CLB point is either the end location or the predicted location where the aircraft climbs above the maximum noise abatement altitude.

The flight trajectories and fuel predictions were generated using a modified version of the GE Aviation Systems U11 Flight Management System designed for the Boeing 737 aircraft. These trajectories were then converted into the ASIF file format for use with the Aviation Environmental Design Tool (AEDT) 2a. The AEDT was then used to simulate the noise produced by the different flight scenarios.

5 Benefits Analysis

The benefits analysis was performed based on simulated takeoffs and climbs departing from John Wayne Airport (KSNA) runway 19R. Noise monitoring locations were simulated at the John Wayne Airport 1S through 7S (South) noise monitoring stations as seen in Figure 5. The flight trajectories and fuel predictions were generated using a modified version of the GE Aviation Systems U11 Flight Management System designed for the Boeing 737 aircraft. These trajectories were then converted into the ASIF file format for use with the Aviation Environmental Design Tool (AEDT) 2a. The AEDT was then used to simulate the noise produced by the different flight scenarios.

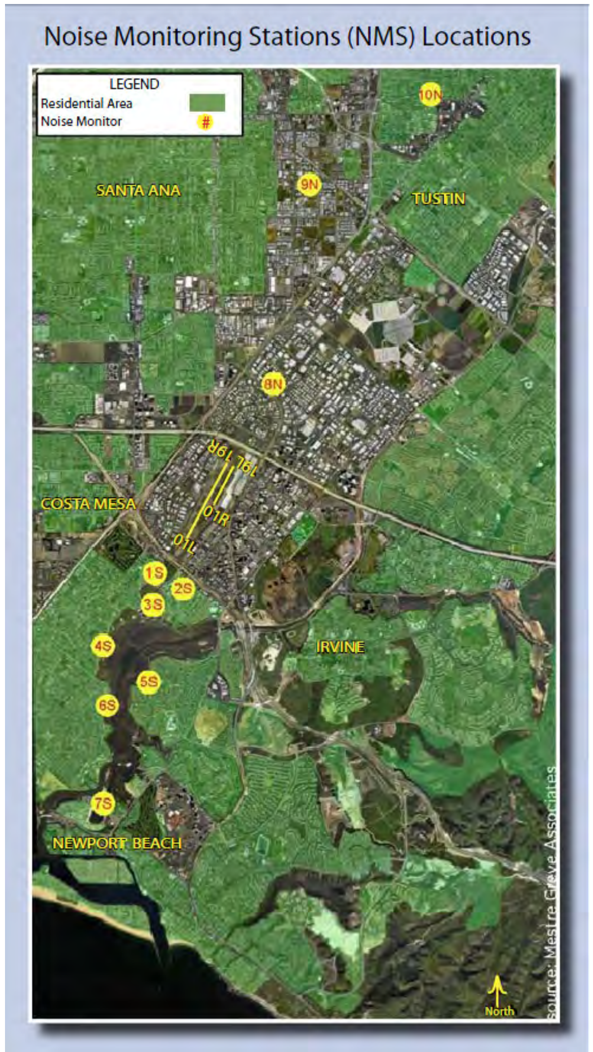

Figure 5 – Noise Monitoring Stations
http://www.ocair.com/generalaviation/noiseabatement/NMSMap-02-02-2012.pdf
Downloaded: 03/29/2012

This setup was then executed on the following 18 scenarios using the BAYMED departure procedure (Figure 6) with differing cutback and restore locations for different gross weights:

Case Description	Start Point	End Point	Gross Weight
No cutback or restore	NA	NA	130 klbs
			150 klbs
Early cutback – Late restore	SN506	SN530	130 klbs
			150 klbs
Early cutback – Early restore	SN510	SN522	130 klbs
			150 klbs
Late cutback – Late restore	SN522	MUSEL	130 klbs
			150 klbs
Late cutback – Early restore	SN526	SN530	130 klbs
			150 klbs

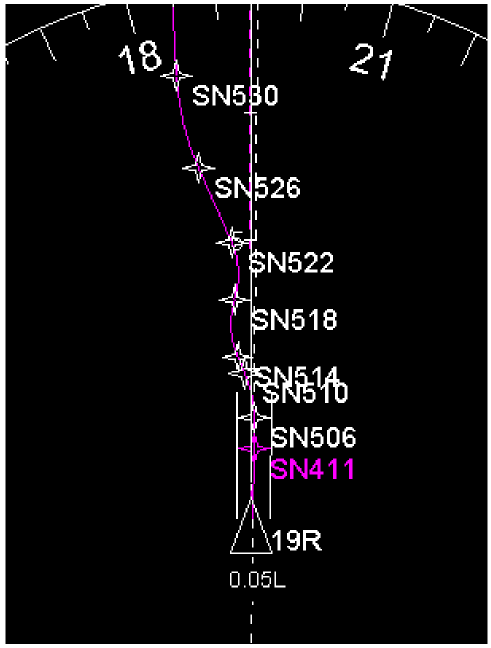

Figure 6 – BAYMED Departure Procedure

5.1 Fuel

As a baseline, the fuel at the top of descent for a flight using no quiet climb methods was run. The values for fuel were the highest of all the runs for both the 130 and 150 klbs cases, supporting the idea that faster takeoff/climb outs provide superior fuel performance. Subsequent runs for each case described in Section 5 involved comparing one of the noise abatement departure methods with a more advanced method and comparing the effects on both fuel and noise.

Overall, between all the different runs an average fuel savings of ~60 pounds per flight was achieved by using more advanced noise abatement methods.

5.1.1 No Cutback or Restore Points

Gross Weight	T/D Fuel
130 klbs	16,389 lbs
150 klbs	16,113 lbs

5.1.2 Early Cutback and Late Restore Points

For this case, the location-only noise abatement method was compared with the more advanced location- and altitude-based noise abatement method. This case simulates the scenario where an aircraft has the climb capability to exit the noise abatement procedure due to altitude instead of waiting until the exit geographical location has been reached.

Gross Weight	T/D Fuel – Location Only	T/D Fuel – Location and Altitude	Fuel Savings
130	16,258 lbs	16,322 lbs	+64 lbs
150	15,928 lbs	15,990 lbs	+62 lbs

5.1.3 Early Cutback and Early Restore Points

For this case, the altitude-only noise abatement method was compared with the more advanced location-only method. This case simulates the scenario where an aircraft leaves the geographic area of concern with respect to noise prior to climbing high enough to satisfy the altitude-based method.

Gross Weight	T/D Fuel – Altitude Only	T/D Fuel – Location Only	Fuel Savings
130	16,327 lbs	16,336 lbs	+9 lbs
150	15,992 lbs	16,018 lbs	+26 lbs

5.1.4 Late Cutback and Late Restore Points

For this case, the location-only noise abatement method was compared with the more advanced location and altitude method. This case simulates the scenario where an aircraft can climb out of the noise abatement area prior to having departed the geographical area of interest.

Gross Weight	T/D Fuel – Location Only	T/D Fuel – Location and Altitude	Fuel Savings
130	16,160 lbs	16,323 lbs	+163 lbs
150	15,841 lbs	15,990 lbs	+149 lbs

5.1.5 Late Cutback and Early Restore Points

For this case, the altitude-only noise abatement method was compared with the more advanced location and altitude method. This case simulates the scenario where an aircraft leaves the geographic area of interest prior to climbing out of the noise abatement area. These particular cases showed a slight savings using the older noise abatement method. However, since the differences are less than 5 pounds of fuel the two trajectories are essentially identical.

Gross Weight	T/D Fuel – Altitude Only	T/D Fuel – Location and Altitude	Fuel Savings
130	16,327 lbs	16,322 lbs	-5 lbs
150	15,992 lbs	15,990 lbs	-2 lbs

5.2 Noise

For each scenario presented in paragraph 5.1, the following values were compared to determine the noise increases/reductions between the different noise abatement methods:

- average noise value over the seven monitoring stations
- maximum noise value
- average of the three noise monitoring stations closest to the airport
- average of the four noise monitoring stations furthest from the airport

Overall, 75% of the noise abatement methods resulted in a reduced total average noise value when compared with a full rated takeoff/climb. Additionally, 62.5% of the advanced noise abatement scenarios resulted in superior or negligibly different noise profiles.

No Cutback or Restore Points

Weight	Average Total Noise	Max Noise	Average 1-3	Average 4-7
130	88.8172 dB	100.1143 dB	90.6248 dB	87.4615 dB
150	88.8286 dB	100.1393 dB	90.5893 dB	87.5082 dB

Early Cutback and Late Restore Points

Weight = 130 klbs

Noise Value	Location Only	Location and Altitude	Noise Difference
Total Average	87.3294 dB	87.3295 dB	+0.0001 dB
Maximum	100.2247 dB	100.2247 dB	0.0000 dB
1-3 Average	91.1623 dB	91.1623 dB	0.0000 dB
4-7 Average	84.4548 dB	84.4550 dB	+0.0002 dB

Weight = 150 klbs

Noise Value	Location Only	Location and Altitude	Noise Difference
Total Average	88.2074 dB	88.0358 dB	-0.1716 dB
Maximum	99.1894 dB	98.4040 dB	-0.7854 dB
1-3 Average	90.8035 dB	90.4787 dB	-0.3248 dB
4-7 Average	86.2604 dB	86.2037 dB	-0.0567 dB

Early Cutback and Early Restore Points

Weight = 130 klbs

Noise Value	Altitude Only	Location Only	Noise Difference
Total Average	86.9185 dB	88.4859 dB	+1.5674 dB
Maximum	99.8255 dB	100.0707 dB	+0.2452 dB
1-3 Average	90.7237 dB	90.5389 dB	-0.1848 dB
4-7 Average	84.0647 dB	86.9462 dB	+2.8815 dB

Weight = 150 klbs

Noise Value	Altitude Only	Location Only	Noise Difference
Total Average	87.4880 dB	87.8246 dB	+0.3366 dB
Maximum	100.7181 dB	98.4063 dB	-2.3118 dB
1-3 Average	89.5511 dB	89.9799 dB	+0.4288 dB
4-7 Average	85.9408 dB	86.2081 dB	+0.2673 dB

Late Cutback and Late Restore Points

Weight = 130 klbs

Noise Value	Location Only	Location and Altitude	Noise Difference
Total Average	89.2852 dB	89.2853 dB	+0.0001 dB
Maximum	100.0708 dB	100.0708 dB	0.0000 dB
1-3 Average	90.5405 dB	90.5405 dB	0.0000 dB
4-7 Average	88.3438 dB	88.3440 dB	+0.0002 dB

Weight = 150 klbs

Noise Value	Location Only	Location and Altitude	Noise Difference
Total Average	88.4921 dB	88.3820 dB	-0.1101 dB
Maximum	98.4064 dB	98.4064 dB	0.0000 dB
1-3 Average	89.9809 dB	89.9809 dB	0.0000 dB
4-7 Average	87.3756 dB	87.1829 dB	-0.1927 dB

Late Cutback and Early Restore Points

Weight = 130 klbs

Noise Value	Altitude Only	Location and Altitude	Noise Difference
Total Average	86.9185 dB	89.2857 dB	+2.3672 dB
Maximum	99.8255 dB	100.0708 dB	+0.2453 dB
1-3 Average	90.7237 dB	90.5406 dB	-0.1831 dB
4-7 Average	84.0647 dB	88.3446 dB	+4.2799 dB

Weight = 150 klbs

Noise Value	Altitude Only	Location and Altitude	Noise Difference
Total Average	87.4880 dB	88.3824 dB	+0.4639 dB
Maximum	100.7181 dB	98.4064 dB	-2.3117 dB
1-3 Average	89.5511 dB	89.9810 dB	+0.4299 dB
4-7 Average	85.9408 dB	87.1835 dB	+1.2427 dB

6 Conclusion

Overall, using an enhanced noise abatement departure procedure produced an average fuel savings of ~60 pounds per flight. Though modest, once deployed across a fleet of aircraft, non-trivial fuel savings could be realized. Additionally, these savings are often achieved with little or no increase in noise at the published microphone locations. Application of enhanced noise abatement departure procedures results in fuel saved for the airlines while satisfying the airport and surrounding communities' need to manage the amount of noise produced by departing aircraft.

Appendix

Noise Data Summary

Noise Data Summary.xlsx