CEE 4674
Airport Planning and Design

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Sample Airport Noise Computations

Topics Covered

- Calculating **SEL** (Sound Exposure Level) for single flyover events
- Calculating Day-Night average sound levels (**LDN**)
- Calculating Equivalent Steady Sound Levels (**Leq**)
  - Applicable over longer periods of time
- FAA Computer Noise Model (AEDT-3)

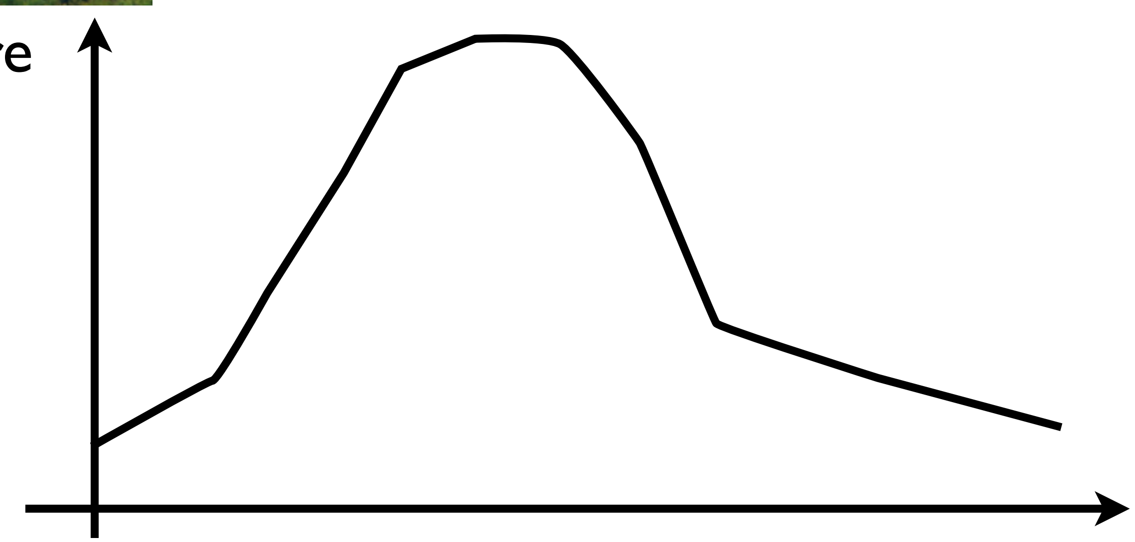
Sound Exposure Level of Single Events
Calculating Sound Exposure Level (SEL)

Measuring Single Flyover Events

Casella CEL SPL Noise Level Instrument

Instruments can Record SPL every Second (slow or fast mode)

Sound Pressure Level (dBA)



Time (seconds)

Integrate Numerically (Using Excel / Matlab)

Sound Exposure Level (SEL)

Measuring Single Flyover Events

$$L_E = 10log\left[\frac{1}{t_0}\int_{t_2}^{t_1} 10^{L(t)/10}\, dt\right]$$

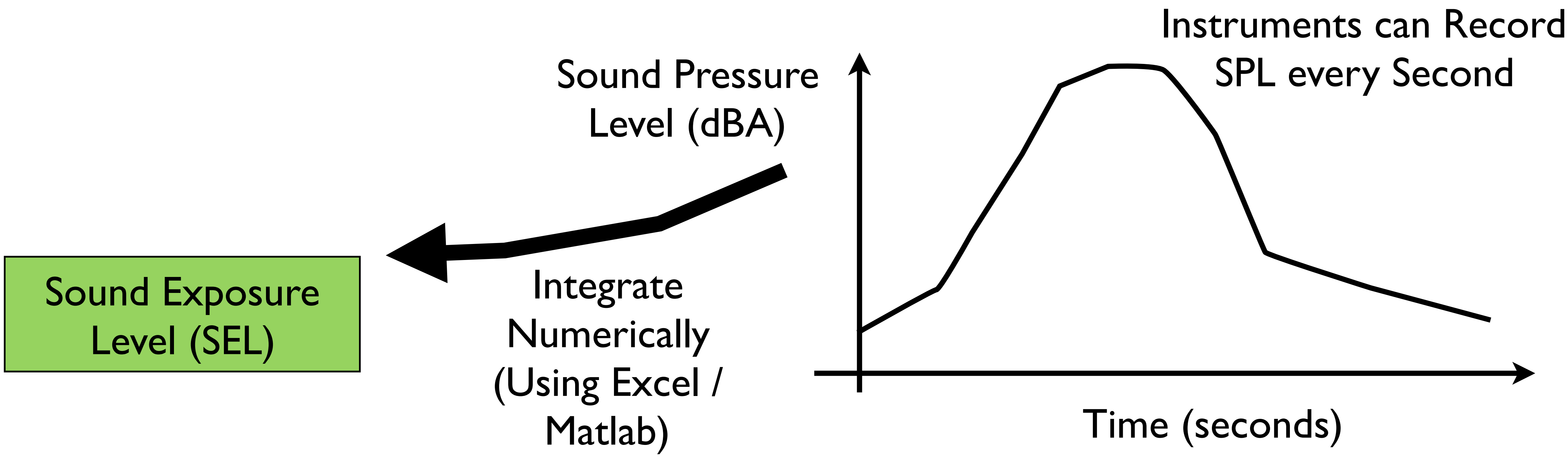
In Practice we use a summation to compute the value of L_E

L_E = Single event noise level (dbA)

$L(t)$ = Instantaneous Sound Pressure Level recorded

t_0 = reference time

t_1, t_2 = times used to perform the numerical integration



Measuring Single Flyover Events

$$L_E = 10log\left[\frac{1}{t_0}\int_{t_2}^{t_1} 10^{L(t)/10}\, dt\right]$$

L_E = Single event Sound Exposure Level (SEL) (dbA)

$L(t)$ = Instantaneous Sound Pressure Level recorded

t_0 = reference time

t_1, t_2 = times used to perform the numerical integration

Sound Exposure Level (SEL)

$$L_E = 10log\left[\frac{1}{t_0}\sum_{i=1}^{N} 10^{L_i/10}\,\Delta t\right]$$

L_E = Single event Sound Exposure Level (SEL) (dbA)

L_i = Instantaneous Sound Pressure Level recorded at discrete intervals of time

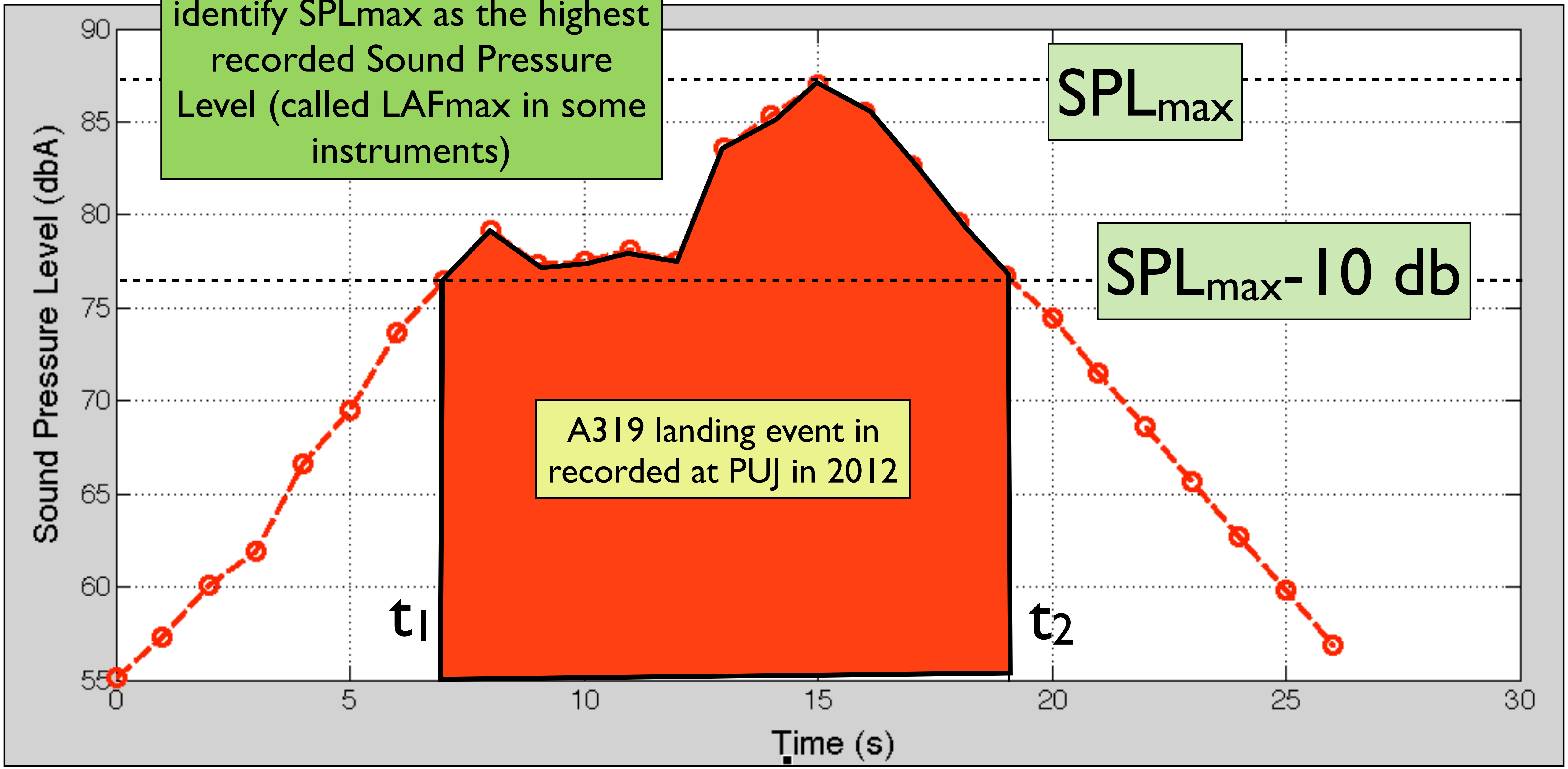
t_0 = reference time

Δt = is the delta time interval (typically 0.5 to 1 seconds)

Numerical approximation of SEL

Numerical Example # 1: Single Flyover

Most SPL noise recorders identify SPLmax as the highest recorded Sound Pressure Level (called LAFmax in some instruments)



Sound Exposure Level (SEL) calculation

t1 and t2 are selected according to the maximum SPL levels recorded - 10 dBA

Sample Single Flyover Event (Airbus A319 Landing at Punta Cana)

Sample calculation (at time 12:56:33)
SPL (LAI) dBA = 73.70
10 ^ SPL/10 = 23,442,288

Highest Value of SPL recorded (known as LAmax) in Casela 240 instrument

Sound Exposure Level (SEL) Calculation using **all values** of SPL dbA recorded

Date	Time	LCA	SPL (LAI) dBA	Ignore LCI	Ignore SPL (LAI) dBC	Scale A Calculation 10^SPL/10
5/29/12	12:56:27	LAI	55.10	LCI	63.2	323,594
5/29/12	12:56:28	LAI	57.30	LCI	64.9	537,032
5/29/12	12:56:29	LAI	60.10	LCI	67.4	1,023,293
5/29/12	12:56:30	LAI	61.90	LCI	70.3	1,548,817
5/29/12	12:56:31	LAI	66.60	LCI	73.7	4,570,882
5/29/12	12:56:32	LAI	69.50	LCI	74.7	8,912,509
5/29/12	12:56:33	LAI	73.70	LCI	76.8	23,442,288
5/29/12	12:56:34	LAI	76.50	LCI	77.8	44,668,359
5/29/12	12:56:35	LAI	79.20	LCI	79.9	83,176,377
5/29/12	12:56:36	LAI	77.30	LCI	78.2	53,703,180
5/29/12	12:56:37	LAI	77.50	LCI	78.7	56,234,133
5/29/12	12:56:38	LAI	78.10	LCI	80	64,565,423
5/29/12	12:56:39	LAI	77.50	LCI	80.2	56,234,133
5/29/12	12:56:40	LAI	83.60	LCI	86.3	229,086,765
5/29/12	12:56:41	LAI	85.30	LCI	89	338,844,156
5/29/12	12:56:42	LAI	87.00	LCI	89.5	501,187,234
5/29/12	12:56:43	LAI	85.50	LCI	87.1	354,813,389
5/29/12	12:56:44	LAI	82.60	LCI	84.2	181,970,086
5/29/12	12:56:45	LAI	79.60	LCI	81.3	91,201,084
5/29/12	12:56:46	LAI	76.70	LCI	78.3	46,773,514
5/29/12	12:56:47	LAI	74.50	LCI	76.7	28,183,829
5/29/12	12:56:48	LAI	71.50	LCI	74.3	14,125,375
5/29/12	12:56:49	LAI	68.60	LCI	74	7,244,360
5/29/12	12:56:50	LAI	65.7	LCI	71.1	3,715,352
5/29/12	12:56:51	LAI	62.7	LCI	68.4	1,862,087
5/29/12	12:56:52	LAI	59.8	LCI	69.3	954,993
5/29/12	12:56:53	LAI	56.9	LCI	69.6	489,779
					sum of values	2,199,392,022
					SEL (dbA)	93.42

Sample Single Flyover Event (Airbus A319 Landing at Punta Cana)

Date	Time	LCA	SPL (LAI) dBA	Ignore LCI	Ignore SPL (LAI) dBC	Scale A Calculation 10^SPL/10
5/29/12	12:56:27	LAI	55.10	LCI	63.2	-
5/29/12	12:56:28	LAI	57.30	LCI	64.9	-
5/29/12	12:56:29	LAI	60.10	LCI	67.4	-
5/29/12	12:56:30	LAI	61.90	LCI	70.3	-
5/29/12	12:56:31	LAI	66.60	LCI	73.7	-
5/29/12	12:56:32	LAI	69.50	LCI	74.7	-
5/29/12	12:56:33	LAI	73.70	LCI	76.8	-
5/29/12	12:56:34	LAI	76.50	LCI	77.8	44,668,359
5/29/12	12:56:35	LAI	79.20	LCI	79.9	83,176,377
5/29/12	12:56:36	LAI	77.30	LCI	78.2	53,703,180
5/29/12	12:56:37	LAI	77.50	LCI	78.7	56,234,133
5/29/12	12:56:38	LAI	78.10	LCI	80	64,565,423
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5/29/12	12:56:40	LAI	83.60	LCI	86.3	229,086,765
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5/29/12	12:56:49	LAI	68.60	LCI	74	-
5/29/12	12:56:50	LAI	65.7	LCI	71.1	-
5/29/12	12:56:51	LAI	62.7	LCI	68.4	-
5/29/12	12:56:52	LAI	59.8	LCI	69.3	-
5/29/12	12:56:53	LAI	56.9	LCI	69.6	-
					sum of values	2,102,457,832
					SEL (dbA)	93.23

Highest Value of SPL recorded (known as SPLmax) in Casela 240 instrument

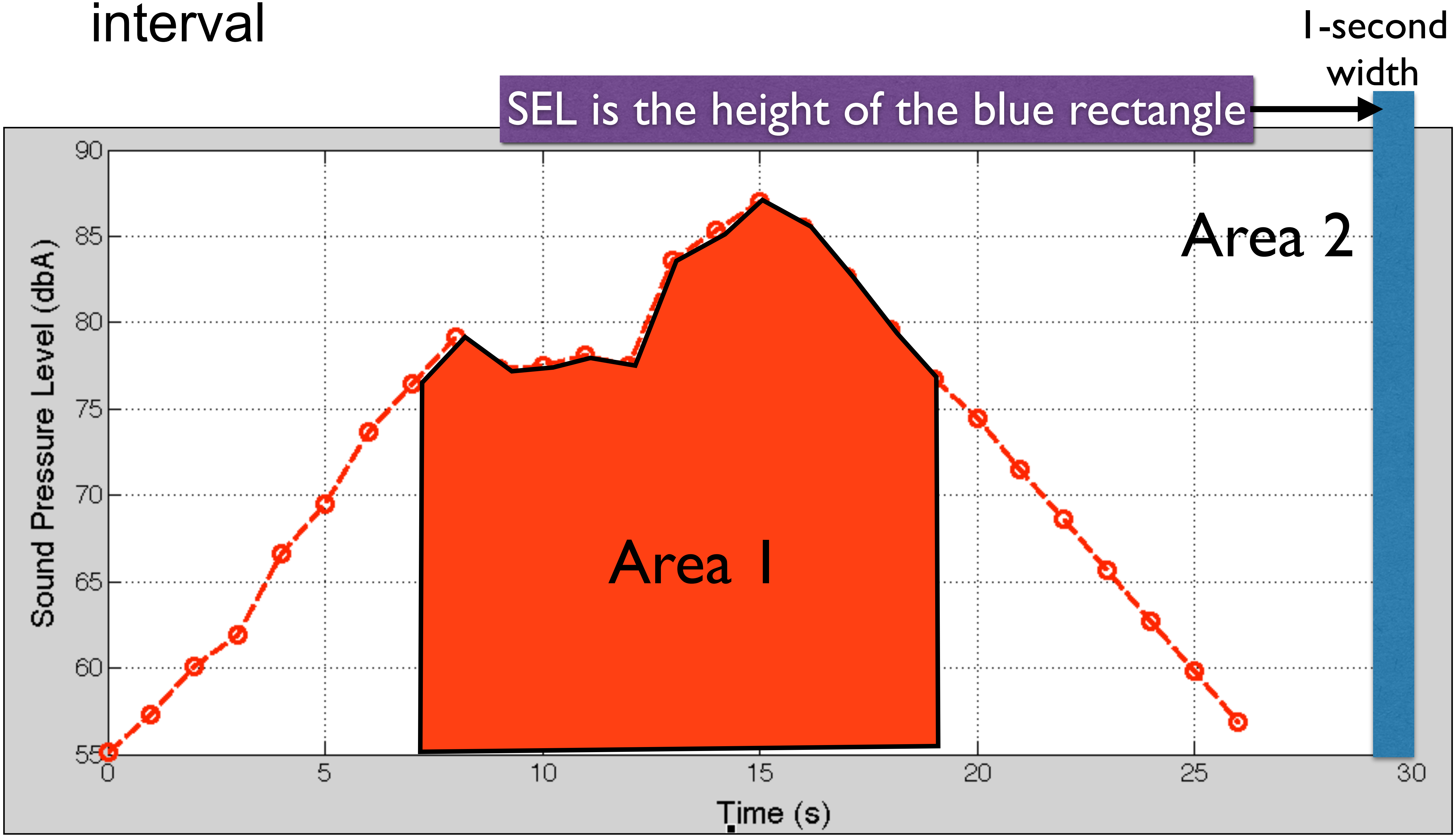
Sound Exposure Level (SEL) Calculation using data from SPLmax to SPLmax -10 db

Observation

- The solution of SEL calculated using the full SPL history trace recorded was 93.42 dBA
- The solution of SEL calculated using the time interval between highest value of SPL recorded and Lamax -10 dbA was 93.23 dBA
- The calculated SEL value using values between t_1 and t_2 shows that 99.8% of the acoustic energy (i.e., integral of the SPL curve) is accounted for and hence it is a very accurate estimate of single flyover noise level

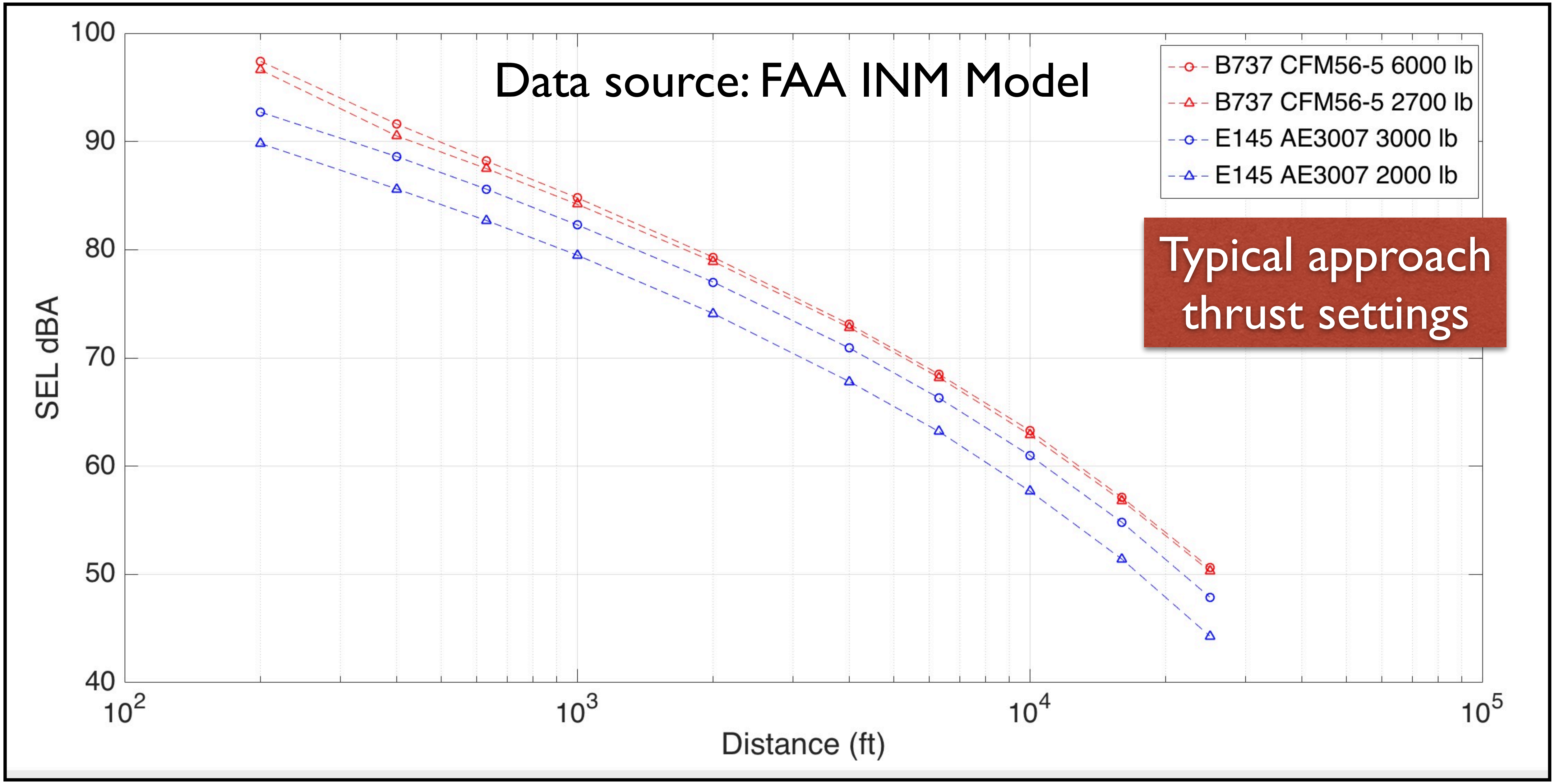
Interpretation of Sound Exposure Level (SEL)

- Total acoustic energy integrated over a one-second interval



Numerical Example # 2

- Estimate the Sound Exposure Level (SEL) at various distances from a runway considering arrival operations (two glide-slope angles 3 and 3.5 degrees) for the Embraer 145 with AE3007 engines



Numerical Example # 2

- Noise Power Curve Data for Embraer 145 with AE3007 engines

Departure Thrust Data (6,000 lbs of thrust)

Distance (feet)	SEL Level (dBA)
200	96.7
400	93.0
630	90.3
1,000	87.5
2,000	82.8
4,000	77.2
6,300	72.8
10,000	67.7
16,000	61.6
25,000	54.9

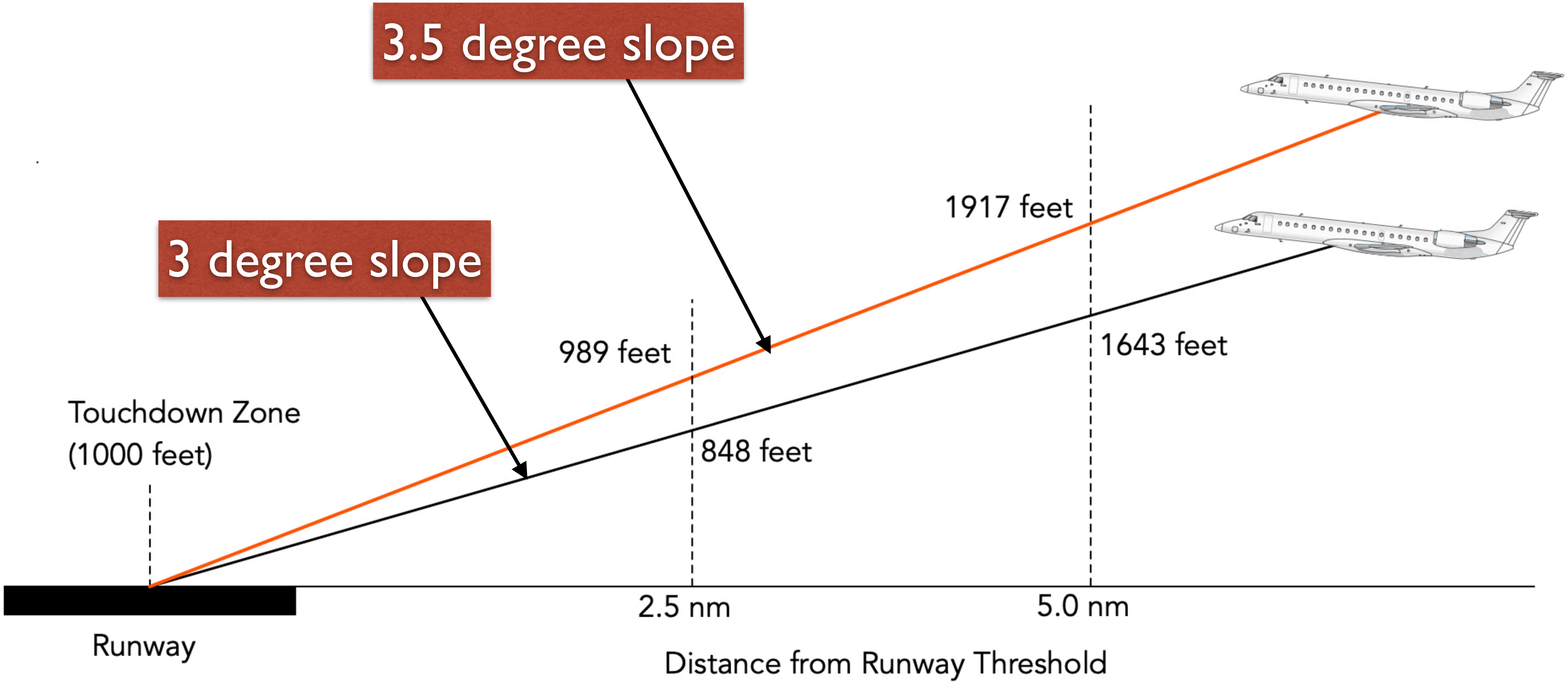
Arrival Thrust Data (3,000 lbs of thrust)

Distance (feet)	SEL Level (dBA)
200	92.7
400	88.6
630	85.6
1,000	82.3
2,000	77.0
4,000	70.9
6,300	66.3
10,000	61.0
16,000	54.8
25,000	47.9

Data source: FAA
INM and AEDT Models

Numerical Example # 2

- Estimation of Sound Exposure Level (SEL) at various locations for arrival operations (two glide-slope angles 3 and 3.5 degrees)
- Aircraft: Embraer 145 with AE3007 engines



Sample Calculation

- Embraer 145 with AE3007 engines (assume 3,000 lbs thrust in the approach procedure)
- Distance to community (an observer underneath the flight path) at 2.5 nm from the runway threshold is 848 feet for a **standard three-degree slope approach**
- SEL value is estimated to be **83.5 dBA** (via interpolation) for 3-degree approach

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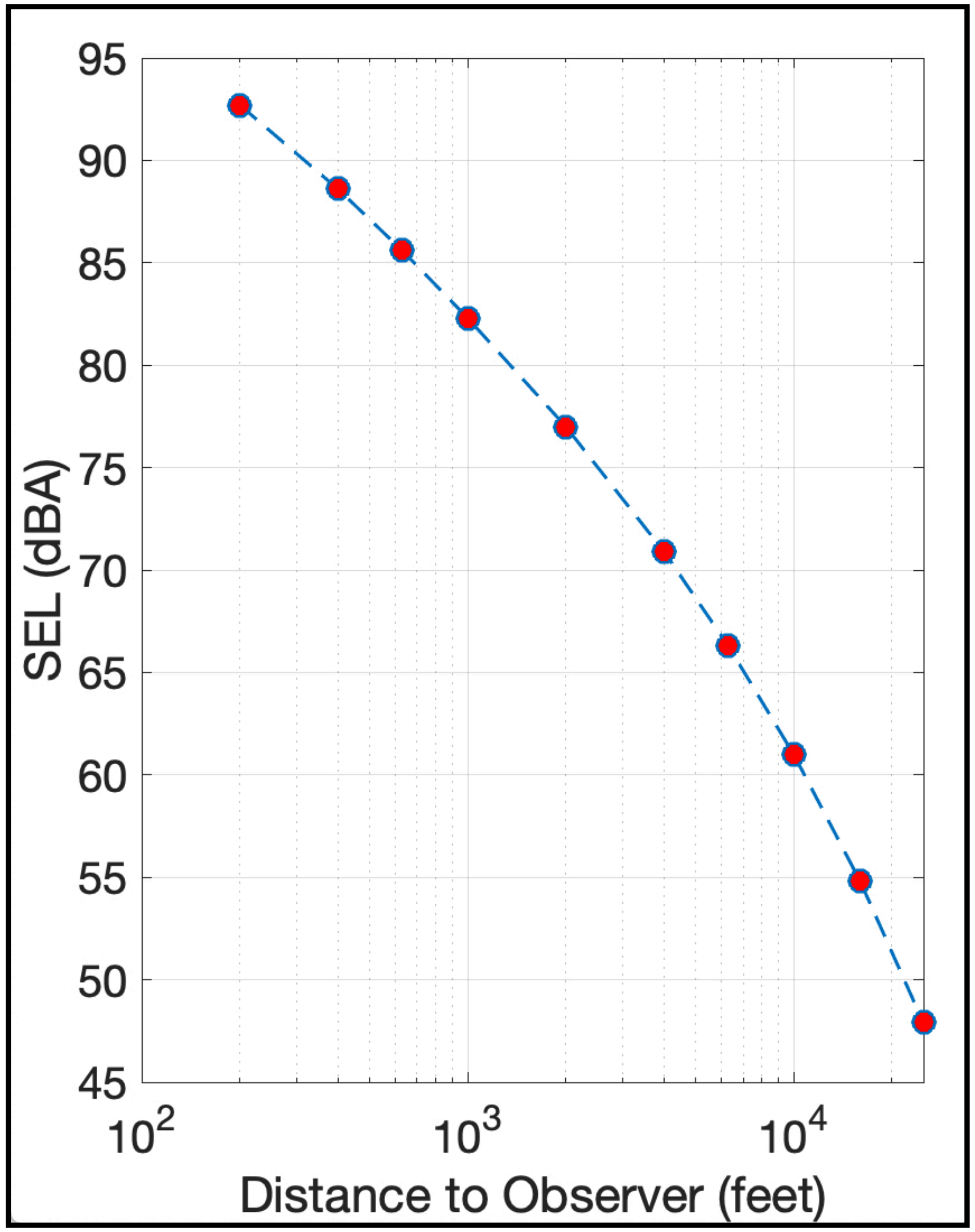
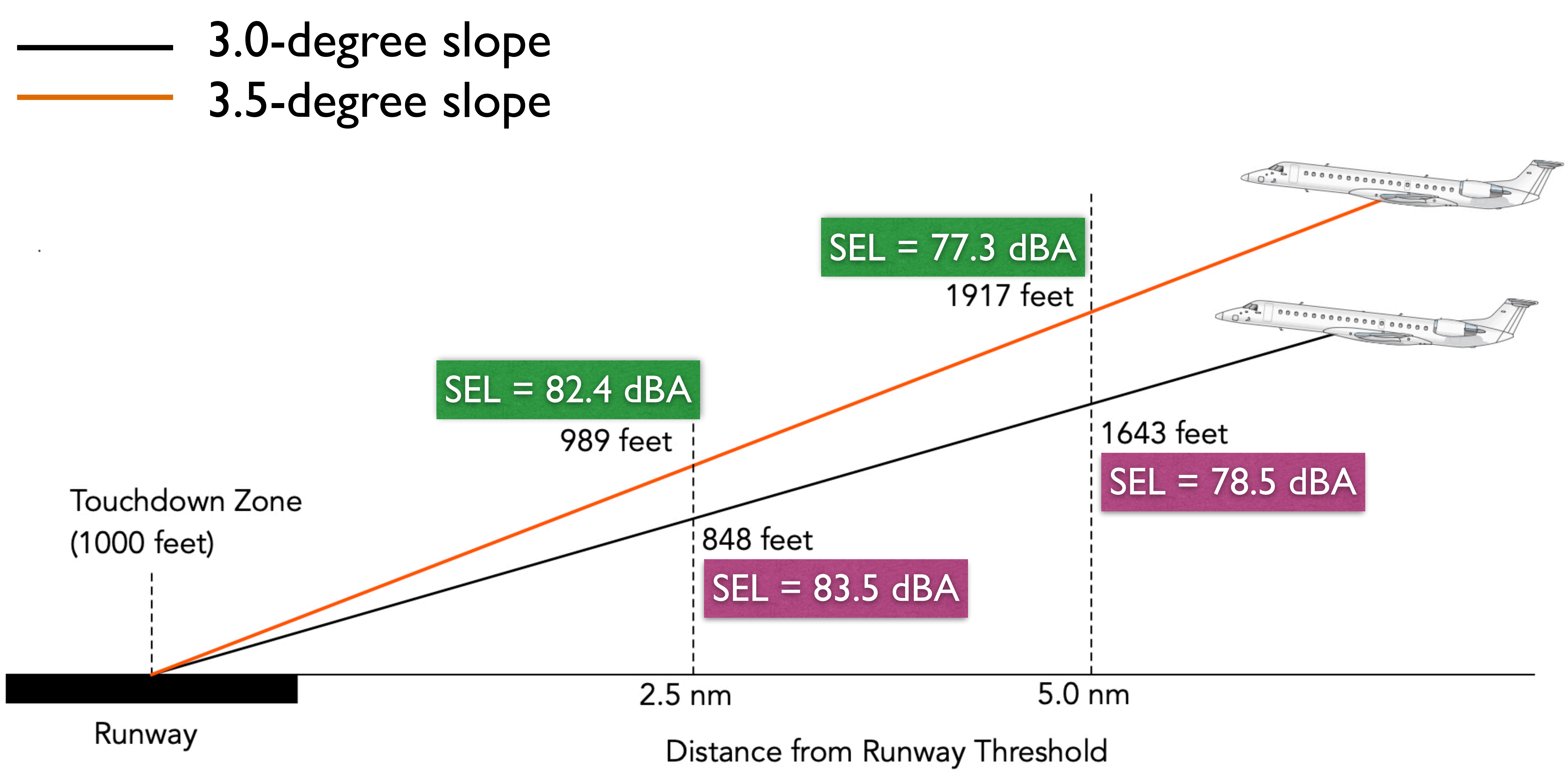
- Distance to community (an observer underneath the flight path) at 2.5 nm from the runway threshold is 989 feet for a **3.5 degree slope approach**
- SEL value is estimated to be **82.4 dBA** (via interpolation)



Numerical Example # 2

- Aircraft: Embraer 145 with AE3007 engines
- Comparison of Sound Exposure Levels (SEL) at various locations for arrival operations (two glide-slope angles 3 and 3.5 degrees)



Community Noise Exposure Metric Calculating Day-Night Sound Level (LDN or DNL)

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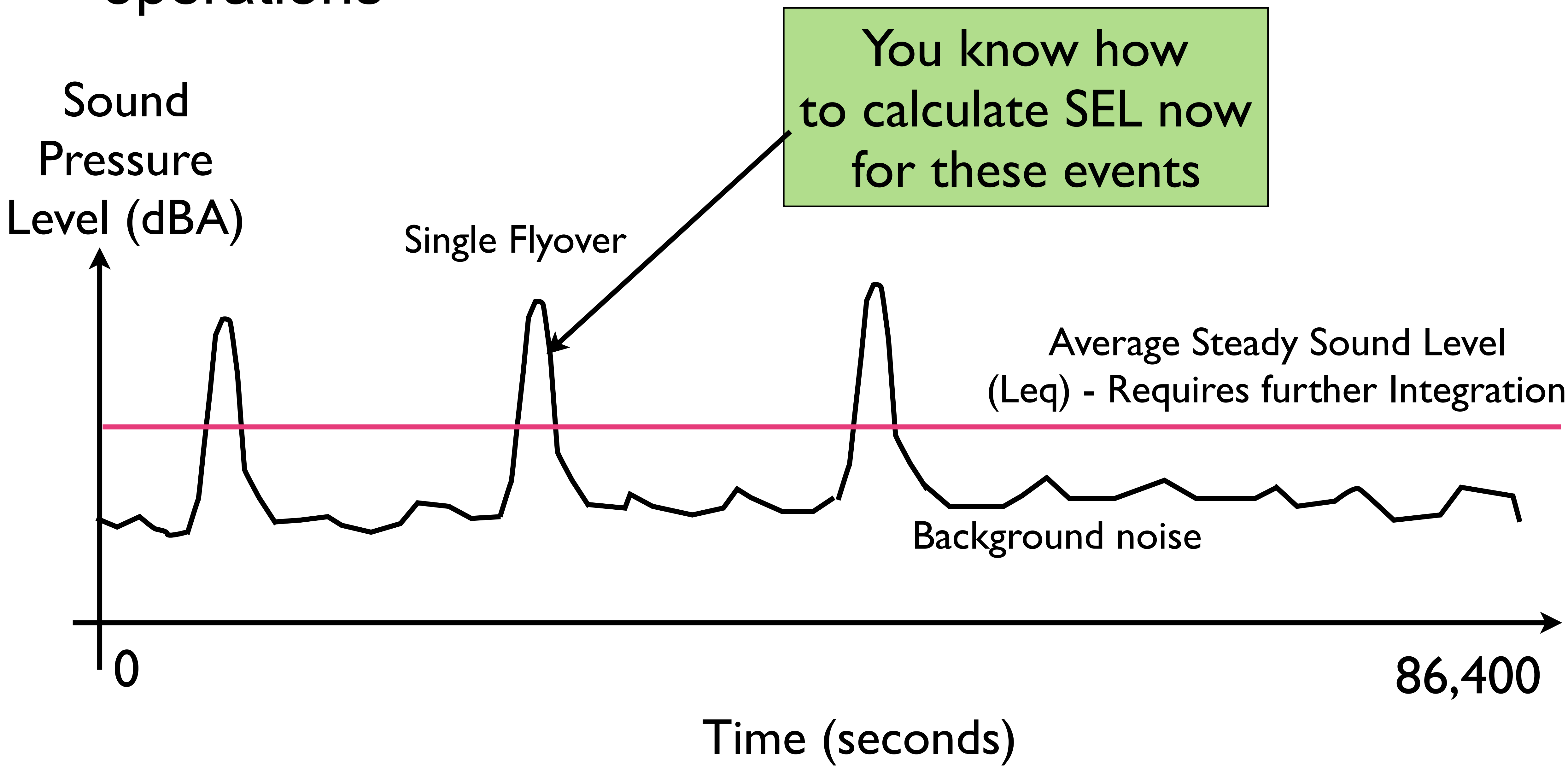
Converting from SEL to Day-Night Average Sound Level (DNL)

- With known values of SEL for each aircraft operation we can piece together a series events throughout the day to estimate the total day-night average sound levels (DNL) produced around the airport
- Flight operations at night need to be corrected by an empirical “annoyance factor”
- For nighttime events (from 22:00 to -7:00 hours) add 10 dBA to the SEL values

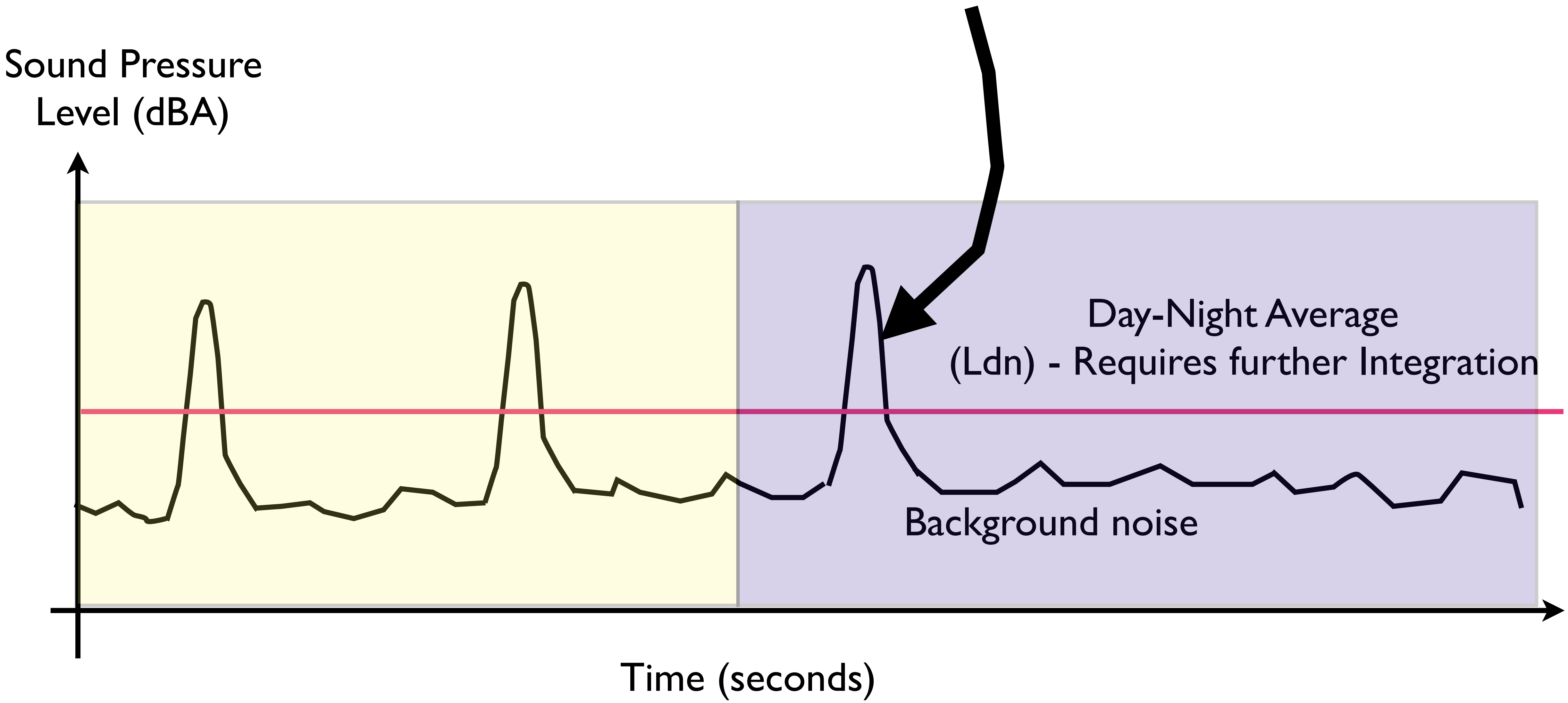
From Sound Exposure Level to Day-Night Average Sound Level

- Background noise at the location can be extracted by readings made during periods of time with no aircraft operations



Day-Night Average Noise Metric (DNL)

- LDN or DNL is computationally similar to Leq
- However, Ldn includes correcting nighttime operations (10 PM to 7 AM) by adding factor of 10 dBA



Aviation-Related Contribution to (L_{DN}) Knowing Sound Exposure Level

$$L_{DN} = 10 log\left[\frac{1}{T}\sum_{i=1}^{N} 10^{(SEL_i + W)_i/10}\right]$$

L_{DN} = Day-night Sound Level (dbA)

SEL_i = Sound exposure level associated with the ith flyover

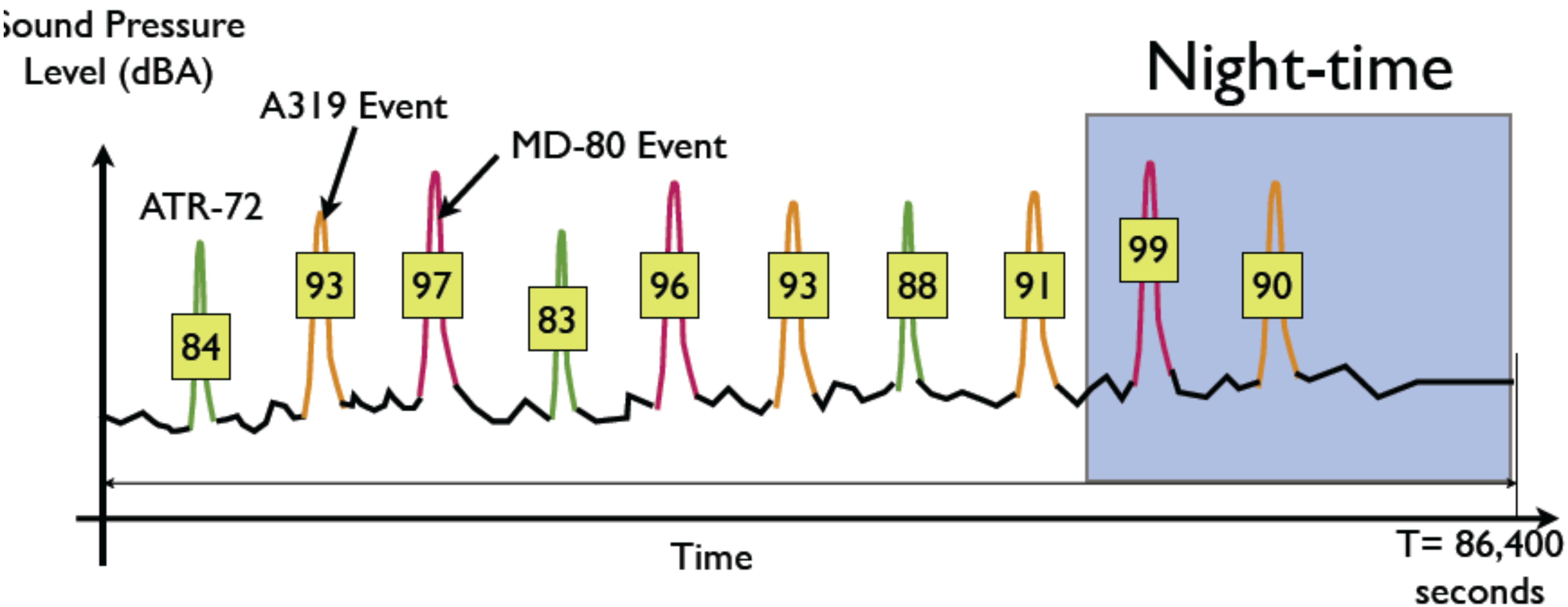
T = Reference time (86,400 seconds in 24 hrs)

The formula shown only accounts for the noise generated by aircraft flyovers

If you want the contributions of ground vehicles and other ramp noise you need to add those noise sources

Example 3 - Calculations for Day-Night Noise (L_{DN})

- Suppose there are 10 aviation noise events in a period of 24 hr period at an airport as shown in the plot (values of SEL are shown in the graphic)
- Find the value of L_{DN} due to aviation events



Sample Calculations for Day-Night Average Sound Level (L_{DN})

$$L_{DN} = 10\log\left(\frac{1}{86400}\left(10^{84/10} + 10^{93/10} + 10^{97/10} + 10^{83/10} + 10^{96/10} + 10^{93/10} + 10^{88/10} + 10^{91/10} + 10^{(99+10)/10} + 10^{(90+10)/10}\right)\right)$$

$$L_{DN} = 60.84 \text{ dBA}$$

The last two noise events occur during the nighttime period and hence they are adjusted by 10 dBA

Example # 4

- Calculate DNL level values at locations 2.5 and 5.0 nautical miles from the runway threshold (consider a glide-slope angle of three degrees) for the Embraer 145 with AE3007 engines
  - 100 daytime operations
  - 25 nighttime operations

Step 1 : Estimate the average altitude above the observer at 2.5 nm 848 feet (three-degree approach)

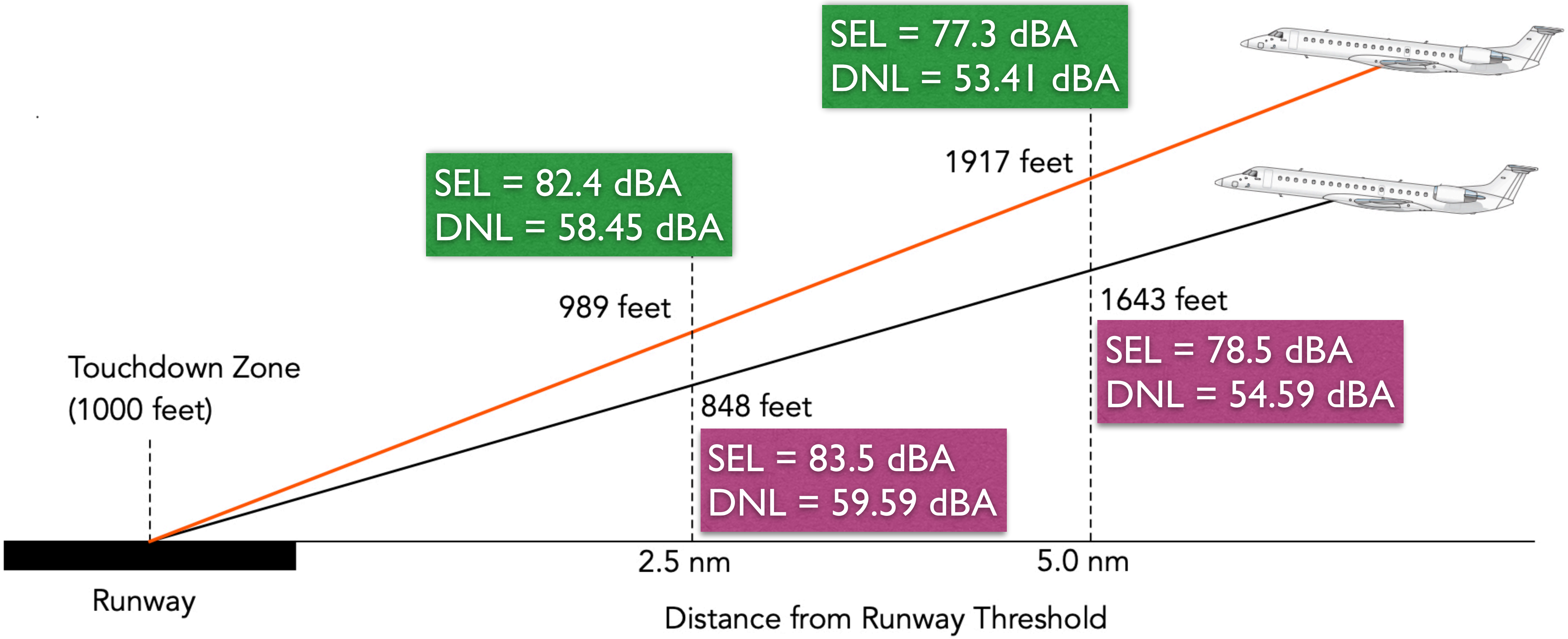
Step 2: Find the value of SEL at 848 feet from the noise power curves provided SEL = 83.5 dBA

Step 3 : Find the value of DNL using the standard equation

$$L_{DN} = 10 log \left[\frac{1}{T} \sum_{i=1}^{N} 10^{(SEL_i + W)_i / 10} \right]$$

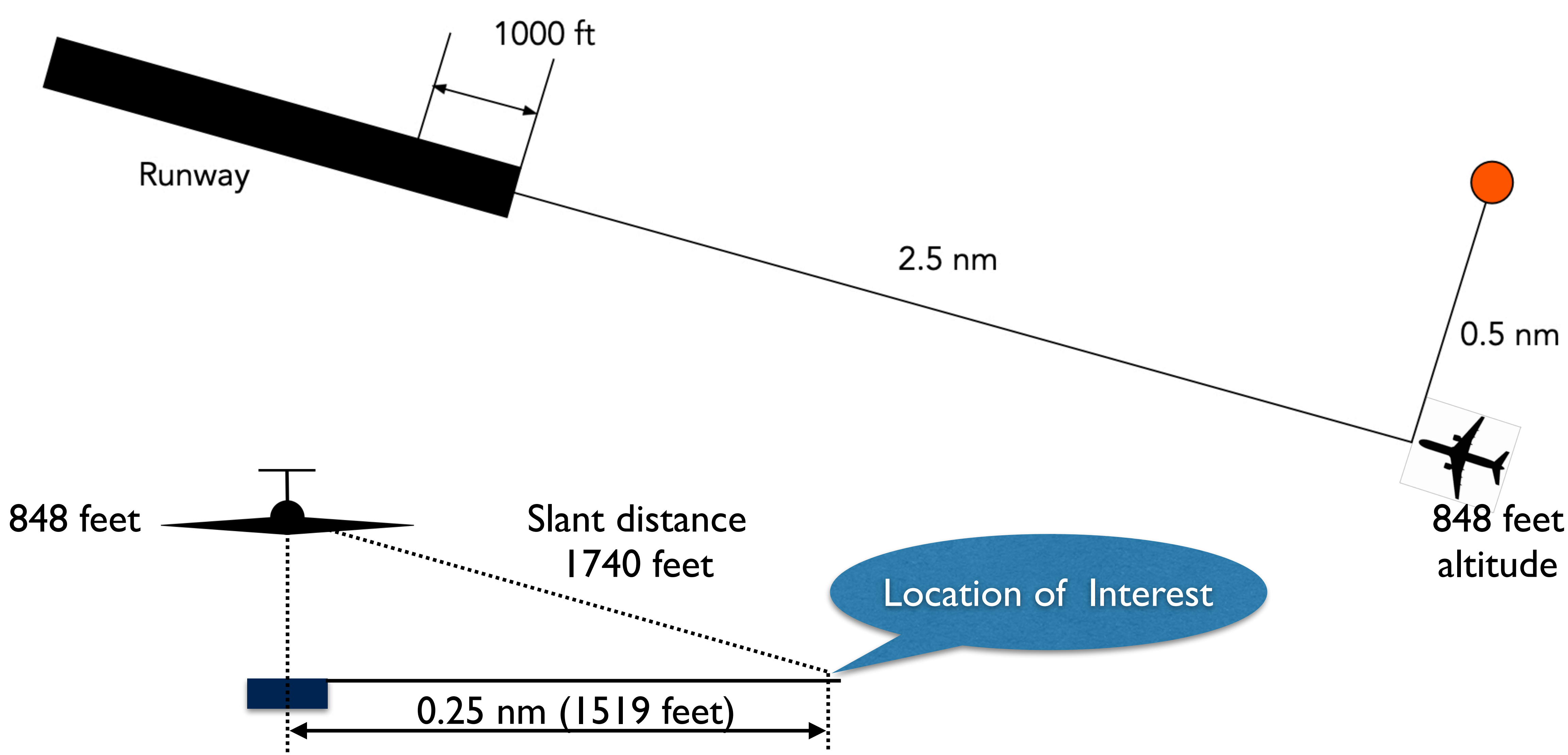
Example # 4 (Continuation)

- Estimated values of DNL at two locations for arrival operations (using the standard glide-slope angle of three degrees) to a runway served by Embraer 145 with AE3007 engines
- 100 daytime arrivals and 25 nighttime arrivals



Example # 5

- Calculate DNL level at a location 2.5 nautical miles from the runway threshold and 0.25 nm offset from the extended runway centerline for the Embraer 145 with AE3007 engines
  - 100 daytime operations and 25 nighttime operations
- Find the number of people highly annoyed at the DNL level found



Example # 5

Step 1 : Estimate the average altitude above the observer at 2.5 nm 848 feet (three-degree approach)

Step 2: Find the slant distance from the aircraft to the point of interest (**1740 feet**)

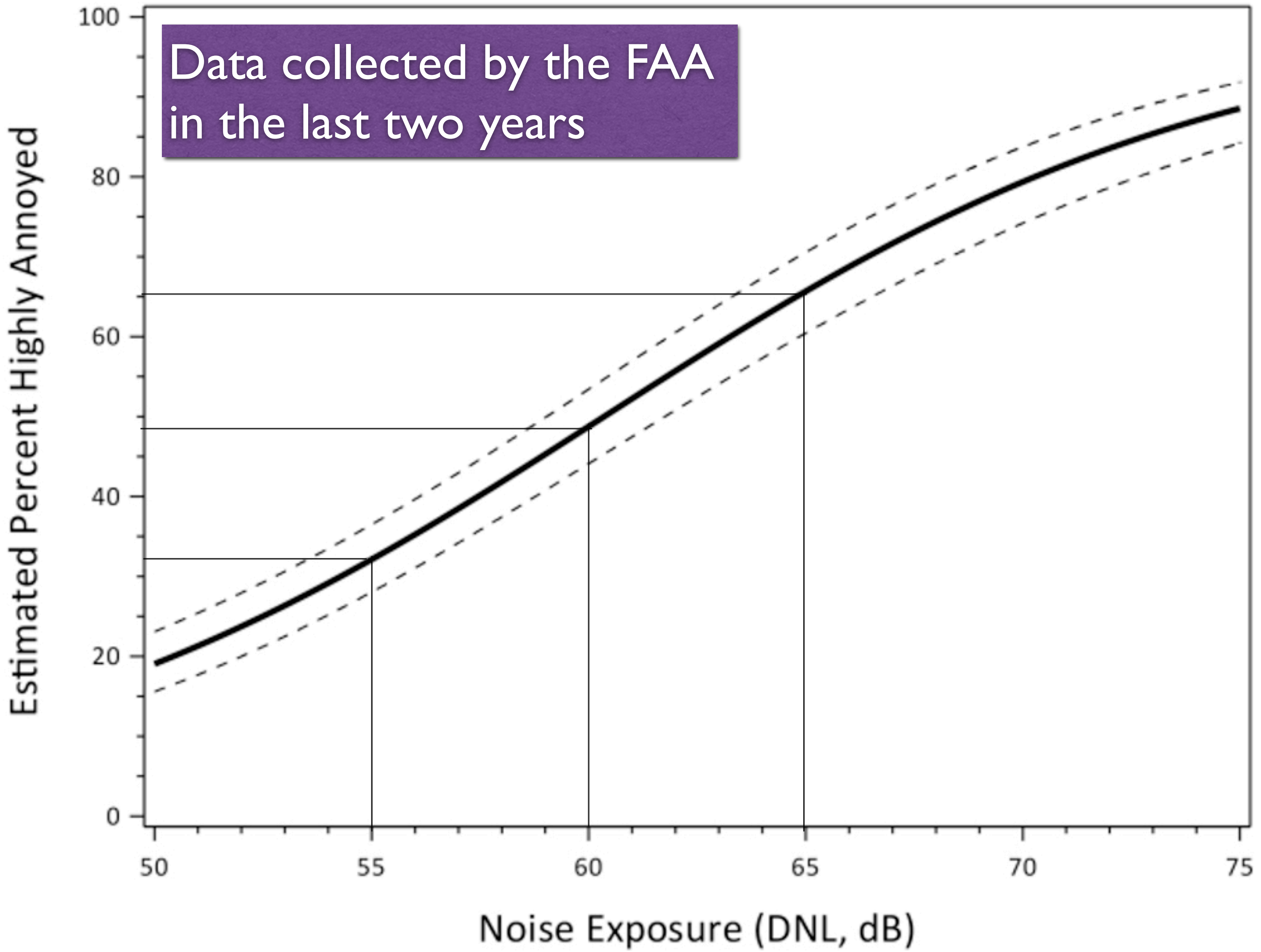
Step 3: Find the value of **SEL at 1740** feet from the noise power curves provided SEL = 78.08 dBA

Step 4 : Find the value of DNL using the standard equation

$$L_{DN} = 10log\left[\frac{1}{T}\sum_{i=1}^{N}10^{(SEL_i+W)_i/10}\right]$$

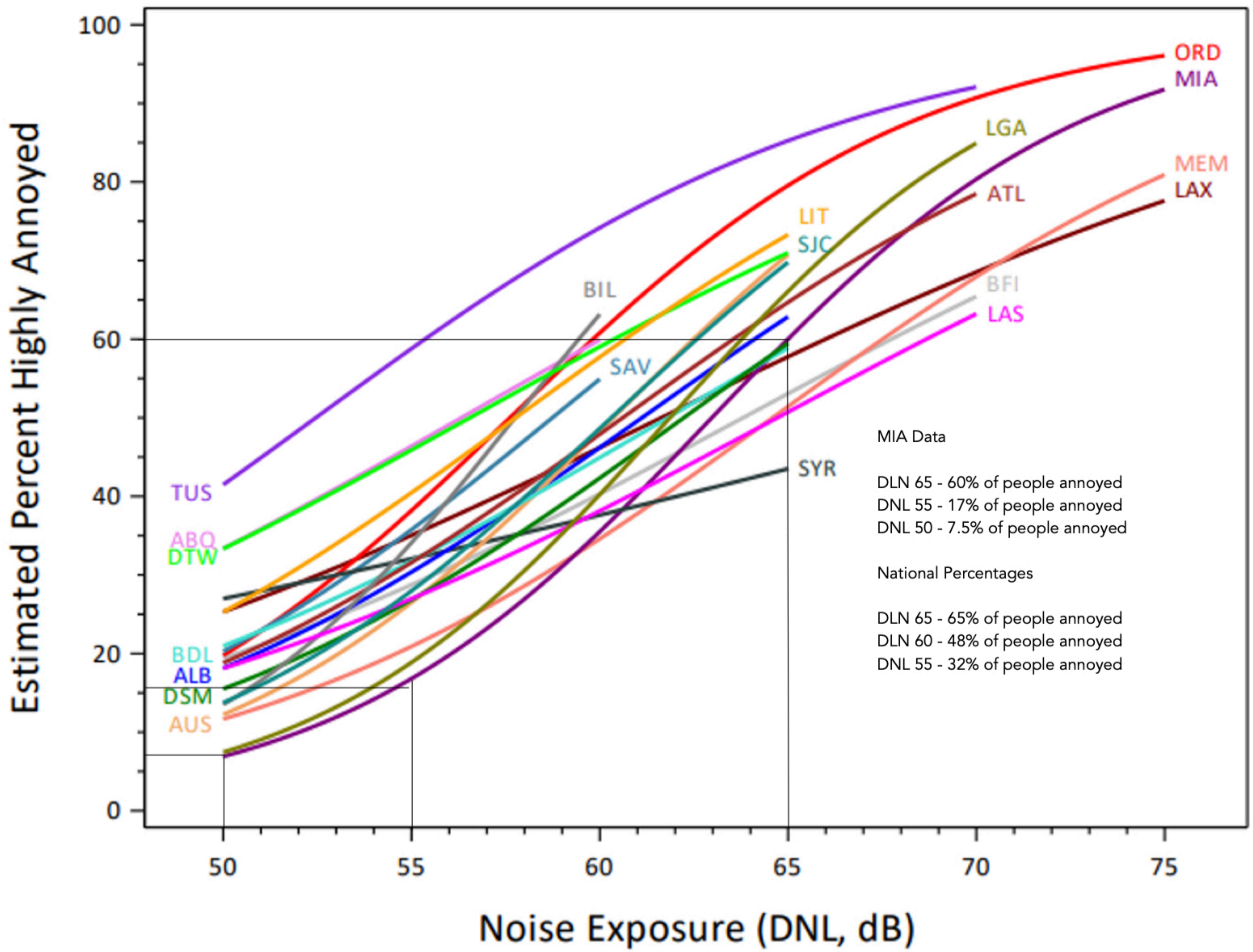
The estimated value of DNL is 51.72 dBA

FAA Neighborhood Environmental Survey

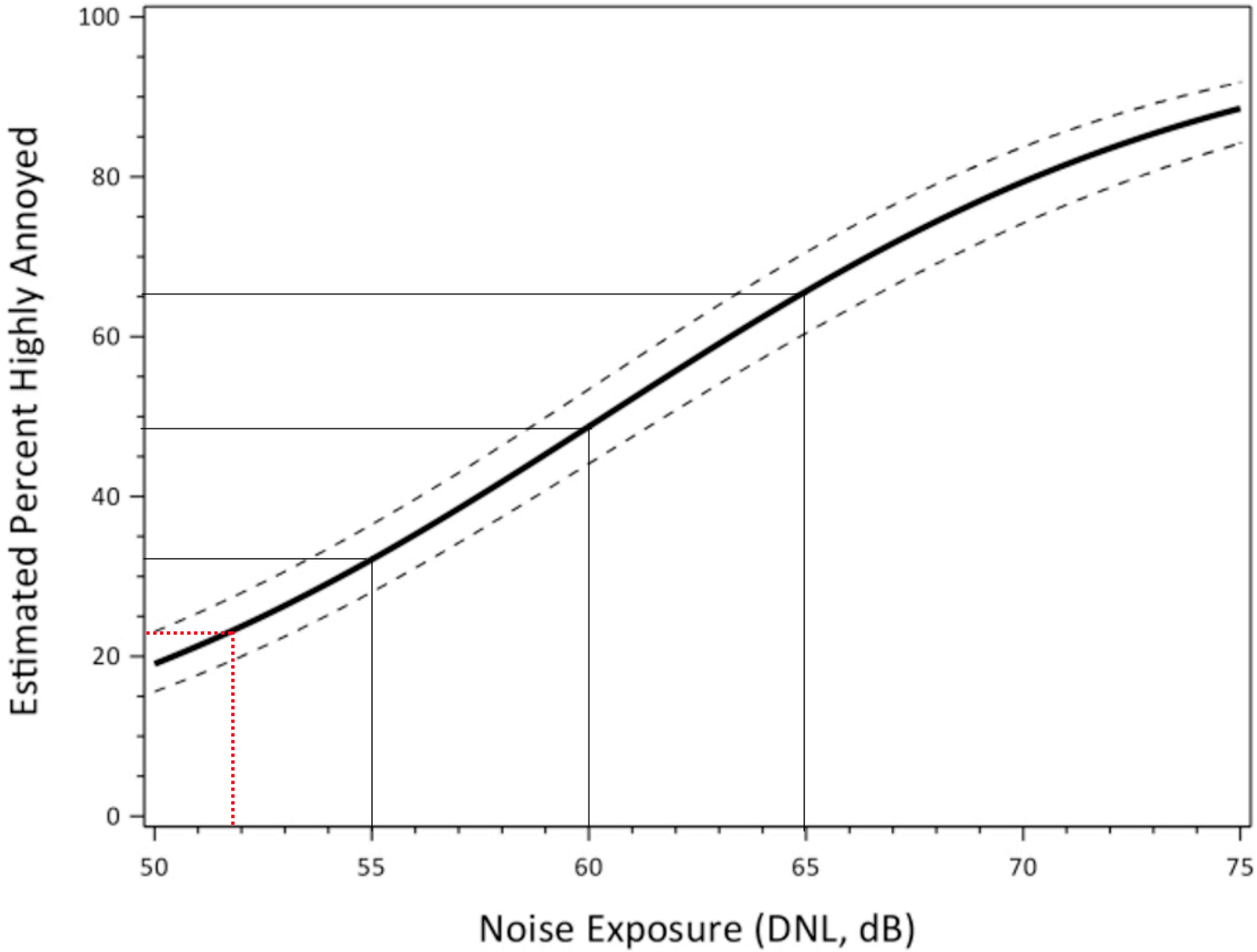


https://www.faa.gov/regulations_policies/policy_guidance/noise/survey/

FAA Neighborhood Environmental Survey



At a DNL Level of 51.72 dBA 23% of the Population will be Highly Annoyed

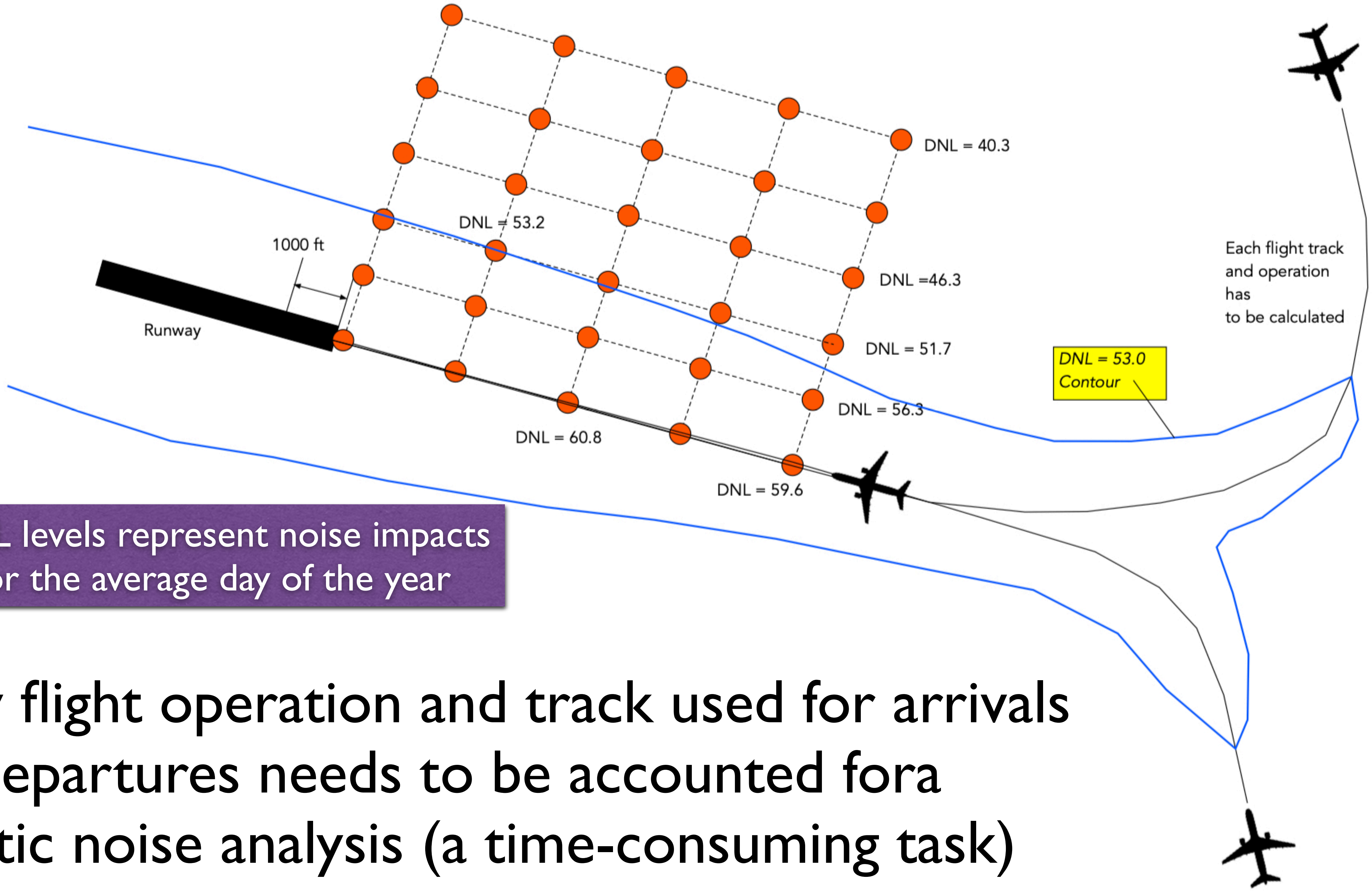


Airport Noise Contours

- Using the single flyover SEL values project DNL for each aircraft flying individual tracks at the airport
- Generate a flight schedule for one day (24-hour period) that represents the average day of the year of operations
- Use the methods explained in examples 2-5 to estimate the values of DNL around the airport

Airport Noise Contours

Repeated analysis over a grid allows us to create a complete noise contour around the airport



DNL levels represent noise impacts for the average day of the year

Every flight operation and track used for arrivals and departures needs to be accounted fora realistic noise analysis (a time-consuming task)

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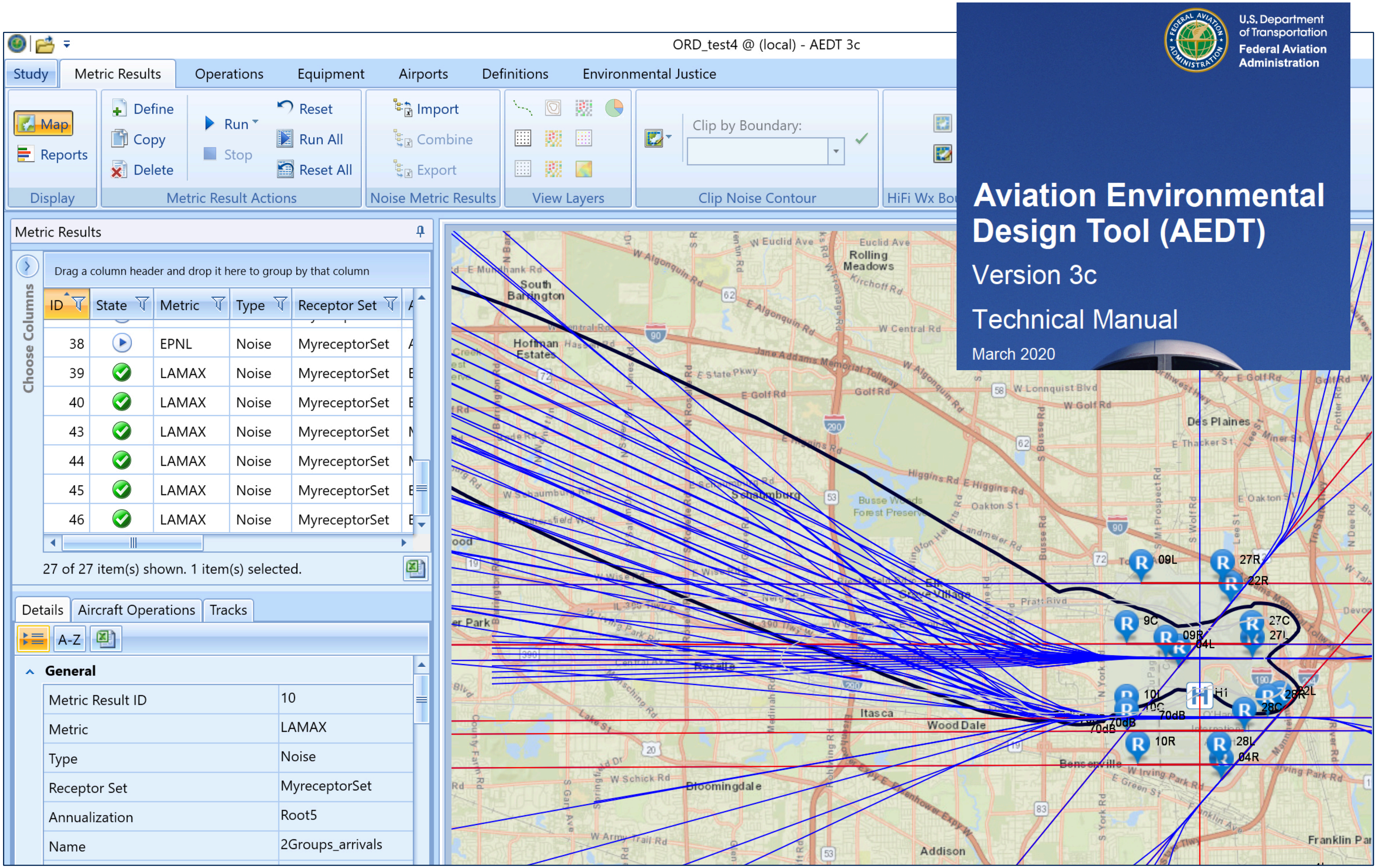
Computer Models to Estimate Noise Contours

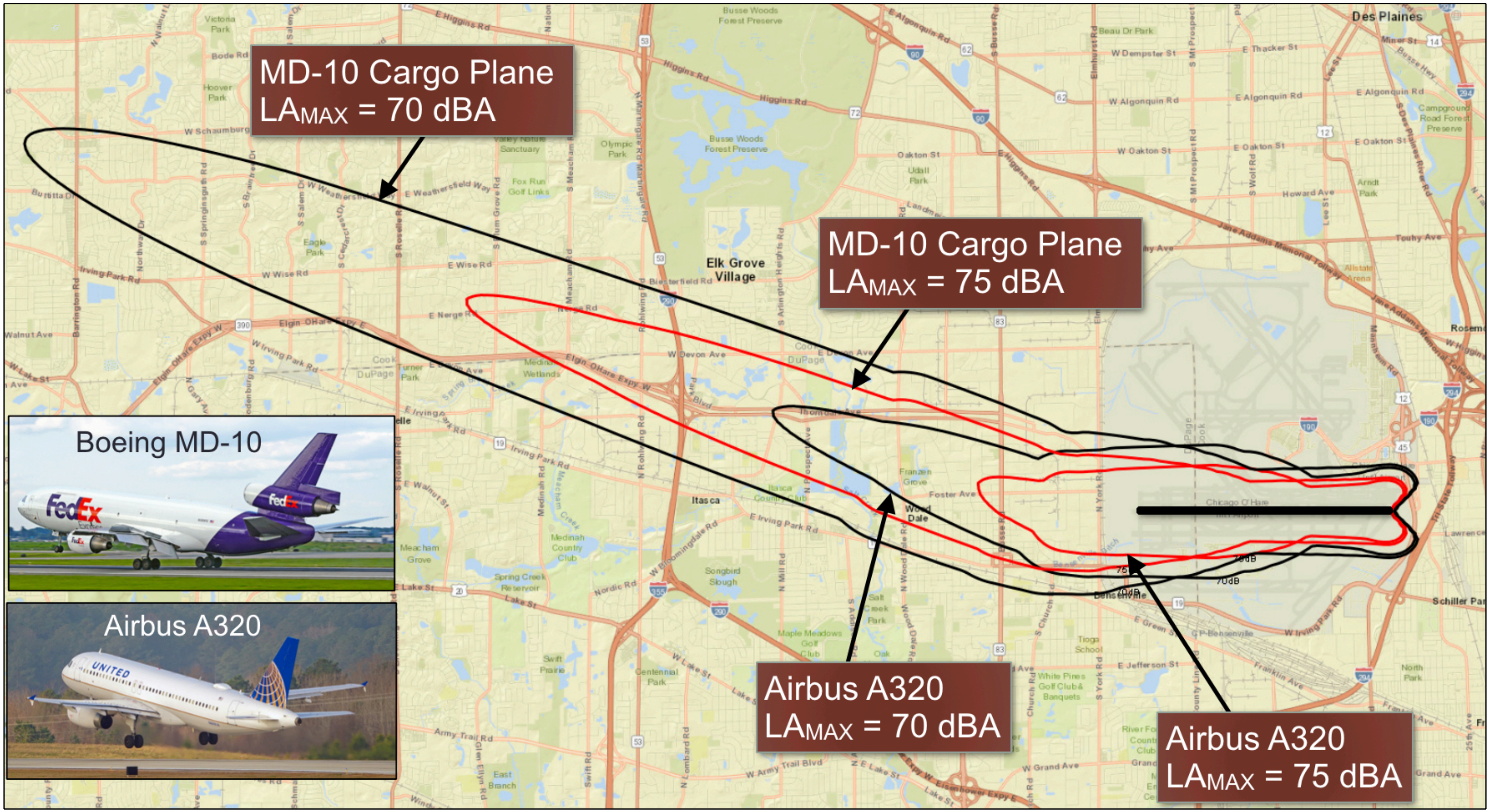
- Noise calculations require the calculation of thousands of DNL value around the airport operations
- The FAA has developed AEDT-3d to facilitate such calculations
- AEDT replaces the old Integrated Noise Model described in Notes 18-20 of this class

The FAA released the new version of the Aviation Environmental Design Tool (AEDT) on March 26, 2020

AEDT-3 is a Computer Model to Estimate Noise Contours

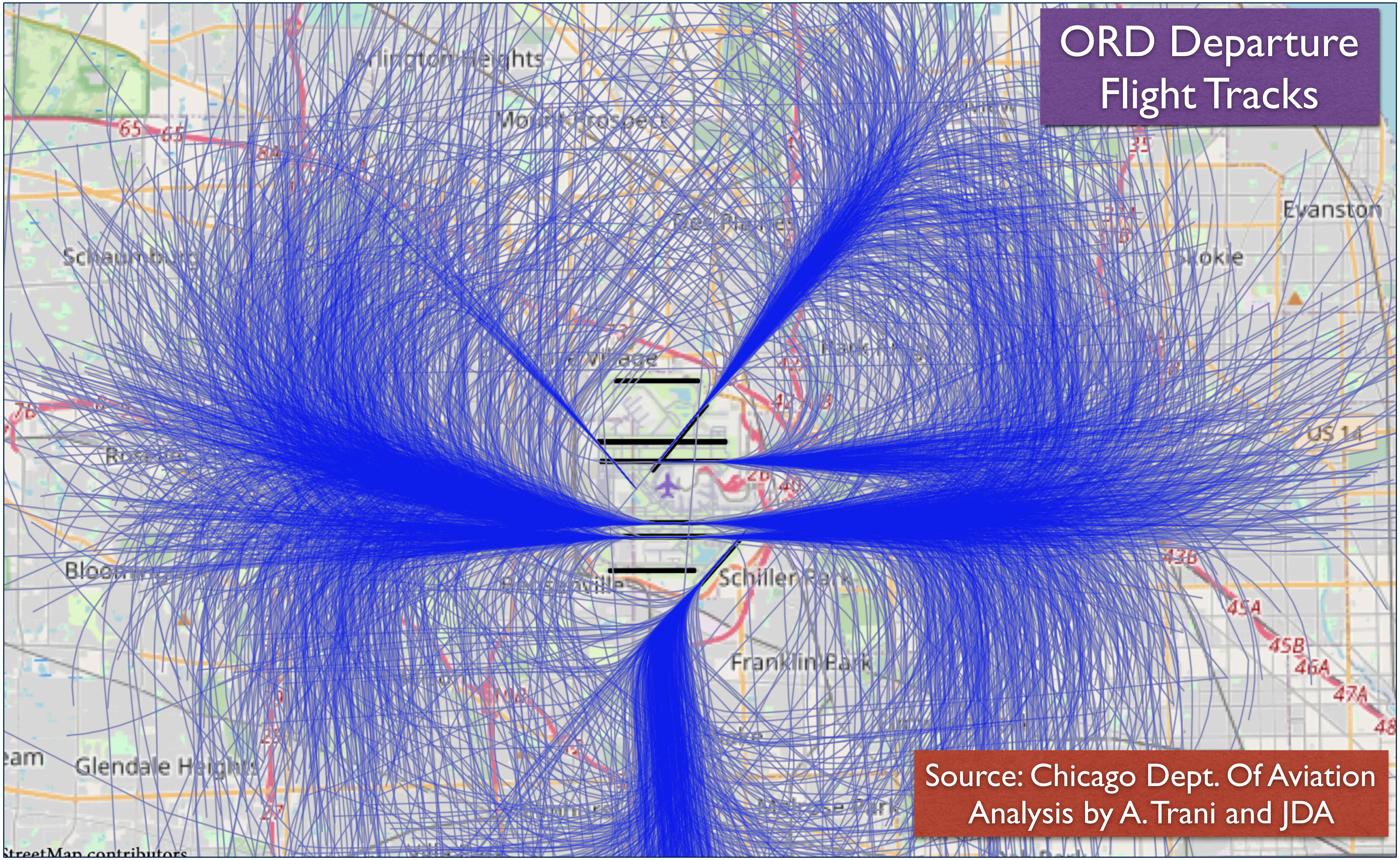


Examples of Noise Contours for Different Aircraft (ORD Runway 28R)



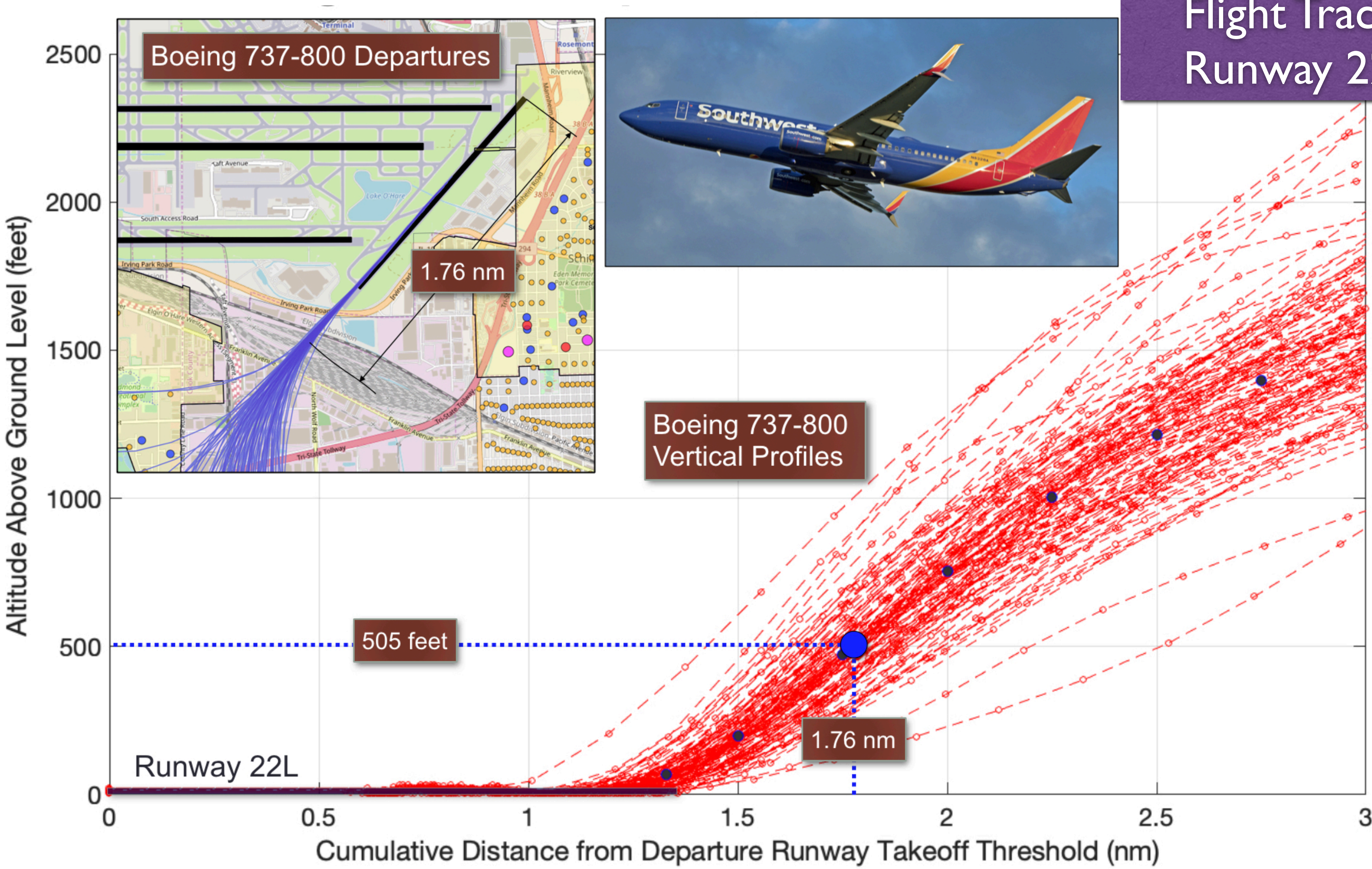
Heavier aircraft produce more noise

Computer Models are Required to Model Flight Tracks and to Estimate Noise Contours

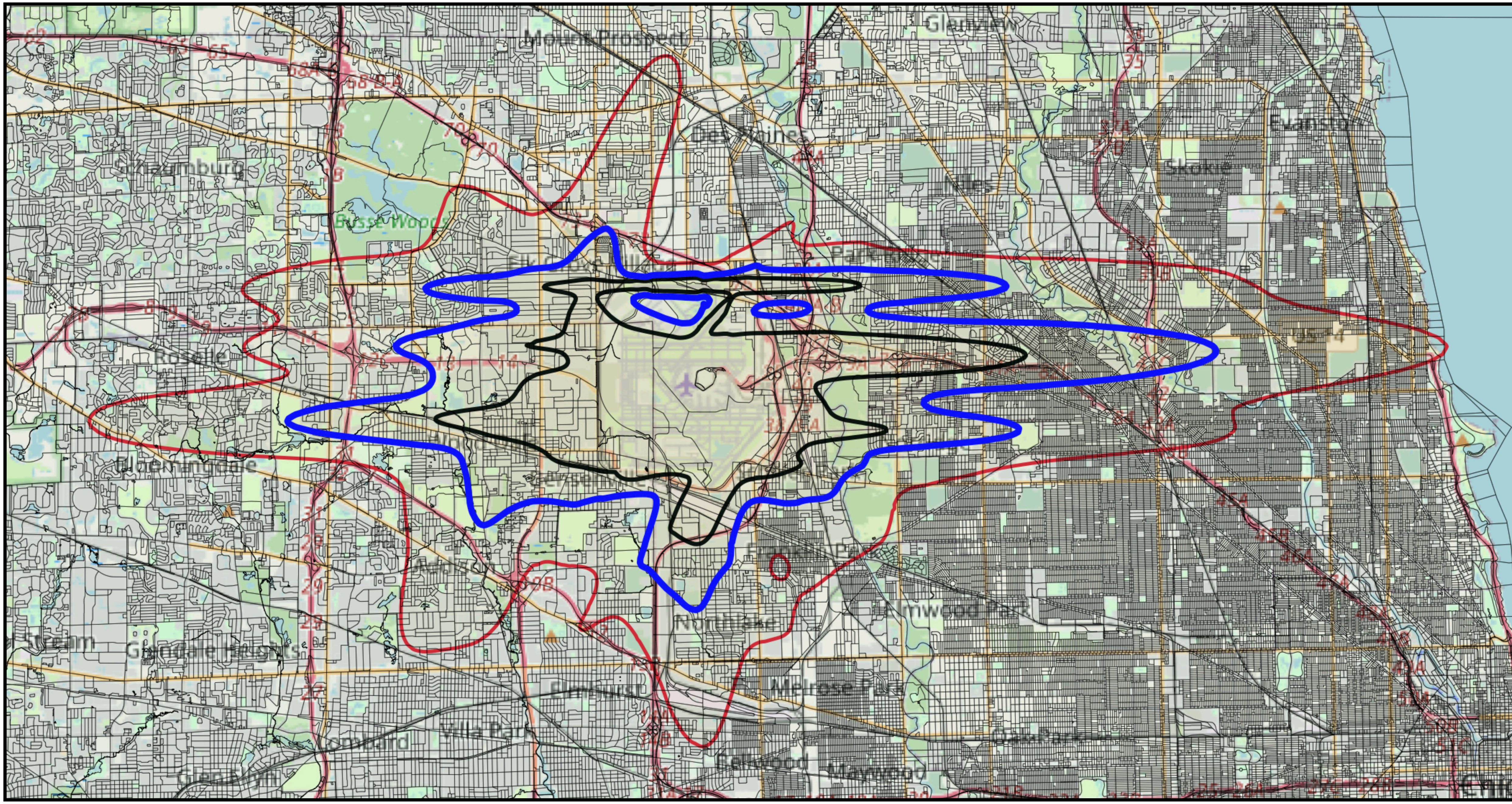


Computer Models Require Vertical Profiles of Flight Tracks Estimate Noise Contours

ORD Departure
Flight Tracks
Runway 22L

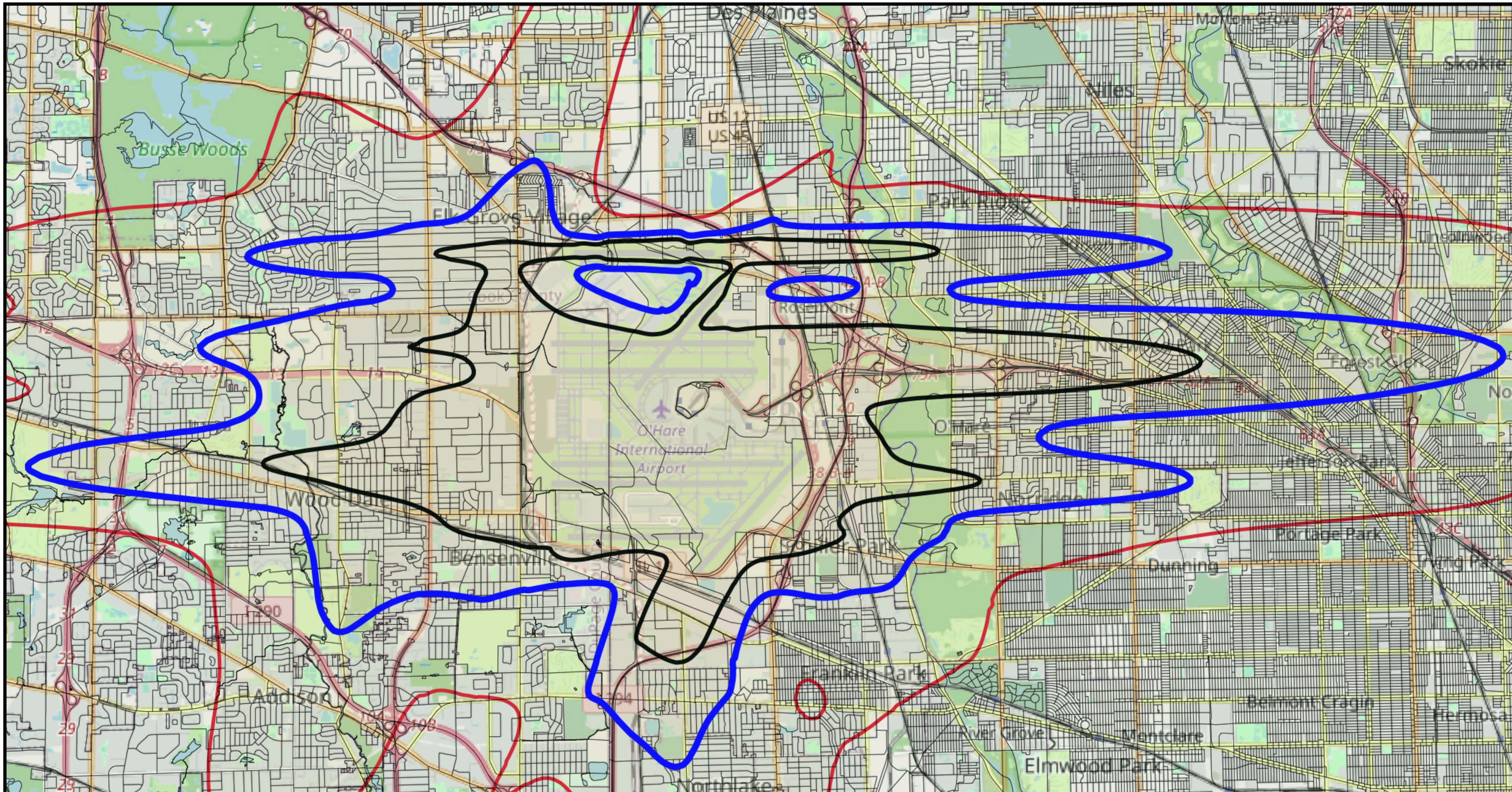


Future DNL Contours at Chicago ORD Airport (3070 Daily Operations)



65 DNL   60 DNL   55 DNL

Future DNL Contours at Chicago ORD Airport (3070 Daily Operations)

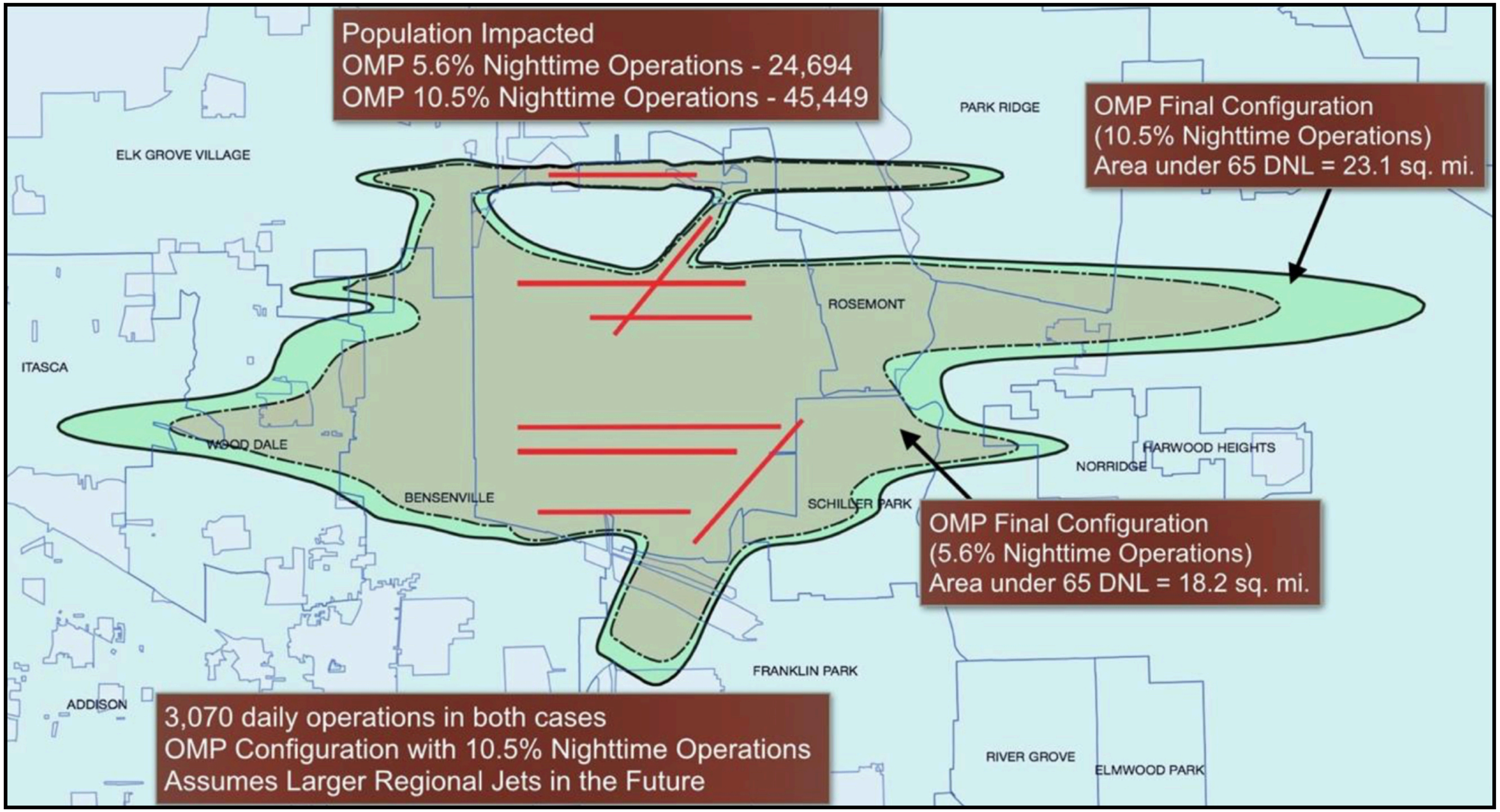


65 DNL — 60 DNL — 55 DNL

Source: JDA and A. Trani

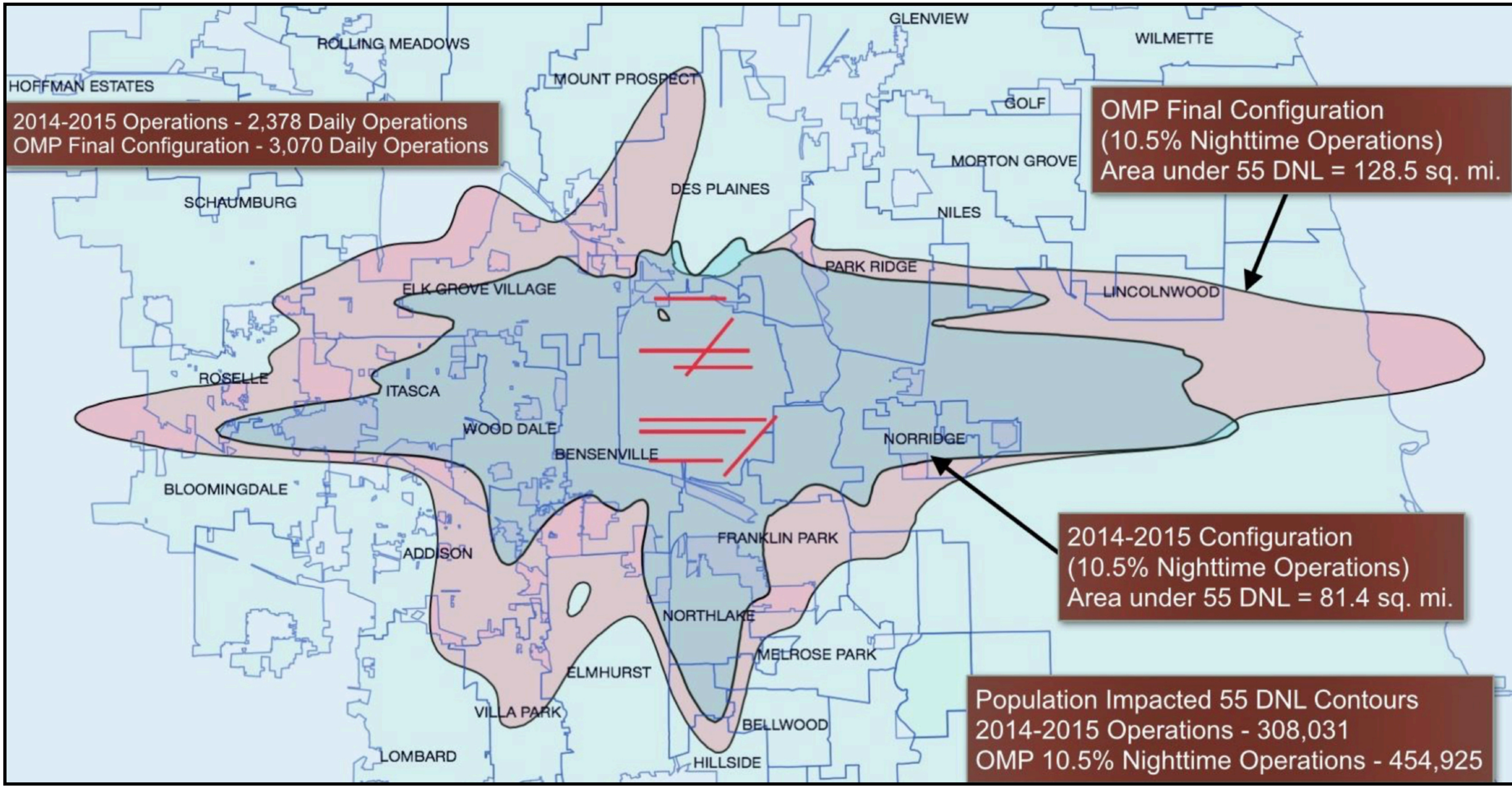
Use of Noise Contour Analysis

- Inform community of current and future noise impacts
- Guide decision makers on possible noise mitigation strategies



Source: https://jdasoc.files.wordpress.com/2015/11/jda-soc-ord-noise-study-summary-report-111915.pdf

Computer Modeling can Project Future Contours and Associated Population Impacts



Source: https://jdasoc.files.wordpress.com/2015/11/jda-soc-ord-noise-study-summary-report-111915.pdf

Measuring Average Sound Levels over a Long Period of Time

Equivalent Sound Level (Leq)

- Measures the equivalent sound level over a longer period of time
- Used to measure noise over a long time
- Applications:
  - Ramp noise at the airport
  - Runway operation noise etc.

Equivalent Steady Sound Level (Leq)

$$L_{eq} = 10log\left[\frac{1}{T}\sum_{i=1}^{N}10^{L_i/10}\Delta t\right]$$

L_{eq} = Equivalent steady sound level (dbA)

L_i = Instantaneous Sound Pressure Level recorded at discrete intervals of time

T = time period to measure Leq

Δt = is the delta time interval (typically 0.5 to 1 seconds)

Ramp Noise at the Punta Cana Airport

- The objective is to measure the noise around a ramp position at the Punta Cana International Airport
- We use a Casella CEL 242 (Type 2) digital sound level noise meter

Casella CEL 242

Punta Cana Ramp Area

Virginia Tech Students

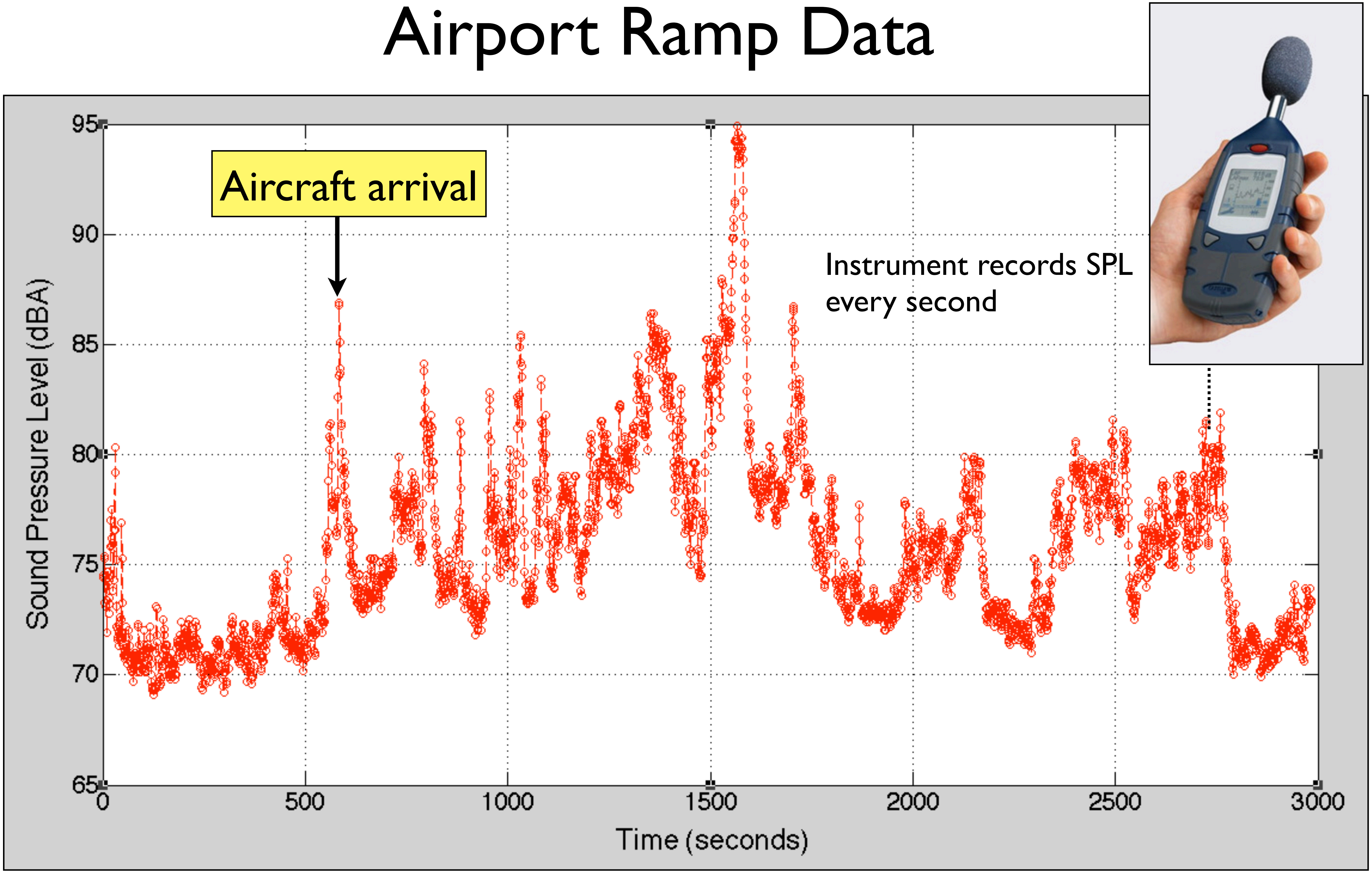
Equivalent Steady Sound Level (Leq) Numerical Example# 2 : Ramp Noise

<CEL-242 Data>	
Version	509-01
<Run>	
Start	6/8/13 12:09
Duration	0:49:44
Serial Number	1539079
Run	12
Range	60-130 dB
Overload	No
Battery Low	No
Interval Seconds	1
<Broadband>	
LASmax	94.9
<Profile LASmax>	SPL dBA
6/8/13 12:09	74.5
6/8/13 12:09	74.4
6/8/13 12:09	73.3
6/8/13 12:09	75.3
6/8/13 12:09	75.4

Data captured at PUJ airport

Data sampled every second

Equivalent Steady Sound Level (Leq) Airport Ramp Data



Equivalent Steady Sound Level (Leq) Airport Ramp Data

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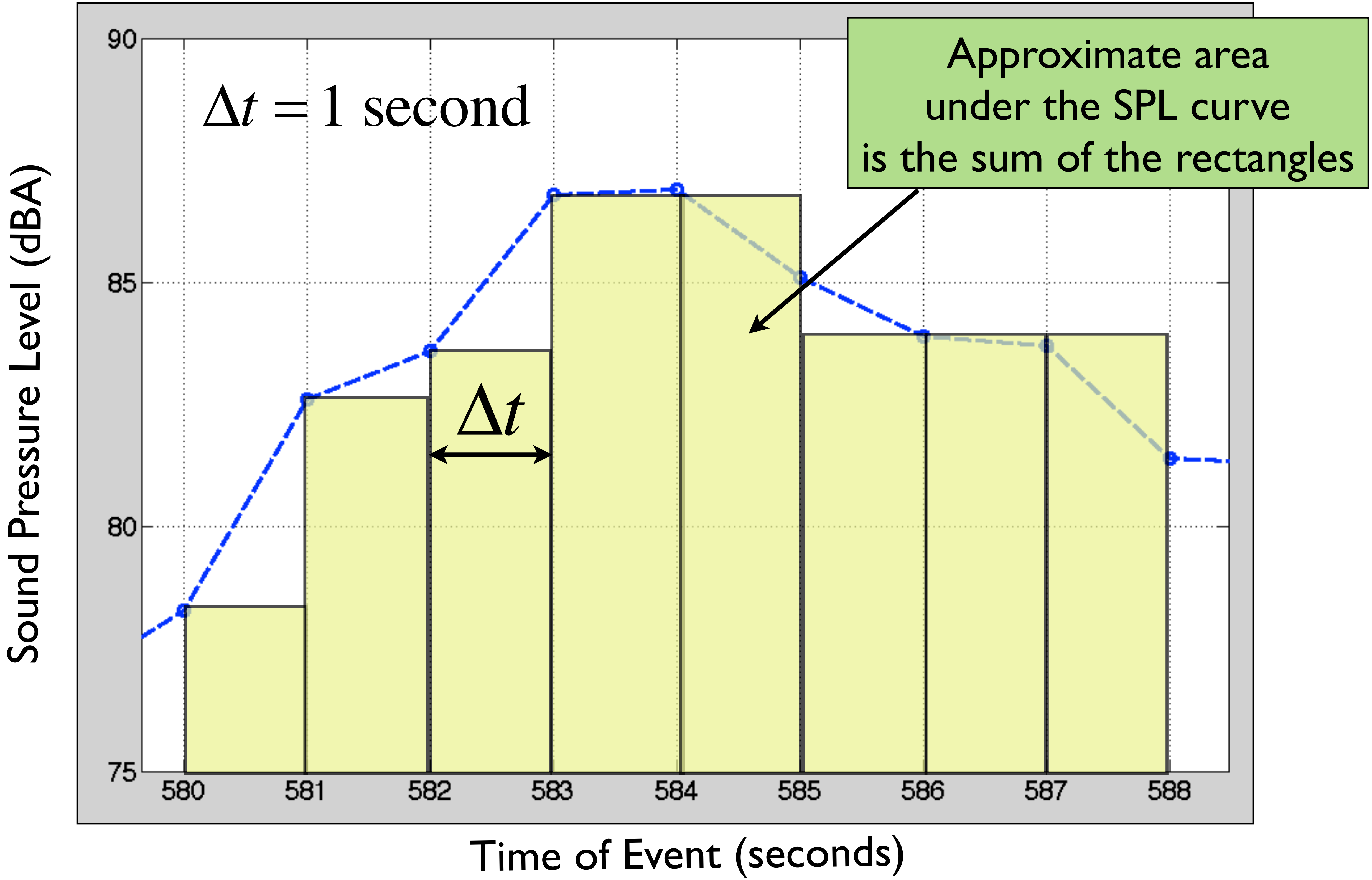


Equivalent Steady Sound Level (Leq) Computations using Excel

<CEL-242 Data>		
Version	509-01	
<Run>		
Start	6/8/13 12:09	
Duration	0:49:44	
Serial Number	1539079	
Run	12	
Range	60-130 dB	
Overload	No	
Battery Low	No	
Interval Seconds	1	
<Broadband>		
LASmax	94.9	
<Profile LASmax>	SPL dBA	10^spl/10
6/8/13 12:09	74.5	28183829.31
6/8/13 12:09	74.4	27542287.03
6/8/13 12:09	73.3	21379620.9
6/8/13 12:09	75.3	33884415.61
6/8/13 12:09	75.4	34673685.05
6/8/13 12:09	74.5	28183829.31
6/8/13 12:09	74.3	26915348.04
6/8/13 12:09	73.1	20417379.45
6/8/13 12:09	71.9	15488166.19

$$L_E = 10 log\left[\frac{1}{T}\sum_{i=1}^{N} 10^{L_i/10}\,\Delta t\right]$$

Calculations of

$$10^{L_i/10}$$

Equivalent Steady Sound Level (Leq) Computations using Excel

1	<CEL-242 Data>		
2	Version	509-01	
3	<Run>		
4	Start	6/8/13 12:09	
5	Duration	0:49:44	
6	Serial Number	1539079	
7	Run	12	
8	Range	60-130 dB	
9	Overload	No	
10	Battery Low	No	
11	Interval Seconds	1	
12	<Broadband>		
13	LASmax	94.9	
14	<Profile LASmax>	SPL dBA	10^spl/10
15	6/8/13 12:09	74.5	28183829.31
16	6/8/13 12:09	74.4	27542287.03

2989	6/8/13 12:58	73.4	21877616.24
2990	6/8/13 12:58	73.1	20417379.45
2991	6/8/13 12:58	73.5	22387211.39
2992	6/8/13 12:58	73.1	20417379.45
2993	6/8/13 12:58	72.9	19498446
2994	6/8/13 12:58	73.9	24547089.16
2995	6/8/13 12:58	73.9	24547089.16
2996	6/8/13 12:58	73.4	21877616.24
2997	6/8/13 12:58	73.3	21379620.9
2998	6/8/13 12:58	73.4	21877616.24
2999			
3000		Sum	2.30925E+11
3001		T	2984
3002		SUM/T	77387591.49
3003		Leq	78.8867133

$$L_E = 10log\left[\frac{1}{T}\sum_{i=1}^{N} 10^{L_i/10}\Delta t\right]$$

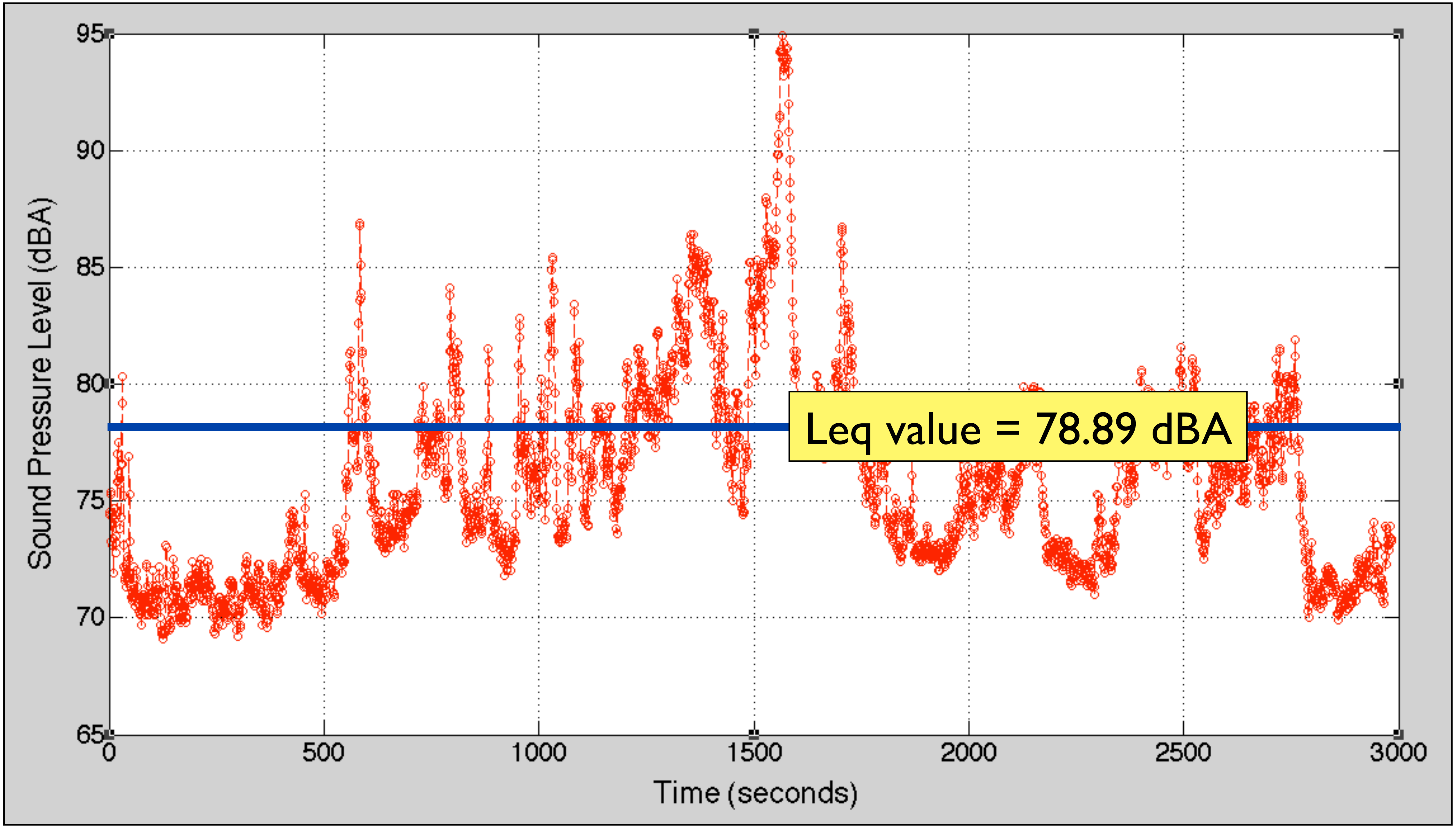
Thousands of recordings at Punta Cana airport

T=2984 seconds

$$\Delta t = 1 \text{ second}$$

Value of Leq

Equivalent Steady Sound Level (Leq) Punta Cana Data



Conclusion

- Noise is an important environmental impact caused by airport operations
- Noise metrics vary from instantaneous noise levels (SPL) to complex multi-aircraft, multi-track day-night average sound levels (DNL)
- The Sound Exposure Level is a single flyover metric that estimates the total acoustic energy produced by a single aircraft flying over an observer (normalized to one second)
- Computer models (like INM and AEDT-3) are needed to assess noise contours around airports