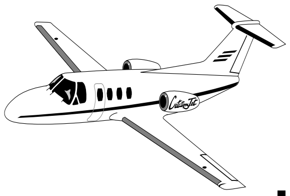
Noise Issues

CEE 5614
Analysis of Air Transportation Systems

Dr. Antonio A. Trani
Professor



What is Noise?

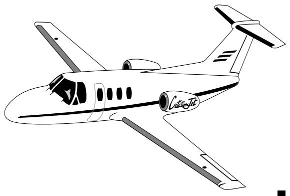
Many definitions of noise exist

- "Unwanted sound"
- "Any acoustic signal that detracts from the primary task in hand"

Aviation noise is the net result of aircraft flyovers as well as any other activity at the airport that produces unwanted sounds

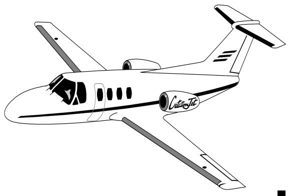
- Auxiliary Power Units (APU)
- Boilers and Chillers
- Automobile activity

Is Noise Important?

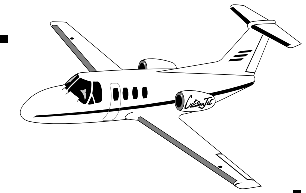


- One the most limiting factors in airport and aviation infrastructure expansion
- Many communities resent noise and thus limit airport and airspace growth activities
- Some airports (like **Haneda** in Japan and **Munich** in Germany) have taken 30 years to build new runways due to noise concerns
- In the U.S. noise is a big factor as well. Many airports face strict scrutiny due to noise-related complaints

Measuring Noise



- Noise is usually measured in Sound Pressure Level units (SPL - in Bels or decibels - dB)
- Annoyance due to noise is measured in Noys (see any human factors book for more information)
- Complex metrics have been developed to estimate the annoyance of aviation noise (flyovers and airport operations)
  - DNL - Average Day-Night Sound Level
  - CNEL - Community Noise Exposure Level
  - NEF - Noise Exposure Forecast



Definition of Sound Pressure Level

- Definition of SPL

$$SPL = 20\log\left(\frac{P}{P_0}\right) \qquad (1)$$

where:

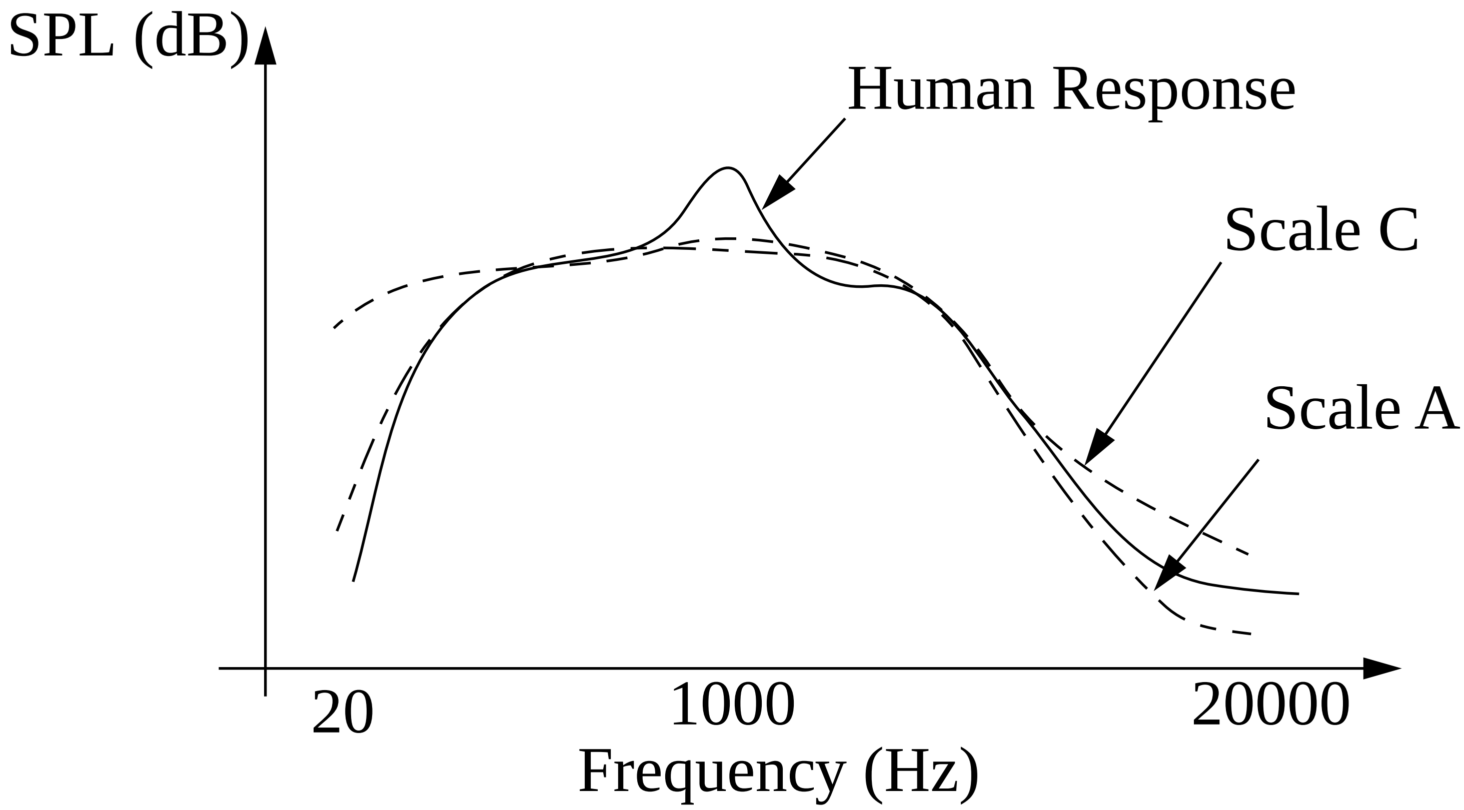
SPL is the sound pressure level (in dBA)

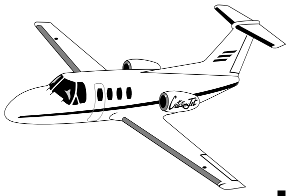
P is the pressure generated by the noise in question

P_o is the minimum audible pressure (0.002 Dyn/cm^2)

Human Frequency Response to Noise

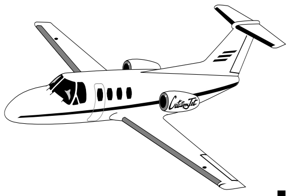
- Humans perceived noise at various frequencies according to the following notional response curve





Human Response

- A weighing scale assigns arbitrary values of SPL across the frequency domain
- Typically band centers for each weight are: (31.5, 63, 125, 250,500,1000, 2000, 4000, 8000, 16000 Hz)
- A single value of SPL can then be derived that includes all bands
- Of all possible weighting scales across frequency usually the A-scale is employed in aviation noise - labeled as **dBA**



Noise Attenuation Models

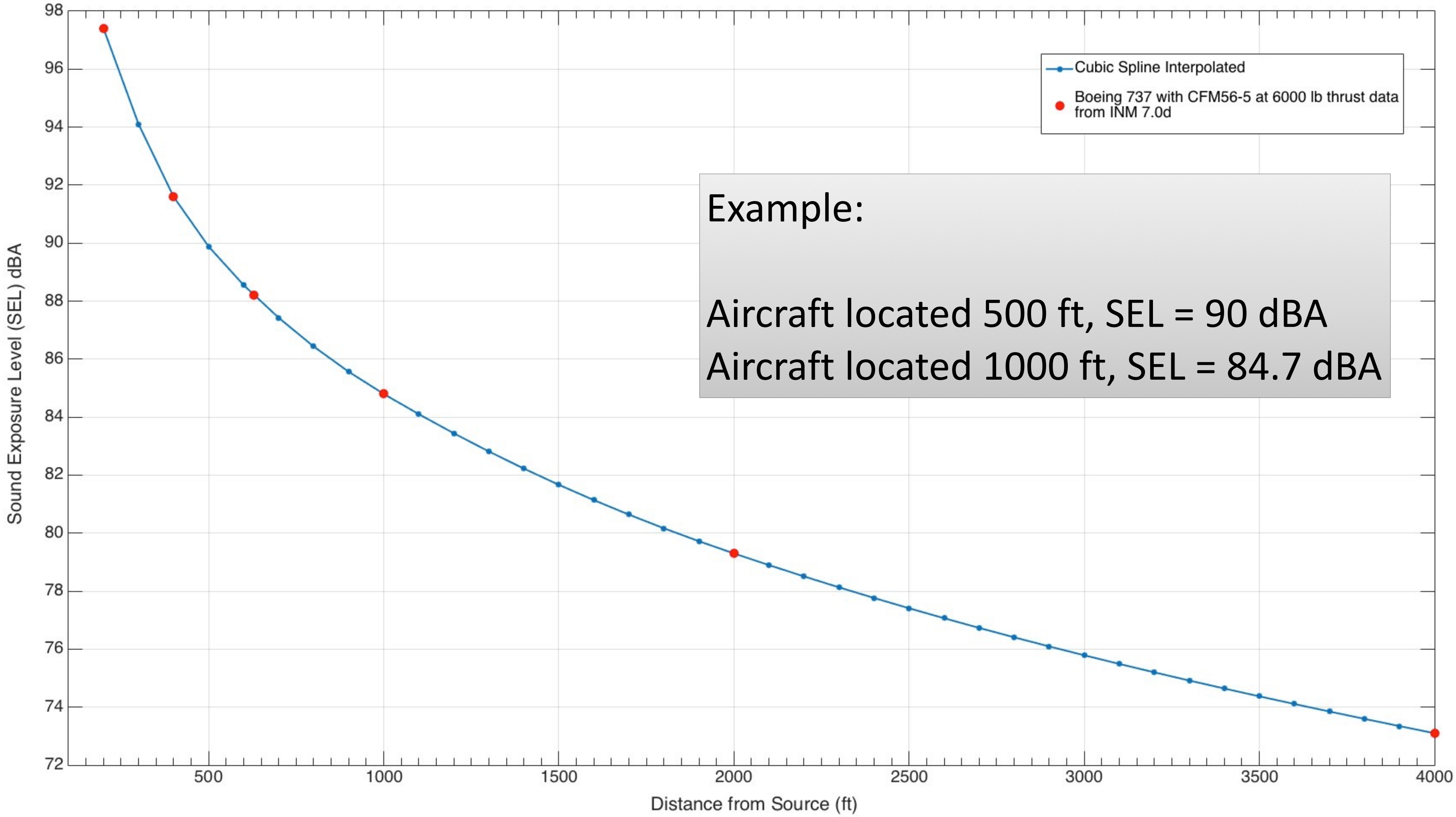
- Several theoretical and empirical models have been developed
- Linear Inverse-law Model (LIM)
- Power Inverse Models (PIM)
- Empirically derived models (such as those used in aviation noise computer applications)
- Most attenuation models correct for atmospheric effects (temperature and pressure)

Linear Inverse Law Model (LIM)

$$\frac{d_r}{d_2} = \frac{P_2}{P_1}$$

- d_r is the reference distance (typically 15 m. or 50 ft.),
- P_r is the noise pressure at the reference distance d_r,
- d_2 is the pressure measured at the distance d_2 from the noise source, and
- P_2 is the noise pressure measured at distance d_2 from the source

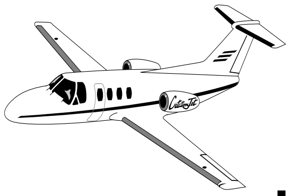
Sound Exposure Level (SEL) vs Distance Curves
Linear Scales



Example:

Aircraft located 500 ft, SEL = 90 dBA
Aircraft located 1000 ft, SEL = 84.7 dBA

source: INM 7.0d model



Example Problem

An engineer measures the noise generated by an aircraft engine (in a runup operation) using an accurate SPL meter as 102 dBA at 15 m. What would be the SPL at 200 m if the LIM model applies?

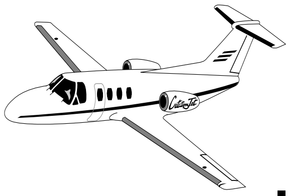
Convert SPL to pressure (at reference point)

- P_r = 251.7851 Dyn/cm^2
- P_2 = 18.8839 Dyn/cm^2

then convert this new pressure to SPL

- SPL_2 = 79.5012 decibels

LIM Model Characteristics



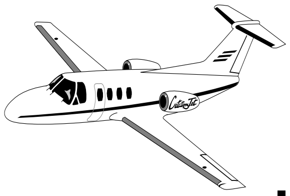
$$\frac{d_r}{d_2} = \frac{P_2}{P_r} \text{ LIM Model}$$

- Good for modeling point noise sources (aircraft in the airspace and in the airfield can be considered point sources)
- Nominal attenuation is 6 dBA per doubling distance
- Generally over predicts attenuation of real processes

Power Inverse Law Model (PIM)

$$\frac{d_r}{d_2} = \left(\frac{P_2}{P_1}\right)^n$$

- d_r is the reference distance (typically 15 m. or 50 ft.),
- P_r is the noise pressure at the reference distance d_r,
- d_2 is the pressure measured at the distance d_2 from the noise source,
- P_2 is the noise pressure measured at distance d_2 from the source,
- n is an empirically derived parameter.



LIM Model Characteristics

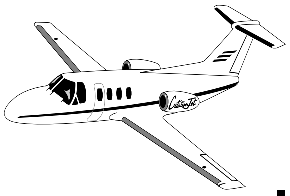
$$\frac{d_r}{d_2} = \left(\frac{P_2}{P_r}\right)^2 \text{ PIM-2 Model}$$

- Good for modeling line noise sources (a long train can be considered a line source)
- Nominal attenuation is 3 dBA per doubling distance
- Generally under predicts attenuation of real processes

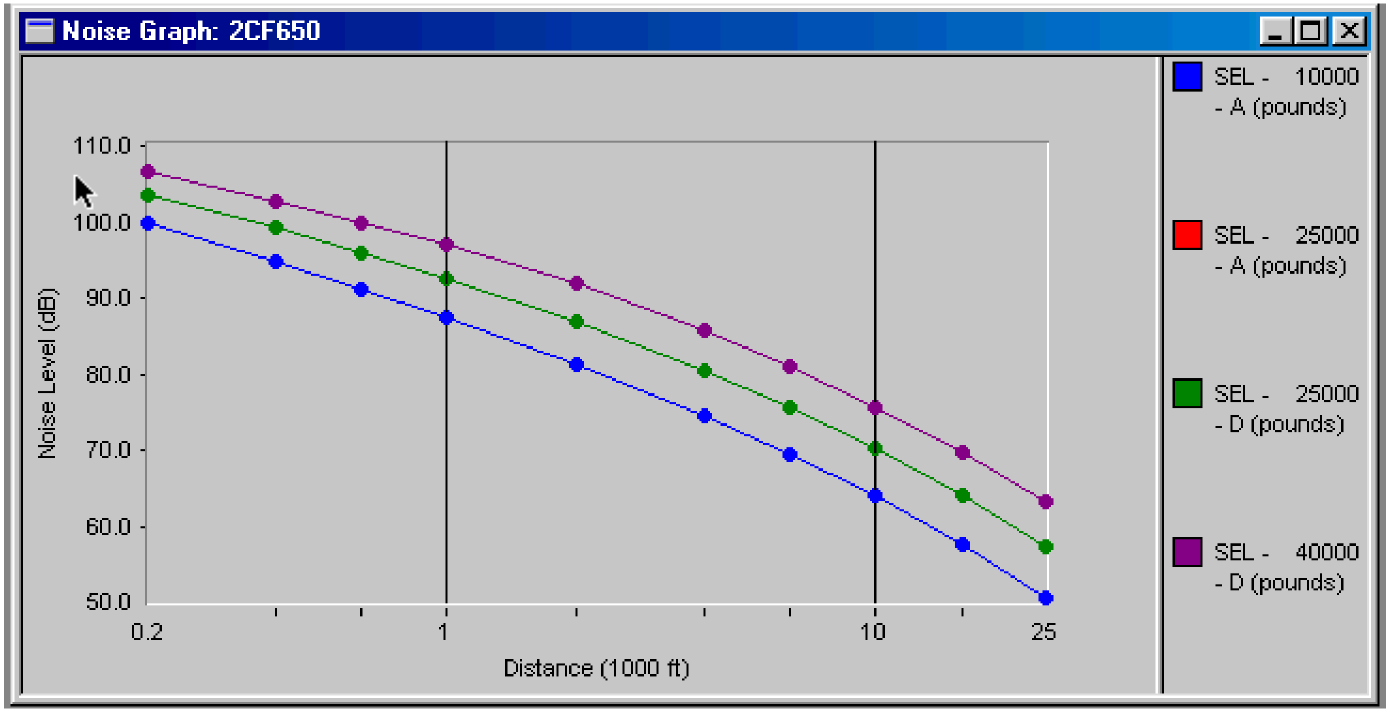
Empirical Models

- Many of them derive SPL from actual measurements in the field
- SPL is plotted as a function of distance
- In aviation applications we employ single flyover noise metrics to determine DNL, CNEL, and others

Sample Noise Attenuation in INM



the following graphic illustrate the typical noise attenuation curves (Noise-Power-Distance curves) contained in INM - the Integrated Noise Model



Single Flyover Noise Metrics

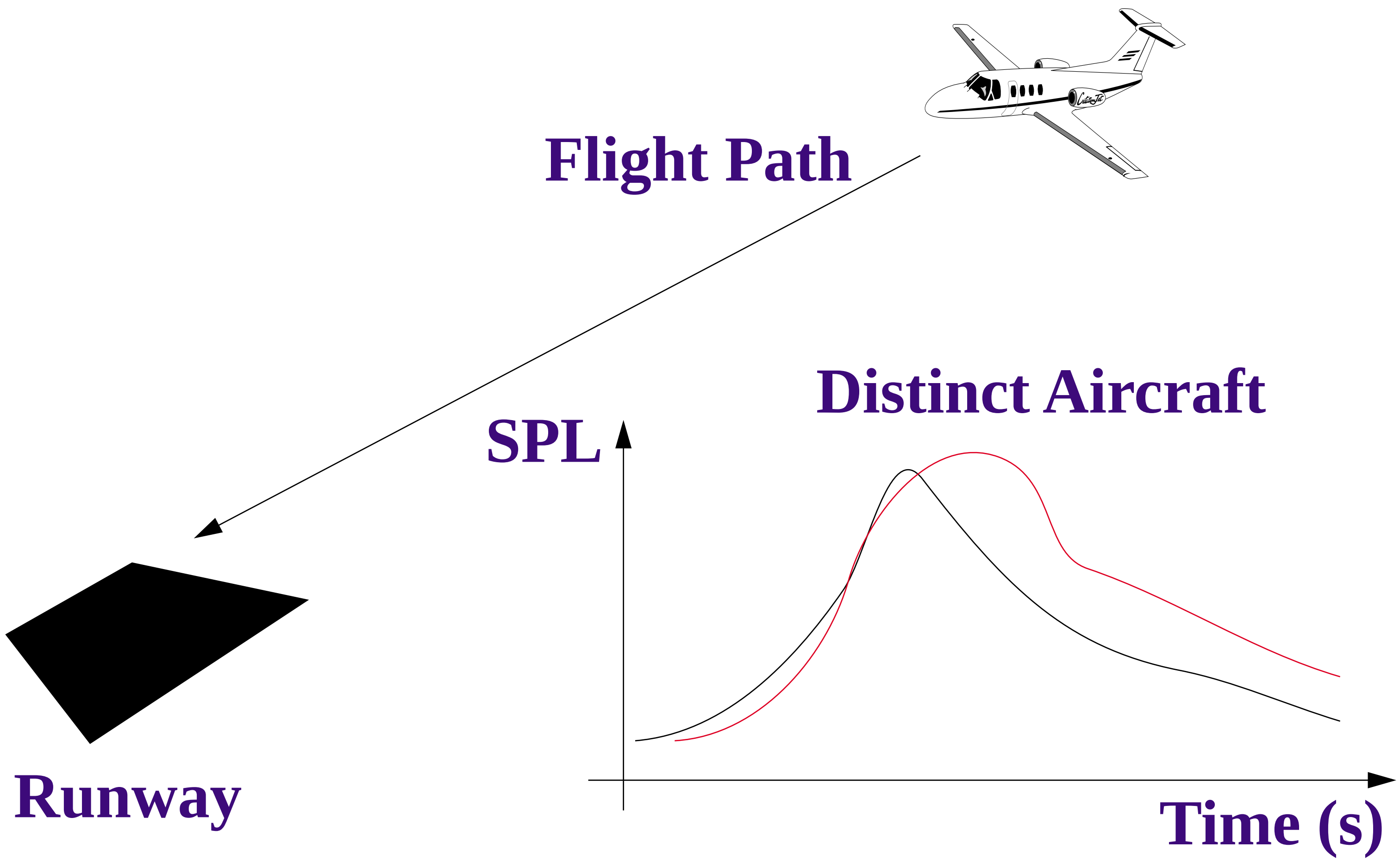
Two important metrics are used:

- EPNL - Effective Perceived Noise Level (dBA)
- SEL - Sound Exposure Level (dBA)

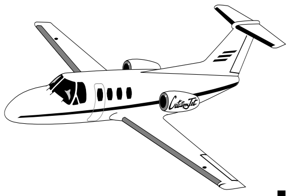
The main difference in the way they correct for pure tones (in the case of EPNL)

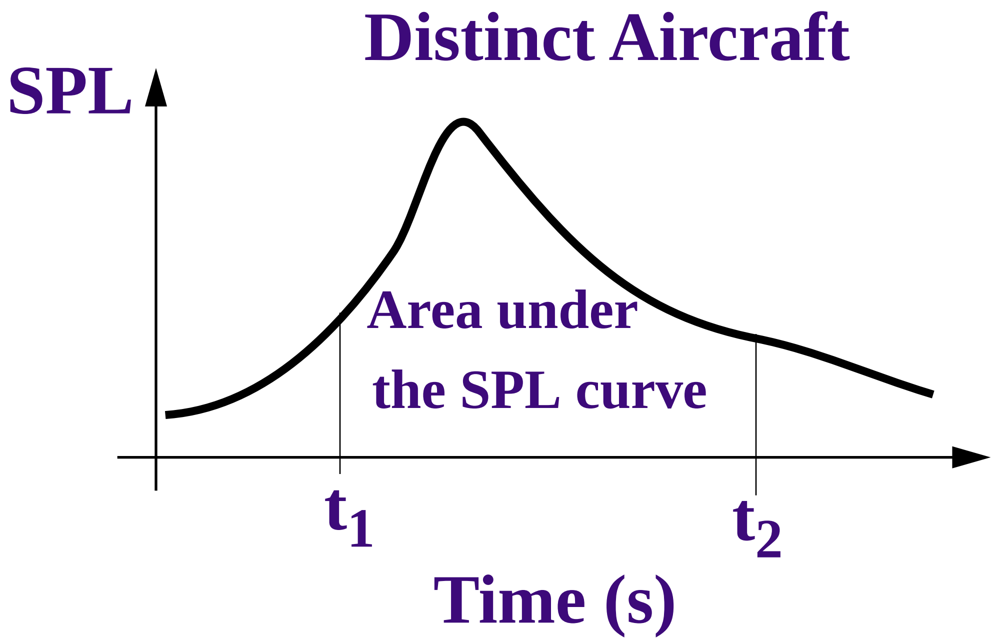
These two A-scale metrics are used during aircraft certification under FAR Part 36 or ICAO Annex 16

Sample Single Flyover SignatureSample



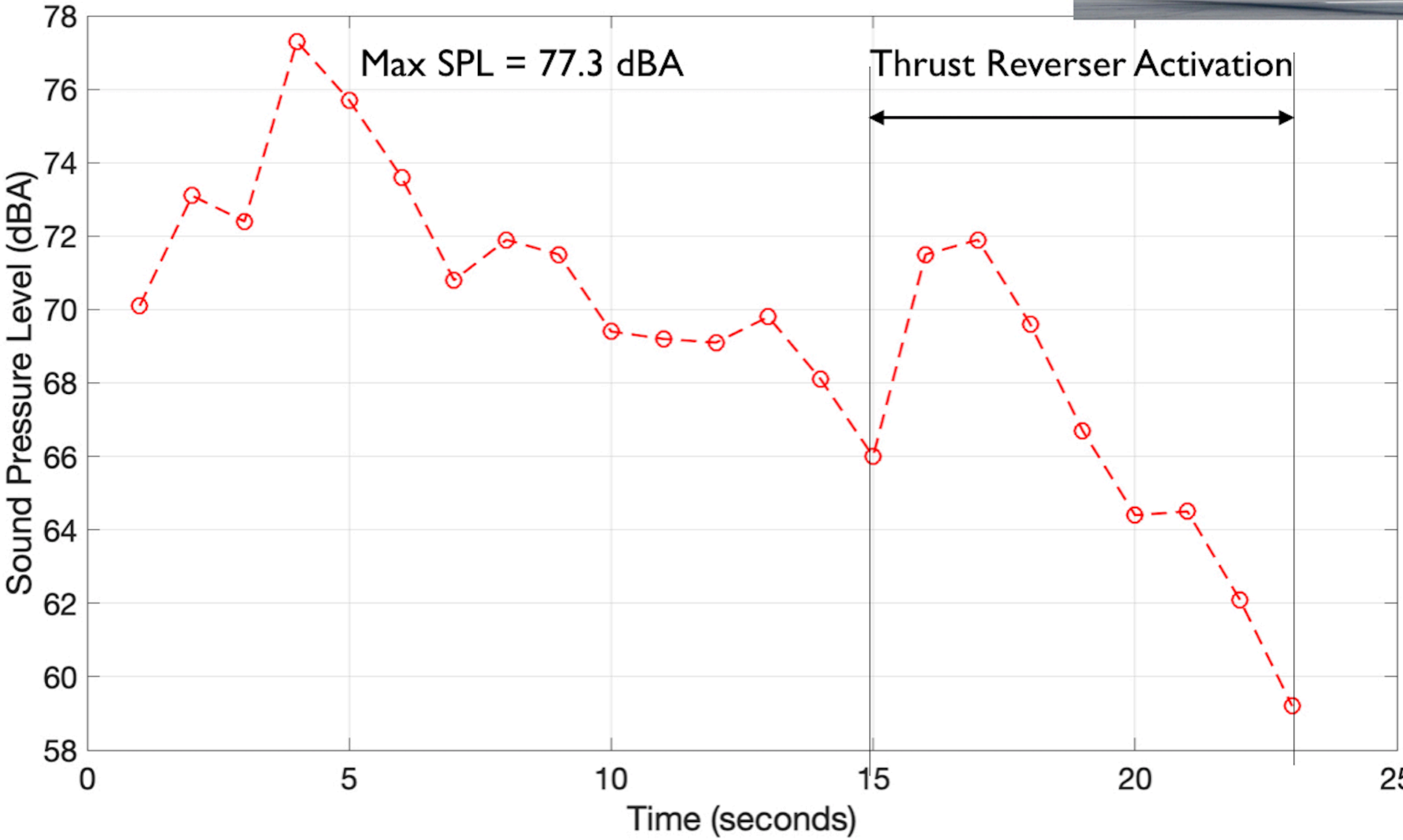
Acoustic Energy of a Single Flyover





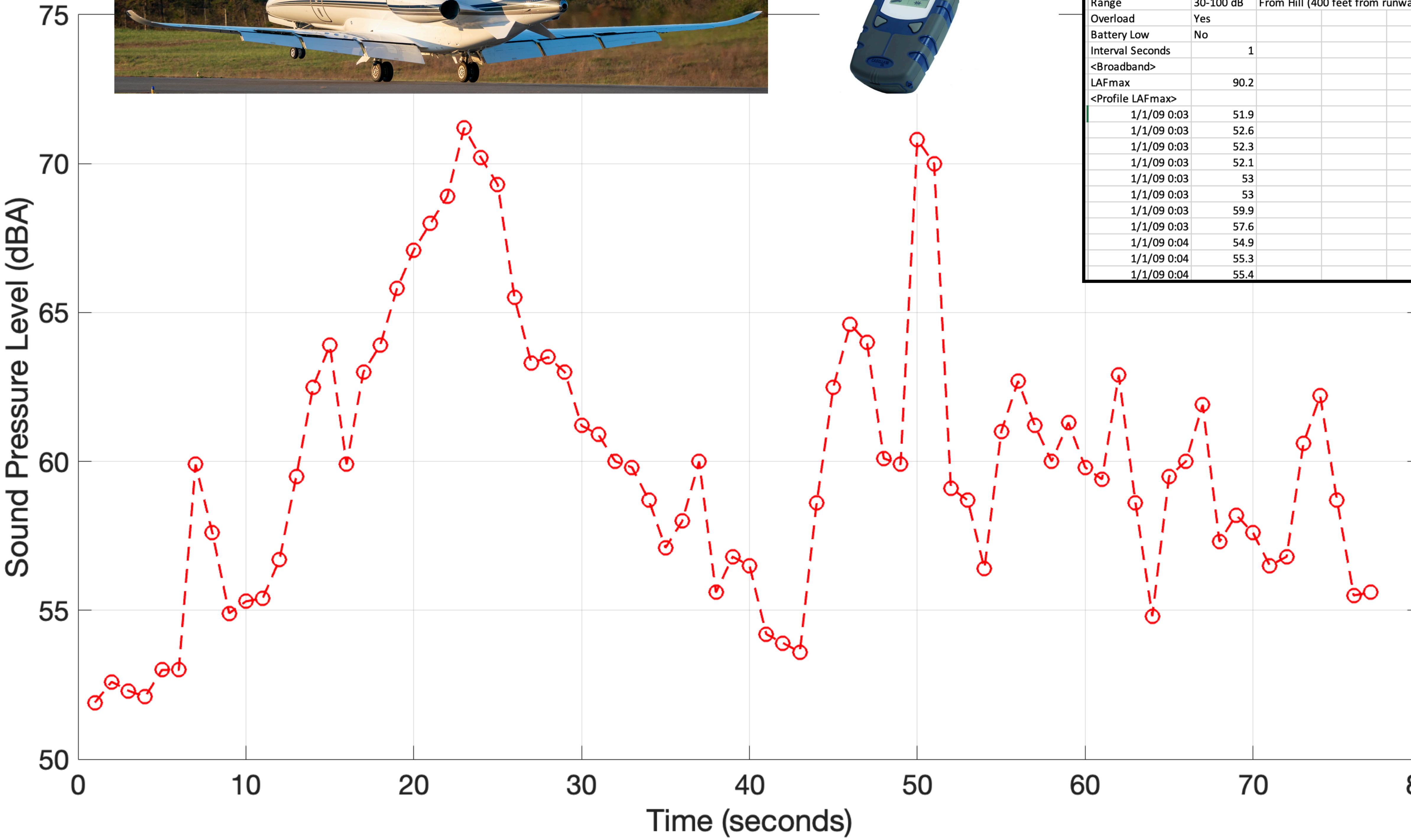
Energy = Area under the SPL curve (integral from t_1 to t_2)

BeechJet 400 (N520WS) Landing Event

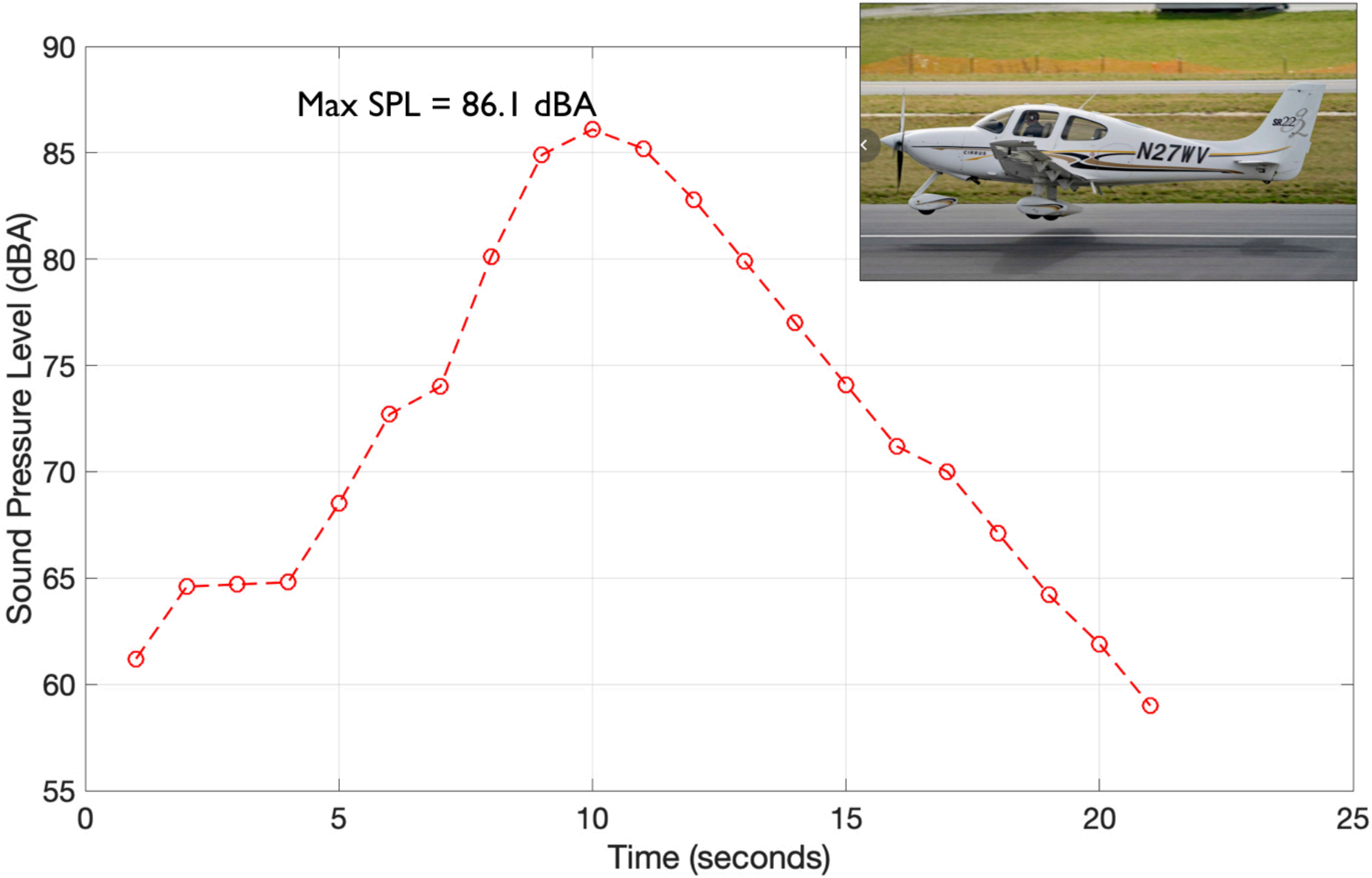


Cessna Citation Latitude (Landing)

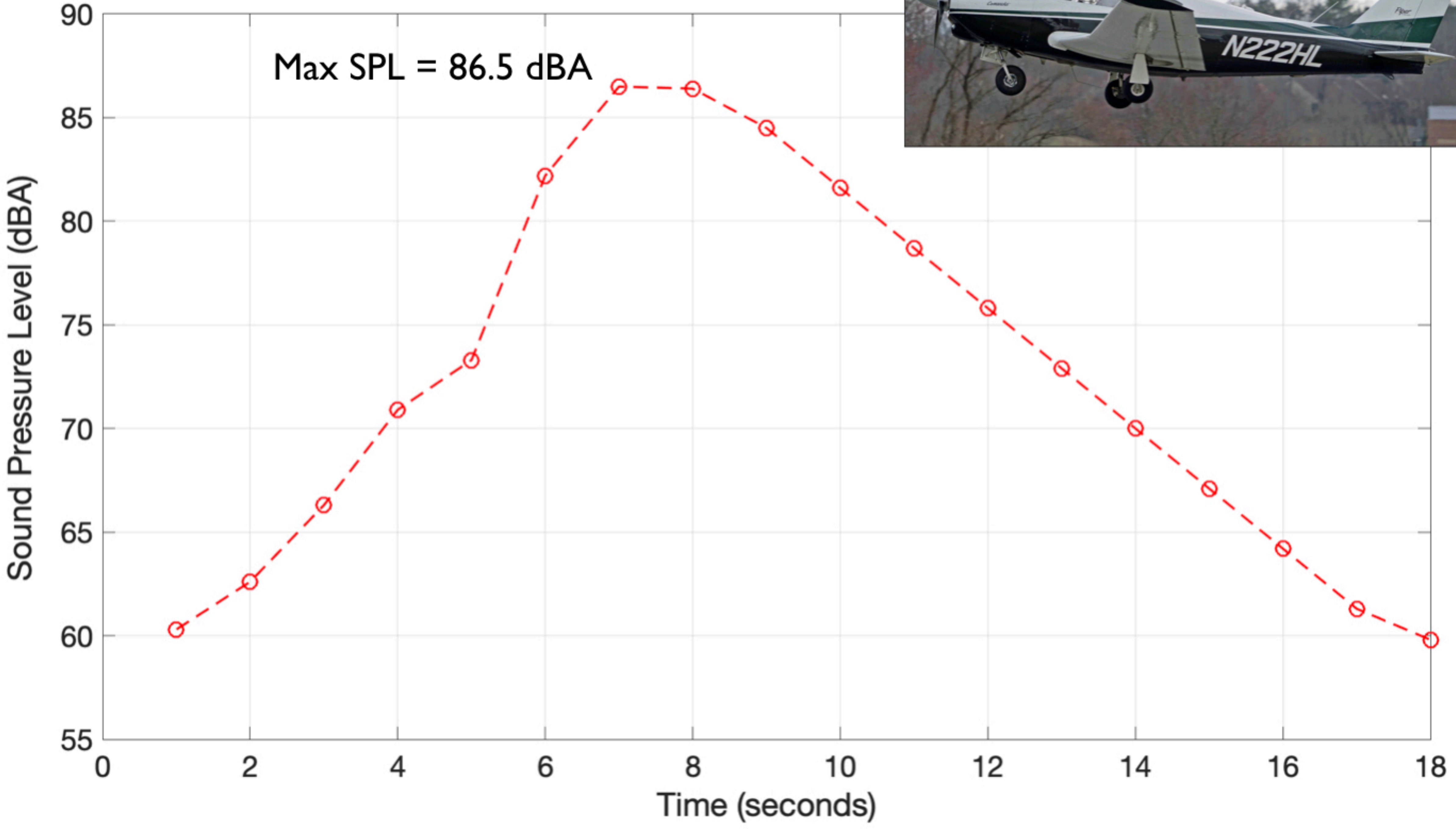
<CEL-242 Data>		
Version	035-07	
<Run>		
Start	1/1/09 0:00	
Duration	0:04:47	
Serial Number	1321460	
Run	6	Cessna Latitude anc Learjet 45
Range	30-100 dB	From Hill (400 feet from runway centerline)
Overload	Yes	
Battery Low	No	
Interval Seconds	1	
<Broadband>		
LAFmax	90.2	
<Profile LAFmax>		
1/1/09 0:03	51.9	
1/1/09 0:03	52.6	
1/1/09 0:03	52.3	
1/1/09 0:03	52.1	
1/1/09 0:03	53	
1/1/09 0:03	53	
1/1/09 0:03	59.9	
1/1/09 0:03	57.6	
1/1/09 0:04	54.9	
1/1/09 0:04	55.3	
1/1/09 0:04	55.4	



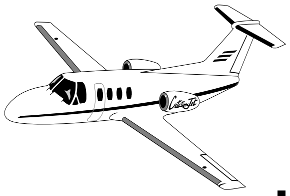
Cirrus SR22 (N27WV): Takeoff Event



Piper Comanche (N222HL): Takeoff Event

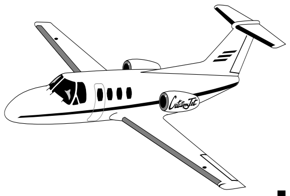


FAA and ICAO Noise Classification



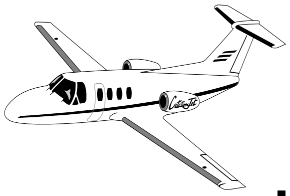
- According to FAR part 36 and ICAO Annex 16 (Environmental Protection Guidelines) aircraft must meet certain certification standards of noise
- Noise certification standards are functions of the Maximum Takeoff Weight (MTOW)
  + Aircraft below MTOW < 75,000 lb are exempt from noise rules
- Multiple stages or groups for certification are differentiated:
  + Stages 1 through 5

FAA and ICAO Noise Classification



- **Stage 1 -** Aircraft certified before January 1967 with no imposition of noise rules
  + First generation jet powered aircraft like the Boeing 707, Douglas DC-8, etc.
  + This group was banned from the skies of the US in December, 1988
- **Stage 2 -** Aircraft certified between Jan 1967 and November 1975
  + To this group belong most second generation jet powered aircraft like the Boeing 727, Douglas DC-9, Boeing 737-200, old Boeing 747s, etc.
  + A phaseout program is in effect to retire all Stage II aircraft by the end of the year 2000

FAA/ICAO Noise Classifications



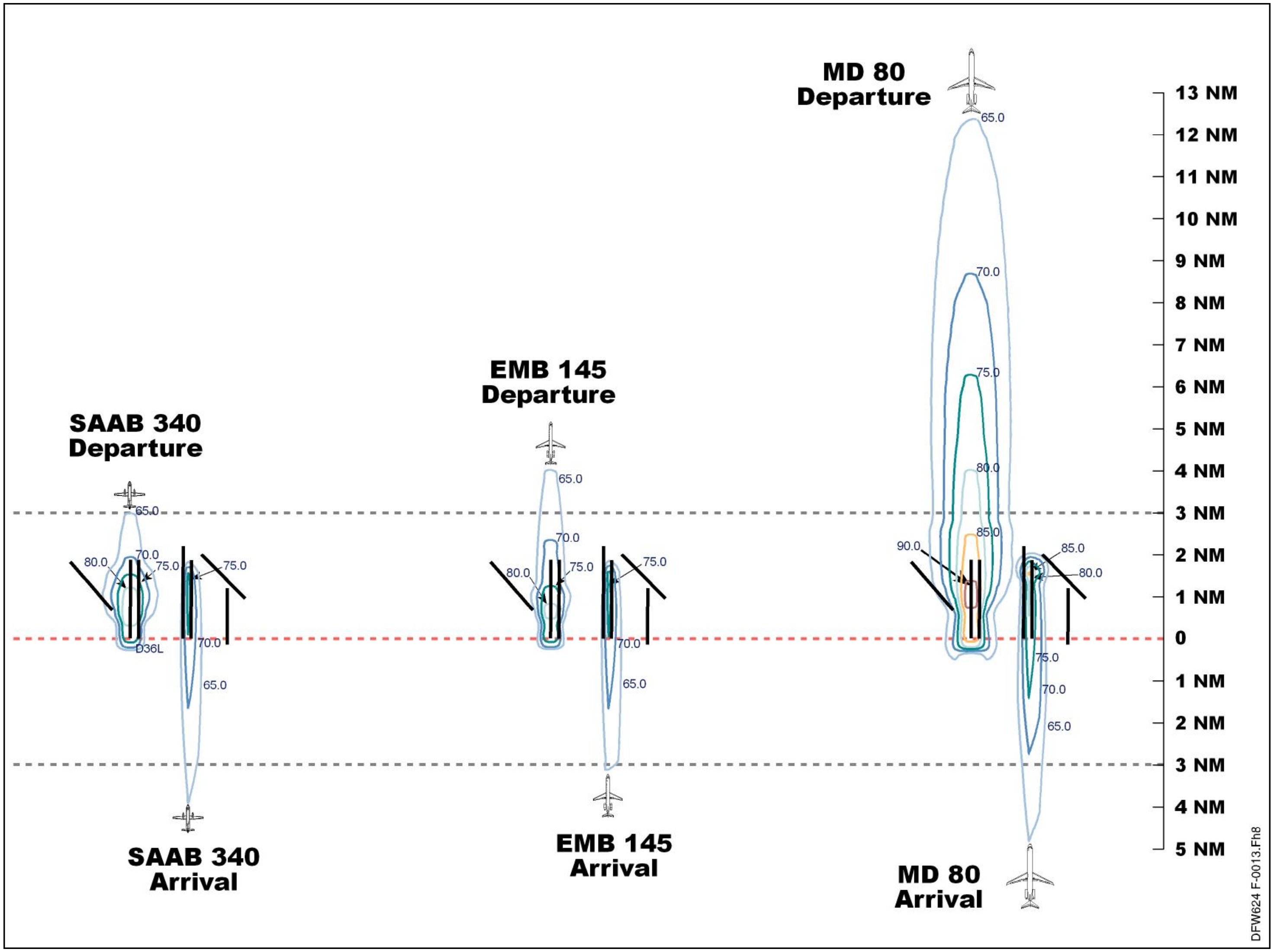
- **Stage 3** - Aircraft certified after November 1975
  - + To this group belong most third generation jet powered aircraft like the Boeing 757, 767, Airbus A-300, Airbus A-320, MD-80's , Boeing 737-300, new B-747s, MD-11, A330, A340, B777, etc.
  - + NOTE: some stage 2 and stage 1 aircraft can be re-engined to meet stage 3 norms like the Boeing 727-200 with new Rolls-Royce Tay engines or the Douglas DC-8 with GE/SNEMCA CFM-56 engines
  - + Several hush-kit options exist in the market to bring older aircraft into compliance of Stage 3 rules

Stage 4 and 5 Noise Criteria

- Stage 4 proposed on March 2002
- Implemented in January 1, 2006
- 10 dbA below Stage 3 standards
- Applies to aircraft > 12,500 lb.
- Stage 5 is the current standard applied by FAA and ICAO
- Stage 5 applies after December 2020
- Stage 5 applies to certain aircraft with a maximum take-off weight of less than 121,254 pounds (FAA)

Noise Footprint Comparison

- Noise footprints vary drastically among various aircraft

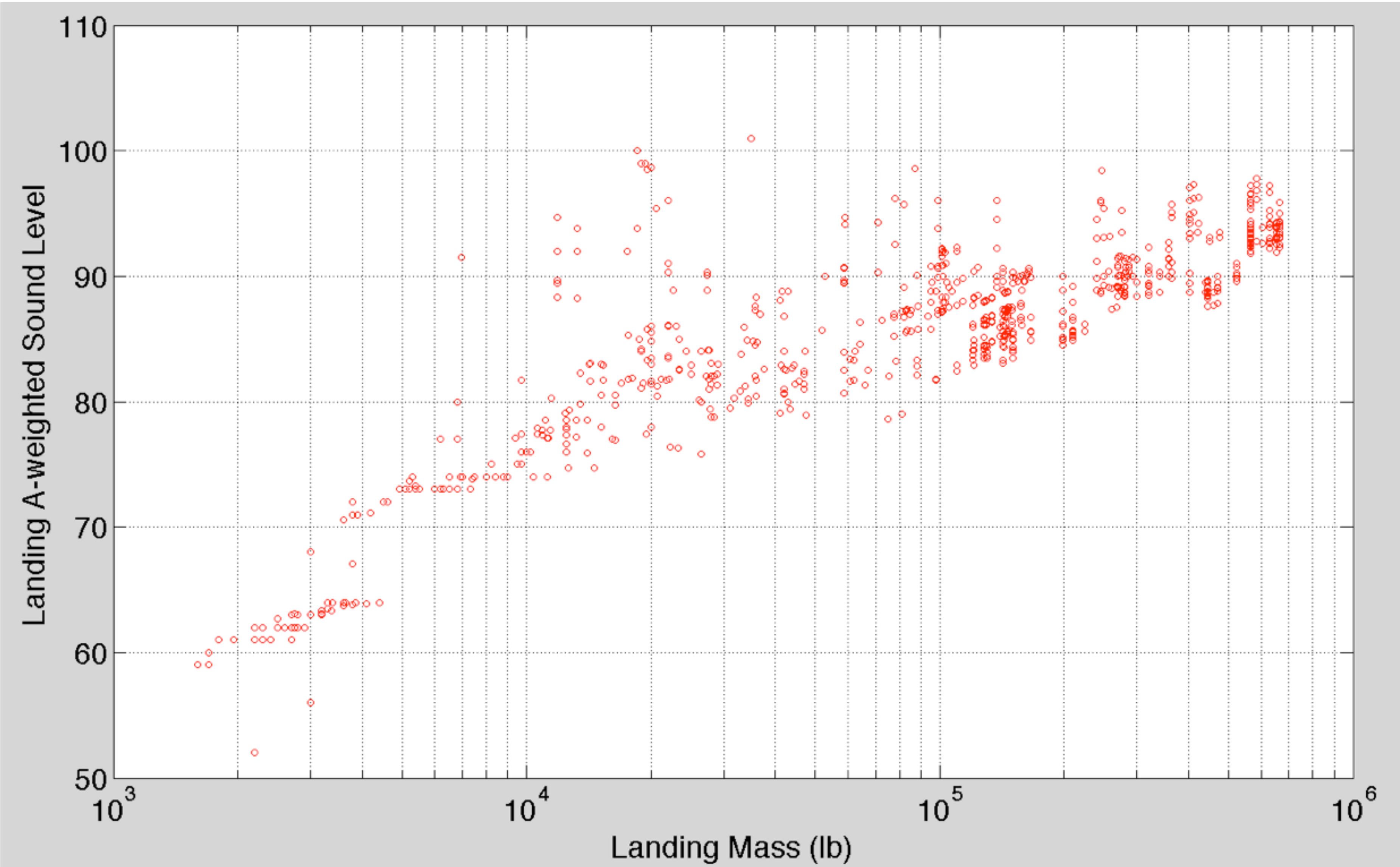


source: Mark Lundsford (Jacobs Airport Consultants)

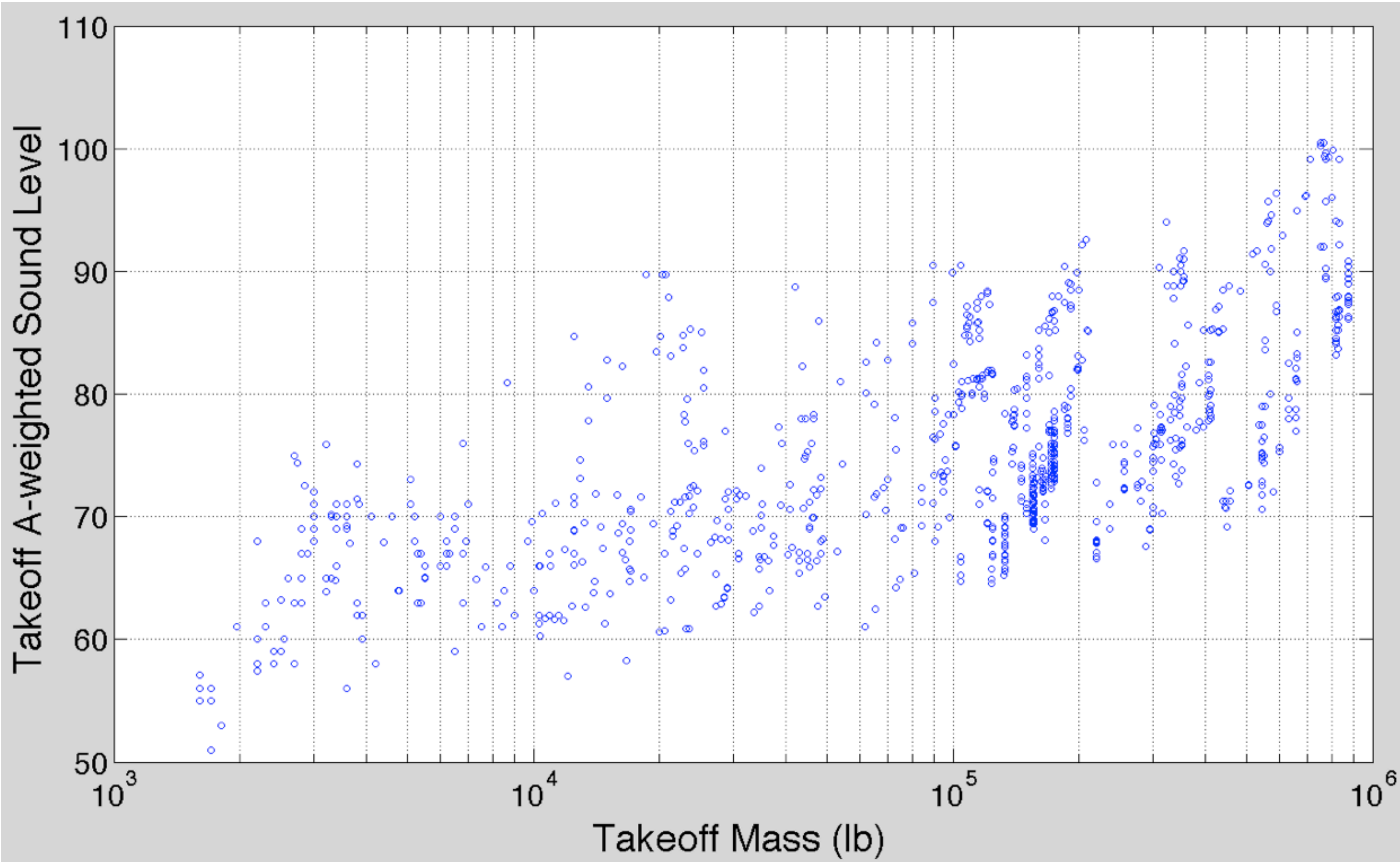
Observations

- Noise contours (65 dBA) of noisy aircraft like the MD-80 extend 12 nm from the departure takeoff point
- Regional jets such as the Embraer 145 have contours that extend 4 nm from the takeoff point
- Turboprop aircraft have substantially smaller contours
- The effects are magnified when multiple operations are superimposed

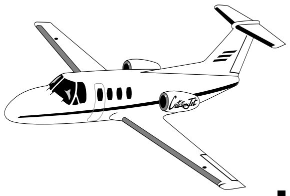
Landing Noise Values (dbA L-Level)



Takeoff Noise Values (dbA L-Level)



Aviation Noise Modeling Metrics

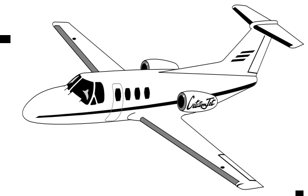


- CNEL - Community Noise Exposure Level
  - + Developed in California to address highly sensitive noise areas
  - + Includes information on track and type of aircraft
  - + Weighs night, evening and day time operations differently
- Ldn - Average Day-Night Noise Level
  - + The most standardized method to measure noise around airports
  - + Accepted by FAA and EPA (and OSHA)
  - + Weights night and daytime operations differently

Aviation Noise Modeling Metrics

- NEF - Noise Exposure Forecast
  - + An old noise evaluation formulation
  - + Considers different tracks and aircraft combinations
- TNEL - Total Noise Exposure Level (**ICAO Method**)
  - + Considers aircraft and flight tracks as well

CNEL Basics



$$NEF_{ij} = EPNdB_i + 10\ LOG(N_d + 16.7\, N_n)_j - 88$$

where:

NEF_{ij} is the noise exposure forecast for aircraft i in track

$EPNdB_i$ is the effective perceived noise level of aircraft i

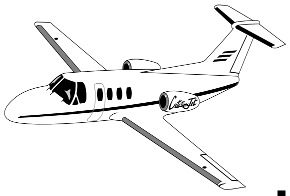
N_d is the number of daytime operations (07:00 to 22:00)

N_n is the number of night operations (22:00 to 07:00)

To estimate the NEF for a group af aircraft flying on the same trac we use:

$$NEF_j = 10\ LOG \sum_{i=1}^{n} \text{antilog}\left(\frac{NEF_{ij}}{10}\right)$$

DNL or L_{dn} Basics



- Poposed by EPA and now also used by FAA
- Incorporates the effects of day and night operations
- Also includes the aircraft types and tracks flown

$$L_{dn(ij)} = SEL_{ij} + 10\ LOG(N_d + 10N_n) - 49.4$$

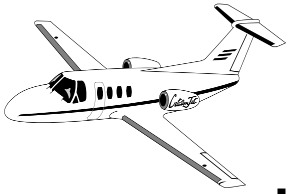
where:

SEL_{ij} is the sound exposure level of aircraft i flying track j (dBA

N_d is the number of daytime operations (07:00 to 22:00)
N_n is the number of night operations (22:00 to 07:00)

$$L_{dn} = 10\ LOG \sum_{j=1}^{m} \sum_{i=1}^{n} antilog\left(\frac{L_{dn(ij)}}{10}\right)$$

Community Noise Exposure Level (CNEL)



- Developed in California to assess the noise impact on very sensitive communities
- The formulation includes differences of aircraft and tracks flown

$$CNEL_{ij} = NEL_{ij} + 10\ LOG(N_c) - 49.4$$

$$N_c = N_d + 3\ N_e + 10\ N_n$$

where:

NEL_{ij} is the noise exposure level of aircraft i flying track j (dBA

N_c is a composite number of equivalent operations

N_d is the number of daytime operations (07:00 to 19:00)

N_e is the number of evenning operations (19:00 to 22:00)

N_n is the number of night operations (22:00 to 07:00)

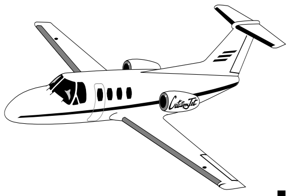
Adding CNEL Components

- Adding CNEL's for a flight track or for a point can be accomplished with a standard logarithmic addition formula

$$CNEL_j = 10 \, LOG \sum_{i=1}^{n} \text{antilog}\left(\frac{CNEL_{ij}}{10}\right)$$

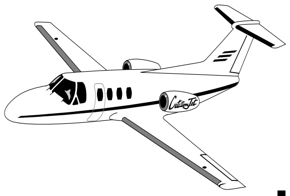
where:

$CNEL_j$ is the community noise exposure level below track j



Land Use Compatibility (General)

Land-Use Zone	Noise Exposure	L_{dn}	NEF	CNEL	Noise Controls
A	Minimal	0-55	0-20	0-55	No special consideration
B	Moderate	55-65	20-30	55-65	Land-use controls considered
C	Significant	65-75	30-40	65-75	Noise controls and easement
D	Severe	75 and up	40 and up	75 and up	Containment within airport boundary



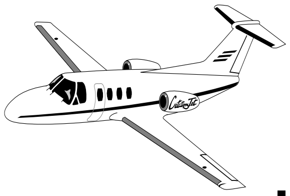
Land Use Chart (FAA Part 150)

Land use	Below 65	65-70	70-75	75-80	80-85	Above 85
Residential						
Residential, other than mobile homes and transient lodgings	Y[a]	N(1)	N(1)	N	N	N
Mobile home parks	Y	N[b]	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N

a. Y (Yes) = Land Use and related structures compatible without restrictions.

b. N (No) = Land Use and related structures are not compatible and should be prohibited.

Noise Computer Modeling

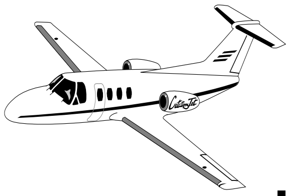


Several computer models exist to estimate aviation noise projected to populated communities

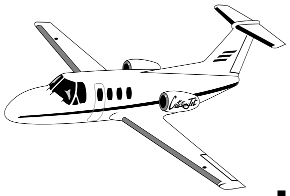
- INM - Integrated Noise Model
- HNM - Helicopter Noise Model
- Military noise model (Noisemap)
- AEDT 2 - New noise model (includes emissions)

Most of these models employ similar computational algorithms (INM, HNM, and AEDT 2) and some share the plotting routines to show noise contours

Justification for Noise Computer Models



- After 1969 every transportation project (including airport upgrades and plans) require a detailed environmental study
- The only way to convey information to communities around an airport is to compute potential noise levels before constructing a facility
- Noise prediction is a tedious process for real airports as there are too many aircraft and tracks that need to be analyzed in determining the noise at a point on the ground

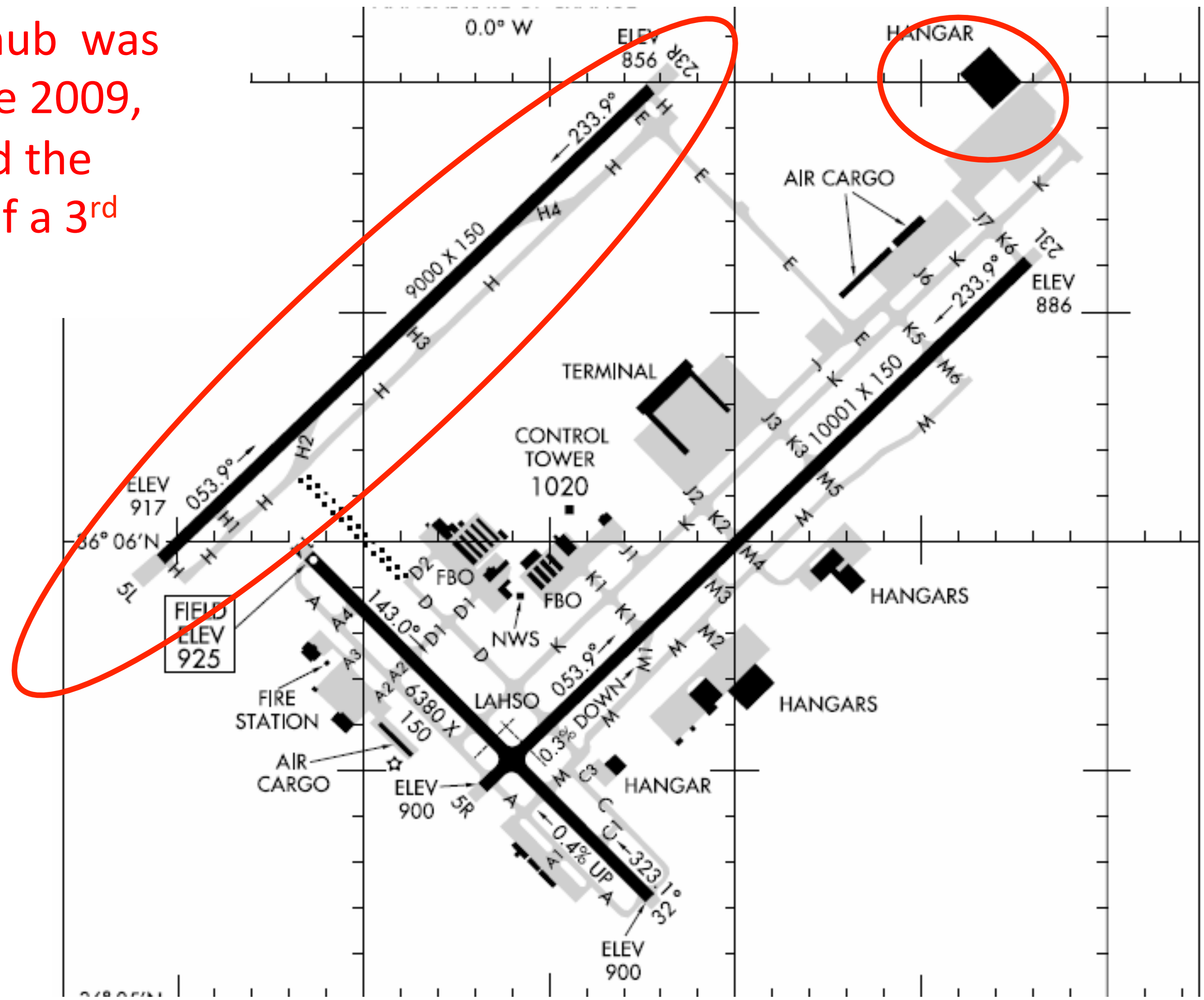


Types of Noise Studies

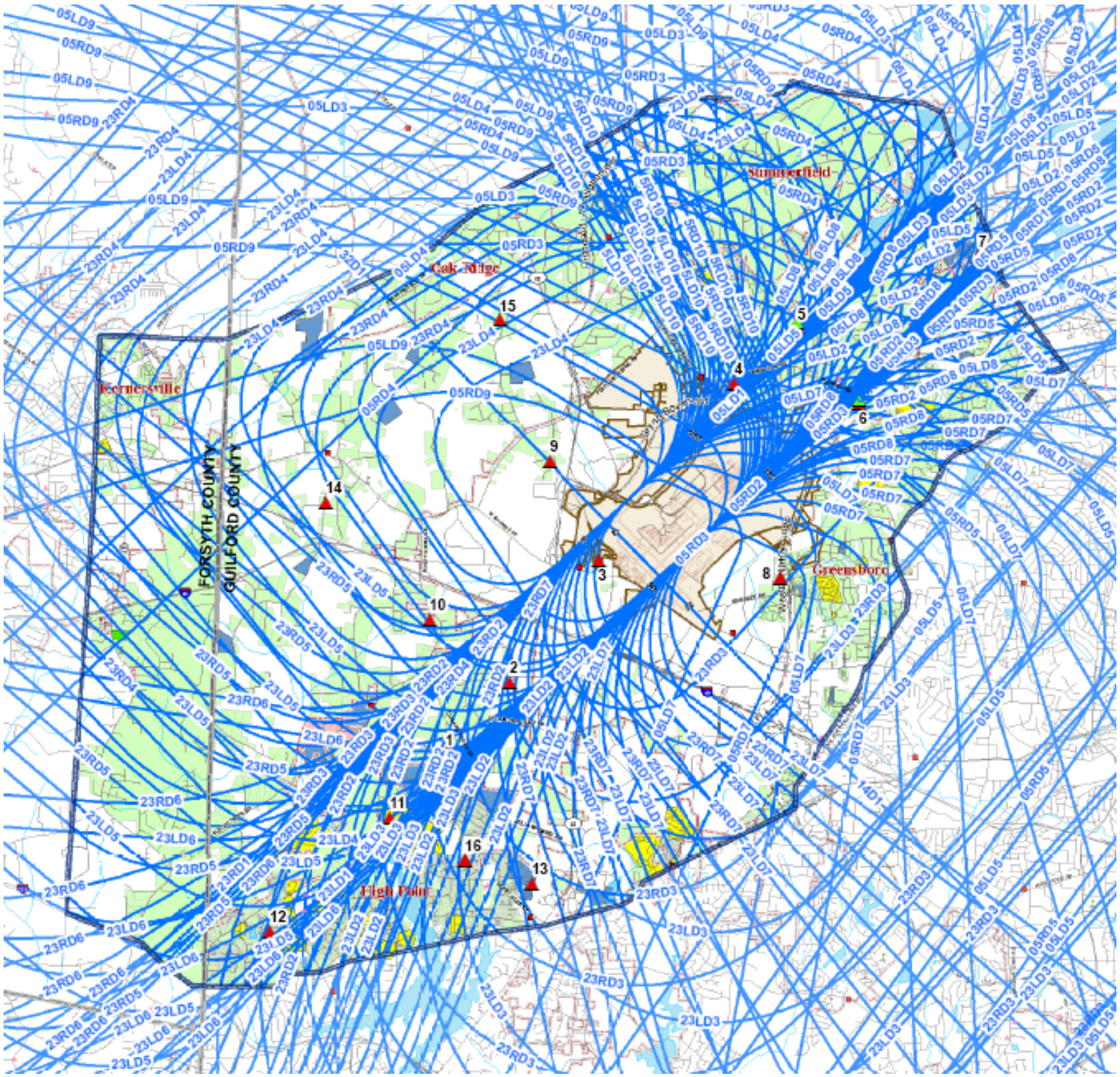
- Economic studies to assess noise impact on community
  - + Study the effect of housing relocation and sound insulation programs
  - + Land use planning around airports and zoning control
  - + To effectively restrict of incompatible land uses around an airport facility
- Part 150 airport noise compatibility studies
- FAA has in place a noise compatibility program for airports where noise problems have provoked community concerted complaints

GSO Noise Study

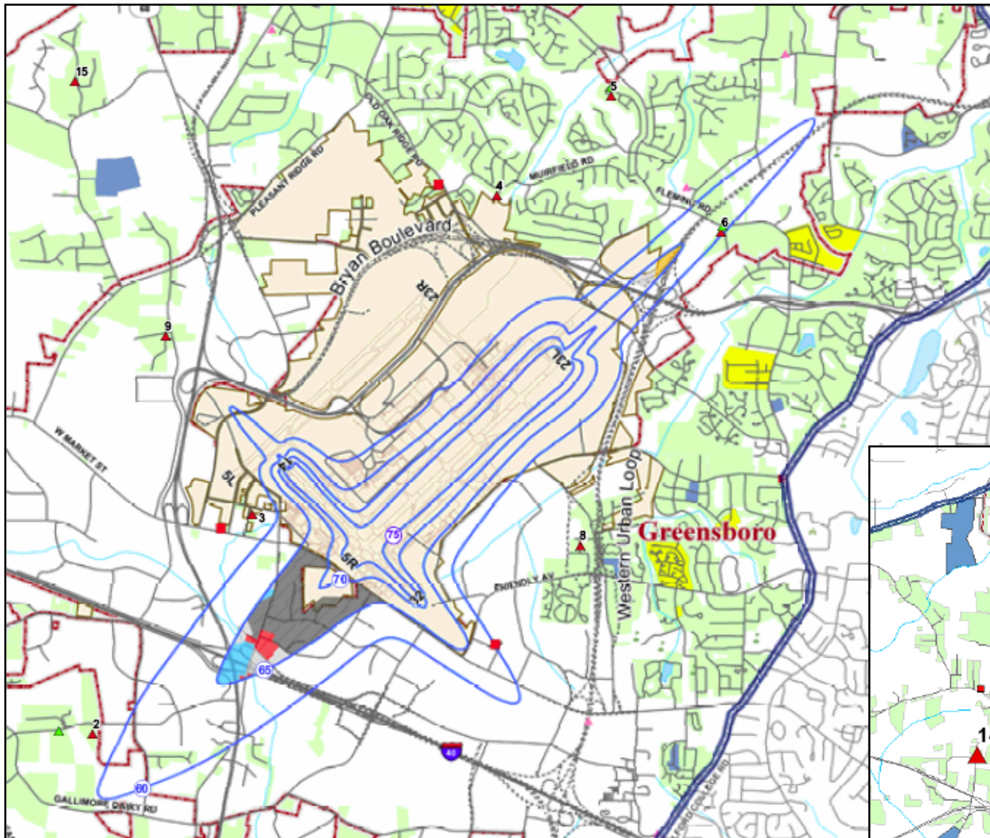
A new FedEx hub was opened in June 2009, which involved the construction of a 3rd runway

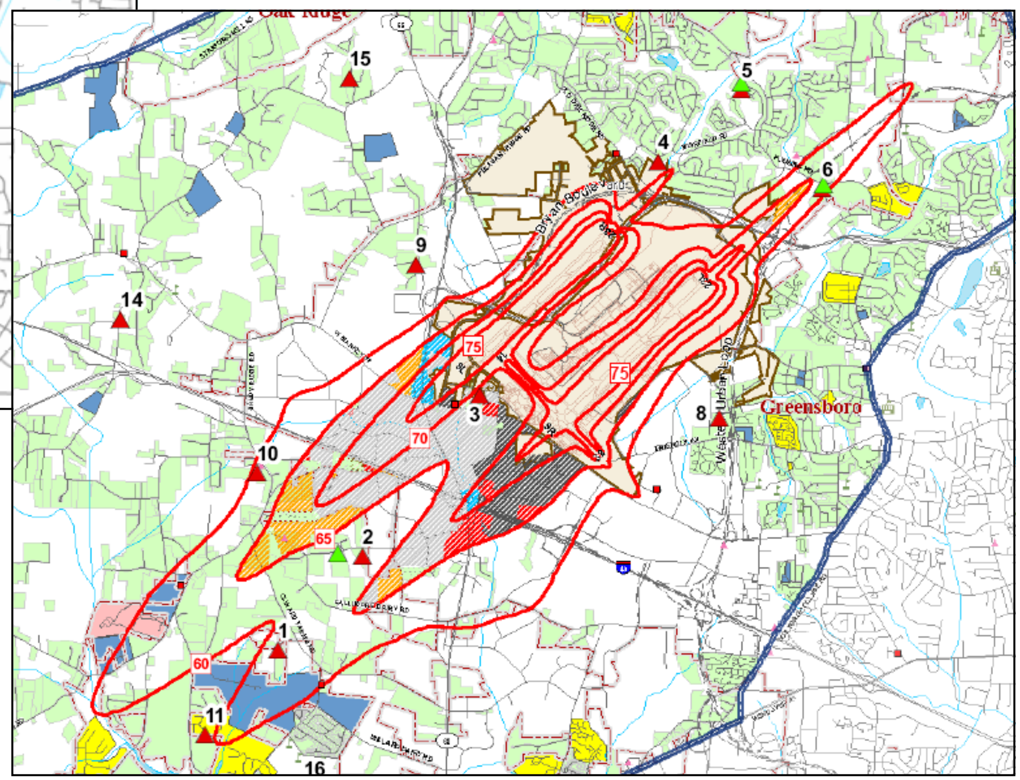


Modeled Flight Tracks

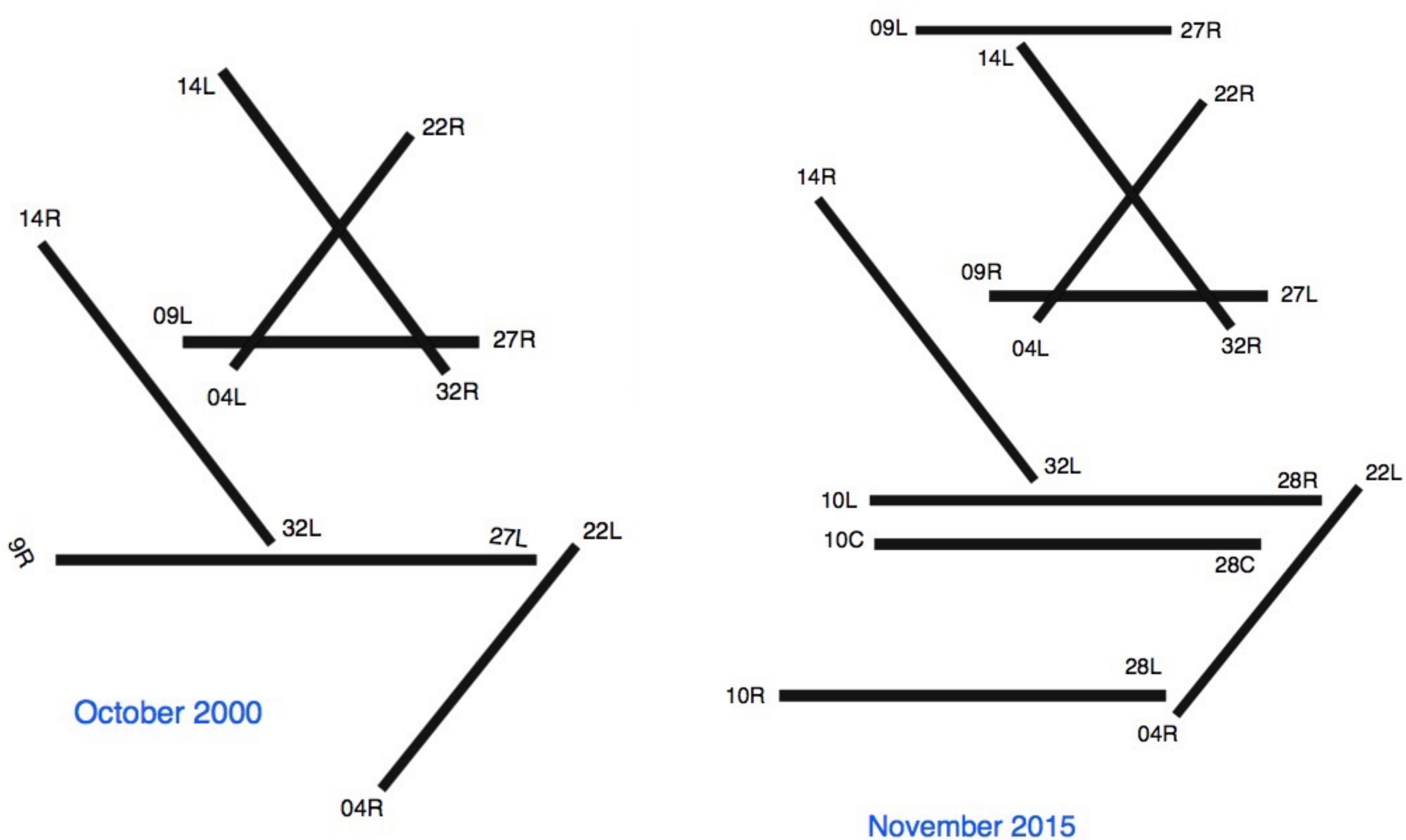


Noise Analysis (Baseline vs. 2014)



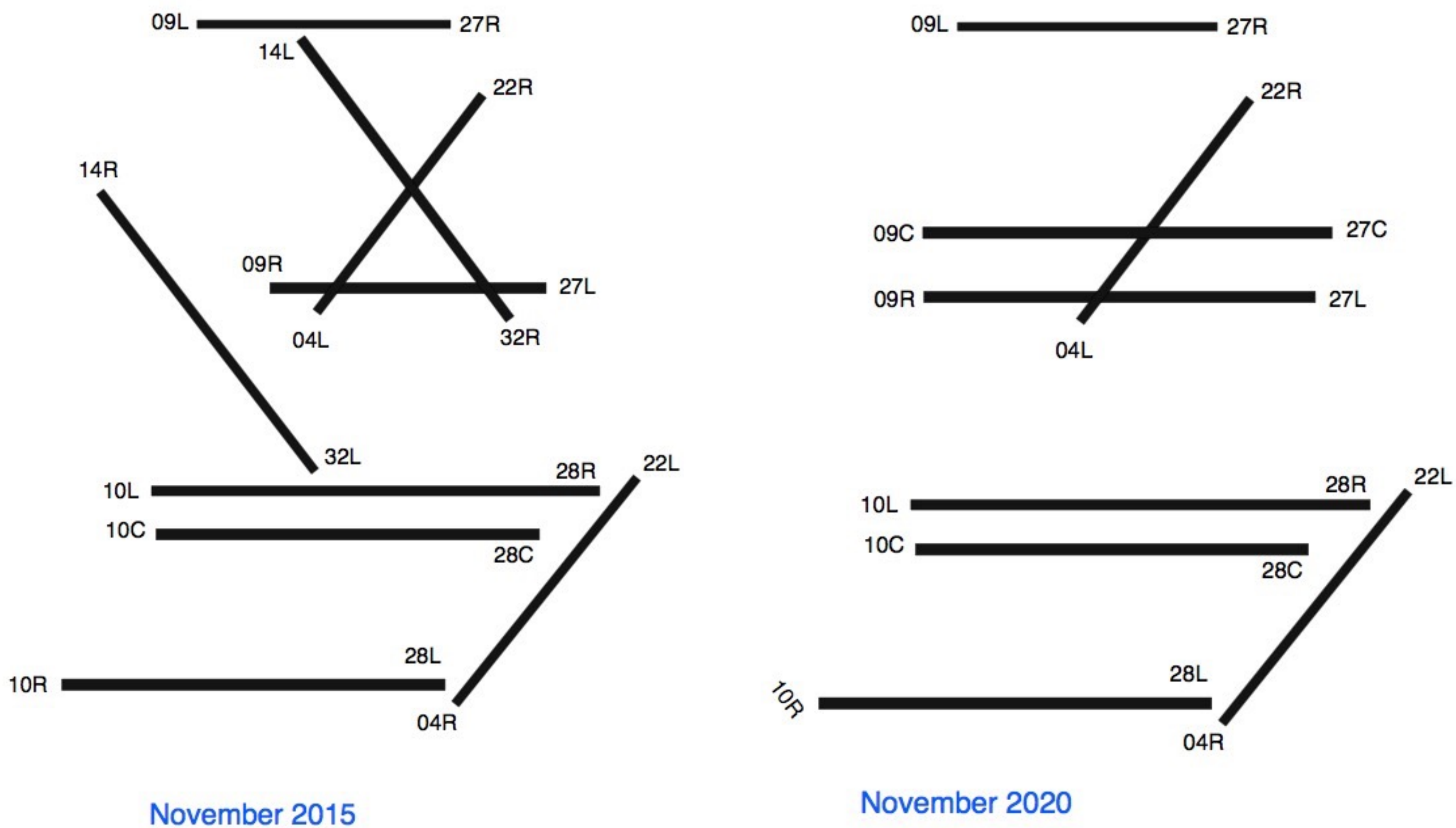


Chicago ORD Noise Study



Airport Configurations

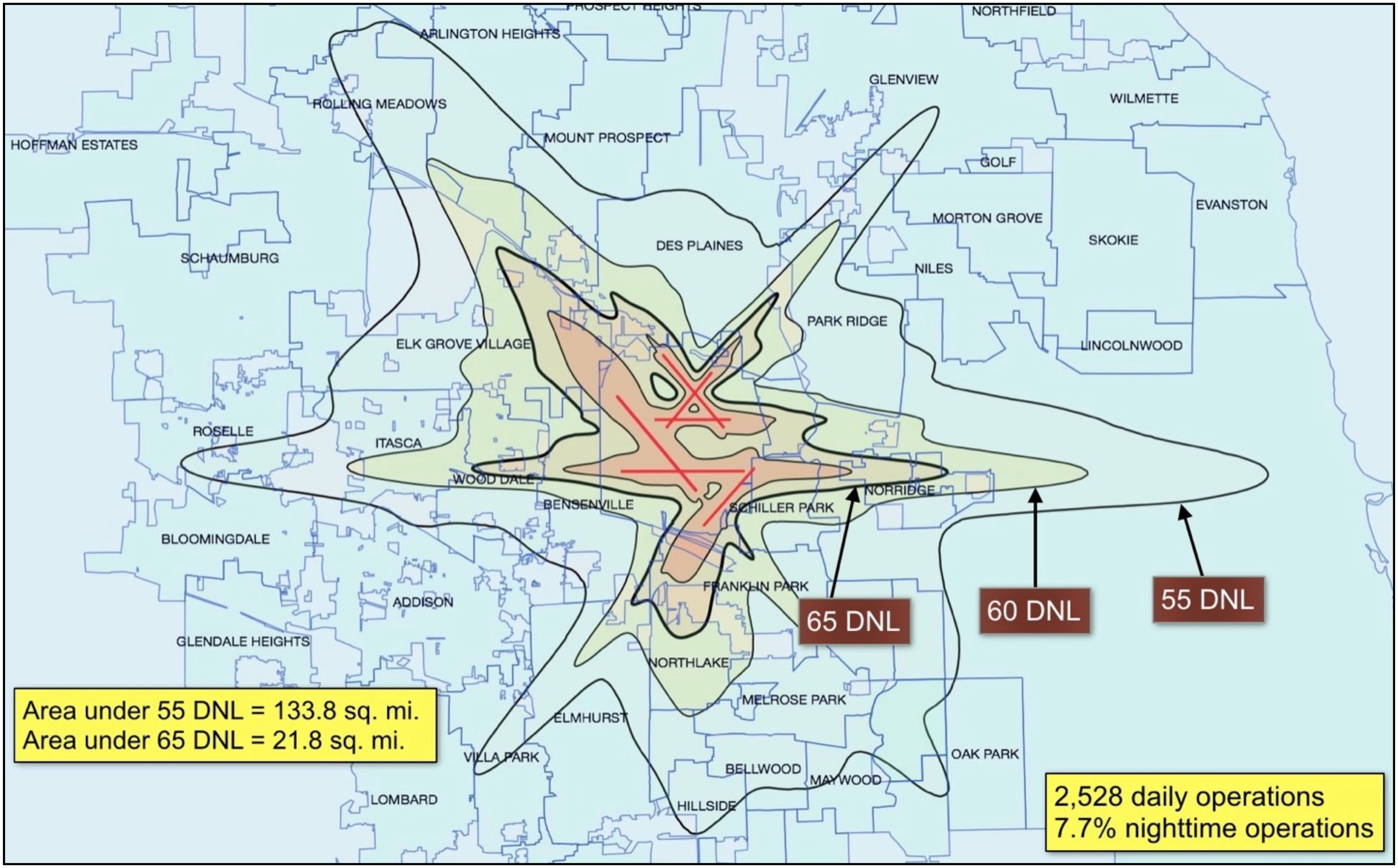
Chicago ORD Noise Study



Airport Configurations

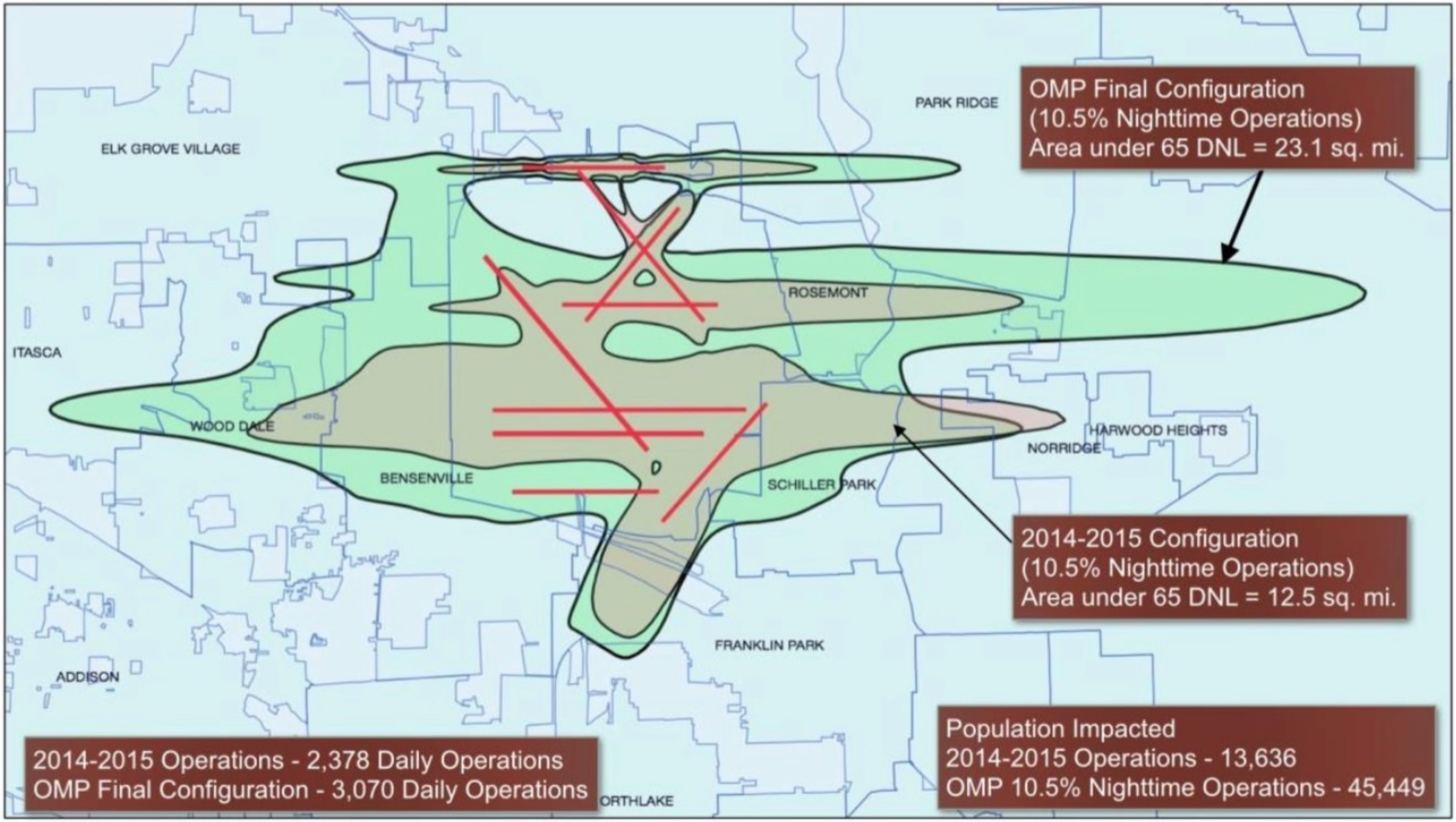
Virginia Tech Invent the Future

Chicago ORD Noise Study (2004 Noise Contours)



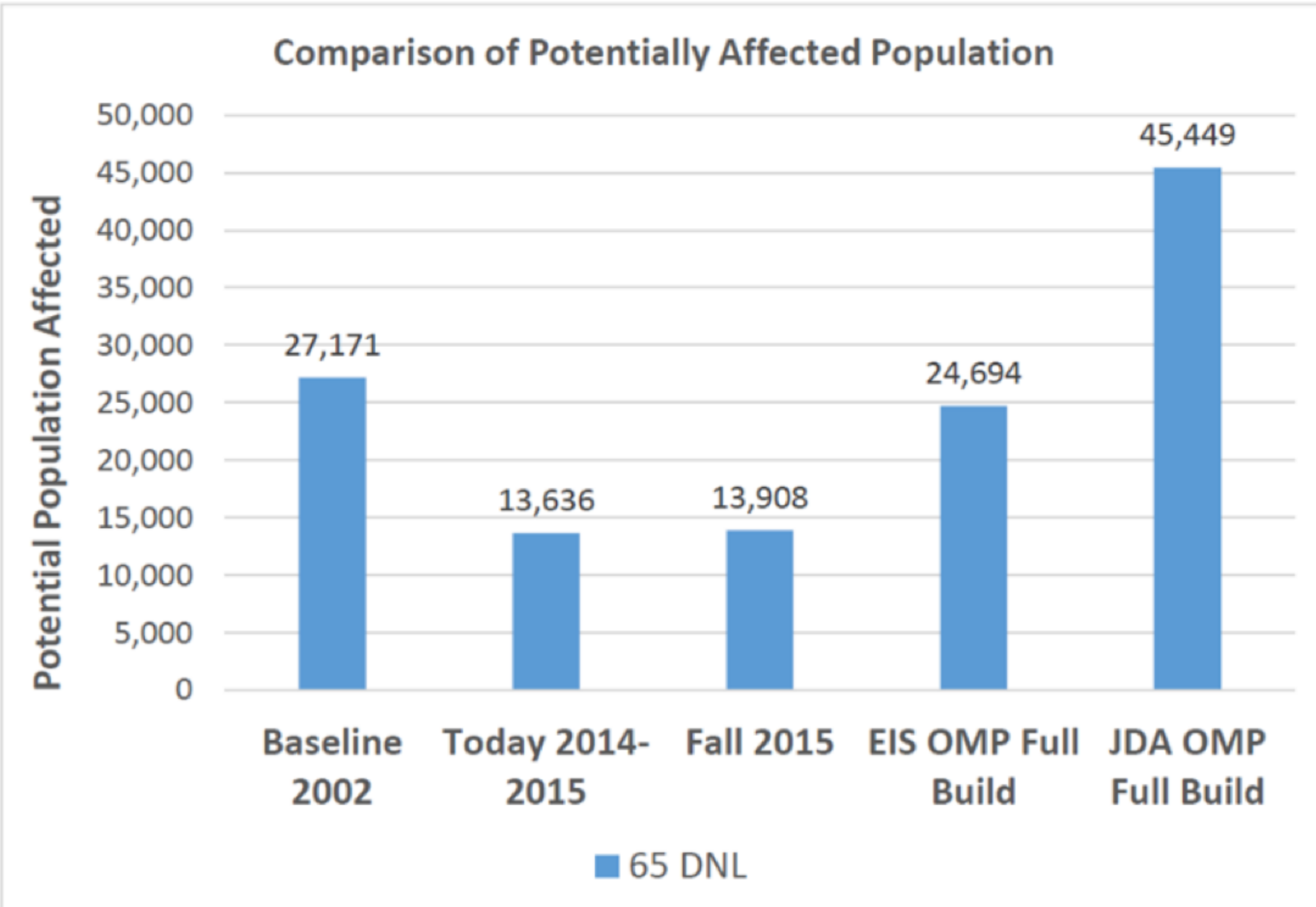
source: JDA Aviation (https://jdasoc.files.wordpress.com/2015/11/jda-final-ord-noise-study-report-to-soc-111915.pdf)

Chicago ORD Noise Study



source: JDA Aviation (https://jdasoc.files.wordpress.com/2015/11/jda-final-ord-noise-study-report-to-soc-111915.pdf)

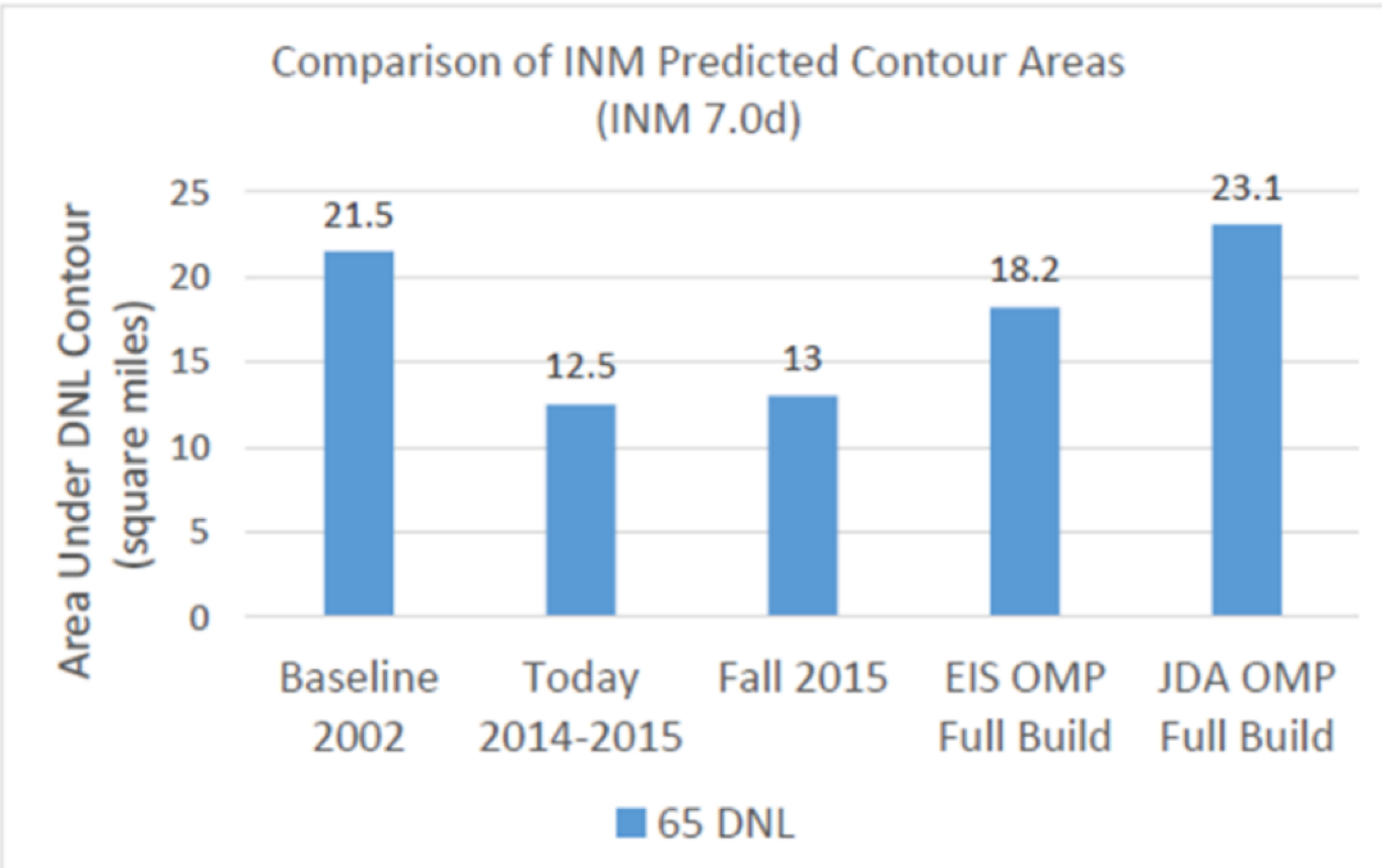
Chicago ORD Noise Study



ORD Forecast Noise Impacts on Population (JDA/A. Trani)

Chicago ORD Noise Study

- Aircraft technology has made good progress to mitigate noise
- However, the number of operations at airports constitute an important factor in determining how many people gets affected by noise



ORD Forecast Noise Contours (JDA/A. Trani)

Some Conclusions

- Noise contour predictions depend on many uncertain factors:
  - Aircraft fleet mix
  - Number of future operations
  - Traffic patterns
- It is imperative that noise analyses focus on a variety of scenarios that could show how communities get affected