This work supports the Revolutionary Vertical Lift Technology project at NASA

Urban Air Mobility (UAM) presents new opportunities for dynamic aviation transportation systems

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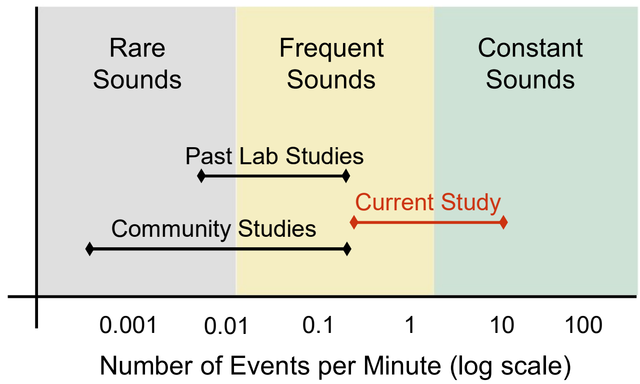
- Urban Air Mobility (UAM) is a subset of Advanced Air Mobility (AAM)
- UAM allows point-to-point transportation of people and goods via air taxis and drones, etc.
- NASA is a technical partner to industry and communities and not a regulator nor manufacturer
- Noise is a concern for entry into service, but no public data available on human response to UAM noise
- We at NASA are conducting psychoacoustic research to understand the human response to these vehicles

The “noise and number” problem:
How do people respond to a frequent sound? What metric to use?



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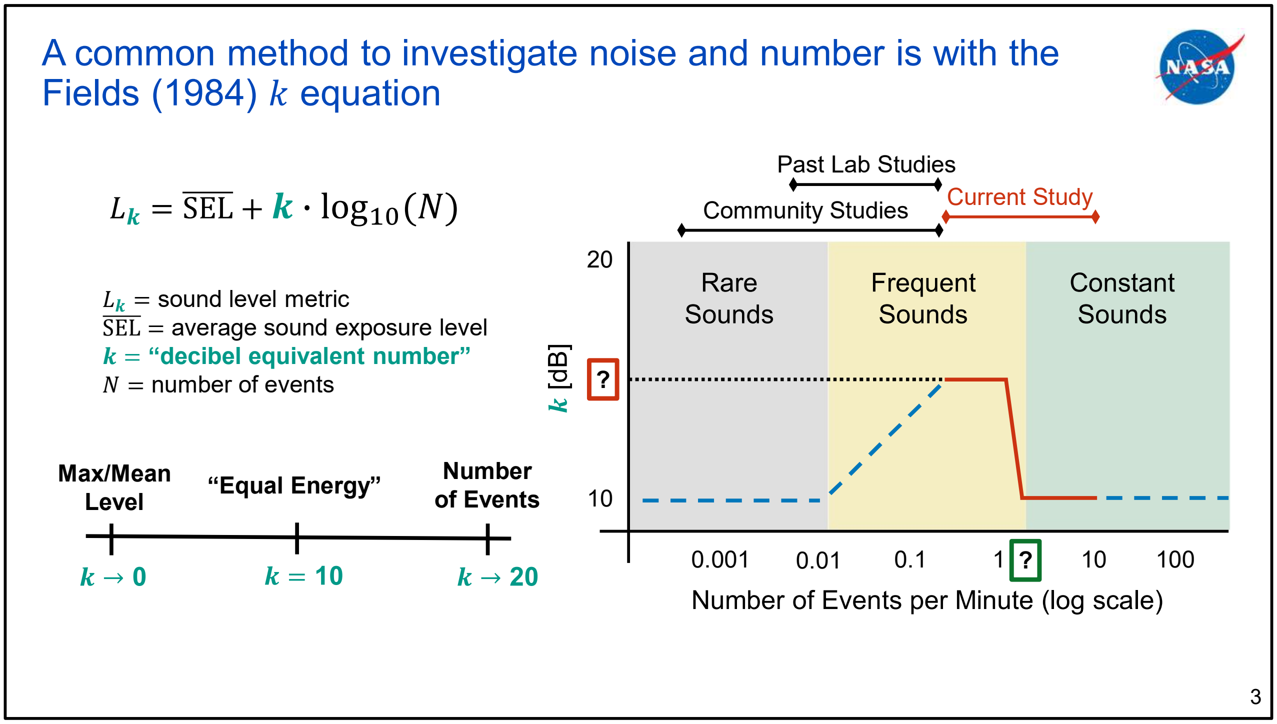
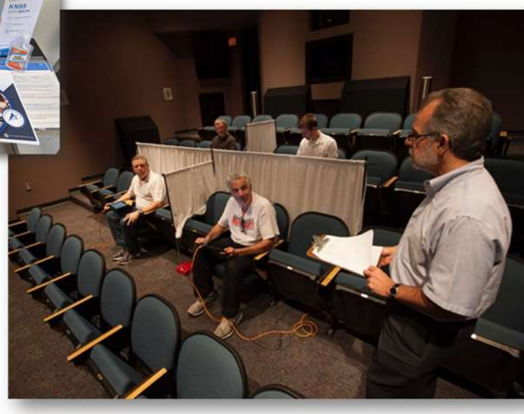
- One challenge in community noise response, dubbed the “noise and number” problem, addresses how people respond to a sound that is frequent
    - How does annoyance integrate over time?
- “Frequent” in contrast to rare or single events and continuous sounds
- Rare sounds:
    - Garbage truck in residential neighborhood (1x per week)
    - Airplane takeoff and landing (rare to frequent)
- Constant sounds:
    - Busy freeway
- Previous lab studies and community studies have focused in the rare to frequent sound regimes
    - Response to single flyovers
    - Limited by airport operations
- Current study addresses transition from frequent to constant sound response



- One method to assess a penalty to number of events is Fields' k equation
- The equation produces a sound level metric from
  - the average equivalent sound level
  - k "decibel equivalent number"
  - and N number of events
- k is a number of dB the metric should increase for a 10-fold increase in N
- $k = 10$ corresponds "equal energy"
  - Assumes equal tradeoff between level, number, and duration (e.g., DNL)
- As $k \to 0$, number of events becomes irrelevant and $L = \overline{\mathrm{SEL}}$
- As $k > 10$, greater weighting to N
  - $k > 20$ not observed in previous data
- What k value does the data support?

Noise and number study of UAM noise with 38 subjects conducted in the Exterior Effects Room at NASA Langley in January 2023



EER Noise and Number Test Response Sheet

Subject #	Seat #
Group #	Date/Time

Instructions: We are studying the impact of noise on people. You are going to hear a number of scenarios which involve flyovers of new kinds of aircraft. Each scenario will last about 4 minutes. Some of these scenarios may have many flyovers in them, and some may only have a few. Some scenarios may have loud flyovers, and some may have quieter flyovers. What we would like you to do is to listen to the scenario as a whole while reading, and then give a response to the question below when prompted by the test director.

Scenario Number	**Question:** (circle one) What number from 0 to 10 best shows how much you are bothered, disturbed, or annoyed by the noise?	**Comments/Notes** Use this space as you like
1	0 1 2 3 4 5 6 7 8 9 10	
2	0 1 2 3 4 5 6 7 8 9 10	
3	0 1 2 3 4 5 6 7 8 9 10	
4	0 1 2 3 4 5 6 7 8 9 10	
5	0 1 2 3 4 5 6 7 8 9 10	

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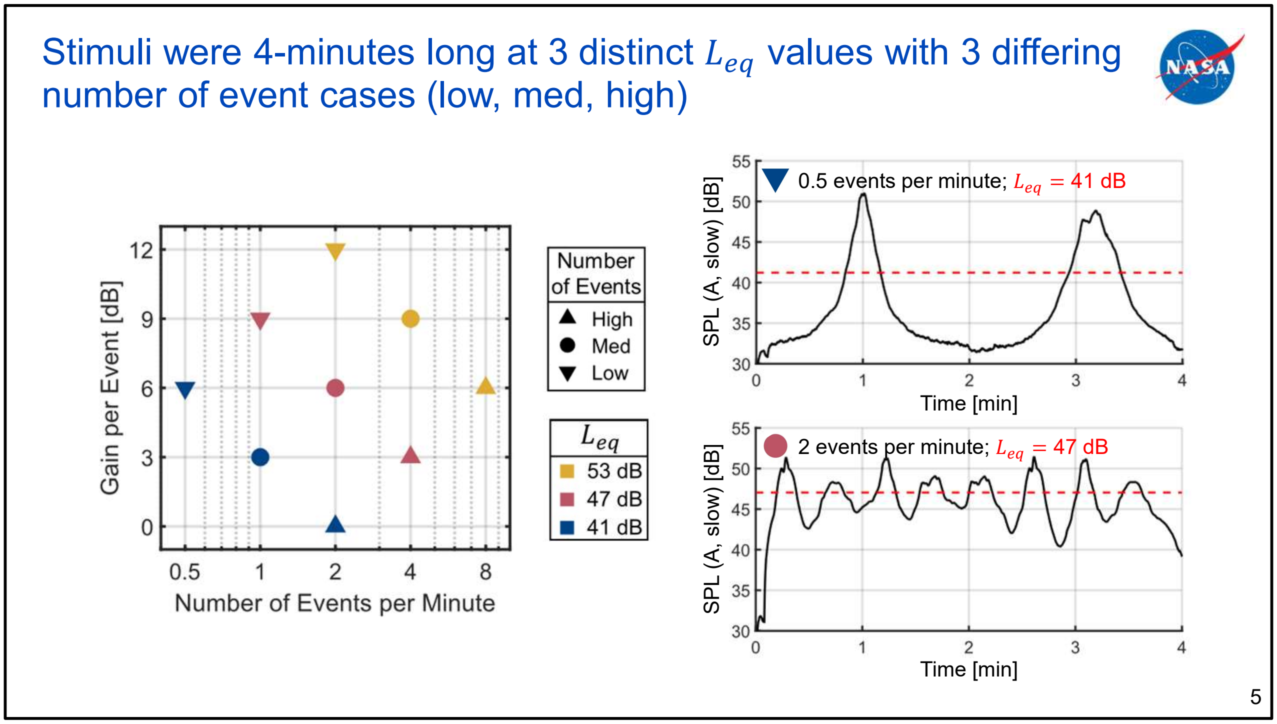
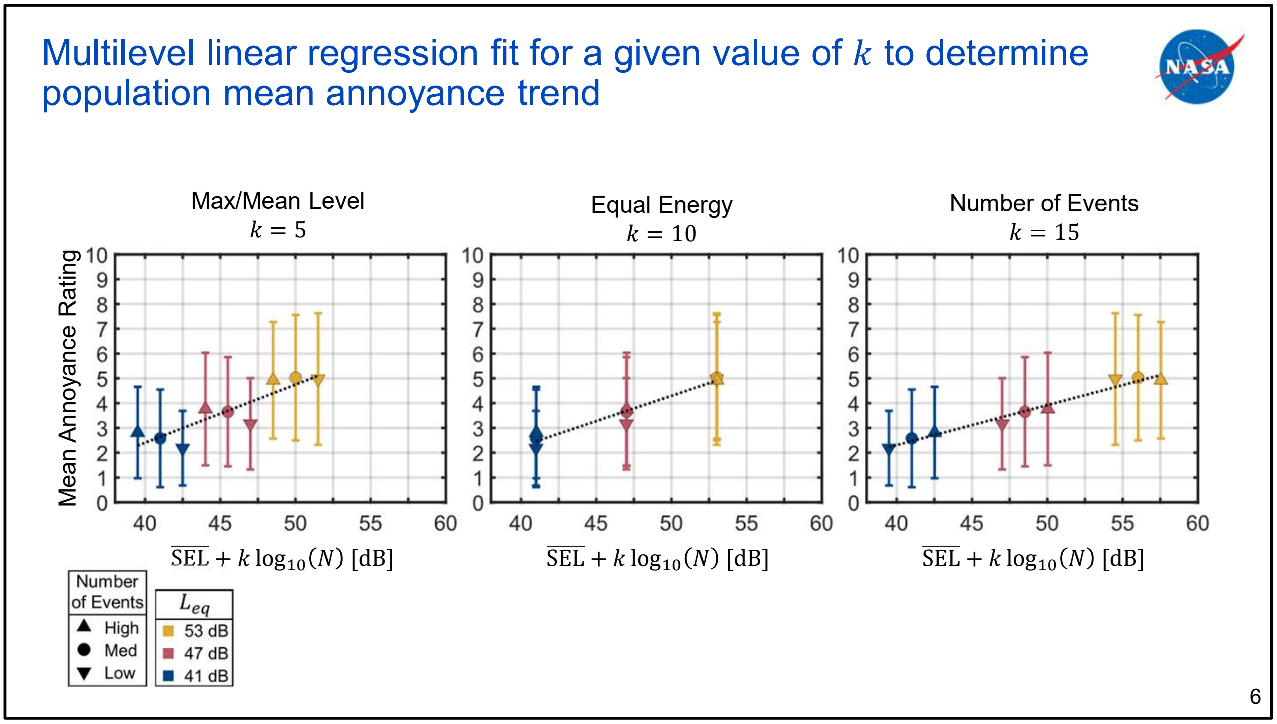
- We conducted a noise and number study in the Exterior Effects Room at NASA Langley in January 2023
- Sounds were of UAM vehicle flyovers
- During the test, participants were given reading materials
- 38 subjects successfully participated, 4 at a time as shown above
- Participants provided their annoyance response on the numerical 0 to 10 ICBEN scale

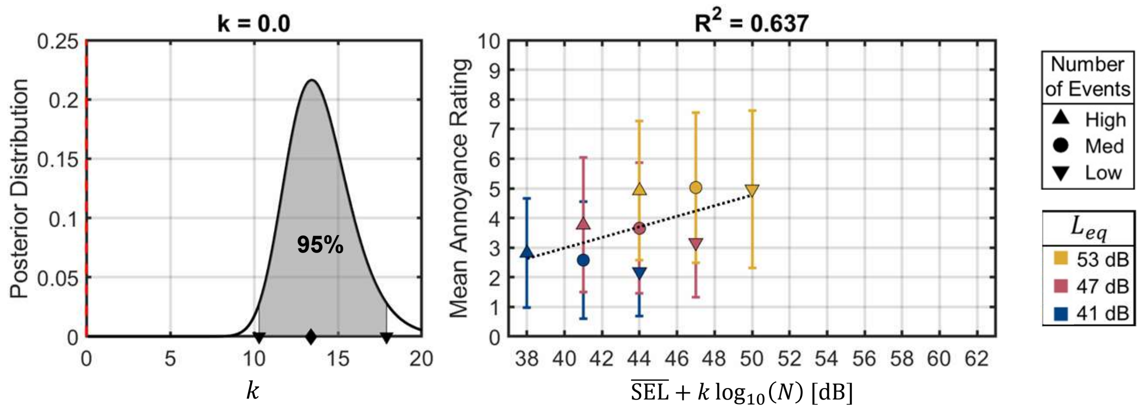


- Nine 4-min-long test sessions
    - Values given by EEH ($k = 10$)
    - 3 sets of L_{eq} as noted by the color
    - 3 different case of number of events, noted by symbol
- Equal span in L_{eq}, Gain, and equivalent N (given by EEH)
    - If EEH holds true, then results collapse to 3 points (noted by color) of indistinguishable annoyance
- Example plots of sound level over time
    - Events are distinguished by peaks
    - Increasing number of events makes them less distinguishable → constant sound



- This is a review of previous work on population results
    - Going through these results, then to trends of individuals
- Using a multilevel linear regression to show population mean annoyance trend
    - Varying the noise metric, not annoyance responses
- Error bars show SD of annoyance responses across subject pool – about the data not line, represents scatter not confidence bound
- Results shown for 3 different k values
    - $k = 5$, with less weight to number and more to max or rather mean level since they are all equivalent in this case
    - $k = 10$, which is the equal energy (like DNL), collapse
    - $k = 15$, greater weighting to number of events
- Data seems to collapse for $L_{eq} = 53$ case (yellow), but at lower L_{eq} (with fewer events) that the data have a positive slope, suggesting $k > 10$
- At what k do we get our best fit to the data?

Determine the best value of k by evaluating a goodness of fit for each k from 0 to 20 and plot result as a posterior distribution



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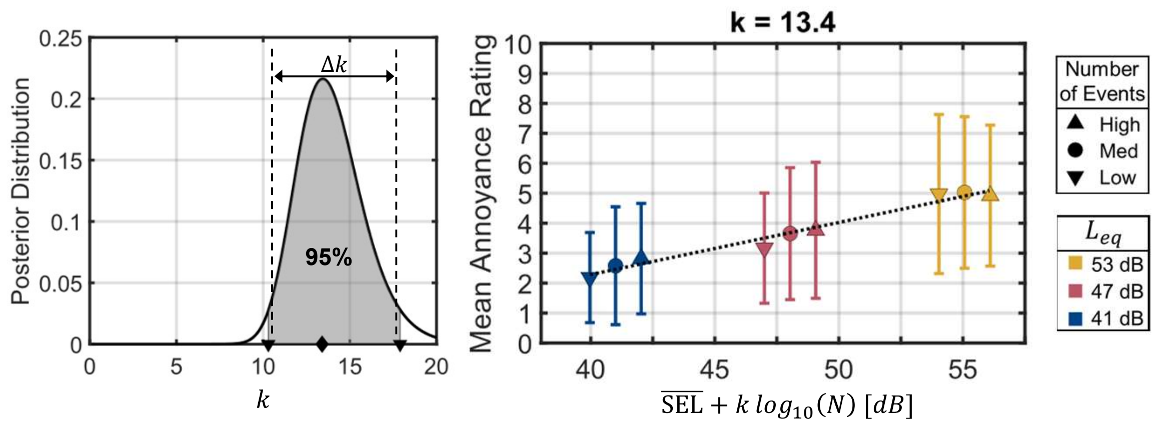
- This animation demonstrates the analysis with k from 0 to 20
- A distribution of k values is created that describe the best fit
- At each k, evaluate the log likelihood, which is a log sum of residuals as a measure of goodness of fit
- Compile the values and normalize area under curve to 1
- Peak denotes "best" k and confidence bound notes precision about that estimate of k
- We also note the coefficient of determination, R^2
- It is clear that the best fit to the data occurs $k > 10$

- The peak is $k = 13.4$, meaning that the number of events is penalized or weighted greater than suggested by EEH ($k = 10$)

Population best fit occurs at $\boldsymbol{k = 13.4}$, meaning more weight to number of events than suggested by “equal energy”



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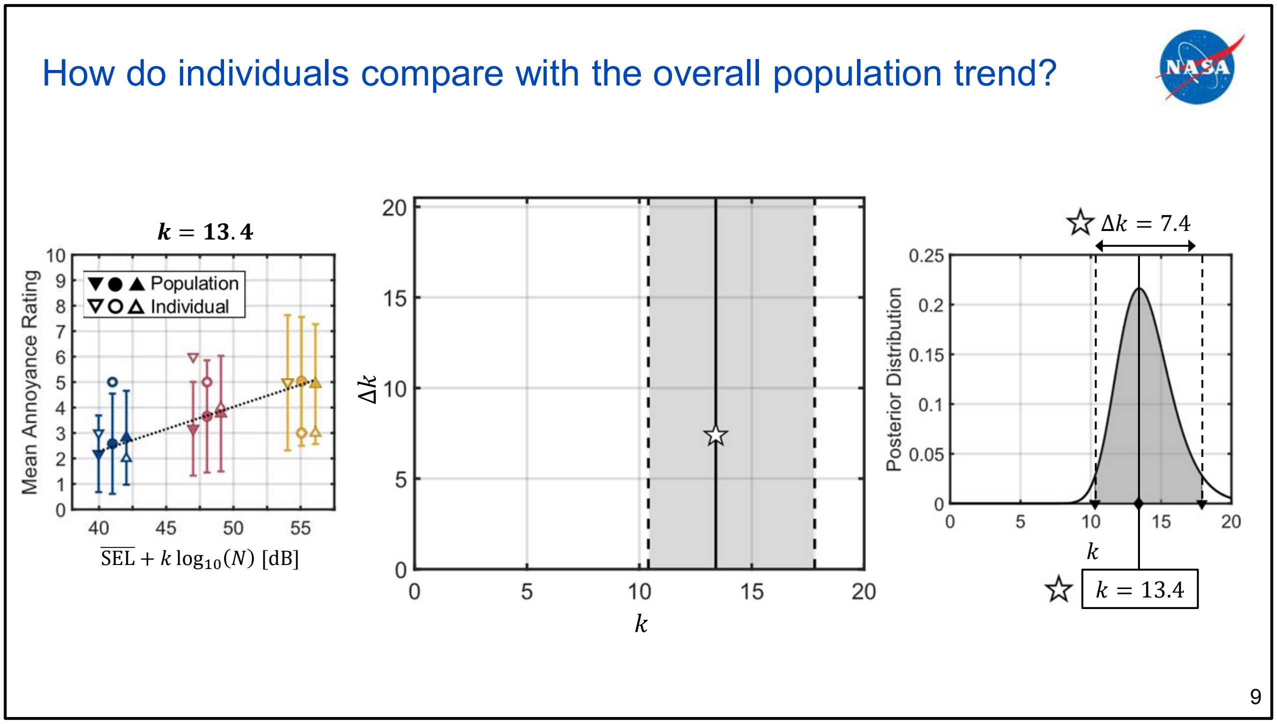
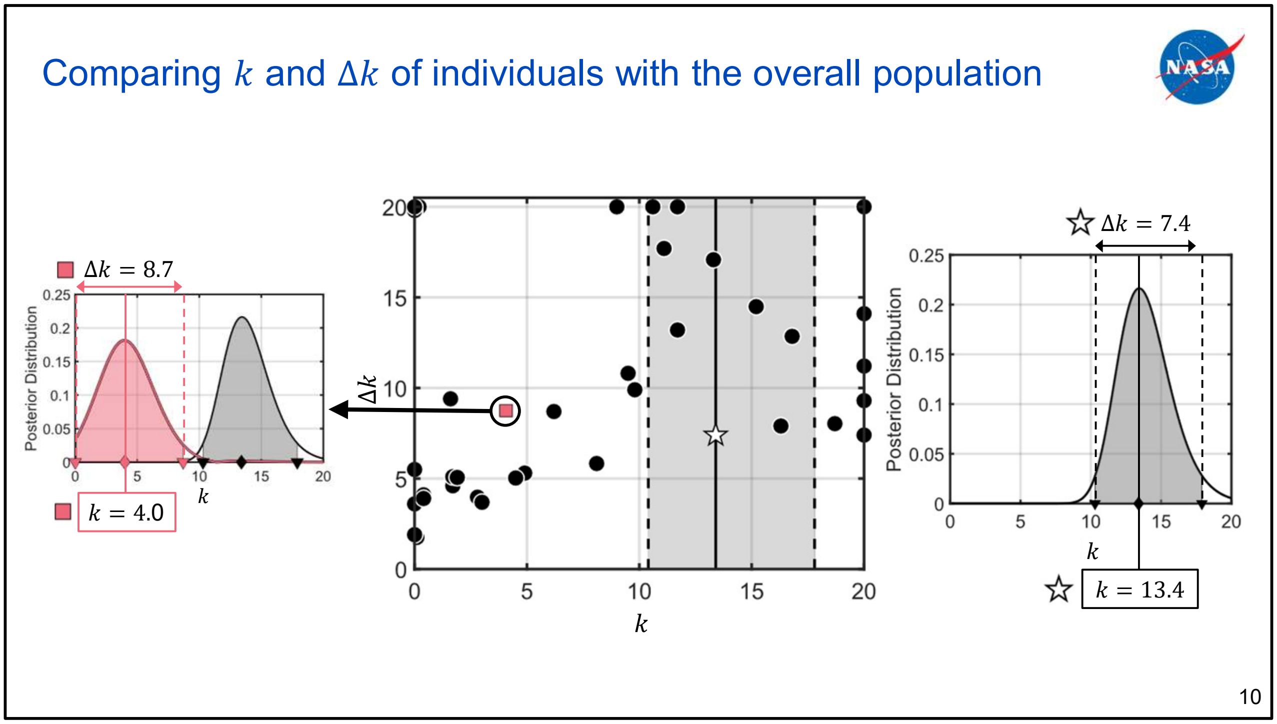
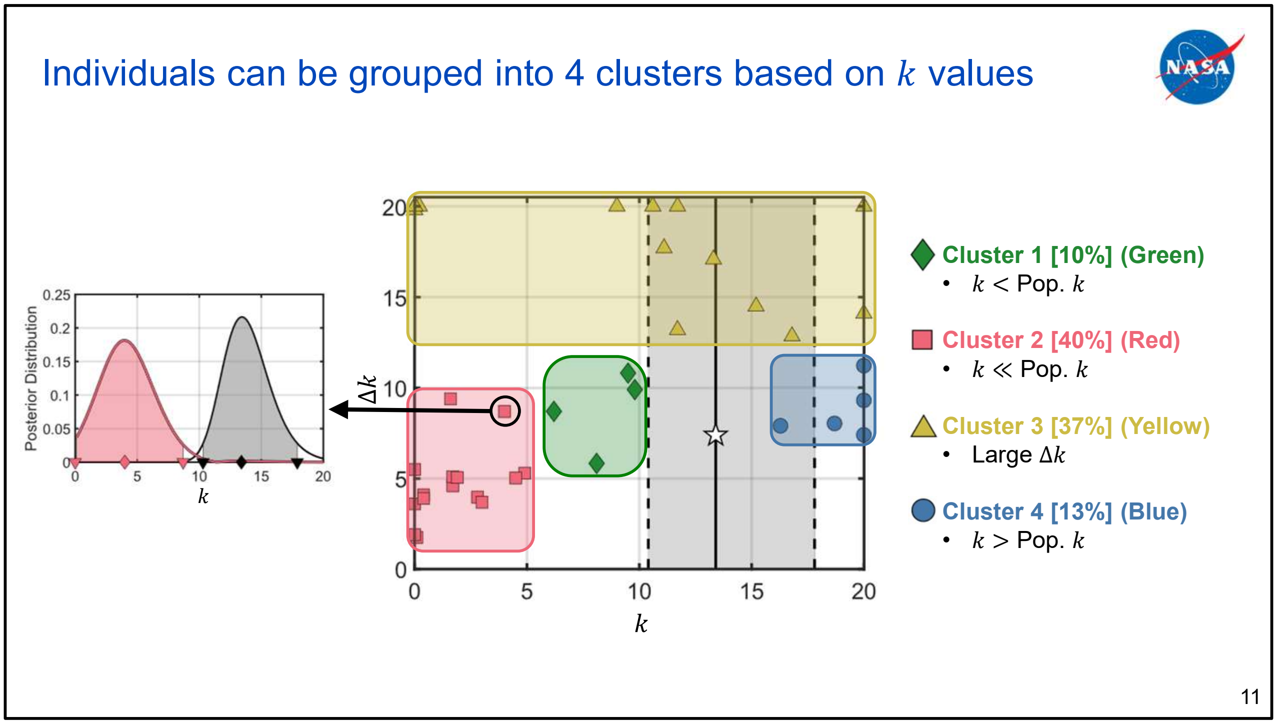
- The peak is $k = 13.4$, meaning that the number of events is penalized or weighted greater than suggested by EEH ($k = 10$)
- This is for the population with all the data grouped together



- We're going to use the middle plot as a framework to compare individuals with the population trend
- First, left plot shows an example of an individual's responses compared to the overall populations
  - Individual likely has more scatter, they may be using different part of the response scale
  - Comparing individual data with the overall provides insight on whether individuals support population trend
- Middle plot has the star noting the peak k value and the Δk for the confidence interval width.
  - Vertical solid line also notes the peak k value and vertical dashed lines and shading note the confidence interval
  - These values are shown on the right



- Now we are plotting 38 dots representing where individuals fall in this $k - \Delta k$ space
  - Each person with responses to 9 stimuli
- Reminder, k tells the best guess, Δk suggests precision on that guess
- Example on left of an individual with a peak below the populations



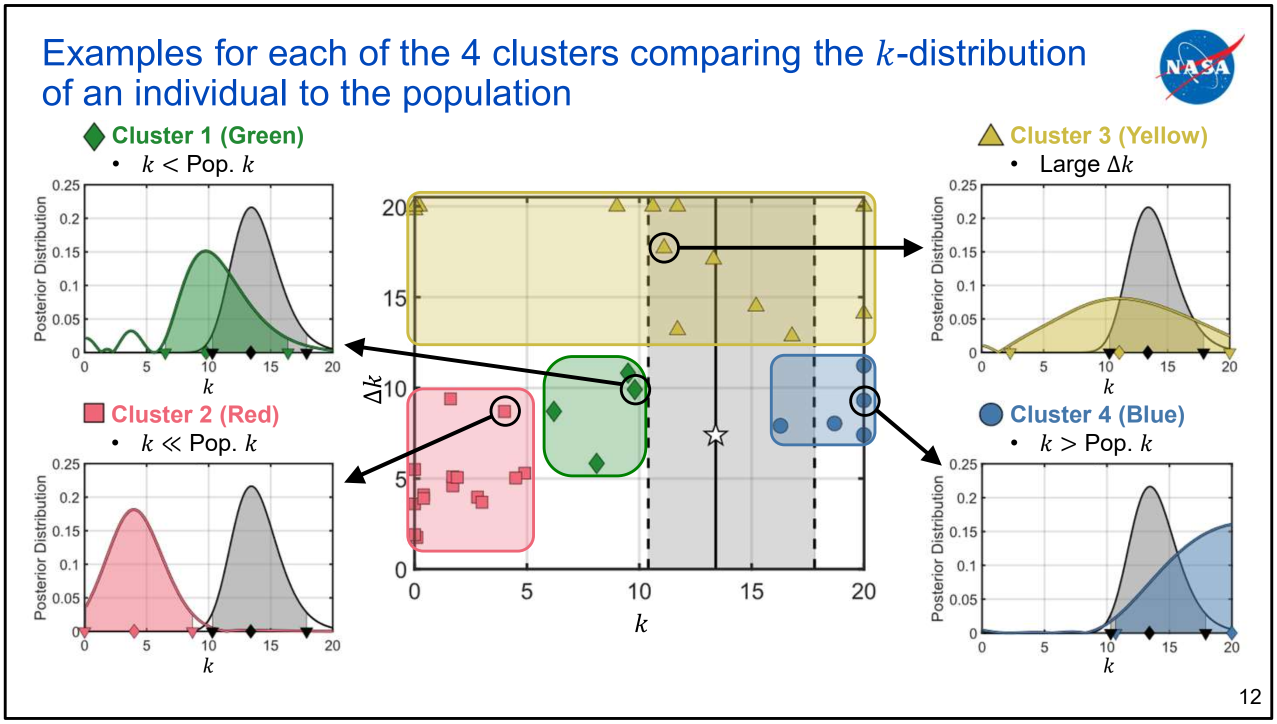
- Create 4 clusters based on a combination of k-means clustering (which is a little confusing since our variables are also called k) and our intuition of what these k values mean relative to our population

Cluster 1 (Green) [10%]
- $k <$ Pop. k
- $6 < k < 10$

Cluster 2 (Red) [40%]
- $k \ll$ Pop. k
- $k < 5$

Cluster 3 (Yellow) [37%]
- Large Δk
- $\Delta k > 13$

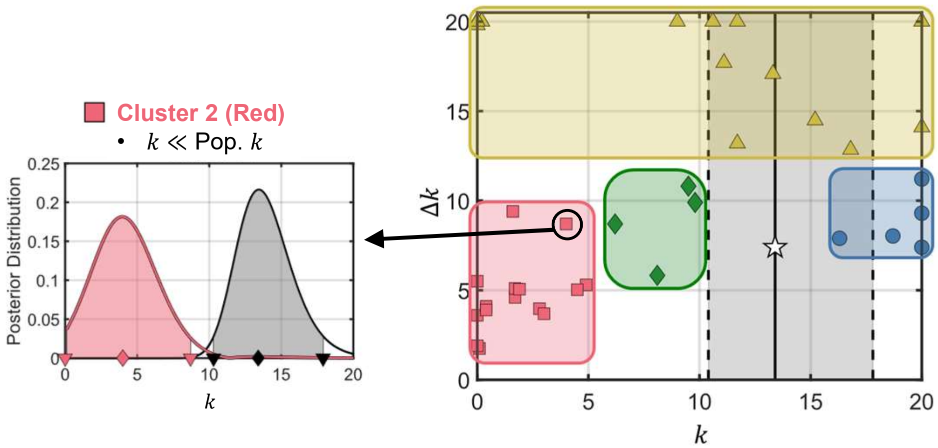
Cluster 4 (Blue) [13%]
- $k >$ Pop. k
- $k > 16$



- Examples of distributions for each of the 4 clusters
  - Cluster 1 (green) overlaps with population but peaks at lower k
  - Cluster 2 (red) same example as previously shown, very interesting that a lot are peaking much lower than k
    - Not overlapping with population
    - Point out that the average of these k values does not necessarily become the population average. But it does seem like there's a group that may be more annoyed by or responding to the mean/max level than the number of events
  - Cluster 3 (yellow) broad uninformative for k
  - Cluster 4 (blue) peak greater than population, k bounded to 20
- Again, averaging these might not equate to population. Yellow, green, and blue groups seem reasonable, red is unexpected
- What if policy is made that follows population, and over time, level decrease and number of operations increases? Blue might become disproportionately more annoyed

Summary of UAM Noise and Number Test:

- Number of events impacts population response ($k > 10$)
- Individuals group in 4 clusters, 1 differs significantly from population trend
- Only focusing on the population may obscure differing trends of individuals



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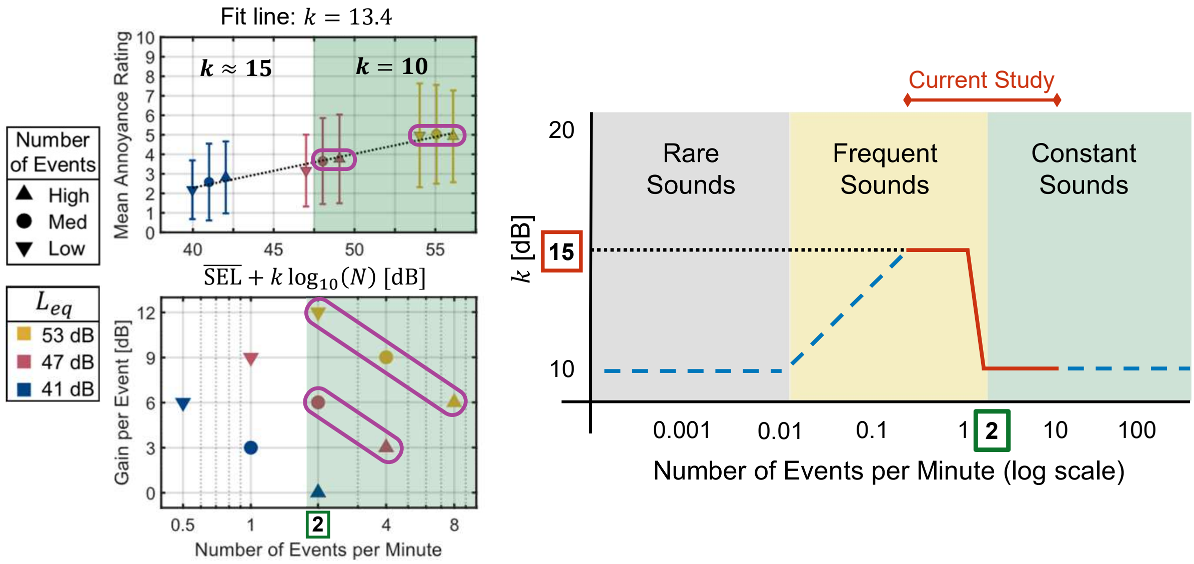
(BACKUP)
Results suggest transition from “frequent” to “constant” sounds at about 2 events per minute



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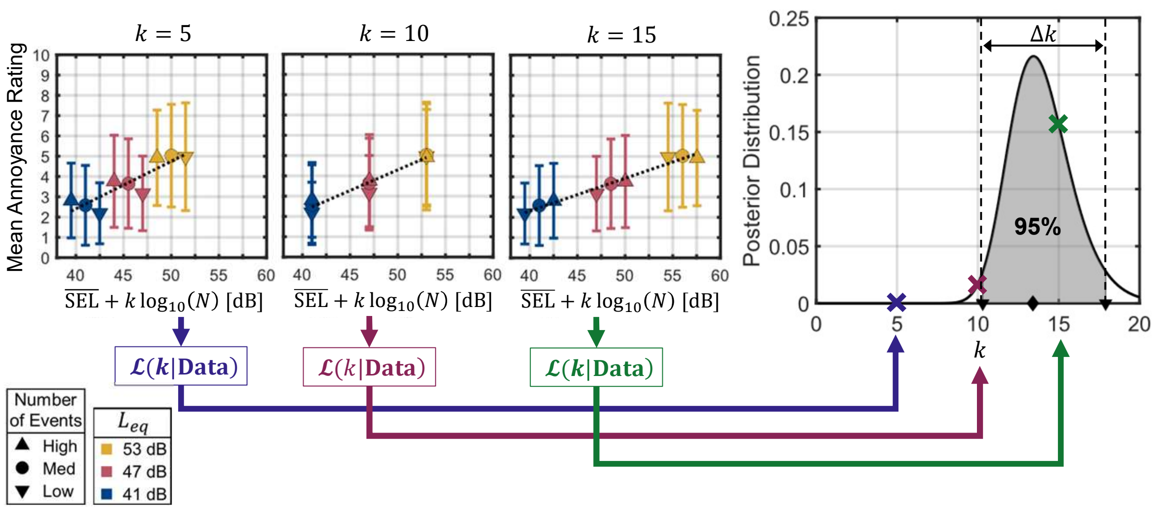
- We noted that the data points don’t collapse at lower L_{eq} but do at higher L_{eq}
- Rather than some sort of L_{eq} cutoff, this more likely corresponds to a number of events transition from frequent to constant
- We see the yellow ($L_{eq} = 53$ dB) and upper 2 red collapse, which corresponds to 2 events per minute on test matrix
- So, $k \approx 15$ for the lower part of the curve, and $k = 10$ at about 2 events per minute
- These are population trends; how do individuals hold up against this?

(BACKUP)
Determine the best value of k by evaluating a goodness of fit for each k from 0 to 20 and plot result as a posterior distribution



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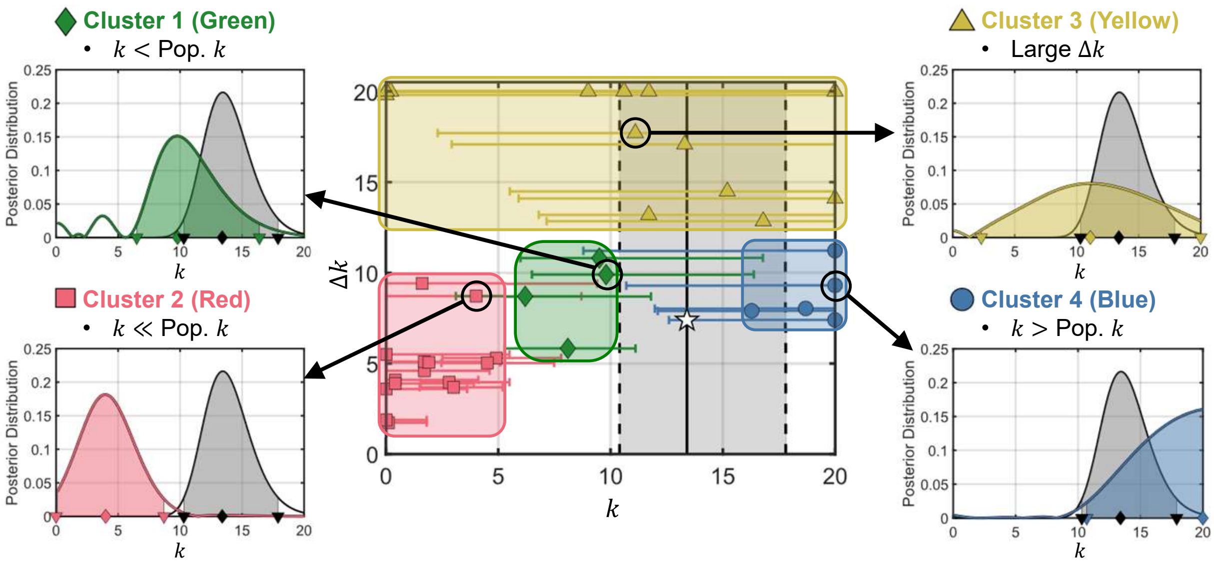
- Create a distribution of k values that describe the best fit
- At each k, evaluate the log likelihood, which is a log sum of residuals as a measure of goodness of fit
- Compile the values and normalize area under curve to 1
- Peak denotes “best” k and confidence bound notes precision about that estimate of k
- This posterior distribution is the result from this study

(BACKUP)
Examples with 95% confidence intervals



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