Thomas C. Rindfleisch August 11, 2015

Report on Some Quantitative Measurements of Aircraft Overflight Noise in Palo Alto

Discussions have been underway for some time about intrusive aircraft overflight noise levels in Palo Alto and other communities under the new re-routing instituted by the FAA NextGen program. This report is to begin to provide quantitative information about the character of the noise resulting from those decisions, the impact it is having on our community, and some recommendations for how to move forward.

Introduction

Some time ago I wrote about recordings I made in June illustrating subjectively the interference of aircraft overflight noises with TV watching at our house (see this link). Such subjective examples do not have much credibility with the FAA, SFO, etc. when objecting to noise levels, even though a survey (also summarized at the above link) indicates that over 70% of residents find the newly increased noise from aircraft overflights to be extremely intrusive and disruptive.

To better quantitate the aircraft noise we are exposed to, I began working on noise monitoring in July. I bought a Reed SD-4023 Sound Level Meter/Datalogger to start collecting our own data, so that we might compare that with noise monitoring data the FAA and SFO may begin collecting in Palo Alto sometime in August. This is a report on the quantitative results I have obtained to date, which I believe support the subjective impressions of very persistent and intrusive overflight noise levels from low-flying aircraft in our community since late last winter.

I believe the preliminary data I describe below is accurate and revealing. It is highly suggestive that the changes in noise levels over Palo Alto from NextGen exceed the thresholds set by the FAA for a finding of objectionable noise, and we would like to see this new regime reconsidered through an open, frank, and earnest discussion about how we might take advantage of the bay area's unique geography and access routes to minimize the noise over any populated areas. Our intention is not to push the noise to another community but, rather, to find a rerouting of the traffic that is a suitable compromise between safety, noise impact, and efficiency. We believe that there are alternatives to the re-routing (including the bay or other more lightly populated areas such as the regional open space properties) that would be a better solution for everyone.

The need to objectively understand the extent and nature of the noise effects Palo Alto has come to experience is an important step toward these goals. This requires more comprehensive noise surveys and analyses that we hope the FAA will undertake (but which the citizens could tackle as a kind of crowd-sourced study if the FAA does not). If the early results presented here hold, then the FAA should take appropriate action.

My studies should be seen as a work in progress in several respects:

(1) My sound measurements were taken over a limited period of time so far (July 12-16, 2015) and must be extended over time to more thoroughly characterize the temporal (daily, weekly, monthly, seasonal, and long-term trend) aspects of aircraft noise in our community.

(2) The measurements were taken from a single residential location (my home) and must be broadened to reflect the noise characteristics throughout the community.

(3) Finally, much of what I have done is to develop a feasible methodology to measure and analyze physical noise data from various perspectives to better characterize the impact aircraft noises are having on our community under NextGen routing. The computer programs and tools I have built are prototypes and need to be polished for more routine production use.

(Note: this subject is fairly technical so I will try to explain what I did in intuitive terms first, and include at the end some more technical detail for those interested.)

Raw Data

The Reed meter measures sound energy falling on its microphone, taking samples every 2 seconds with a sensitivity curve simulating the frequency response of the human ear. These measurements are time stamped and written to a small SD card whose contents can be uploaded to a computer and analyzed in Excel or other data analysis programs. The recorded intensity values are expressed in decibels (dBA), a logarithmic scale commonly used for sound level measurements as compared to the faintest audible sound. (A logarithmic intensity scale is used because the dynamic range of sounds is so large – see this link for more detail on sound measurements).

As a first step, I logged data for 5 days starting at 8:22 AM on Sunday, July 12 in my back yard (31 Tevis Place, Palo Alto, CA 94301), and running continuously until 7:38 AM on Thursday, 7/16. I then organized the records by day (0:00 AM - 23:59 PM; i.e., 43,200 records per day) for analysis. A typical set of raw measurements for Monday, July 13 is shown in Figure 1.

You can see that the data include a noisy ambient background ranging from about 38 dBA at night to about 50 dBA during the day. A number of narrow vertical spikes are superimposed on this background corresponding mostly to aircraft overflights, but also including other localized ambient noise events. Recall that a measurement is taken every 2 seconds, so individual spikes are not resolved on the plot at the scale shown in Figure 1. They can be seen more clearly in Figure 2, which shows a small portion (7:30 - 8:30 AM) of the record in Figure 1, blown up on the horizontal (time) axis.

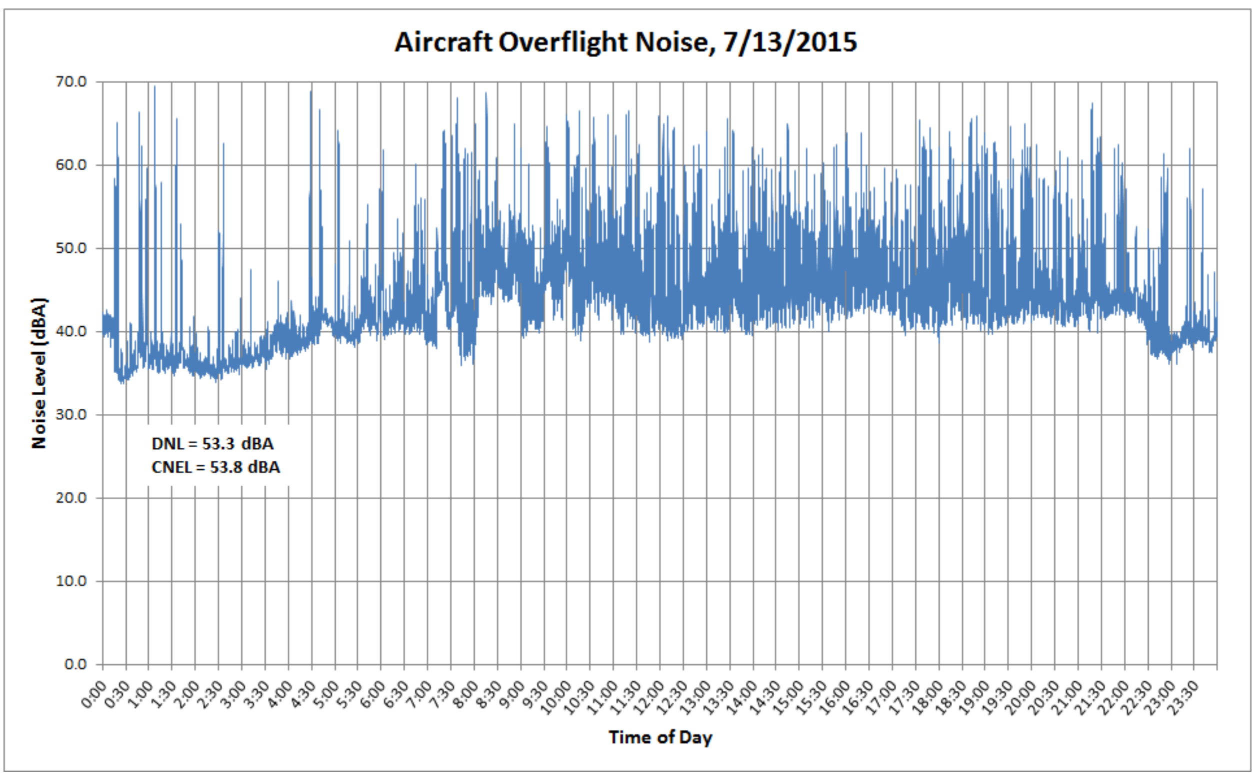

Figure 1. Raw data from Reed sound meter for July 13, 2015.

In Figure 2 you can clearly see the background (between about 40 and 50 dBA) and the 11 peaks corresponding to aircraft overflights that occurred in this one-hour period. This background comes from the ambient neighborhood noise and the peaks are either sharp noises (like an object falling, a yell, etc.– look at the narrow peaks just before 7:36 and 7:52 marked with red arrows) or low-altitude airplane overflights seen as the wider peaks (around 1-1:30 minutes in duration).

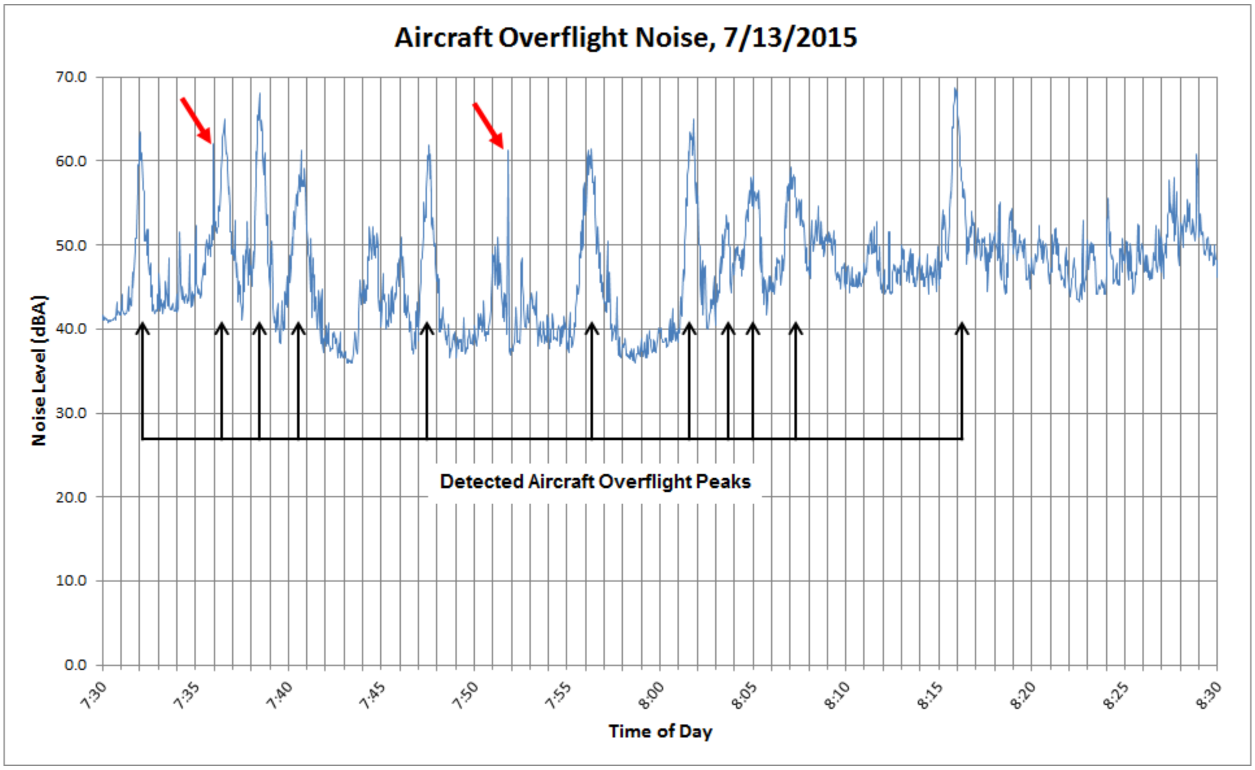

Figure 2. Expanded view of the interval 7:30 8:30 AM from Figure 1.

Data Analyses

In addition to simply plotting these data as above, we can do various calculations of interesting noise measures. For example:

> The FAA **Day-Night Average Sound Level (DNL)** — is a single number, the day-long average of a sound intensity record shown such as shown in Figure 1 (the average is done in linear intensity space and then converted back to dBA units). The DNL supposedly represents an assessment of the impact of aircraft noise, and "accounts for increased human sensitivity to noise at night by applying a 10 dB penalty to nighttime events (during the 10:00 PM to 7:00 AM time period). The DNL value for Figure 1 is 53.3 dBA.
>
> The **California Community Noise Equivalent Level (CNEL)** — CNEL is a variant of the DNL developed in California, which includes an extra 5-decibel penalty on noise during the 7:00 PM to 10:00 PM evening time period, as well as the 10-decibel penalty on noise during the 10:00 PM to 7:00 AM time period. The CNEL is again a single number that purports to represent the impact of aircraft noise. The CNEL value for Figure 1 is 53.8 dBA.

The problems with the DNL and CNEL measures are well-known in that these overall average noise measures do not account for the disruption of localized intense and often recurring sounds during daily activities. The best noise metric(s) to accurately quantify the impacts of aircraft noise on human health, learning, annoyance, speech disruption, sleep disturbance, etc., particularly in situations where communities were previously unaffected by aircraft noise, have yet to be determined. Although the FAA is pursuing some research efforts in this area, they are not progressing at a rapid pace and governments in Europe have taken the lead. These traditional measures are nevertheless the criteria the FAA uses to judge impact of aircraft noise and unless the DNL/CNEL is greater than 65 dBA, they are not obligated to do any mitigation.

For a person under the flight path of low-flying aircraft, what matters most is not the average noise over a 24-hour period, but rather, for common activities, the extent to which one's concentration on a task at hand is broken by aircraft noise. This means that we need to worry in some detail about when, how much, how long, and how often we are exposed to aircraft sounds in our analyses.

To do this, we have to isolate each aircraft overflight peak and measure some more directly relevant parameters: such as how big each peak is, how long it lasts, and how close it follows on to similar events around the same time. I spent a fair amount of time writing, testing, and tuning a computer program to analyze the raw data to identify and extract each peak corresponding to an overflight event. This is a fairly complicated program in that it has to find the upper bound of the dynamically varying ambient background noise to establish a threshold to detect bigger aircraft noise peaks. It also has to make sure that candidate overflight peaks are neither too short nor too long. Once a peak is found that matches these criteria, its location in time, its maximum height, and its overall size (total sound energy under the peak) are calculated. (See further details near the end of this message.)

DNL & CNEL Values with and without Aircraft Noise

One of the simplest things we can do is estimate the values of DNL and CNEL with and without aircraft noise. This is relatively easy once we have identified the locations and extents of aircraft noise peaks. Using a spreadsheet program (like Excel), we can replace each peak with the average ambient background noise level seen near the peak, and recalculate DNL and CNEL values. Table 1 shows the result of doing this for each of the 24-hour sound records in the 5-day recording I made.

Effect of Overflight Noise on DNL and CNEL Estimates	**With Overflight Noise**		**W/O Overflight Noise**		**Change Adding Overflights**	
	DNL (dBA)	**CNEL (dBA)**	**DNL (dBA)**	**CNEL (dBA)**	**Δ DNL (dBA)**	**Δ CNEL (dBA)**
Mon, 7/13 (Full day)	53.3	53.8	48.3	48.7	+5.0	+5.1
Tue, 7/14 (Full day)	54.4	54.7	48.3	48.7	+6.1	+6.0
Wed, 7/15 (Full day)	55.0	55.5	49.8	50.4	+5.2	+5.1

Table 1. Effects of presence/absence of aircraft noise on DNL/CNEL

As can be seen, the presence of overflights in the data adds approximately 5-6 dBA to the FAA measures, corresponding to a factor of 3.5-4 increase in average intensity of the sound. Now clearly Palo Alto has always had a certain level of noise from aircraft in the past, so it might be argued that these differences in DNL and CNEL measures could be a bit of an overestimate. On the other hand we have visually scanned all of the daily noise records at high time-axis resolution to be sure the extracted peaks are reasonably overflight events. There were a few small dubious peaks that slipped through, but more often, there were peaks that were most likely overflights that were below the conservative detection threshold level. This means we are including in the background some of the smaller amplitude overflight noise (probably from aircraft that did not come close to flying directly over my house).

As a result, we believe the table above shows a fairly accurate estimate of the significant changes brought on by the recent realignment of aircraft flight paths with the new NextGen system. One of the qualities that Palo Alto has enjoyed as a community is that it has always been a relatively quiet place to live. The NextGen changes have affected that profoundly.

Sound Exposure Level (SEL) Calculations

Another calculation we can do is to replace each recorded overflight peak with a simulated peak that is a composite metric that represents both the intensity of the sound and its duration. This measure is called a *Sound Exposure Level (SEL)* and it represents the total acoustic energy transmitted to the listener during the overflight event. Mathematically, an SEL is the intensity of a constant sound that would, in one second, generate the same acoustic energy as the actual time-varying noise event. For sound from aircraft overflights, each of which typically lasts 30 seconds to a minute or more, the SEL represents a better metric to use in assessing noise levels from overflight events, although it does not capture the effects of the repetitiveness of successive overflights nor the duration of an episode of high traffic.

Figure 3 shows the record for Monday, July 13, with the recorded overflight peaks converted to SELs. You can see that the peaks are now uniformly narrow (1 second wide) and have amplitudes of around 70 - 80 dBA, corresponding to the integrated sound energy delivered by the whole recorded peak. The heights of the SEL peaks may more closely represent the impact of individual events, but the DNL and CNEL statistics are only changed moderately. When computed over the SEL chart in Figure 3, the DNL(SEL) statistic is 55.7 dBA (instead of 53.3) and CNEL(SEL) is 56.3 dBA (instead of 53.8). We believe that the use of the SEL measure still falls short of capturing the local repetitiveness and duration effects of vexing aircraft noise.

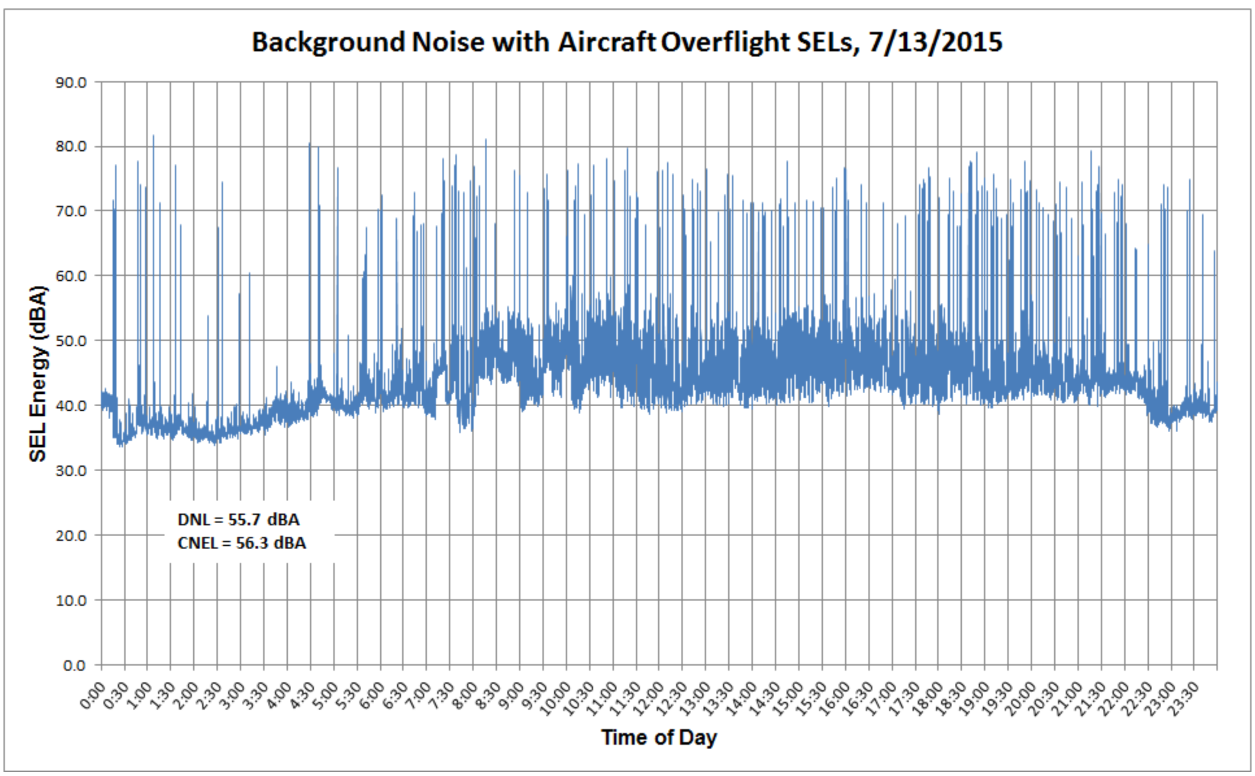

Figure 3. SEL representation of aircraft noise peak magnitudes for July 13.

Overall Magnitude of Aircraft Overflight Disruptions

There are a number of metrics that have been studied to try to capture various aspects of the impact of overflight noises (see these links, link-1 and link-2, for a discussion):

- Time Above a Specified Level (TA)
- Time Above Ambient Level (TALA)
- Time Audible (TAUD)
- Number-of-events Above a Specified Level (NA)

These can be computed over various time intervals, such as high-traffic and low-traffic times of the day. These each suffer from being single figures of (de)merit though that leave out other dimensions of the noise context (e.g., maximum amplitude and the distribution of amplitudes are ignored in the TA and NA series, and the duration of events is ignored in the NA measure).

In the following, we explore some multi-parametric ways to characterize the magnitude of repetitive aircraft overflight noise intrusions from our data set. One approach is to calculate histograms of raw peak heights and SEL amplitudes to show the distribution of aircraft noise intensities we are exposed to. Having the peaks now isolated and measured makes this easy to do with a spreadsheet program like Excel. Rather than doing this analysis just for Monday, July 13, we summarize the data from all 5 days during which data were recorded. Figure 4 shows the overall histogram for raw peak heights and Figure 5 shows the histogram for SEL heights (a total of 866 peaks are included in the histograms).

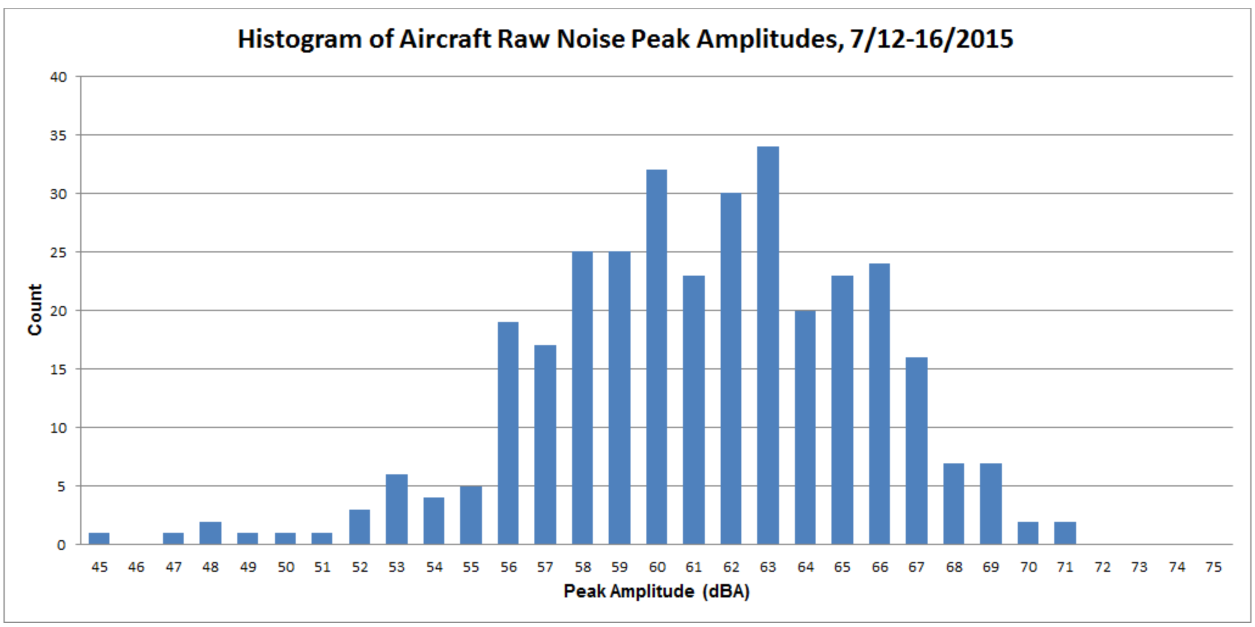

Figure 4. Distribution of raw aircraft overflight event intensities for July 12-16.

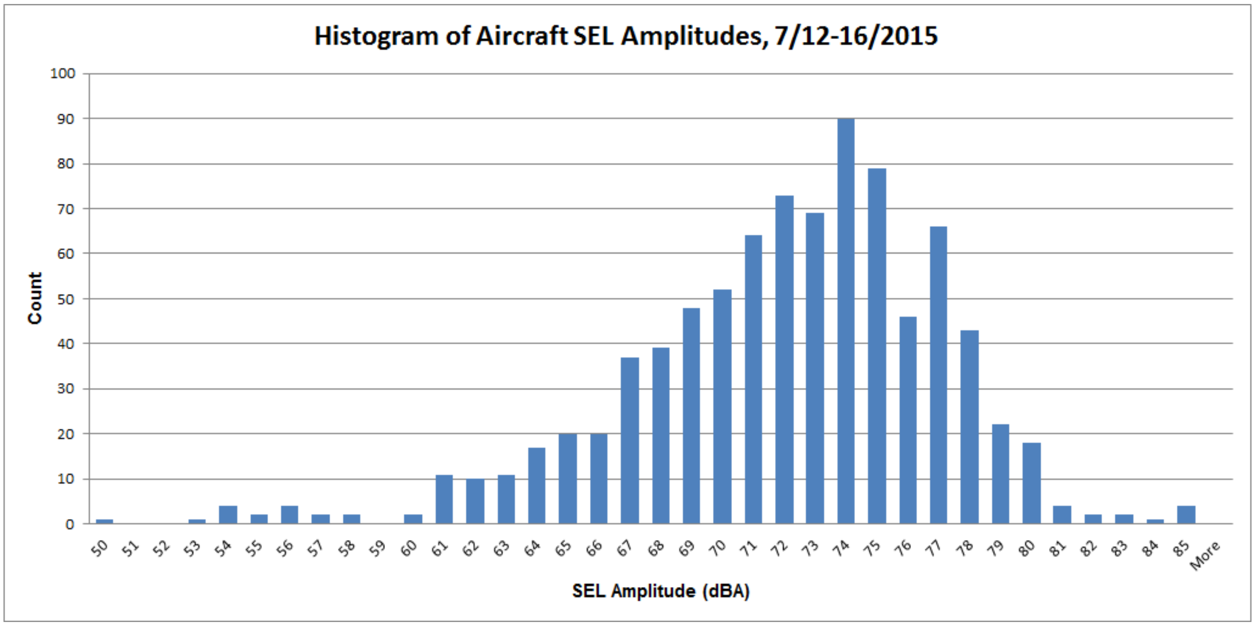

Figure 5. Distribution of aircraft overflight event SELs for July 12-16.

The mode of the distribution of raw peak heights is about 62 dBA with a half width variation of about +/- 8 dBA. The mode of the distribution of SEL heights is about 74 dBA with a half width variation of about +/- 9 dBA. These noise levels, especially at the higher end of the distributions, represent a significant disruption to daily activities. This way of presenting the data clearly leaves out the detailed time dimension of overflight events, although the histogram counts and the time interval covered in the histogram gives a measure of how often especially intense events happen. Such disruptions are immediately felt events *when* they happen, and are not an assessment done at the end of the day when you might imagine tallying your overall noise experience (DNL or CNEL) for the day. What matters if a conversation or other activity is interrupted because of disruptive overflight noise is that in that moment the effect is felt and evaluated.

The Frequent and Incessant Nature of Overflight Disruptions

From these same tabulations of overflight peak parameters, we can calculate other measures of the repetitive nature of these events. One measure is the frequency of overflight events based on the time between successive peaks. In order to have a more stable measure, we smooth out peak-to-peak time interval variations by measuring the mean time intervals separating successive running groups of 5 adjacent overflight peaks. The admittedly rather cluttered graphs of Figure 6 show smoothed diurnal event frequencies for each of the 5 days during which data were recorded.

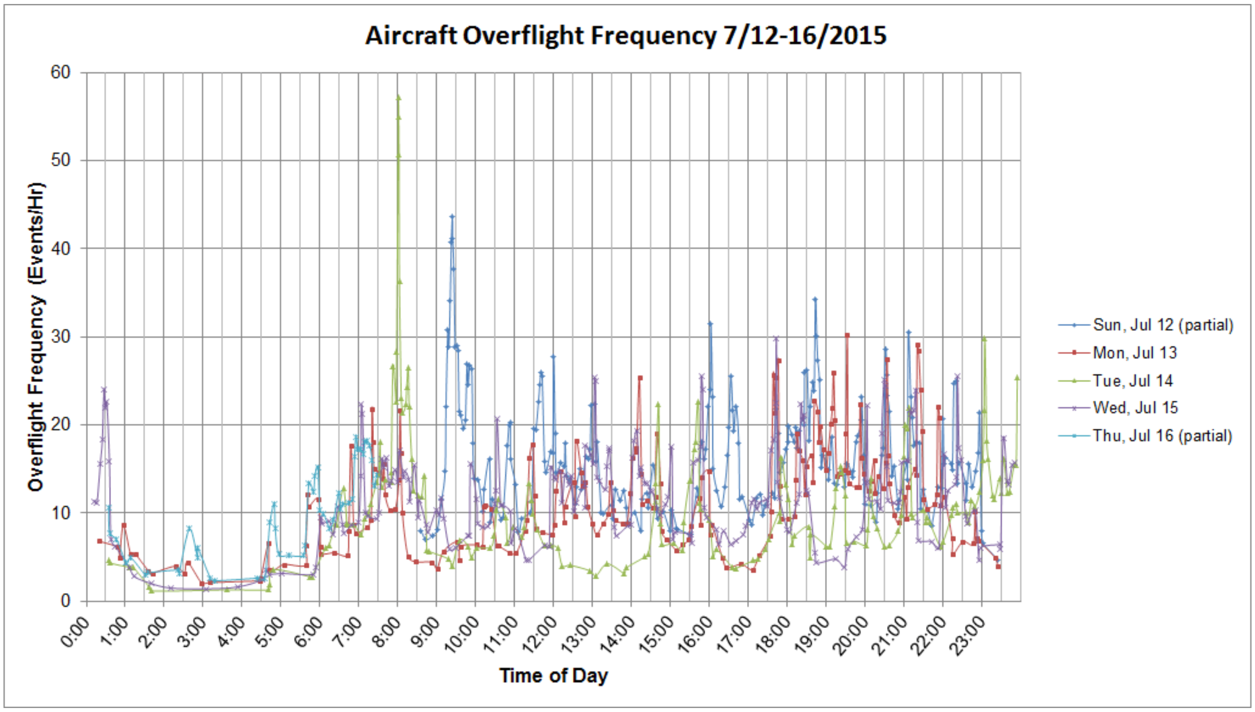

Figure 6. Overflight event frequencies for successive peaks as a function of time of day.

In its current form in Figure 6, this chart ignores event amplitude information, although one could imagine adding another dimension to the chart showing graphs for varying amplitude thresholds. A take-home message from this plot is that there seems to be no obviously consistent pattern of overflights from day to day. One should expect some natural schedule and statistical variability, as well as variations from day to day due to interactions among the airports in the metroplex (SFO/OAK/SJC) where the configuration of one airport can affect the traffic patterns of the others. Nevertheless, some general features can be seen in the frequency patterns in Figure 6, as better illustrated in the *histogram* of event frequencies shown in Figure 7 (846 overflight frequency measurements are tabulated in this histogram). These features include:

(a) traffic decreases (but does not disappear!) during the middle-of-the-night hours. In fact there are highly intrusive flight events just after midnight, until around 4:00 AM. Then, beginning around 4:30 AM, overflight frequencies start increasing toward the waking hours of the new day;

(b) flight traffic starts to increase noticeably at around 5:00 - 6:00 AM with big early morning peaks until about 10:30 AM;

(c) there are bursts of traffic throughout the mid-day and afternoon; and

(d) traffic again increases significantly from around 5:00 PM to 11:00 PM or midnight.

During the main part of the waking day, we see consistent traffic at a rate of around 10 - 12 overflights per hour (one every 5-6 minutes!). These frequencies increase during some times of the day to 20-25 flights per hour (one flight every 3 minutes!).

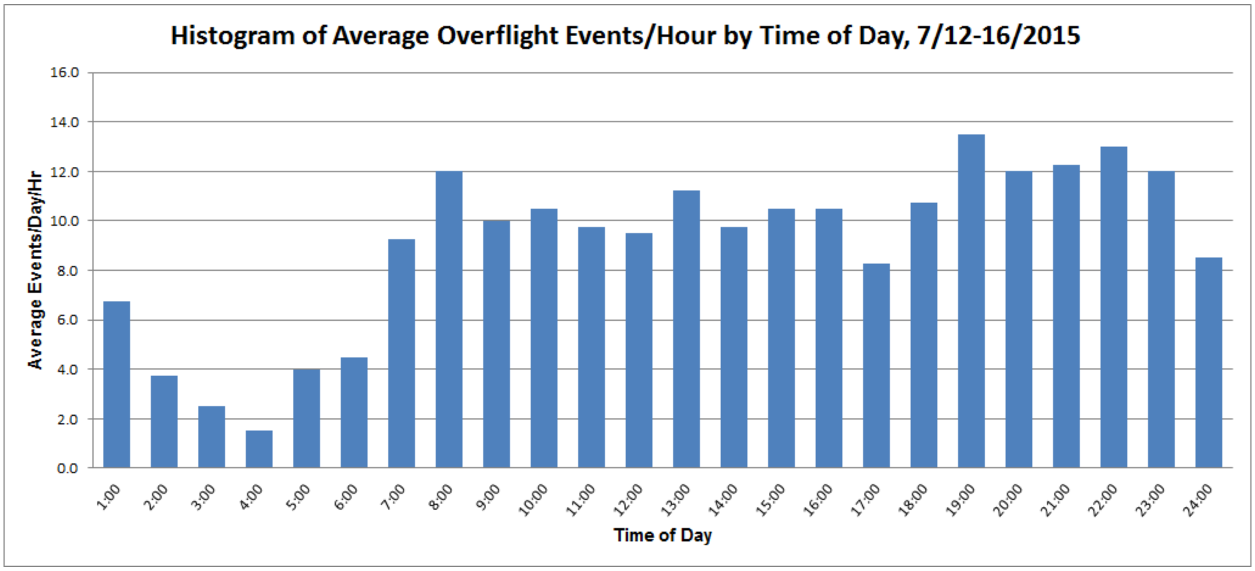

Figure 7. Histogram of overflight events as a function of time of day. Note that events in a given hourly bin do not necessary come in succession at that hour on a given day.

Another way to illustrate the statistics of overflight event frequencies is to compute a histogram of the frequency measurements themselves as derived from Figure 6. This histogram is shown in Figure 8 (again, 846 overflight frequency measurements are included in this histogram).

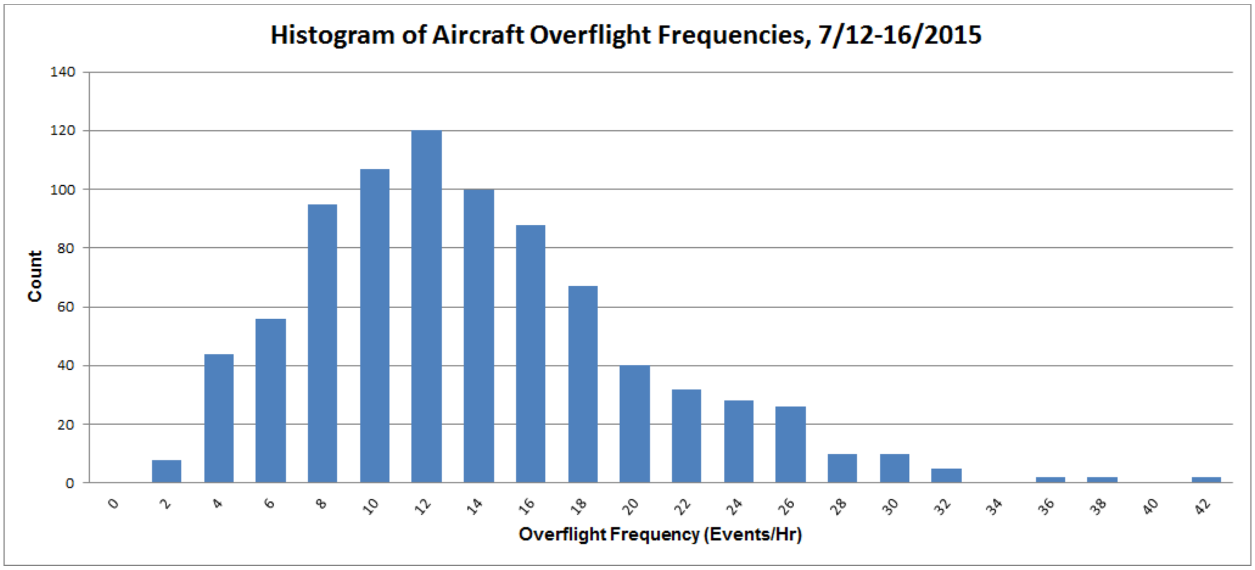

Figure 8. Histogram of frequencies for successive overflight events.

Clearly the mode of the distribution is at 12 events per hour (one every 5 minutes), but the distribution has a long tail so that on a significant number of occasions we have up to 30 events per hour (one every 2 minutes). These high rates happen during the busiest times for flight traffic which interfere significantly with resident morning and evening hour activities. Remember, these overflight frequencies measure the average time intervals between 5 successive peaks, not instantaneous frequencies. Thus, they represent sustained repetitive noise patterns that are especially annoying at the higher frequencies.

Conclusion

The bottom line, whether or not aircraft noise disturbs you, is that these data support the claims by residents that aircraft overflights have become very loud and occur frequently and repetitively during the day and night. In particular, the data shown in Table 1 (comparing DNL values with and without overflight noise peaks) suggest that in re-routing the flight paths around SFO/OAK/SJC, the FAA may have violated their own rules (less than 5 dBA increases in areas with ambient DNL levels in the 45-60 dBA range). This observation, and the search for better metrics to assess noise impacts on residents, argue strongly for reconsideration of the decisions leading to the current NextGen traffic patterns. I believe these reconsiderations should include:

(a) a more detailed and comprehensive survey of noise in the Palo Alto area as a function of geography and time, with an eye toward comparisons with other impacted communities since any solution is largely a zero-sum game,

(b) an examination of alternative flight re-routes that are higher in altitude and take place primarily over the bay to minimize noise exposure, and

(c) an examination of improved approaches to ensure that the noise that does remain over populated areas is not concentrated over a few unfortunate communities.

In the meantime, I and my colleagues will continue to collect and analyze data to see how stable over time and geography these analyses are.

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Acknowledgement

It is a pleasure to acknowledge Juan Jose Alonso, Professor of Aeronautics and Astronautics at Stanford University, for a number of very helpful conversations to critique and refine the work described here.

More Technical Details

In my measurements, the Reed sound level monitor unit was set to use A-profile weighting, slow response, and 2 second sampling to conform to FAA measurement guidelines. I used the vendor calibration unit (SC-05) and a foam wind shield (SB-01). The vendor specifications for the unit are as follows:

Specifications:

Measuring Range: 30 to 130dB
Resolution: 0.1dB
Accuracy: 31.5Hz ± 3.5 dB, 63 Hz ± 2.5 dB, 125 Hz ± 2.0 dB, 250 Hz ± 1.9 dB, 500 Hz ± 1.9 dB, 1 kHz ± 1.4 dB, 2 kHz ± 2.6 dB, 4 kHz ± 3.6 dB, 8 kHz ± 5.6 dB
Frequency Weighting: A: Human Ear Listening; C: FLAT Response
Time Weighting: Fast: 200ms; Slow: 500ms
Frequency Range: 31.5 to 8,000Hz
Auto Sampling Time: 1, 2, 5, 10, 30, 60, 120, 300, 600, 1800, 3600 seconds
Microphone: Electric Condenser Microphone
Memory Card: SD memory card, 1 GB to 16 GB
Data Output: USB/RS232 PC computer interface
AC Output: 0.5 Vrms corresponding to each range step
Output Impedance: 600Ω
Power Supply: 6 x 1.5V UM3/AA batteries
Dimensions: Meter: 245 x 68 x 45mm; Microphone: 12.7mm dia.
Weight: 489g (1.08 lb)

The device appears to be accurate and stable for the purposes of this study, good to +/- a couple of dBA. I also checked the degree to which the wind shield might affect measured values without wind present and found it to be negligible.

Our neighborhood is very quiet and I believe that most of the sharp peaks (at least those with widths typically around 20-60 seconds, such as illustrated in Figures 2 and 10 below) correspond to aircraft overflights. I have checked quite a few random peaks with the playback feature of *Flightradar24* to verify this, but have not done so for all because I don't have access to the radar database to do that programmatically (doing it by hand is too tedious)

The most important features of my data analysis computer program are (a) being able to measure an appropriate upper bound for background ambient noise levels as a function of time of day, and (b) detecting aircraft overflight sound peaks that rise above this dynamic threshold while filtering out peaks that are too narrow or too wide for a typical overflight. All calculations are done using linear scale sound intensity values rather than decibel values. Starting with a nominal background estimate, I measure the background mean and variance using simple exponential weighting functions to track changes with time. If y(t) is the signal level at time t, then the new weighted average value, v(t), is:

$$v(t) = y(t) + f * v(t-1)$$

where f is a weighting constant less than 1. The closer f is to 1, the longer the "memory" of the weighting.

"v" is not updated during the analysis of a possible peak. The upper bound I use for the background threshold at time t is the background mean at t plus 3.5 times the square root of the variance at t (standard deviation). This is quite a stringent criterion for detection meaning that we only find large peaks.

Noting that the peaks of louder aircraft events stay above threshold longer than quieter overflights, I adjust the upper width threshold for detecting valid aircraft peaks proportional to the square root of the log of the peak maximum (as if the peak had a Gaussian shape). If several overflights take place within an interval less than that of a single aircraft transit, their sound level peaks may get merged and counted as one event rather than several.

To illustrate the results of this procedure, Figure 9 below shows the computed background mean (green) and the peak detection threshold (red) for the day-long record on July 13, and Figure 10 shows these values for the sub-period, 7:30 - 8:30 AM, with higher resolution.

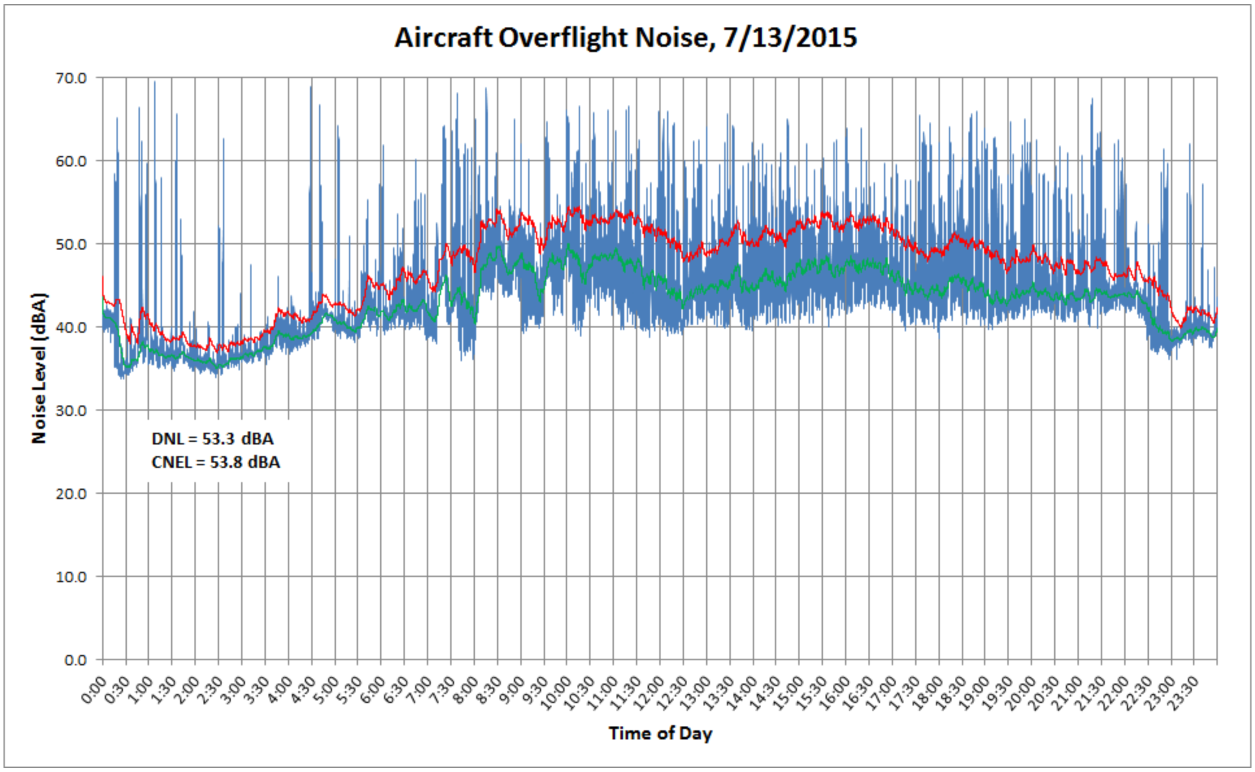

Figure 9. Raw data from Reed sound meter for July 13, 2015 showing the estimated mean background (green) and the associated peak detection threshold (red).

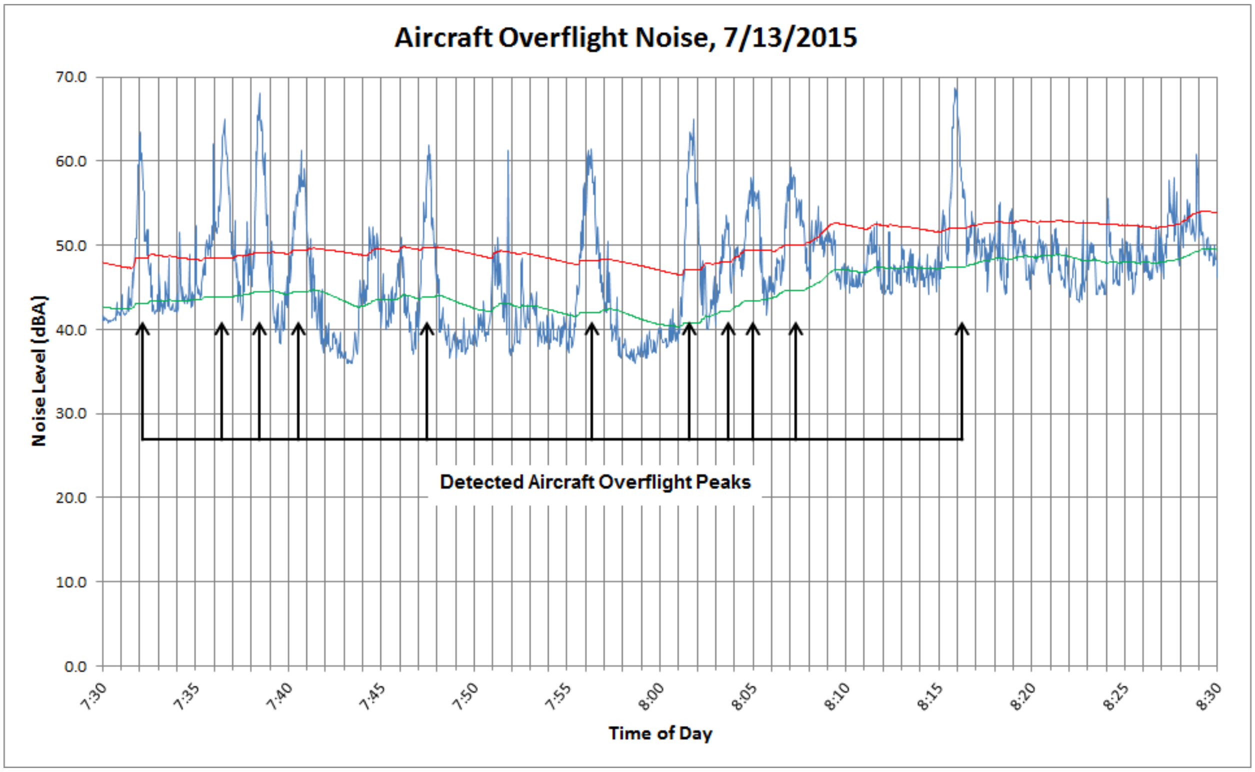

Figure 10. Expanded view of the interval 7:30 8:30 AM from Figure 9.

As can be seen, this peak detection algorithm is conservative in calculating SELs in that it ignores peaks that are near the background noise level and it does not include the wings of peaks extending below the threshold.