Aircraft Noise Event Identification Methods for *msnsound.com*

February 4, 2024

Noise events associated with aircraft operation in the vicinity of the Dane County Regional Airport are identified here in two stages: ADS-B based identification and non-ADS-B identification.[1] With a few notable exceptions, FAA regulations require aircraft operating near the airport to transmit ADS-B Out data continually. The key exception to the ADS-B Out requirement is that tactical military aircraft, including the F-16C and F-35A fighter jets based at Truax field are not required to transmit ADS-B Out. Since these aircraft do not transmit position data, noise events associated with their operation must be derived from the noise-meter data alone. However, as described in more detail below, most fighter-jet operations near the airport produce distinct noise signatures than can be readily—if tediously—manually identified.

ADS-B Based Noise Event Identification

ADS-B-based identification is used for nearly all commercial and general aviation noise events. It is also used for military traffic that transmits ADS-B information. ADS-B-based noise event identification proceeds as follows:

1. One-second ADS-B position and noise-meter data for a given month are consolidated and compiled. The ADS-B data are limited to aircraft positions that are within 10 statute miles of the airport and below 5,000 ft MSL in altitude.
2. A Flight ID number is generated for each aircraft on each date based on the unique hex code for each airframe that is transmitted in the ADS-B Out broadcast. This is further split into individual flight segments if there is a gap of more than 20 minutes in the ADS-B data for the aircraft—as might occur if an aircraft arrives, parks for some time, and then departs; or if an aircraft flies away from the airport, then later returns.
3. There are typically gaps in the one-second ADS-B data on position, altitude, speed and track: these are interpolated, within limits according to variability in the aircraft heading and speed on either side of the gap.
4. Algorithms are used to classify each flight event by operation type and runway based on the ADS-B position, altitude and speed data. For example, arrivals show generally descending altitude and a sudden decrease in speed along a track associated with one of the three DCRA runways; departures show an increase in speed and altitude with position hits along one of the runways during the take-off roll; touch-and-Go operations show multiple take-offs and landings within the same flight segment.

---

[1] ADS-B is an acronym for Automatic Dependent Surveillance – Broadcast, in which individual aircraft broadcast information about position, altitude, speed and other parameters via 1090 and (less commonly) 978 MHz radio signals. The information is broadcast continuously and can be easily intercepted and digitized with an appropriate radio receiver, antenna, and software. ADS-B data used here are collected from a single 1090 MHz receiver located about 2.5 miles south of the airport.

5. The noise-meter data for each meter are processed to establish the background noise levels on a one-minute basis. This is done by taking the median of the one-second decibel readings for each minute of the hour and then taking a rolling 11-minute median of the medians, centered on the middle minute.
6. The data for each noise meter are evaluated against all Flight segments that come within 1.5 miles of the meter at some point in the flight segment. Each flight segment is evaluated against the noise meter data as follows:
    a. Analysis is limited to 90-seconds on either side of the time of minimum approach distance by the aircraft.
    b. L_{max} for the candidate event is identified as the data point with the highest decibel reading within 10 seconds of minimum approach distance.
    c. In decibel terms, aircraft noise events typically show a roughly triangular shape, with an abrupt beginning and ending (see figures on following pages). These beginning and ending points are identified by separately finding best-fit linear regressions for the approach and retreat phases of the event[9]. The regressions sequentially evaluate candidate event start/stop elapsed seconds (S_{elap}) relative to L_{max}. For each candidate start/stop value of elapsed seconds (i) from L_{max}, noise meter decibel readings for 90 seconds before/after L_{max} are regressed against min(abs(S_{elap}),i). Candidate start/stop times are evaluated over a range from 5 to 60 seconds before/after L_{max}, and the value with the highest regression r^2 is chosen. A final combined regression model that combines the approach and retreat phases is run to get an overall regression fit.
    d. In addition, noise meter decibel readings within 90-seconds of L_{max} are regressed against horizontal distance to the aircraft, separately for the approach and retreat phases of the event.
    e. A candidate noise event is rejected if any of the following is true (with classification code):
        i. The number of available observations before or after L_{max} is < 3 (**OBS**).
        ii. L_{max} is < 10 dB above the background level (**ELEV**).
        iii. L_{max} is <65 dBA during the daytime (7AM to 10PM) and <55 dBA at night (10PM to 7AM) (**LMAX**).
        iv. The calculated event start or end times from Step C above are less than 4 seconds from L_{max} (**DURATION**).
        v. The combined elapsed-time regression fit in Step C has an r^2 value < 0.5 (**R2**).
        vi. Either slope term from the combined elapsed-time regression fit in Step C is statistically insignificant (at a 95% confidence level) or shows a magnitude of 0.2 dBA per second or less (**TIME SLOPE**).
        vii. Either distance-regression fit in Step D above is statistically insignificant or not of the expected sign (decreasing noise with increasing distance) (**DISTANCE SLOPE**).
    f. Candidate noise events are evaluated in order of minimum approach distance. Once a candidate event has been evaluated, that time period is excluded for subsequent candidate events for more distant aircraft.
    g. Candidate noise events that pass the above screens are further screened for signal-to-noise ratio as follows:

i. The identified event period is compared to 90 seconds before and 90 seconds after the event (excluding any other identified noise events).
ii. The root-mean-square deviation of 1-second dBA readings relative to the background level (see Step 5 above) is calculated, separately for the event period (RMS_{event}) and the combined before- and after-event periods ($RMS_{before/after}$).
iii. The candidate event is rejected if RMS_{event} / $RMS_{before/after}$ < 2.0 (**SNR**).

Table 1 shows how approximately 560 thousand candidate ADS-B based noise events between January 2021 and July 2023 (across all monitored locations) were classified by the above algorithms. The figures that follow provide examples of events that either passed the screening or were rejected for various reasons.

Table 1. Disposition of all candidate aircraft noise events (all meter locations) between January 2021 and July 2023.

Classification	Rejection Code	N		Percent
REJECT	OBS	7,787	1.4%	80.5%
	ELEV	265,255	47.2%	
	LMAX	65,143	11.6%	
	DURATION	0	0.0%	
	R2	73,394	13.1%	
	TIME SLOPE	27,645	4.9%	
	DISTANCE SLOPE	9,281	1.7%	
	SNR	4,517	0.8%	
PASS		109,583		19.5%
	Total	562,605		

Figure 1. Example of an identified noise event from a departing commercial airliner passing directly over a noise meter. There is a clear, nearly linear relationship between decibels and both elapsed time and distance between the aircraft and the meter for this event, which occurred during a time of minimal variability in background noise level.

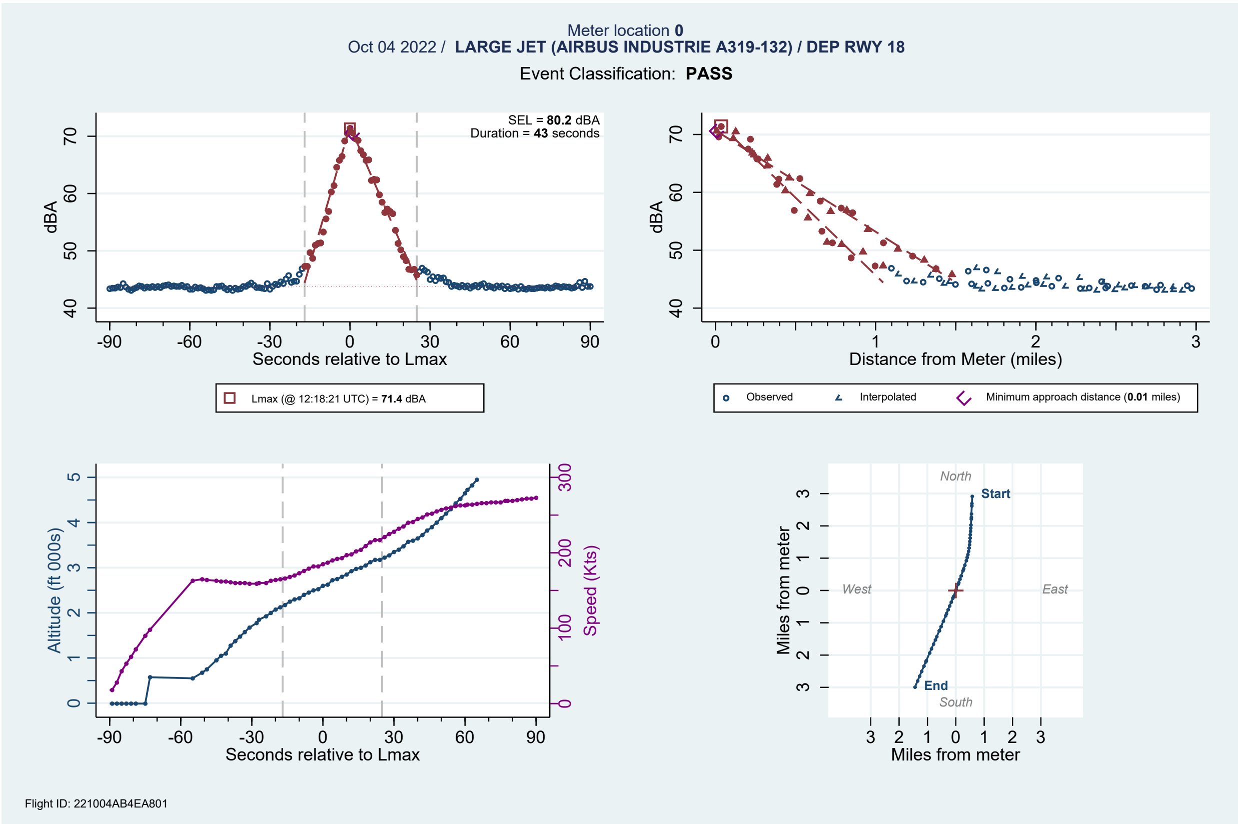


Figure 2. Another example of a noise event from a departing commercial airliner that passes nearly directly overhead as it turns to the east. Background decibel levels are more variable in this case.

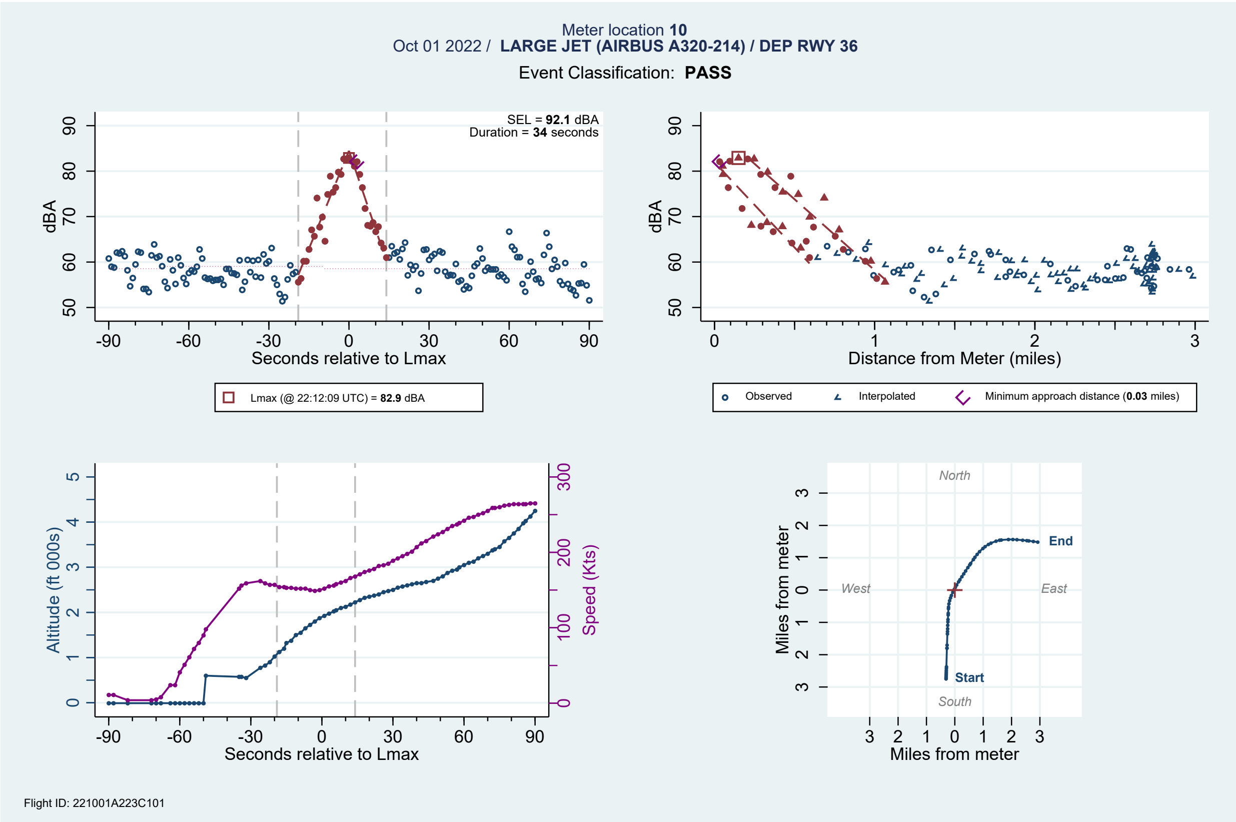


Figure 3. Example of an identified noise event from an arriving commercial airliner that passes less than 0.1 miles from the noise meter.

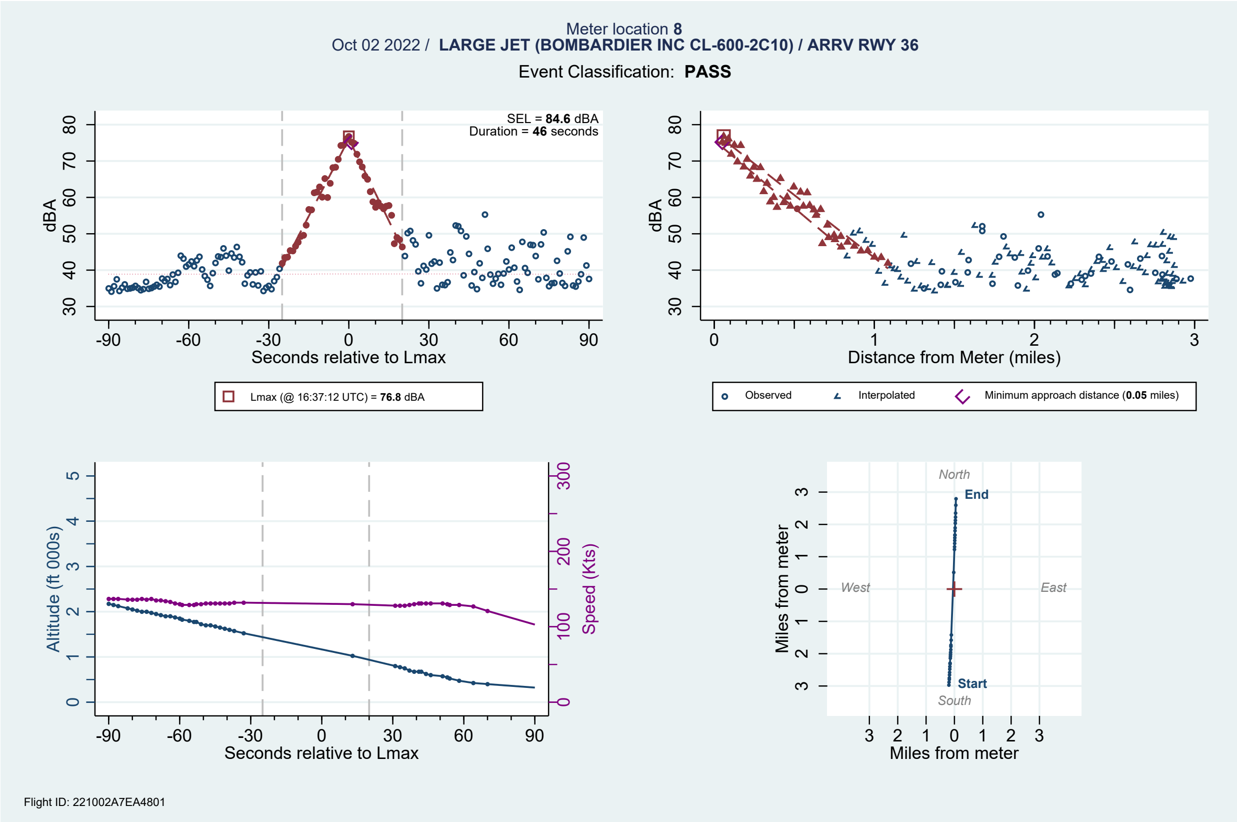


Figure 4. Example of a noise event for a departing military fighter jet passing within about 0.4 miles of the noise meter. Transient T-38 training jets often transmit ADS-B Out, but most fighters, including the locally based 115th Fighter Wing, do not.

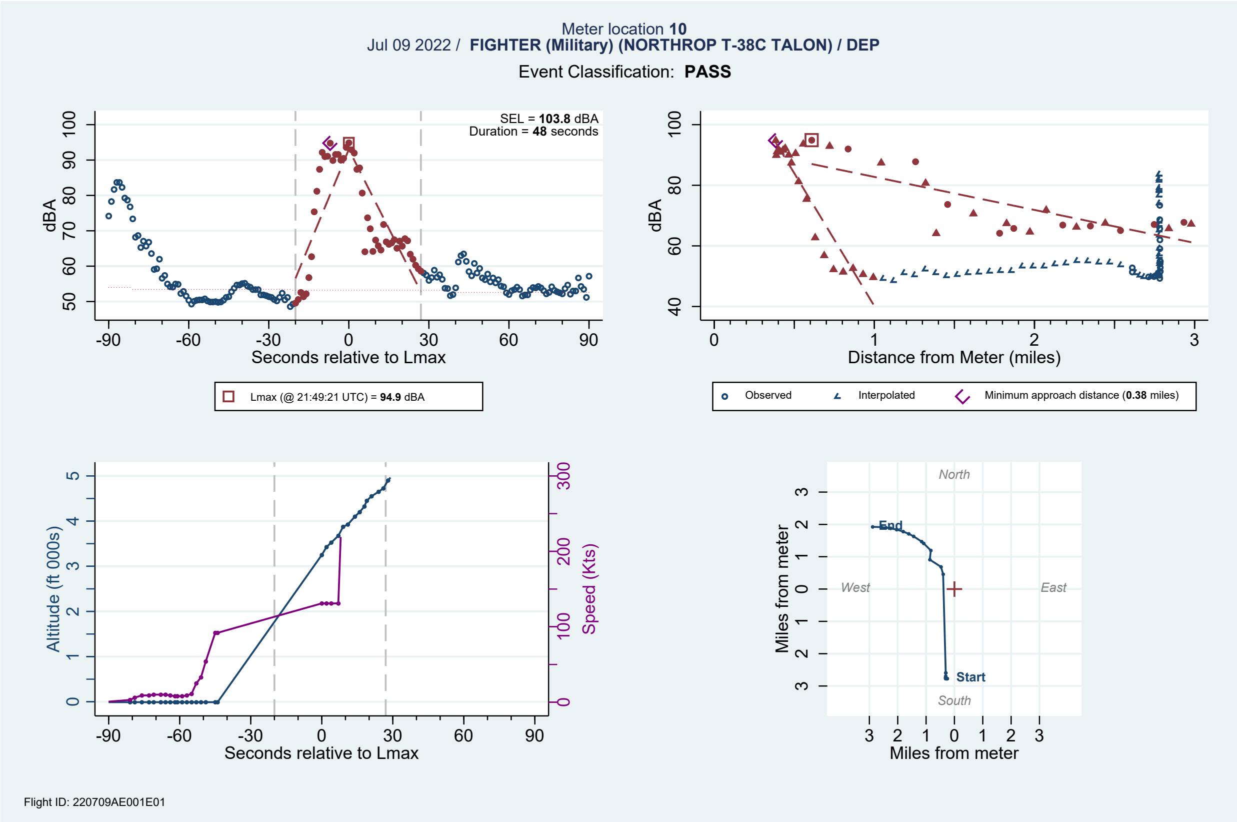


Figure 5. Example of an identified noise event for a small general-aviation aircraft passing within about 0.3 miles of the noise meter. This event just meets the minimum L_{max} threshold of 65 dBA to be counted as a daytime noise event.

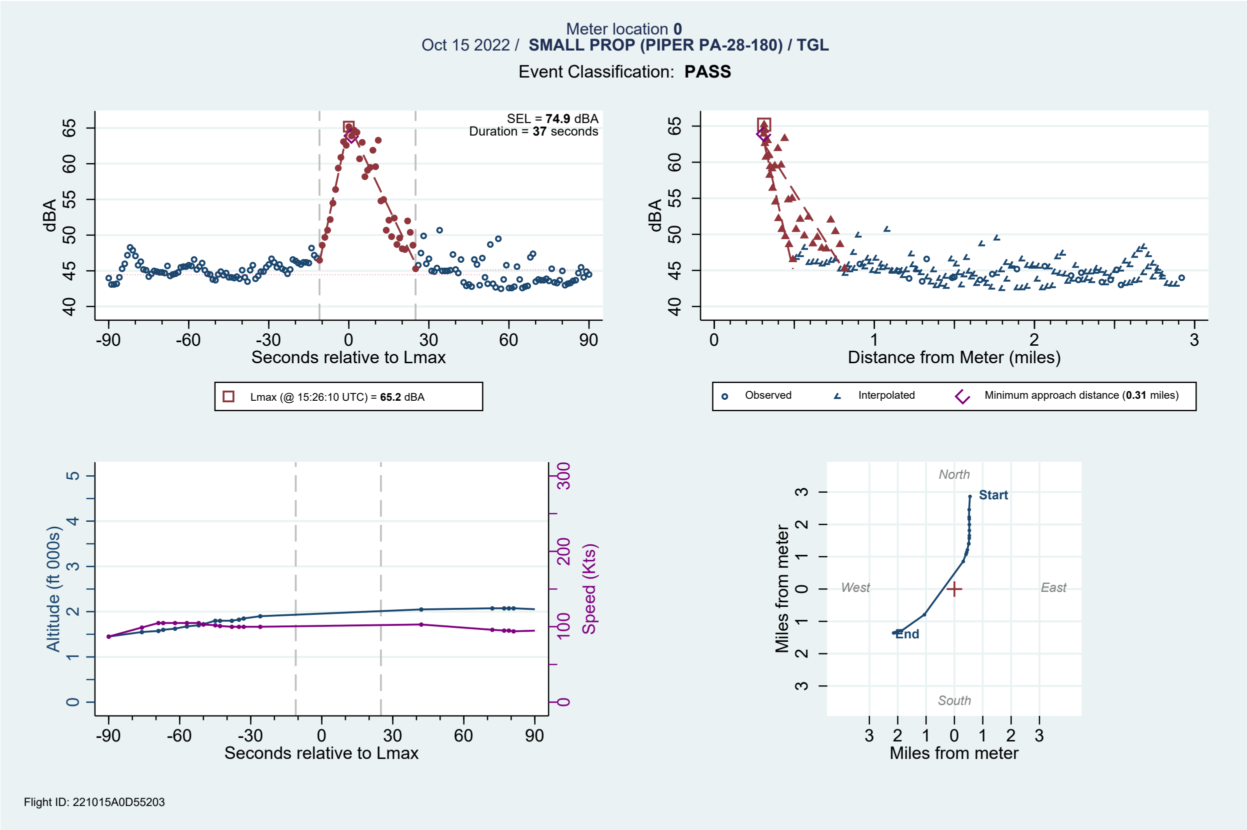


Figure 6. Example of an identified noise event for a small business jet departing to the south and turning east, passing within about 0.35 miles of the noise meter. There is a good relationship between decibel level and both time from L_{max} and distance despite the fact that the aircraft is turning as it passes near the meter.

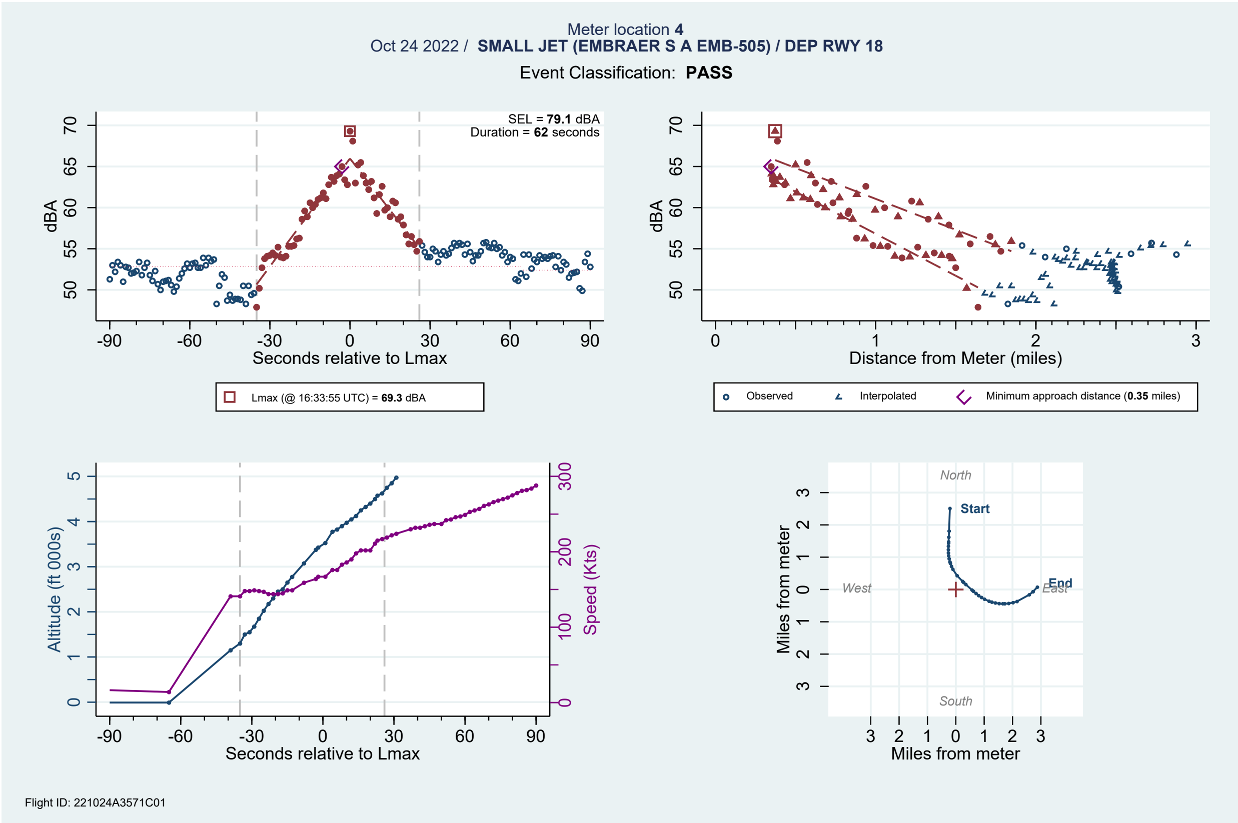


Figure 7. Example of an identified aircraft noise event from the arrival of one or more military helicopters passing within about 0.3 miles of the noise meter. Locally-based UH-60 military helicopters often fly in formation with only the lead aircraft transmitting ADS-B Out.

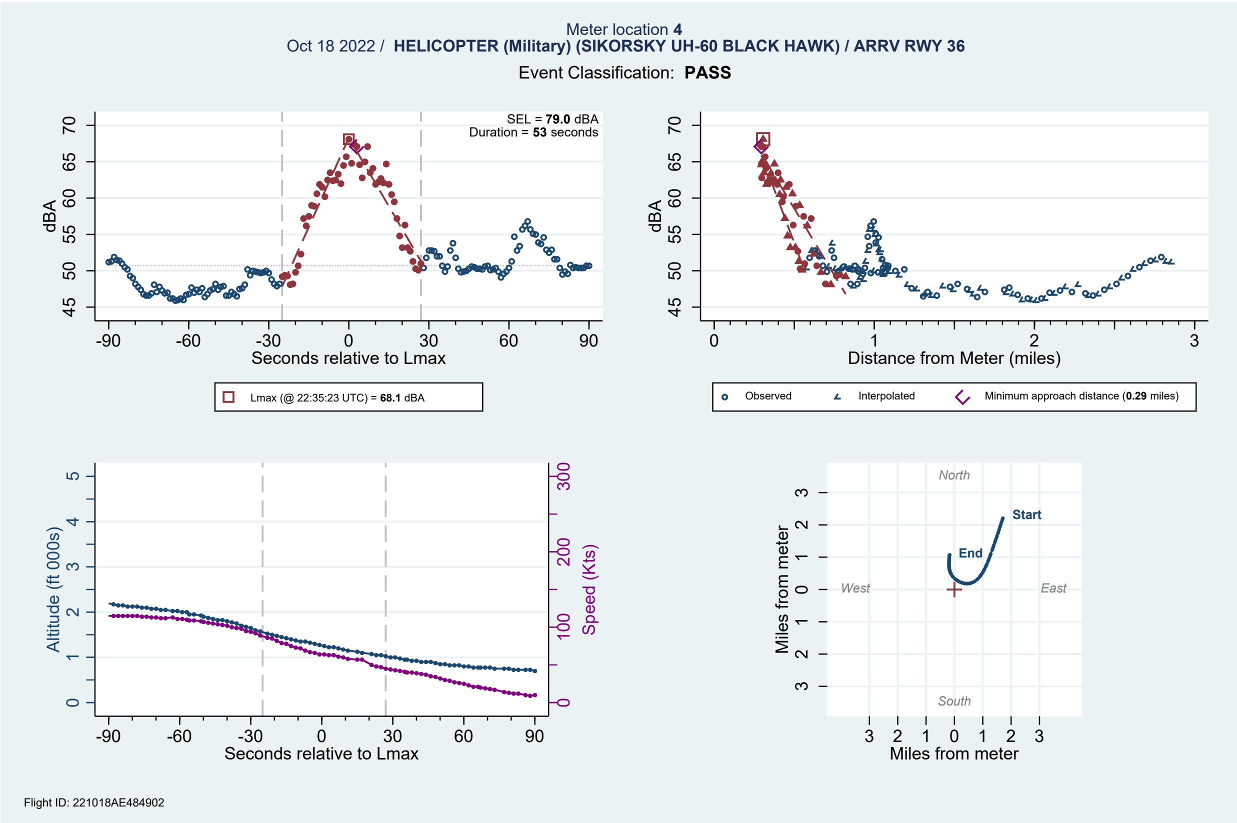


Figure 8. Example of a candidate aircraft noise event rejected due to L_{max}<65 dBA, as well as being <10 dB over background level.

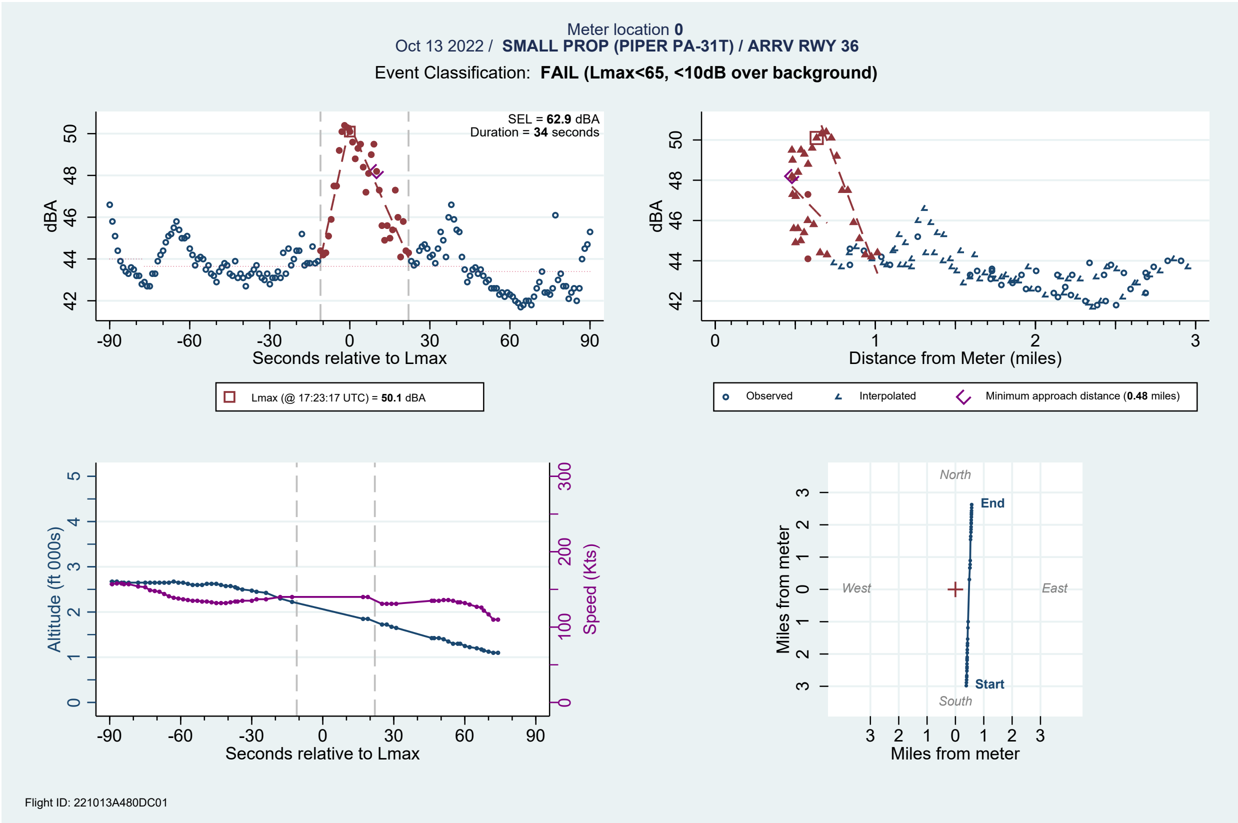


Figure 9. Example of a candidate aircraft noise event rejected due to poor fit (regression r^2). Here, the noise meter is about 1.2 miles aft of a departing commercial airliner.

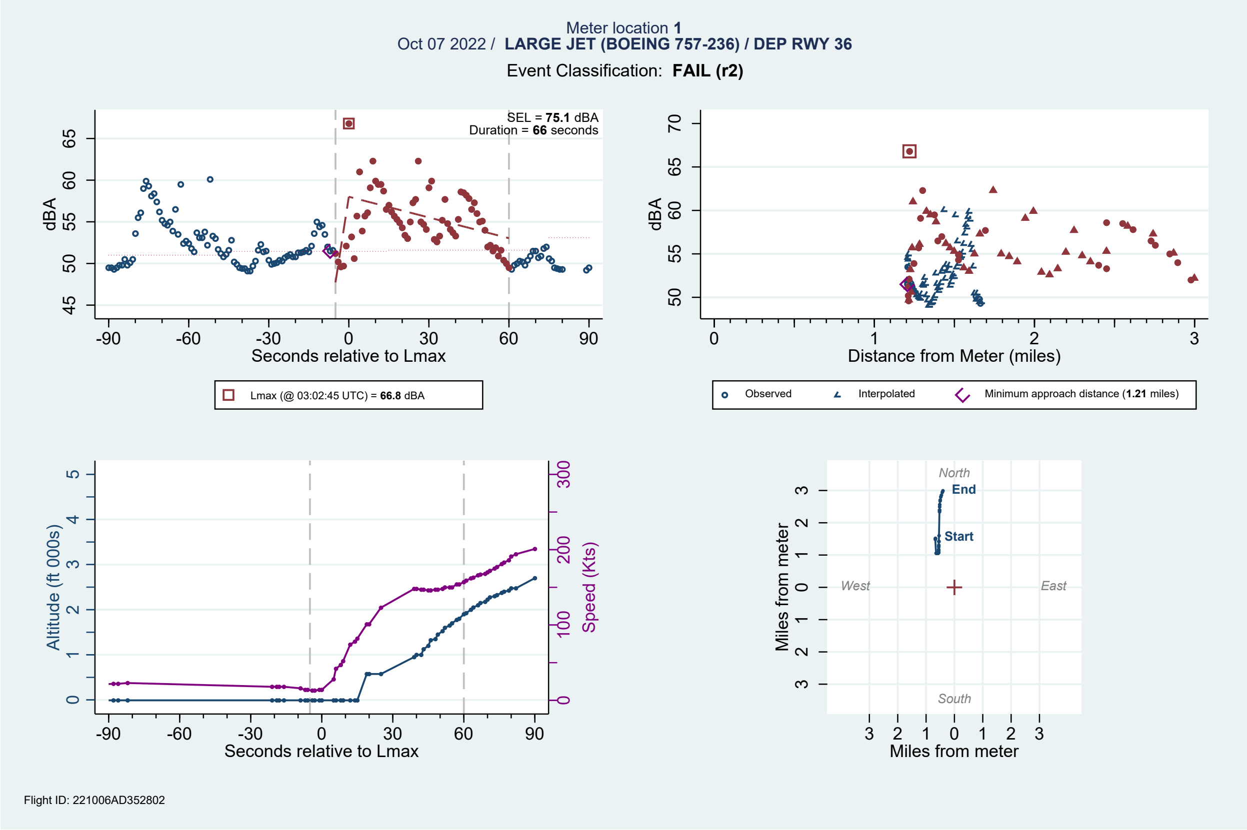


Figure 10. Example of a candidate noise event rejected due to magnitude or sign of the slope terms for the dBA vs. elapsed-time regression.

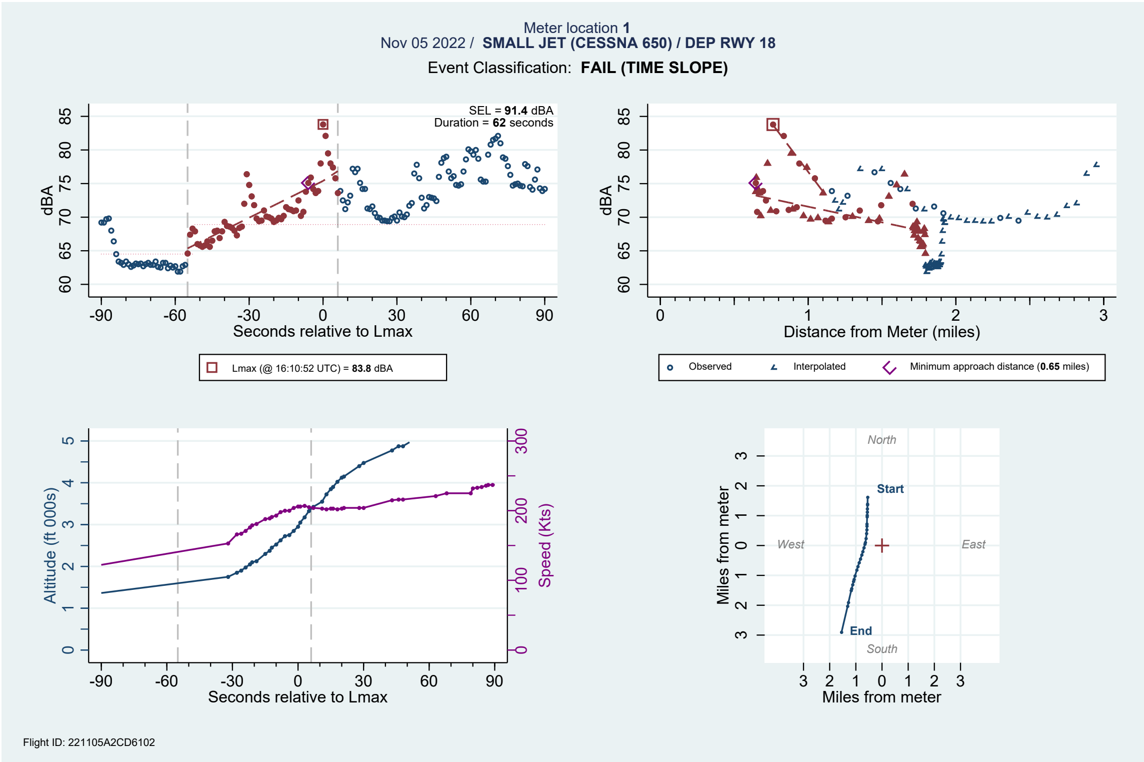


Figure 11. Example of a candidate noise event rejected due to low signal-to-noise ratio (1.1). This meter is located about a mile west of the airport and near a road with frequent passing traffic, making it difficult to distinguish aircraft noise from road-traffic noise except for noise events that rise well above the road noise.

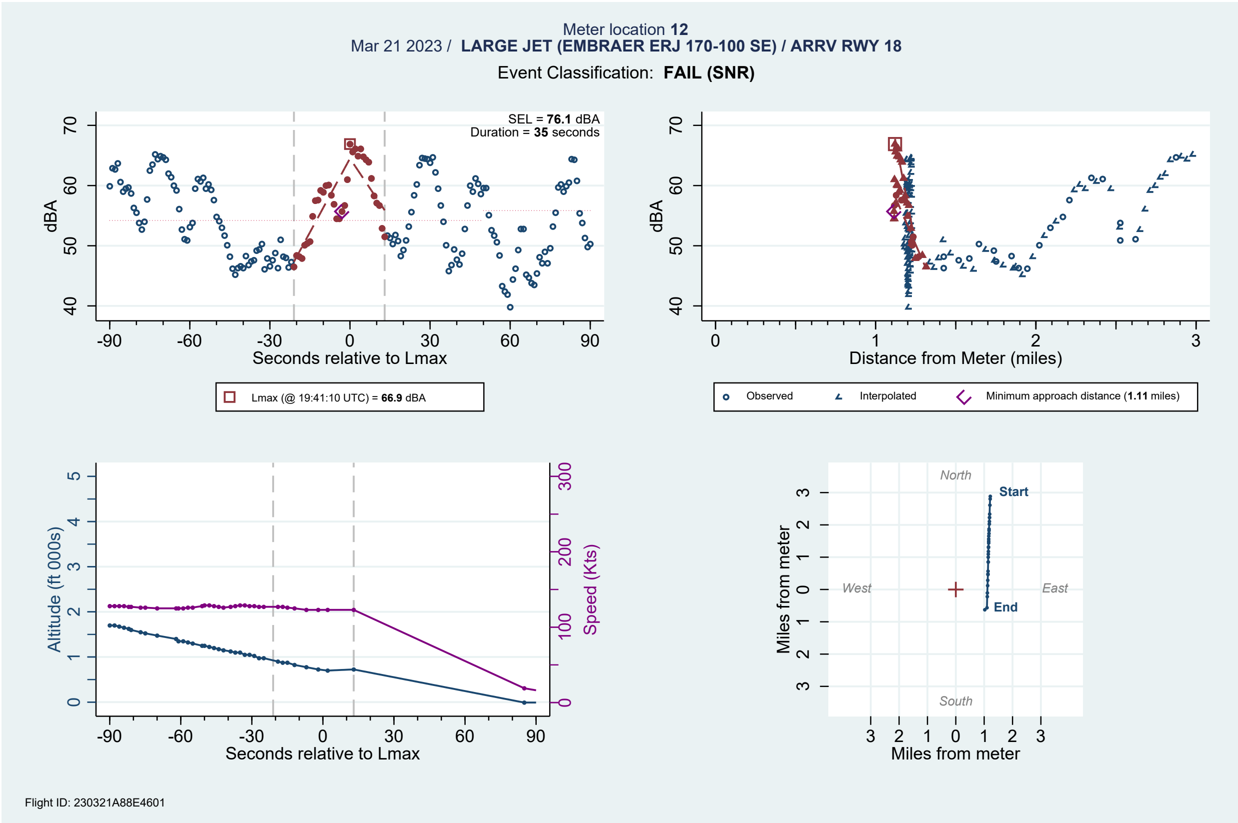


Figure 12. The same busy-road location as the previous example but showing an aircraft noise event with adequate signal-to-noise ratio (3.7).

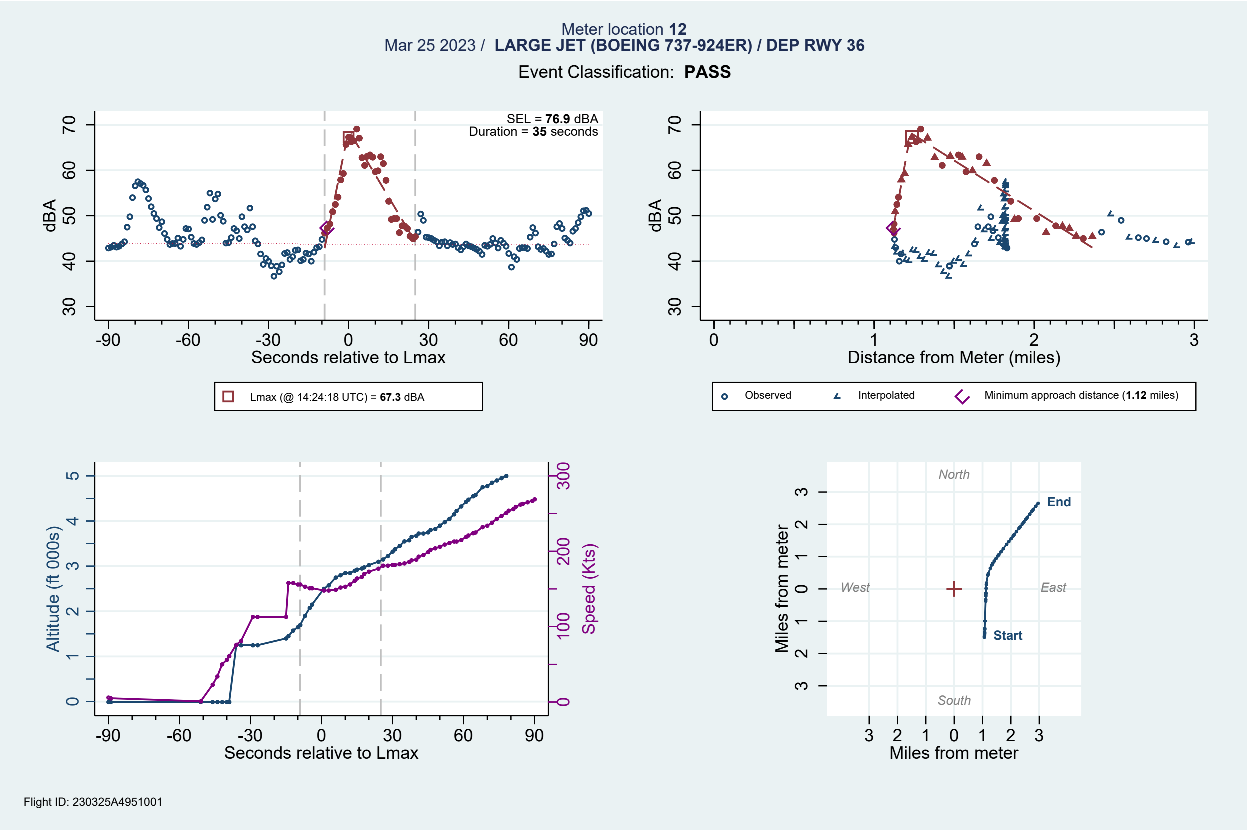
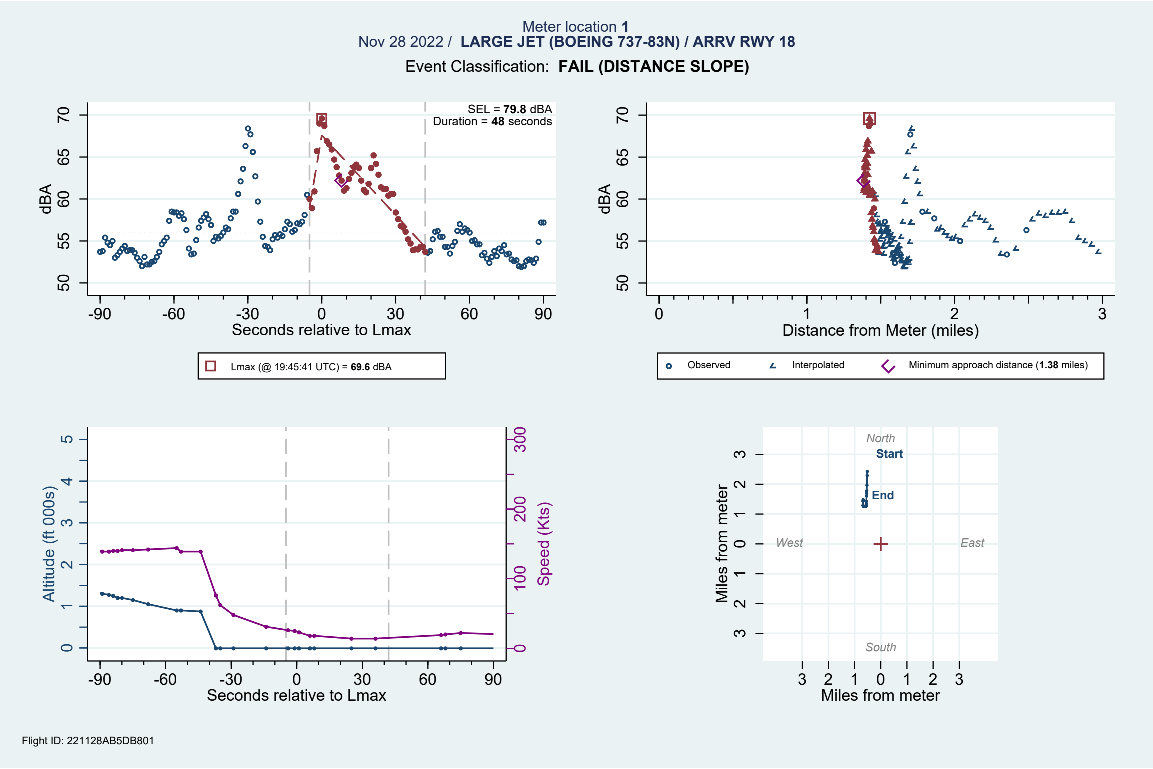


Figure 13. Example of a candidate noise event rejected due to the sign of the dBA vs. distance regression. The noise meter is about 1.3 miles forward of an arriving commercial airliner.



Non-ADS-B Based Noise Event Identification

The main goal of the non-ADS-B identification is to identify noise events for fighter jets that do not transmit ADS-B data and therefore cannot be identified using the ADS-B-based methods described above. The analysis proceeds in two steps. First, candidate noise events are identified. These events are then manually reviewed for noise levels and patterns that are characteristic of fighter-jet noise events.

Candidate Event Classification

Candidate events are identified as follows:

(1) The one-second noise-meter dBA readings are converted to sound pressure level:

$$SPL = 10^{(dBA/10)}$$

Missing data are assigned SPL = 0.

(2) Identified ADS-B-based aircraft noise events from the preceding analysis are removed by setting SPL to zero.

(3) The average SPL is calculated for each second across all noise meters with non-zero values for SPL, and a rolling 2-minute overall average SPL is calculated. This overall average is converted back to decibels as $dBA = 10*\log_{10}(SPL)$

(4) A candidate noise event is identified for each period where the rolling overall-average dBA level rises above 60 dBA: that is, the candidate event begins when the rolling overall dBA level rises above 60 dBA and ends when it falls below 60 dBA.

Generally, the above procedure flags a candidate period if 20 percent or more of the meters show aircraft-like spikes in noise levels that peak at about 80 dBA, or if a single meter shows a peak at 90 dBA or higher. A typical month of data yields 200 to 1,000 candidate events.

Manual Review of Candidate Events

To manually review candidate events, plots in the form shown in Figure 14 is generated for each event. The lefthand panel for the plot shows the dBA readings for all meters over the course of the event in a single graph that is color-coded by meter location (see Figure 15). Note that noise level readings associated with previously-identified ADS-B-based noise events are omitted from this plot. The righthand portion of the figure shows the individual traces for each meter in separate plots, along with the rolling 10-minute median background level as a solid red line. The data in these plots are color-coded as follows:

- Grey shows dBA readings that are less than 5 dB above the background level
- Light blue shows readings that are 5 to 10 dB above the background level
- Dark blue shows readings that are 10 or more dB above the background level
- Red indicates an previously-identified ADS-B identified noise event

Figure 14 exemplifies most candidate events that upon closer inspection turn out to *not* be aircraft related. In this case, the event was flagged because of three very brief noise spikes (of unknown origin) at a single meter.

Figure 14. Example review plot for an algorithmically derived candidate non-ADS-B noise event. This candidate event does not show any aircraft noise events beyond those already identified from the ADS-B based analysis (seen in red in the righthand plots). It was flagged as a non-ADS-B candidate because of several short but loud noise spikes on a single meter (Meter Location 1).

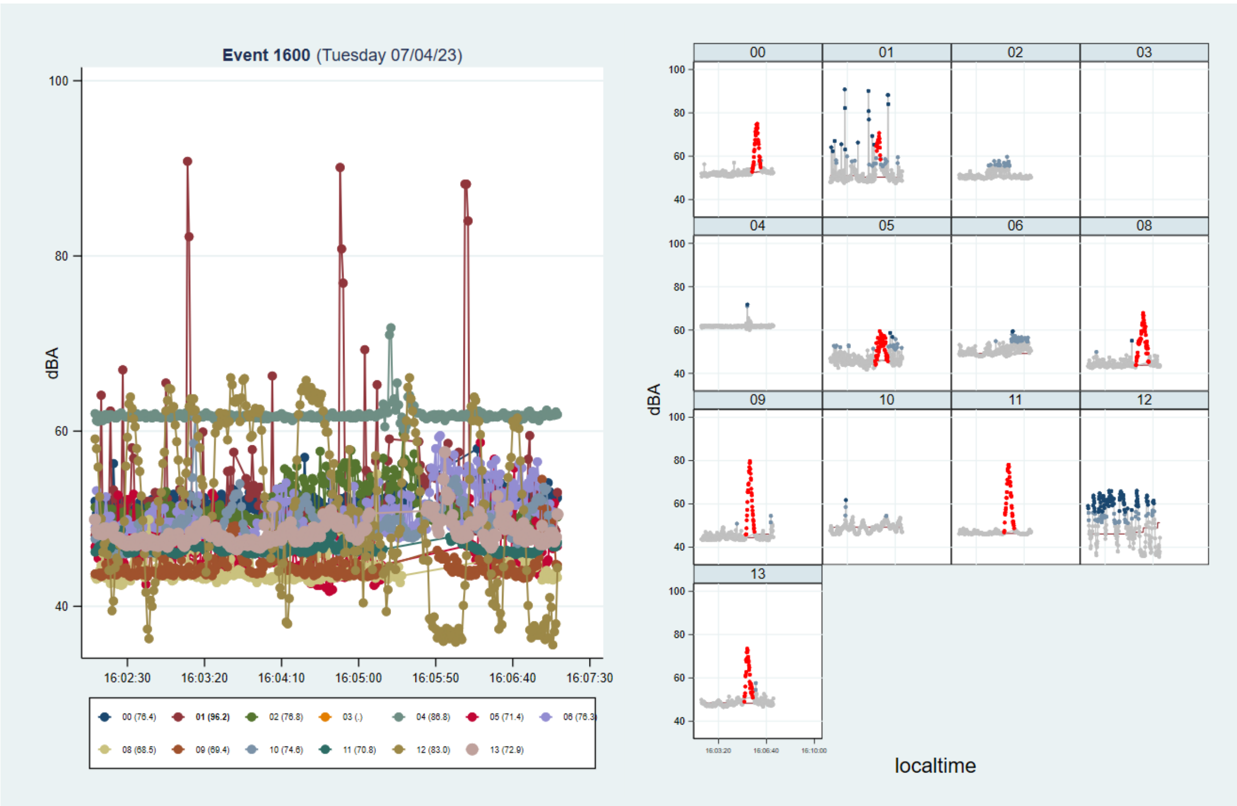
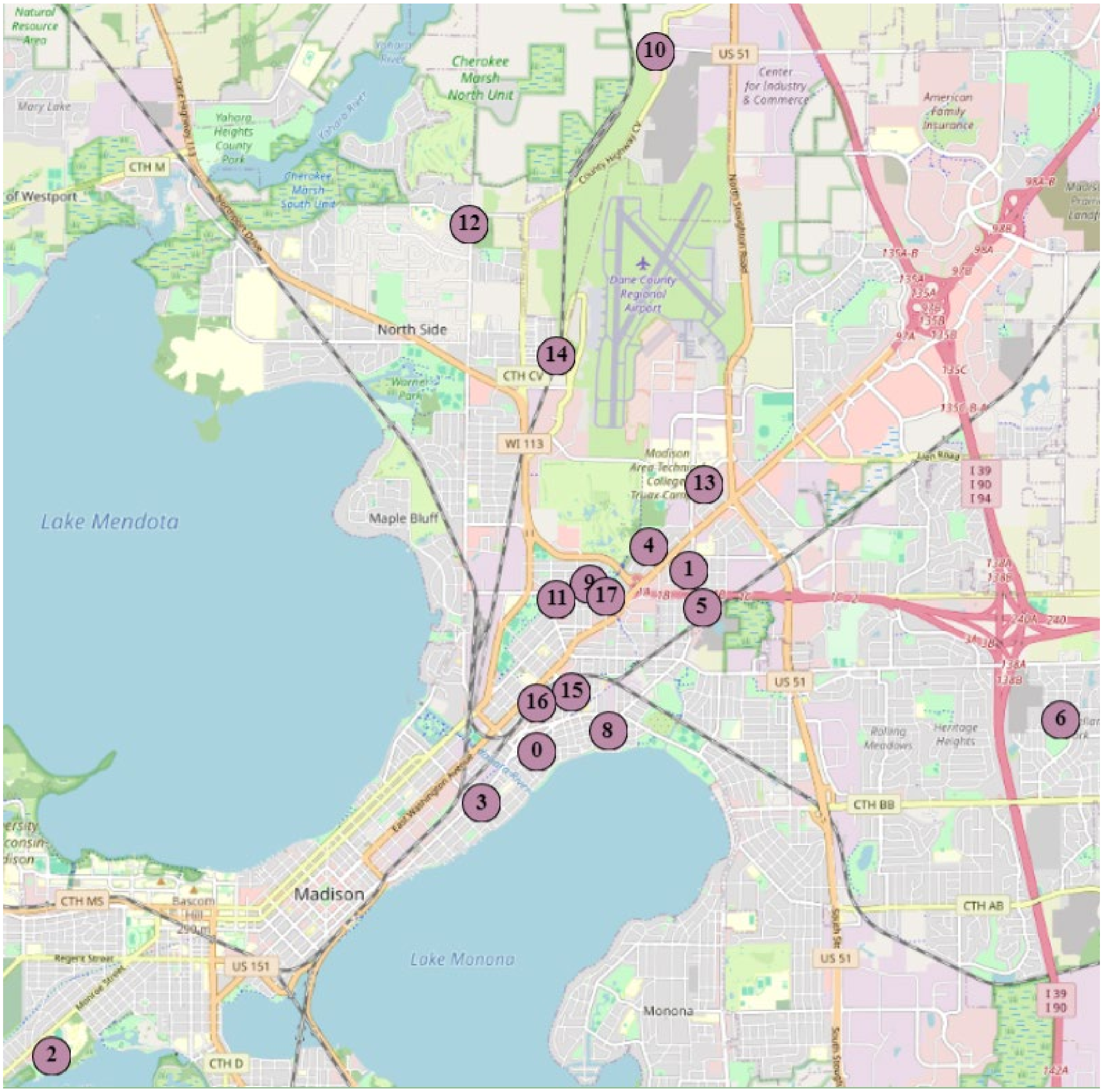
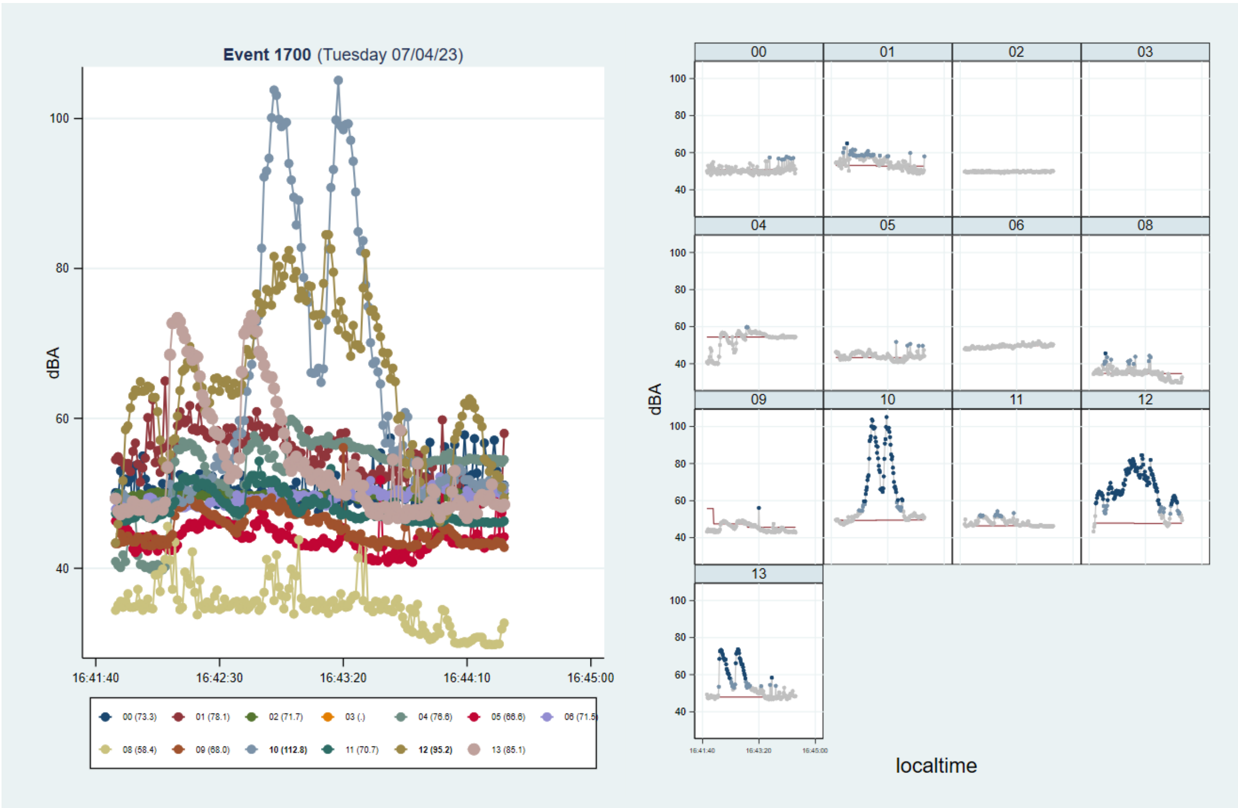


Figure 15. Noise meter locations (as of January 2024).



In contrast, Figure 16 shows the noise signature for an actual fighter-jet departure. Such events are characterized by 20- to 60-second noise events that spike well above background levels—and often exceeding 100 dBA—that occur across multiple meters at slightly different times. Often, as is the case here, there are two or more closely spaced noise peaks that are characteristic of formation departures of multiple fighter aircraft. The noise signature for this event indicates a formation departure of two fighter jets, which in this case were visually confirmed to be F-35A jets. The departure was to the north (Runway 36), as evidenced by the fact that the noise peaks for Location 13 (south of the airport) occur earlier than the higher peaks observed for Location 10 (north of the airport).

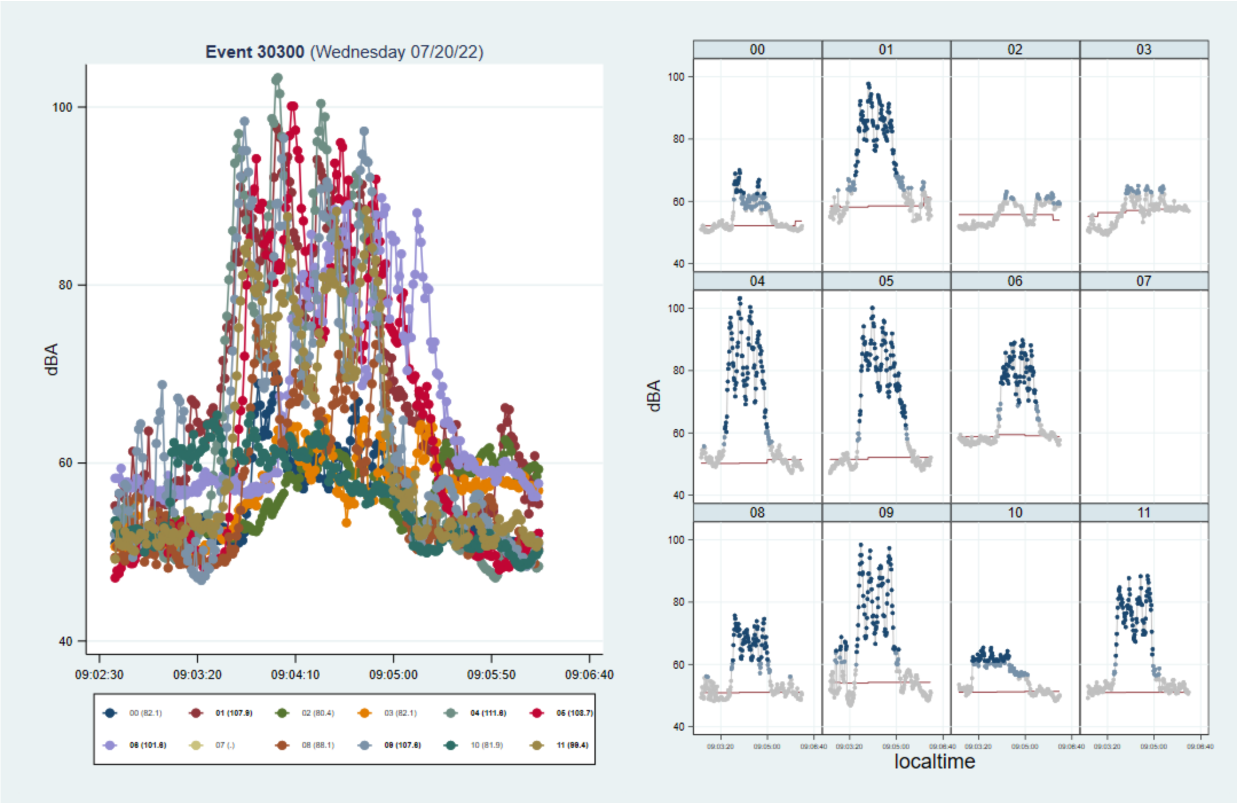
Figure 16. Example of a two-ship fighter-jet departure to the north (visually identified as F-35As).



Fighter jet departures to the south show a different pattern. Per a standing military NOTAM (Notice to Air Missions), military aircraft departing via Runway 18 are required to immediately turn to a heading of 140 degrees (southeast) or further east upon departure. These south departures appear as strong noise peaks on the meters immediately south and east of the airport, especially Locations 1, 4, 5, 9 and 13. Figure 17 shows a four-ship formation departure to the south that lit up nearly all meters immediately to the south of the airport, with a much smaller peak. at Location 10 on the opposite side of the airport.

Note that in isolation, the small increase in noise levels seen for Location 10 in Figure 17 would not clearly be identifiable as aircraft related. But because it coincides with the obvious formation fighter-jet noise signature at other meters, it can be classified as a fighter-jet noise event as well.

Figure 17. Example of a four-ship formation fighter-jet departure to the south.



Fighter jet *arrivals* show a different noise signature. Fighters typically use what is known as an "overhead" arrival pattern in which they overfly the main runway at about 2,500 feet above the ground before breaking to the west and circling around to land (Figure 18). When arriving from the south, this typically cause spikes on the meters immediately to the south of the main runway from the initial pass of the aircraft over the airport, followed a minute or two later by elevated noise at meters to the south and west of the airport when the aircraft pass over while complete the circling maneuver for landing (Figure 19).

Fighter-jet arrivals can be extremely loud at some meters, but they can also be fairly quiet and difficult to reliably detect. Only noise events that are clearly fighter-jet related are classified as such here, which means that many quieter arrival events are missed. This is evident in the fact that of the roughly 1,400 fighter-jet flight events identified between May 2021 and April 2023 from noise signatures alone, 61 percent were departure events and 39 percent were arrivals. If all noise events were being correctly identified, these proportions should be much closer to 50/50.

Figure 18. Example of a fighter-jet "overhead" arrival pattern, in this case for a visiting T-38 fighter jet that was transmitting ADS-B position data (vertical lines show each ADS-B recorded position).

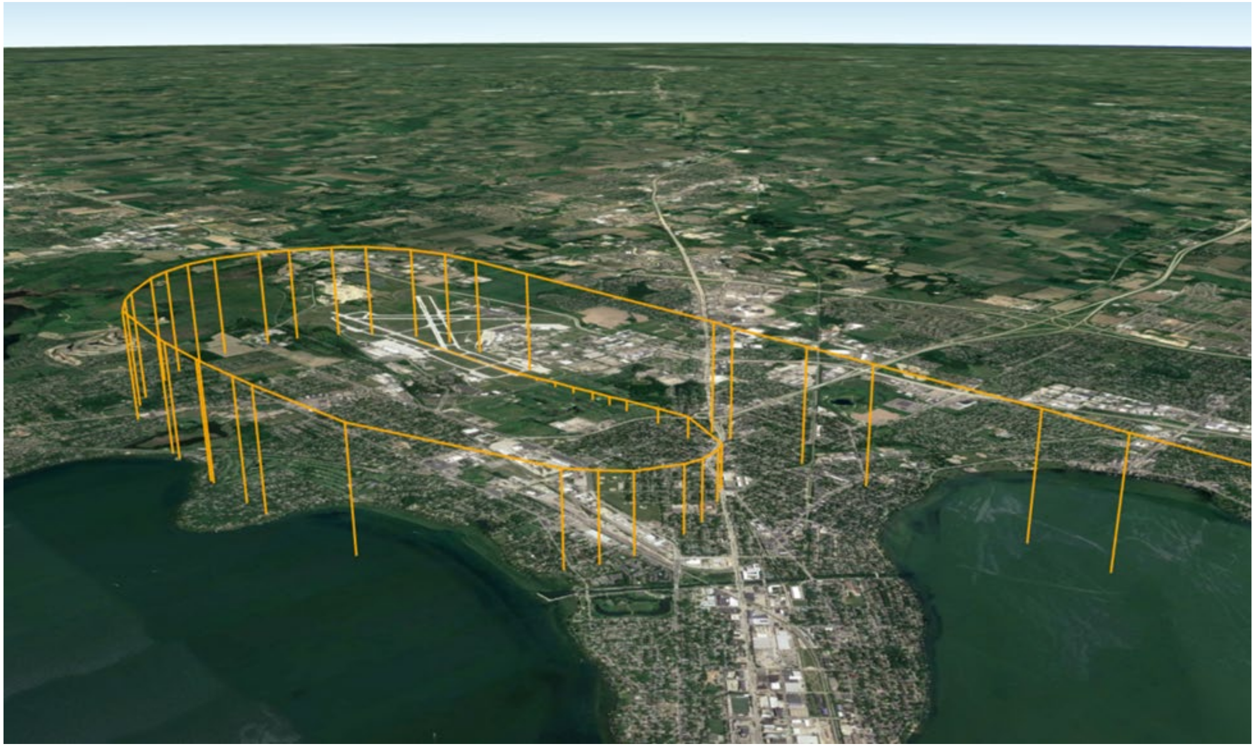
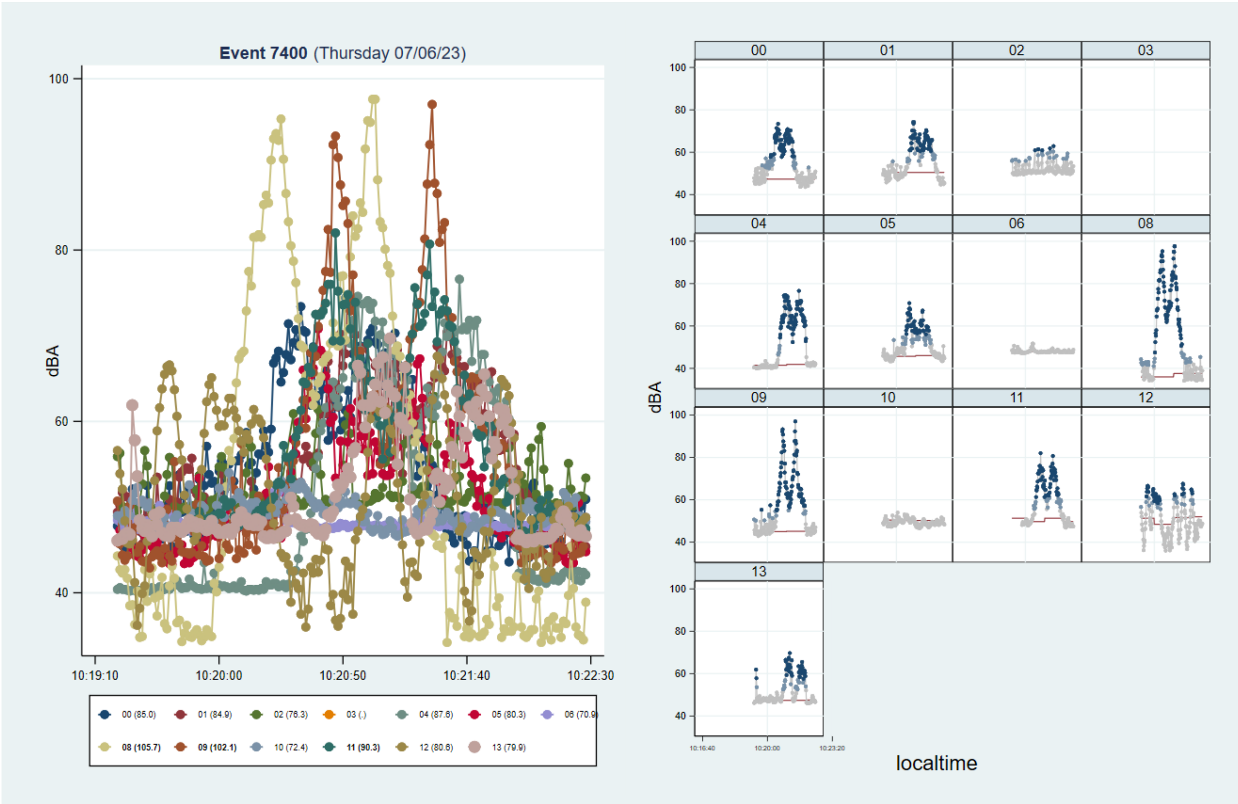


Figure 19. Example of a fighter-jet(F-35A) two-ship overhead arrival from the south.



In general, classifying a candidate non-ADS-B event as a fighter-jet event requires the presence of highly elevated noise levels lasting 20- to 60-seconds at multiple meters as the jet(s) pass overhead or nearby in patterns like those shown above.

In contrast, Figure 20 shows a case of a noise signature that would *not* be classified as aircraft related because it affected only a single meter. Emergency-vehicle sirens can cause patterns like this.

Even nearly coincident noise events at multiple meters are not classified as fighter-jet related unless they conform to the brief, multiple-peak patterns shown in the examples above. Figure 21 shows the very different noise pattern that results from tornado sirens being energized throughout the city.[2] Similarly, thunderstorms and rain or sleet can produce high noise levels on multiple meters (Figure 22), but these typically last much longer than noise created by passing aircraft.

[2] Tornado sirens are tested at noon on the first Wednesday of the month during the summer in Madison.

Figure 20. Example of a candidate non-ADS-B noise event that is not likely aircraft related because it affected only a single noise meter. Aircraft-related noise events almost always affect multiple noise meters in the vicinity of the airport. This event is likely from an emergency-vehicle siren as it passed by the meter at Location 3.

Figure 21. Example of a noise event from a tornado-siren test. Fighter-jet noise events do not last as long, and do not show a noise profile that is as flat as this.

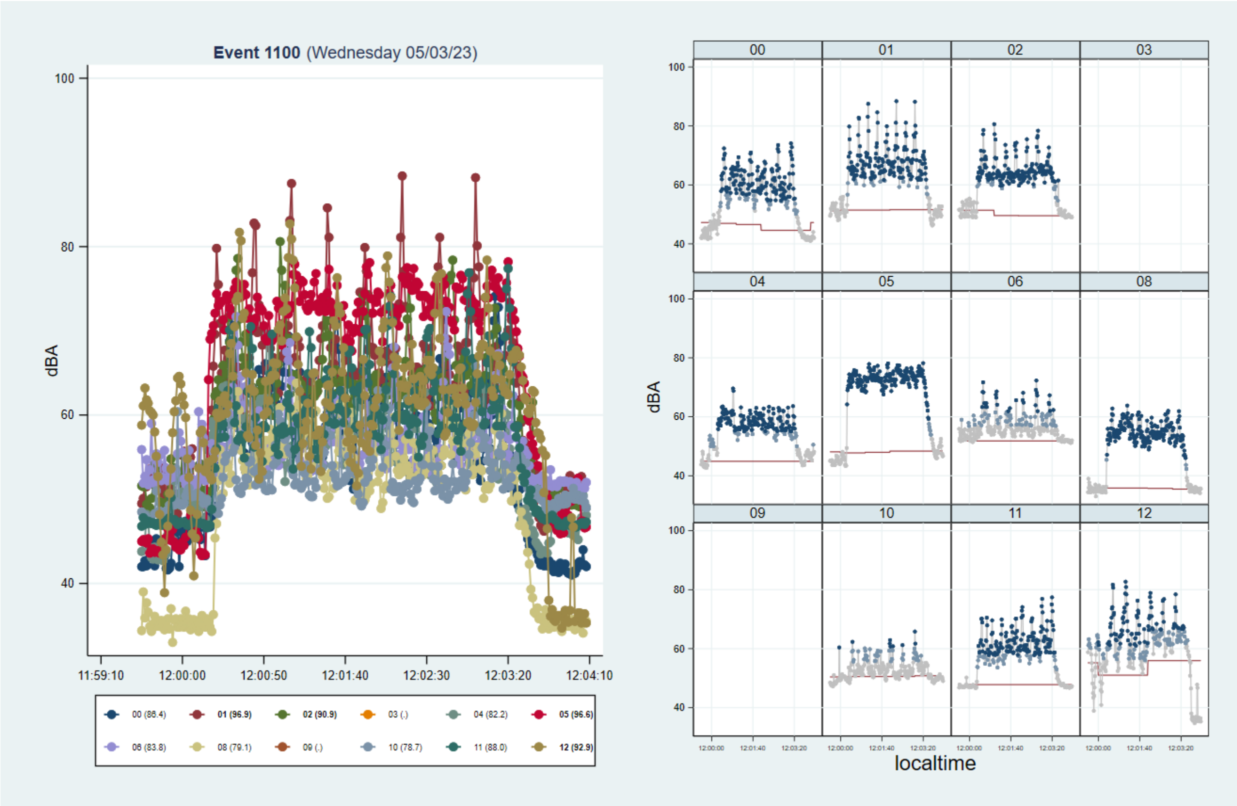
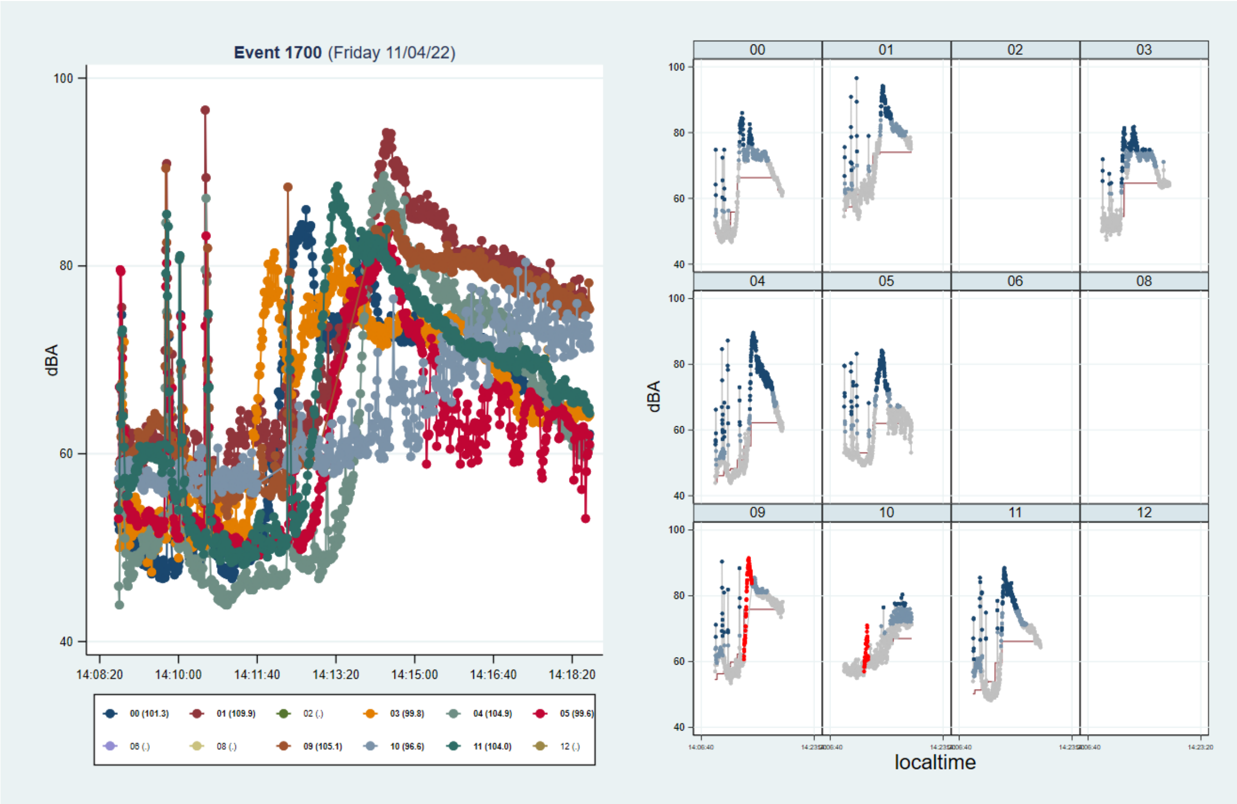


Figure 22. Example of thunderstorm noise event. The peals of thunder on the left side of the plots are too brief to be aircraft-related, and the subsequent rain and wind noise on the right last much longer than aircraft noise.



In addition, day of the week and time of day can be used to help identify fighter-jet noise events: the 115th Fighter Wing typically launches fighters in the middle of the week (Figure 23) between about 9AM and 10AM and again between 1PM and 2PM (Figure 24), and these aircraft typically return 1.5 to two hours later. Occasional nighttime training operations and special-event flyovers are publicly announced ahead of time.

Figure 23. Identified fighter-jet departure events by day of the week.

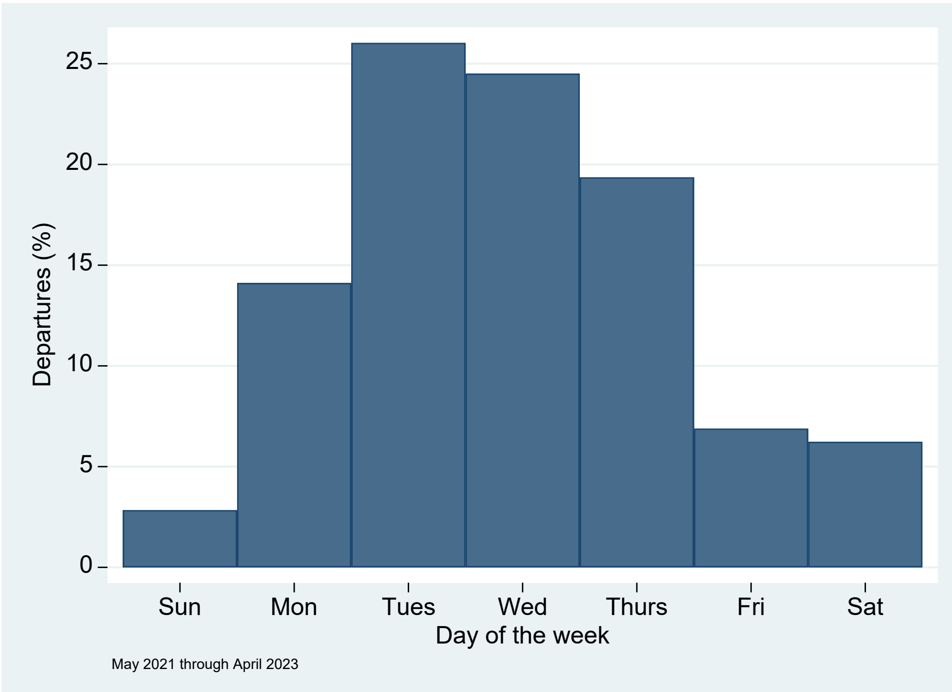
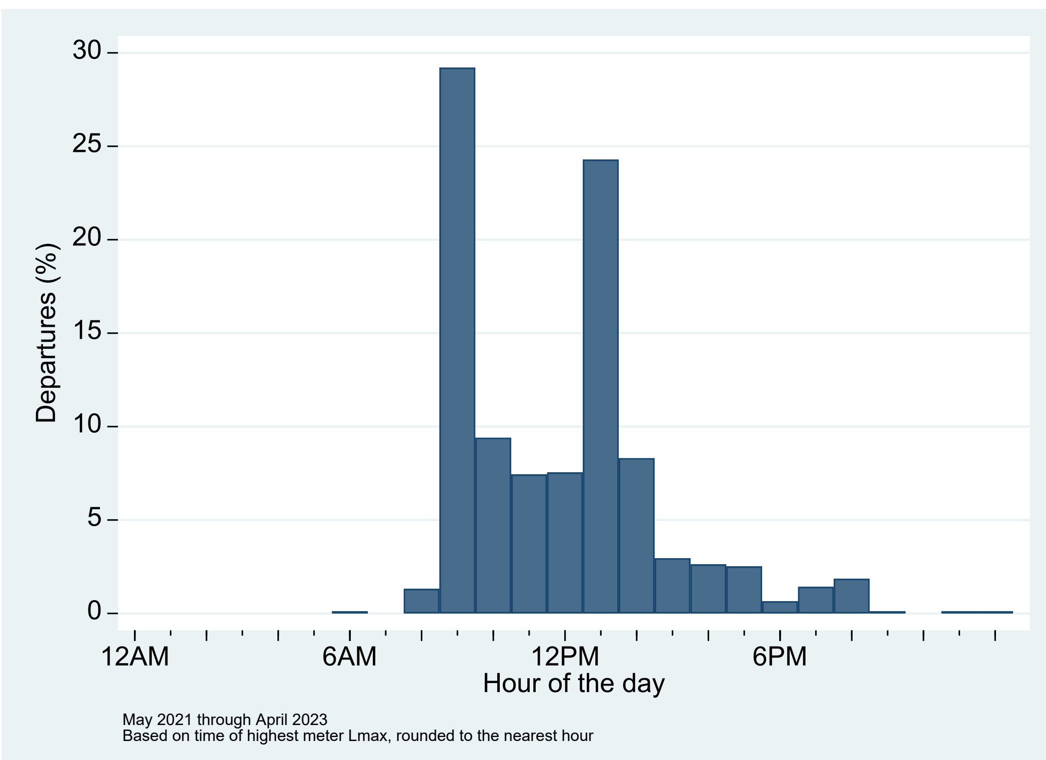
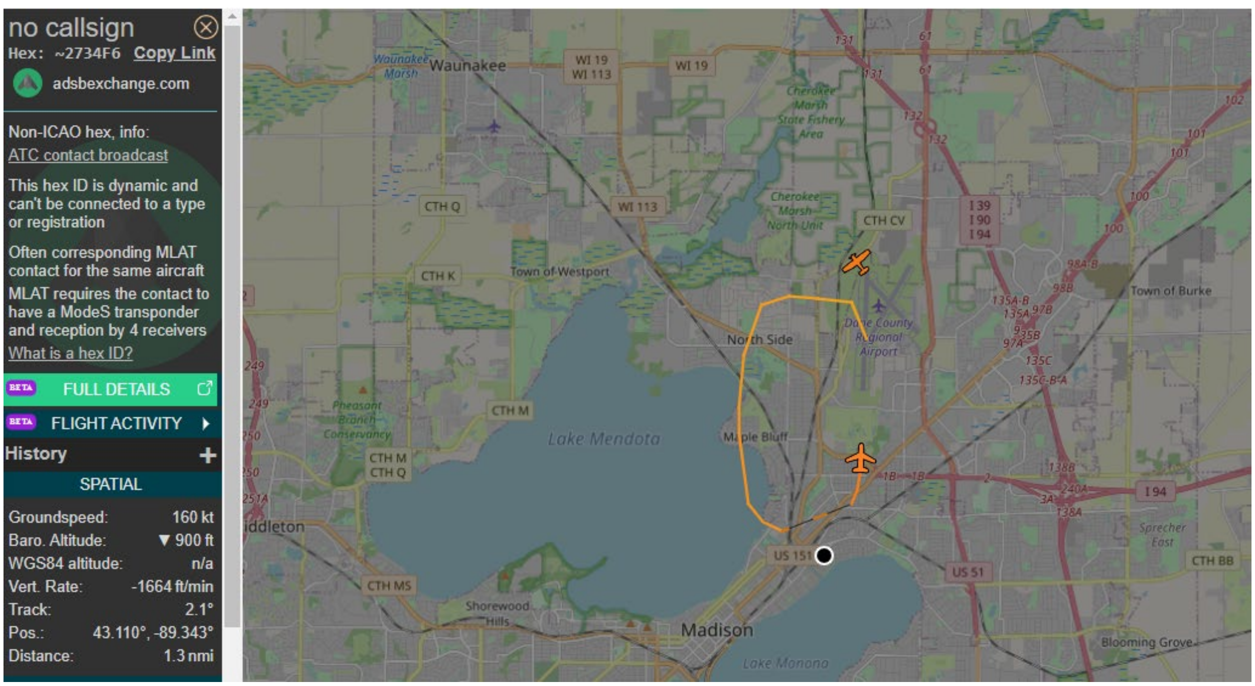


Figure 24. Identified fighter-jet departure events by hour of the day.



While fighter jets typically do not transmit direct ADS-B data, they do sometimes show up on non-filtered public aircraft tracking maps such (as [ADS-B Exchange]) as TIS-B signals. TIS-B (short for Traffic Information Service – Broadcast) is an FAA service that takes radar returns for non-ADS-B aircraft and broadcasts their positions as ADS-B signals from nearby ground stations so that they appear on the screens of ADS-B equipped aircraft in the area (Figure 23). The ADS-B receiver currently used for this website is not within line of sight of one of these ground stations, and so does not receive TIS-B signals, but the history reply feature of public websites such as ADS-B Exchange can be used to help confirm whether fighter jets were operating in the area for a candidate noise event. There are a couple of limitations of this approach, however. First, TIS-B broadcasts are typically only triggered when there are other aircraft in the area to receive the TIS-B broadcasts. A TIS-B aircraft can help confirm that a candidate noise event *is* attributable to fighter jets, but the lack of TIS-B aircraft at the time of a candidate noise event does not prove that the event was not caused by fighter jets. Second, the TIS-B broadcasts do not identify the type of aircraft: while it is straightforward to confirm that a TIS-B signal is a fighter jet (based on speed and the presence of multiple, closely-spaced formation aircraft), it is not possible to use the TIS-B data to distinguish between, say, F-35 and F-16s.

Figure 25. Example of a TIS-B broadcast of a fighter jet overhead arrival pattern at Truax Field, as captured by ADS-B Exchange.



Archived air traffic control communications, such as those maintained on [liveatc.net], can also be used to verify that noise signatures do indeed belong to fighter jets operating in the area—though these archives disappear once they are more than 30 days old, which is typically sooner than the noise-event data processing occurs.

Finally, some observers in the vicinity of the airport visually observe and note fighter-jet operations when able, allowing for confirmation of the type of aircraft. These visual confirmations are the only time that non-ADS-B noise events shown on the website have an aircraft model associated with them.