Essay #9 (there's no #8) in Aspen Fly Right's public-education series, 9 March 2023
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Aircraft noise and the Aspen community

Executive Summary

Aspen's near-downtown airport is convenient for users but noisy for some neighbors. Current plans to rebuild the airside to allow bigger airplanes would admit noisier as well as quieter ones, potentially worsening this nuisance. It could also increase flights to bring in the 24% more passengers planned for 2050. The noisiest flight operations, about as loud below as a gasoline lawnmower or food blender a yard away, are becoming less frequent and slightly milder as the worst old General Aviation planes retire, but the latest Fly Quiet draft report still reveals 206 high-noise events in 2021—reported not as a total but as averaging well under one per day.

The Fly Quiet program emphasizes encouraging quiet operators, not shaming noisy ones, so congratulations far outnumber admonitions to poor operators. Whether offenders' noisy operations are improving—the declared goal of tracking them—remains unmeasured. Fly Quiet's reports summarize partial measurements at one of seven monitoring stations, but no raw data are posted for any station. Previous reports quantified the top 25 high-noise events; the draft 2021 report quantifies none, though it qualitatively lists the dozen poorest operators.

Like the FAA, Aspen uses the weakest noise metric, averaging noise over 24 hours a day including the eight curfew hours so it looks one-third smaller. All noise is counted alike regardless of timing, unlike California and European metrics that penalize evening or nighttime noise. A key metric, noise contours showing the area averaging over 55 dBA, seems to rely on modeling without local experimental validation—a method known to be unreliable. While curfew violations are now penalized, written noise complaints seem to elicit no response and unknown action.

Short-term noise abatements could be strengthened by a soundwall officially proposed in 2018; by providing ground power so parked planes can plug in (like ships at modern ports) and turn off their noisy and polluting onboard generators; by more-orderly European-style pre-takeoff operations; by petitioning FAA for local noise regulation under the statutory process for exemption from federal preemption; by better training General Aviation pilots using holding patterns over Aspen and Snowmass Village; and in some circumstances potentially by new approach routes—not over downtown or noise-sensitive sites, yet now penalized by Fly Quiet as if they were.

The most effective and lasting noise abatements are on the way from the unexpectedly quick emergent shift to superefficient and electrically powered (battery-electric or fuel-cell) aircraft, as described in our 12 January 2023 Essay #5 on aviation innovation. These ultraquiet planes sound several to many times quieter than today's jets, as demonstrated by electric air taxis designed to land vertically on or near buildings. Though many details remain uncertain, the superquiet aviation revolution promises long-overdue noise relief to Aspen neighborhoods sooner than the currently planned airside rebuild to bring in bigger, heavier, fossil-fueled airplanes.

Aspen both enjoys the convenience and suffers the impacts of having the Aspen/Pitkin County Airport just a few miles from downtown—extraordinarily close for the third-busiest airport in Colorado. Flight operations' noise is a longstanding source of community concern and complaint, both in areas often overflown under prevailing winds and in those occasionally overflown in rarer conditions. Noise is a complex and evolving subject, but an important one to understand.

This essay briefly discusses how noise's impacts on the community depend on airplanes' technical characteristics, flight details (numbers, timing, routing), operational procedures in the air and on the ground, abatement measures at the Airport, and potential noise reductions from more-effective community feedback and incentives, stricter standards, or new kinds of airplanes discussed in our Essay #5 (12 January 2023). But first, some fundamentals.

Noise and sound

Noise is a common form of environmental pollution that can affect people physically, psychologically, and socially. Its degree of annoyance depends on circumstances, such as whether one is trying to sleep or converse, or in a place or activity where noise is less perceived or less interfering. Timing is important: noise that wakes you at night may not distract you in the daytime. Surprising noise can be more annoying or startling than accustomed noise, but frequent noise can cause fatigue, stress, distraction, and impatience. Noise[1] is "any unwanted or annoying sound," so it depends partly on the user's tastes. High-frequency sounds tend to be more annoying (though they "carry" less far than low rumbles). So do louder sounds. So do sounds directed towards us. And so do aircraft sounds compared with the sounds of road or rail traffic[2].

Sound is pressure fluctuations in the air that reach the ear, excite the auditory nerves, and produce the mental representation of sound in the brain. Younger people can hear sound in a range from about 20 to about 20,000 cycles per second (Hertz or Hz). Most adults lose some high-frequency response with age, starting with 1,000–6,000 Hz and around age 30. Normal speech is in the 500–3,000-Hz range, and the greatest sensitivity extends to about 4,000 Hz.

People can discriminate between sounds differing in loudness by as little as 1 decibel (dB), but people perceive volume logarithmically, not linearly. Thus each 10 dB increase corresponds to a tenfold increase in physical intensity but is perceived as twice as loud: 0 dB is at the threshold of normal hearing, 10 dB (rustling leaves) has ten times that intensity but is perceived as twice as loud, 20 dB (whisper) is ten times more intense still but only redoubles perceived volume, etc.

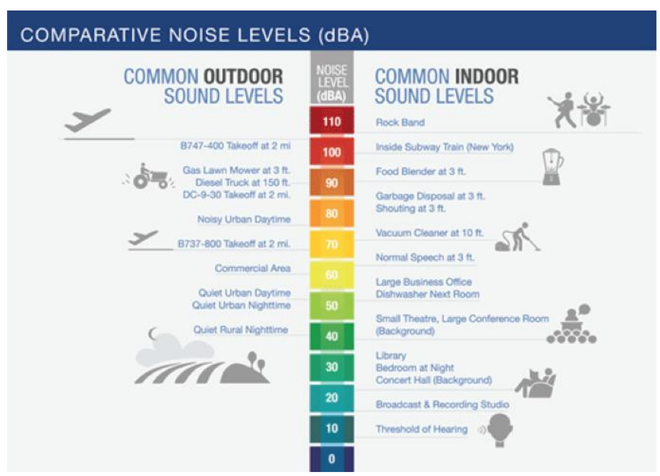
Noise is conventionally expressed using the conservative[3] A-weighted method, in units called "dB(A)" or "dBA." When measured not instantaneously but over some period of time, it's often expressed as a time-integrated average called L_{eq} that allows different noise measurements to be compared, or as its peak value L_{max}. Another metric, L_{dnl} or DNL, averages noise over 24 hours and is used at Aspen. The Federal Aviation Administration (FAA) allows up to 65 dB DNL in residential areas without requiring abatement or adding soundproofing to buildings, but that "may no longer be an adequate guide for federal policy makers" because a recent FAA survey found significant annoyance at 50–55 dB DNL[4]. The more sophisticated European metric L_{den} (Day Evening Night Sound Level), averages sound over 24 hours but adds 5 dB in the evening (usually 1900–2300) and 10 dB at night (usually 2300–0700); moreover, Europe considers L_{den}

above 55 dB excessive for air traffic noise, so it both allows half as much perceived noise and measures it in a stricter way. California's similar CNEL metric[5] penalizes evening noise 3× (4.77 dB) and night noise 10× (10 dBA)[6]. Another common metric, Effective Perceived Noise Level (EPNL) or EPNdB, is used to compare noise from passing aircraft, counting the noise's duration and tonality (which adds a penalty because tonal noise is more annoying than white noise).

Loudness is described by various technical metrics[7]. This quickly gets complicated because perceived loudness depends on frequency as well as intensity, and annoyance depends on a long list of circumstances and psychological factors[8]. For example, a shouting person seems louder than a talking person even if the physical amplitude of the speech is identical. Unexpected, frequent, uncontrollable sounds may seem as irritating as expected, infrequent, or controllable sounds even if they're quieter. Unwanted sounds are especially annoying, reinforcing frustration. Sound can be bounced, focused, or absorbed by the hearer's surroundings, like hard or soft surfaces. Sounds from overhead aircraft can be diffused by wind (so more people hear it but it seems less loud), increased or decreased by clouds or fog, and weakened at night when the ground is warmer than the air[9]. An important review article[10] summarizes such complexities: "[A]nnoyance cannot always be described by metrics and especially by time-average metrics." Another says[11] only a third, perhaps a fifth, of variance in annoyance "can be explained by acoustical factors." Thus meaningful comparisons are challenging—but important, since aircraft noise has been associated with harm to health, such as sleep disturbance, cardiovascular and heart disease, heart attacks, and hypertension, and with slower learning in children[12].

Noise at 120 dB is uncomfortable, 130 dB painful; 140 dB can burst the eardrums. Hearing can be temporarily impaired by a few hours' exposure to noise over 90 dB, and permanently if that exposure occurs, say, 8 hours a day (the OSHA occupational limit) for a few years. Such loud sounds are uncommon among people leading a quiet life, whose experience the FAA illustrates[13] on the left and Pitkin County's emissions consultant[14] (citing FAA) on the right:

SOURCES	LEVEL (dB)
Whispered Voice	20-30
Urban Home, Average Office	40-60
Average Male Conversation	60-65
Noisy Office, Low Traffic Street	60-80
Jet Transports (Cabin)	60-88
Small Single Plane (Cockpit)	70-90
Public Address (PA) Systems	90-100
Busy City Street	80-100
Single Rotor Helicopter (Cockpit)	80-102
Power Lawn Mower, Chain Saw	100-110
Snowmobile, Thunder	110-120
Rock Concert	115-120
Jet Engine (Proximity)	130-160

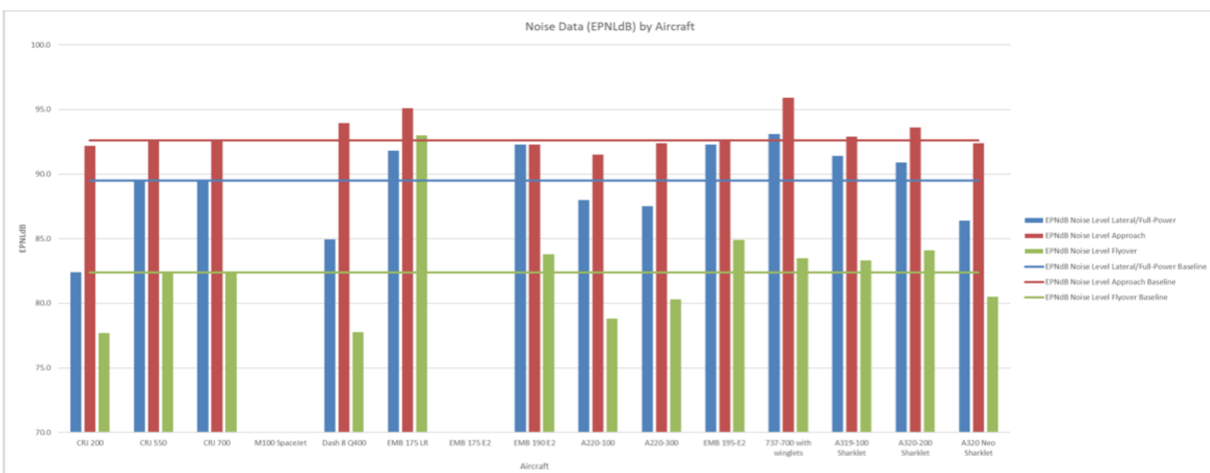


Noise characteristics of existing aircraft

Aircraft noise comes mainly from engines and jet exhaust, propulsors (propellers or fans), and turbulence as the plane pushes through the air—especially when flaps are extended and landing gear is down. Planes on the ground with their engines off can emit considerable noise, often a high-pitched whine, from their auxiliary power unit (APU)—a miniature gas turbine used to power the plane without the engines, and often a significant source of local air pollution. As we'll see below, many improvements in design and technology that can greatly mitigate these noise sources await new-and-improved planes rather than being installable onto existing ones. Quieter designs are about not just specific technologies, like chevrons on the aft rim of jet engines, but about major changes such as mounting engines above rather than below the wings, or, as we'll discuss later, replacing fuel-burning engines with far quieter electric motors.

Noise comparisons between different types of aircraft typically use standard measurements[15] published by the [UN] International Civil Aviation Organization or ICAO. [ASE Vision](#)'s Technical Working Group's first meeting was shown this diagram[16] summarizing 13 aircraft types' ICAO noise ratings, on a linear scale using the Effective Perceived Noise Level mentioned above. The blue bars show EPNdB noise (mentioned above) at lateral full-power operation, red bars on level approach, and green bars on level flyover. For comparison, the colored horizontal lines show noise emitted by ASE's current commercial airplane, the CRJ700:

Combined Noise Data by Aircraft



Source: ICAO Noise Certification Data Base, August 2019

These data show that under nominal conditions, the Dash 8–Q400 (formerly serving Aspen, and still an attractive potential backup option as described in our [Essay #4](#)) is slightly noisier on approach than current ASE airline planes but far quieter in other conditions; that Embraer's E175LR[17], now proposed as Aspen's replacement airline plane, is noisier than today's CRJ700s (by a dismaying 10.6 dB, perceived as twice as loud, in flyover); and that if a redesigned airside removed ASE's current size and weight restrictions, larger new airline planes could include the modestly quieter A220 or other, mostly noisier, models if safety-qualified. All these comparisons are not per *passenger* (the County's preferred metric, which favors larger planes) but per *airplane*—the way people on the ground experience the noise. Bigger planes may be less frequent if their seats are equally filled and if no more total passengers are carried—or more frequent if the planes serve more destinations, don't fly as full, or bring in more people as current plans assume. Since Airport plans assume 0.8% annual growth in passengers, bigger planes may not mean fewer planes. And in any case, airline flights have lately been overwhelmed by private flights, which have fewer seats (and probably fill fewer of them, though that remains unknown). Also of note, ICAO noise data aren't measured in our topography or at our altitude; actuals may differ.

As described in our Essays #3 and #7, Pitkin County policy discussions so far have focused almost entirely on commercial (airline) aircraft rather than on the General Aviation aircraft that account for 59% of Aspen Airport's fuel sales[18], ~83% of operations (takeoffs or landings), and "the vast majority" of 2019 noise complaints[19]. The ASE Vision process too focused overwhelmingly on airlines, but in 2019 showed these nominal noise and fuel data for common GA airplanes[20], to which we add in italics three relevant and currently ASE-qualified commercial types:

	Seats	*EPNdB noise level*				*Fuel kg per LTO cycle*	
		Lat/full-power	*Approach*	*Flyover*	***av/pax***	*per aircraft*	*per pax*
CRJ700	*70*	*89.5*	*92.6*	*82.4*	***1.26***	*234.5*	*3.35*
Dash 8–Q400	*76*	*84.9*	*94.0*	*77.8*	***1.13***		*note*[21]
E-175LR w/extended wingtips	*76*	*91.8*	*95.1*	*93.0*	***1.23***	*245.5*	*3.23*
Boeing 737-BBJ	20	88.2	94.1	81.3	**4.39**	364.9	18.2
Bombardier Challenger 300	9	87.6	89.6	75.4	**9.36**	152.0	16.9
Bombardier Challenger 350	8	89.1	89.5	76.0	**10.61**	157.0	19.6
Bombardier Global 5000	17	88.6	89.7	80.3	**5.07**	299.0	17.6
Bombardier Global 6000	19	88.4	89.7	82.1	**4.56**	299.0	15.7
Cessna Citation CJ1	6	83.3	89.1	73.6	**13.67**		
Cessna Citation CJ2	7	87.5	90.6	75.0	**12.05**		
Cessna Citation XLS, SLX+	9	86.6	92.8	72.5	**9.33**		
Cessna Citation Sovereign	8	87.6	90.2	71.7	**10.40**		
Dassault Falcon 7X	16	89.8	92.1	82.0	**5.50**	144.8	9.0
Eclipse 500	4	79.0	81.9	68.5	**19.12**		
Embraer Phenom 100	7	81.5	86.1	70.7	**11.35**		
Embraer Phenom 399	11	88.8	88.7	70.3	**7.51**		
Gulfstream V	14	89.9	90.8	79.1	**6.19**	295.7	21.1
Gulfstream 650	18	90.0	88.3	76.2	**4.71**	304.6	76.2

and, to illustrate progress from two old types' exceptionally high noise levels[22],

Gulfstream II w/hushkit	12	102.7	98.2	90.9	**8.11**
Gulfstream III	14	103.4	97.3	91.1	**6.95**
Gulfstream IV	14	87.7	91.0	78.6	**6.13**
Gulfstream V	14	89.1	90.8	80.3	**6.20**

These data show that:

- the business-jet BBJ version of the Boeing 737 is roughly as noisy as an existing airline CRJ700;
- the still-popular Gulfstream III is noisier by two of three metrics than the older "hushed" Gulfstream II, and is far noisier than the CRJ700[23];
- most of the common business jets (except the relatively quiet Eclipse) are about comparable to or modestly quieter than the CRJ700 in lateral/full-power and approach noise, while most except the Bombardier GA types are quieter in flyover; and
- using the same per-passenger format that the County uses when comparing commercial aircraft, the average of the three noise metrics (as a rough proxy, in boldface) per

passenger is far greater for GA than for commercial planes because of the major difference in the number of seats per plane.

Reinforcing this point, the two right-hand columns compare per-plane and per-passenger fuel use per "landing-and-takeoff" (LTO) cycle—a rough proxy for CO_2 emissions. In CO_2, air pollution, and noise, the same per-passenger metric that makes bigger planes look better because they have more seats also makes General Aviation planes look worse because they have fewer seats. Whether a per-passenger or a per-airplane metric is more appropriate depends on your question.

Noise monitoring and assessment

Many analysts, including Pitkin County's, base noise plans and policies more on theoretical models than on actual measurements. Correspondence between the two is often weak in global literature[24], and is not tested or established for Aspen due to sparse measurements. Since 2006, Aspen Airport has measured actual noise from GA aircraft at one site in Woody Creek, at times and for durations that are not clearly stated. A summary of the results is partly reported in posted Fly Quiet program reports[25] for 2015–20. The 2015 report shows that the single site had expanded to six noise monitoring locations—the south and north Airport boundaries, W/J Ranch, 262 Woods Road and 240 Doc Henry Road in Woody Creek, and a site in Little Woody Creek—but the other five are used only in winter and summer peak seasons. A report of 2015–17 noise at the single site even seemed to rely on data from only one summer week and one winter week[26]—hardly representative. The draft 2021 report drops one Woody Creek and one Little Woody Creek site but adds Lower Buttermilk, Burlingame Housing, and Aspen Motorsports Park.

The Fly Quiet reports measure excessive single event noise levels (SELs) as the sum of all noise in a takeoff or landing event as if it occurred in one second, so it counts intensity *and* duration. County contractor Mead & Hunt said[27] this SEL metric is ~10 dBA higher for flyovers than the instantaneous L_{max} metric. Using the SEL metric, the loudest aircraft noise events detected at 262 Woods Road[28] were 95.3 dB in winter and 96.4 in summer peak seasons in the 2016 report, surpassed by one 97.3 dB event in the 2017 report. The charts on p 3 above show that these levels are roughly comparable to a food blender or a gasoline lawnmower three feet away. Some people seem to dismiss citizens who complain about aircraft noise as whiners, and their communities as obstreperous, but their concerns are understandable and legitimate.

Surprisingly, none of the six years' posted reports reveals the total number of high noise events detected. However, "nearly all" are ascribed to older business jets—especially those with Stage 2 noise certifications, outlawed after 2015 for General Aviation jets (1999 for airliners) unless equipped with a hush kit, or the similar or sometimes noisier Stage 3. The noisiest remaining jets are typically types like Gulfstream II/III, Lear 24/25, and Falcon 50. Annual average noise levels shown in the 2017 report declined by ~4 dB as Stage 2 planes almost all retired (p 24), though some modified ones like the Gulfstream II can still operate. The newest and quietest generation, called Stage 5, includes all new types certified after 2018, and its sum of all three metrics must be at least 17 dB quieter than Stage 3. However, unlike Stage 2, Stage 3 aircraft are not required to retire, and they're most of the commercial and GA aircraft now flying, so there's ample room to try to influence operators to fly fewer Stage 3 and more Stage 4–5 planes into Aspen.

The 2017 Fly Quiet reports identifies by name and tail number (p 18) the operators of four flights causing high-noise events, but it overwhelmingly emphasizes the quietest operators, particularly fleets, and encourages that class to expand. Thus there are multiple levels of awards, but no comparably prominent booby prizes. As the 2016 report says (p. 4), “Fly Green/Fly Clean is a dynamic venue for implementing noise abatement procedures by praising and publicizing active participation rather than a system that admonishes violations from essentially voluntary procedures.” Or as the 2021 draft report says, “The purpose of the Fly Quiet Program is to, through positive reinforcement, communicate to the aircraft operators the accepted noise abatement procedures and request that pilots fly them as efficiently as possible….Positive reinforcement and good publicity is [*sic*] expected to be a strong incentive for operator performance.” However, the data presented do not track whether poor performers actually improve from year to year, remain repeat offenders, or backslide, so it’s hard to assess the program’s success in meeting its declared goals, and to distinguish its effects from uncontrolled variables such as Stage 2 aircraft retirements and growth in air traffic. Some other airports, such as Seattle-Tacoma, prominently shame operators who violate their voluntary night noise limits; different philosophies of how to influence operators prevail at different airports, and it’s unclear which work best.

Aspen Airport’s Fleet Noise Quality rating aims to have “operators schedule their quietest aircraft at the Airport and be acknowledged for doing so.” The Loudest Noise Event category aims “to reduce and eliminate the highest single event noise levels of aircraft operating” at ASE. To its credit, the 2021 draft report does name the twelve lowest-scoring operators (Table 2, p 22)—but those don’t include two single operators who together caused 23 high noise events. Likewise, the 2017 report says nine Part 135 operators (those providing on-demand unscheduled service, including fractional-ownership and charters) generated high noise events year-round, totaling 11 events; those operators are identified by poor Fleet Noise Quality ratings, but the events are not. And these listings come a year or two after the offense—not as immediate notification letters.

Subsequent reports continue these patterns, with an SEL record (97.3 dB) set in winter 2016/17. The 2018 report lowered the loud-event threshold from 90 to 85 SEL dB to reflect the evolving fleet mix where the loudest events typically come from Stage 3 rather than rare Stage 2 airplanes. Three of the 25 loudest events in winter 2017/18, two in summer 2018, five in summer 2019, and zero in 2020 and 2021 came from airline planes, apparently not previously included[29]. The 2021 report being finalized in late February 2023 for imminent release switches to a calendar-year basis, adds bonus categories for carbon offsets and for the newest and quietest planes (some 10+ dB, or twofold in perception, quieter than Stage 5), and recognizes General Aviation traffic growth by switching from 30 to 60 operations per year as the breakpoint between smaller and larger operators. The 2022 report due around April/May 2023 may bring further evolution.

Issues with the Fly Quiet program

These annual reports raise many questions for residents under or near flight paths, including:

- How does the measurement and analytic system deal with more than one aircraft simultaneously overhead (as is often observed in Woody Creek, one arriving and another departing—are these two separate events or one combined event)? or with some noisy aircraft whose overflight, say some residents, “shakes the valley” not for seconds but reportedly for a minute or more (presumably integrated into the SEL metric, but this seems worth confirming for very long durations, and is sensitive to altitude)?

- Why use a metric that shrinks reported noise by one-third by averaging it over 24 hours even though all flights are prohibited for 8 hours every day[30]? If Aspen Airport, like ~99% of US airports[31], had no curfew, its measured noise would be 50% higher.
- Why does Aspen base its aircraft noise measurements and policies on the least restrictive metric (with no extra weighting for evening noise) rather than, say, California's metric?
- Exactly what measurements, performed when and where, are used in the report?
- Where can citizens see the raw data from the one sensor reported—and from the others? Why shouldn't all this information, obtained at public expense, be routinely posted?
- Are all sensors' detailed locations and surroundings acoustically fair and representative (unlike, say, an official air-pollution sensor surrounded by air-filtering foliage)?
- Why do the reports describe only the expected *percentage* of operations with high noise (~1%, formerly ~3%) but not also their *number*? The text of the 2021 draft report says these events are ~1% of operations—actually 0.48%[32]—but its Figs. 3–7 show *206* high noise events in 2021 if one tediously adds them up. That's a serious imposition on the quality of life, especially in Woody Creek, Aspen Village, the North Forty, and the Airport Business Center.
- Why aren't *all* high noise events in each year, their individual maximum intensity, and their total number clearly stated and graphed, not just the top 25? The 2021 draft report removed that table, so now *no* data are available on maximum noise events (except, in 2021, which operator caused them). All maximum intensity data have also been removed. That doesn't seem a sound balance between influencing operators and informing citizens.
- As for root causes, shouldn't the reports dissect why the size of the 55 dB DNL noise contour held about steady in 2015–21 despite the near-extinction of the noisiest (Stage 2) aircraft? Was that mostly due to traffic growth—which isn't plotted, but should be, along with each year's Figure 9 noise-progress graphs? If traffic growth means we're running harder to stay in place[33], citizens need to understand that consequence.
- Could the report add a clear explanation of which of its data are physically measured and which are modeled, computed, or estimated? Experimental validation, if any, of the noise contours is particularly unclear; they appear to be entirely modeled, and that technique is known to be fraught with significant inaccuracies[34], requiring ground-truth for credibility.

Feedback to aviation operators seems meager and lopsided. The Deputy County Manager writes a private please-improve letter to the worst operators (four each in 2020 and 2021)—and over four times as many publicized attaboy letters to the best operators (18 in 2020, 17 in 2021). The number of operators whose noise evoked citizen complaints was far larger than the number of admonitory letters: just one citizen (not in Woody Creek) filed specific written complaints about more than four high noise events in each of those years. Some citizens also wonder if the Fly Quiet program is changing operators' behavior commensurately with its cost to taxpayers, totaling $314,871 in a recent 23-month period[35]. Without some way to measure changes in poor operators' behaviors, and to compare other ways to achieve those results, it's hard to tell.

Filing a noise or curfew-violation complaint used to be complex but has lately been commend-ably simplified to a single click from www.aspenairport.com. Past curfew enforcement was erratic[36], but recent enforcement, reinforced by vigilant and persistent citizens, seems responsive and strict, so a United curfew violation on 16 January 2023 resulted (on the BOCC's instruction and after five weeks) in a County court summons to operator SkyWest.

That rigor, however, isn't evident with complaints of high noise events during ASE operating hours—events of the sort that makes conversation impossible. Citizens submitting specific noise complaints seem to receive no feedback, discouraging further complaints. No actions or results are visible. We have the impression that written noise complaints are logged (unlike, it seems, FBO prices-and-services complaints[37]) but may have no practical effect. If this impression is wrong, the County should explain exactly what it is doing with noise complaints to change operator behavior and reduce public annoyance. The process should be transparent. A former Airport Director said he took noise complaints very seriously and that each resulted in a phone call to the offending operator[38]. If that is still the practice, the public would welcome the news.

Further abatement opportunities

Aspen Airport could adopt obvious and long-considered noise abatement measures. For example, the 2018 Environmental Assessment contemplated a 14′-high soundwall[39] to block and absorb noise (and reduce often-noted air pollution) flowing from the General Aviation plane-parking area toward neighbors in the North Forty.

Parked aircraft could limit their use of noisy and dirty[40] Auxiliary Power Units (APUs) to a few minutes just after and just before departure, if they could plug into stationary ground power (and perhaps also stationary pre-conditioned air), just as civilian and military ships docked at modern seaports plug into shore power. This is especially important because owners may show up for their departure many hours after they've told their pilots to be ready, causing the APU to run continuously for hours to keep the plane ready to go and at a comfortable interior temperature. It may (and should) be possible for the Airport to discourage, penalize, or prohibit this practice.

Ramp procedures like those common in Europe—where planes preparing to depart execute an orderly and efficient choreography of steps from boarding to takeoff roll—could minimize both APU and engine operating hours, saving time, noise, scarce ramp-crew time, fuel, and emissions. The Safety Task Force of the Airport Advisory Board is learning about these procedures from a local pilot with long experience of them. And perhaps there are ways to encourage operators to "fly light," substituting a smaller and quieter plane for a bigger one when suited to the mission.

Approach routing

Another issue concerns approach routing. In 2020, the Fly Quiet program began to count and penalize Runway 33 arrivals. In this uncommon maneuver, *experienced and ASE-familiar* pilots choose to land heading from upvalley toward downvalley (toward the north, the same direction as nearly all departures)—usually to avoid excessive tailwinds that could make the normal Runway 15 approach unsafe. Fly Quiet discourages[41] *all* Runway 33 landings, on the apparent (incorrect) assumption that these require flying over the City of Aspen and hence cause noise nuisance. *Experienced* local pilots and training flights use Runway 33 approaches without going more than at most a few hundred meters upvalley from Buttermilk, so they don't overfly the Hospital or High School, let alone downtown, the Music Tent, or the Aspen Center for Physics.

Other Runway 33 approaches, such as via the Highlands valley, are also sometimes used. None are suitable for pilots not thoroughly familiar with Aspen's airspace and topography.

These unusual approaches can involve unusually steep descents, but are available using sophisticated avionics in most modern aircraft that can safely fly those profiles. An FAA working group has begun to formalize them for safe use in wider circumstances[42]. Steeper descents than the classical[43] 3˚-slope "stabilized approach," if well controlled for safety, can also significantly reduce noise footprints below, and potentially use scarce airspace more efficiently. Other improvements in Air Traffic Control may be able to reduce small planes' circling[44] in holding patterns over Aspen and Snowmass Village—thus reducing noise and perhaps improving safety.

To be sure, a pilot unfamiliar with Aspen's noise-sensitive zones and accustomed to wide, meandering turns in flat terrain can cause very disruptive noise with a wide circle over downtown Aspen. We've probably all been in the Music Tent when a delicate *pianissimo* passage was drowned out by some GA pilot, or at, say, the Physics Center when all conversation had to cease while several overflights passed (as on 27 July 2022). But those errors are not necessary. They are avoidable by the better GA pilot training required anyhow for safety (Essay #2). Such errors should be memorably penalized when they do occur, but they're not a reason to penalize skilled operators who instead design and execute responsible, safe, low-noise Runway 33 approaches. Those could usefully expand as part of the Airport's portfolio of safety and efficiency improvements, and should not be artificially put into conflict with noise abatement, undercutting the FAA's important efforts to improve ASE's safety and airspace management. It seems that closer coordination is needed between Fly Quiet and the AAB's Safety Task Force.

Of course—given the primacy of our safety concerns in Essay #2 (22 December 2022)—Runway 33 approaches would almost certainly be suspended during events like the X Games and World Cup, lest the large crowds be distracted, annoyed, or potentially endangered (in case of a short-of-runway landing, however tiny that risk is under the guidance of modern avionics). The remaining risk to people on the ground is not zero—there are certainly more people just south than just north of the runway—but may be offset by lower risks from landing on the normal Runway 15 (heading south) in gusty tailwinds and other dangerous conditions.

Noise regulation

Many commentators say the County is powerless to regulate Airport noise because that authority is federally preempted. But this ignores an important exception. A specific six-step statutory petition process[45], if approved, could allow local noise regulation stricter than federal standards. While tedious, this process is available, and our Airport's unusual proximity to downtown and to residential neighborhoods could present a strong case. We are unaware that the County has seriously considered such a petition, but it'd come with strong history and community sentiment.

In 1993, after repeated warnings to end the 1978 Pitkin County curfew (motivated by a series of fatal plane crashes), and under General Aviation groups' lobbying pressure in 1989, the FAA cracked down on the curfew as unjustly discriminating between airline and private planes[46]. The dispute became so bitter that the FAA cut off Aspen Airport's $1-million-a-year federal funding. BOCC Chairman Bill Tuite responded, "If our compromise is not accepted by the FAA, we'll move to take the airport private and pay for improvements and maintenance ourselves"—which then-Commissioner Mick Ireland reckoned residents could easily afford, since the average Aspen home was then valued at $1.2 million. Happily, the FAA accepted the County's compromise offer—similar to the US General Accounting Office's proposal after a study of high-altitude airport safety[47]—that if private planes and pilots meet the same requirements for instrument flight as commercial airlines, they should be able to fly until 11 PM (now 10:30 PM for takeoffs and 11:00 PM for landings). That was close enough to nondiscrimination to satisfy the FAA in 1994.

It's also worth exploring whether any fiscal incentives might be permissible, akin to some European airports like Zürich's, which pioneered charging noisy planes and rebating quiet ones.

Superquiet new aircraft

The new kinds of airplanes described in our Essay #5—superefficient, electric, or hydrogen-fueled—promise the most powerful, fundamental, and durable noise abatements. These innovations are emerging a decade or two sooner than expected when current Aspen Airport plans were made. That Essay showed that they're likely to fly at ASE, with requisite capacity and range, before the planned airside redesigned for bigger, heavier, fossil-fueled planes could be built.

The archetypical superefficient plane, the Celera series from Otto Aviation, uses roughly one-eighth the normal amount of fuel in its original air-taxi version, and will be manyfold more efficient than today's planes in larger sizes—which, as work by Airbus and others shows, could exceed today's regional-jet capacities. These "extensively laminar-flow" planes are typically propelled by a single aft pusher propeller turned by a small diesel engine (far quieter than a jet engine) or, in the planned hydrogen versions, by a nearly silent fuel cell and electric motor. Battery-electric versions would likewise emit no significant noise except from the propeller.

Propeller noise comes largely from turbulence at the blade tips, which can approach supersonic speed. That noise can be modestly reduced by careful shaping or by miniature winglet-like vanes. But a radical reduction just invented at MIT[48] transforms the shape of the propeller from a curved blade to a toroidal loop. Even early versions reduce noise by roughly fourfold (~20 dB)—especially in the 1,000–5,000-Hz range to which the human ear is most sensitive—by distributing the tip vortex across the entire loop so it dissipates more rapidly. We expect this technology may be rapidly developed to make military drones acoustically stealthy. Similarly reshaped boat propellers have already been commercialized and appear ~20% more efficient.

Another approach is to propel an electric-motor-driven plane, powered by batteries or fuel cells, with the highly evolved cowled turbofans developed for jet engines (or, in some designs, with uncowled or "open" fans). The fan and its inlet and exhaust, like the airframe, still generate noise—reducible by many means[49]—but the roughly half of jet-engine noise generated by its combustion core, jet exhaust, and gas turbine[50] is entirely displaced by a quiet electric motor.

Noise specifications are not yet published for superefficient, electric, or hydrogen airplanes. However, it's encouraging that Joby Aviation's four-passenger, 150-mile-range, 200-mph air taxi eVTOL, meant to land near or atop buildings, achieved 50 dBA in 2021 (*vs.* 90 dBA for a helicopter). Its video comparing matched flyovers by five aircraft types is impressive[51] (Fig. 1).

Joby expects to enter urban service in Los Angeles and other cities in 2024, so we shouldn't have to wait long for empirical evidence. Indeed, when NASA engineers measured Joby's full-scale pre-production version in spring 2022, they found 45.2 dBA ground noise from overflights at 100 knots airspeed and 500 m (1640′) elevation. They also measured takeoff and landing profiles at 100 m (330′) side range[52] with noise below 65 dBA, comparable to normal conversation.

An electric retrofit of a Beaver single-engine light plane has also demonstrated 20.8 dBA lower noise on average and 24 dBA lower at peak[53]: the propeller noise can be similar but the piston-engine noise is eliminated. Displacing jet noise should be similarly or more important. Likewise, Archer's Maker eVTOL expects[54] ~45 dBA on the ground from overflight at 2000′.

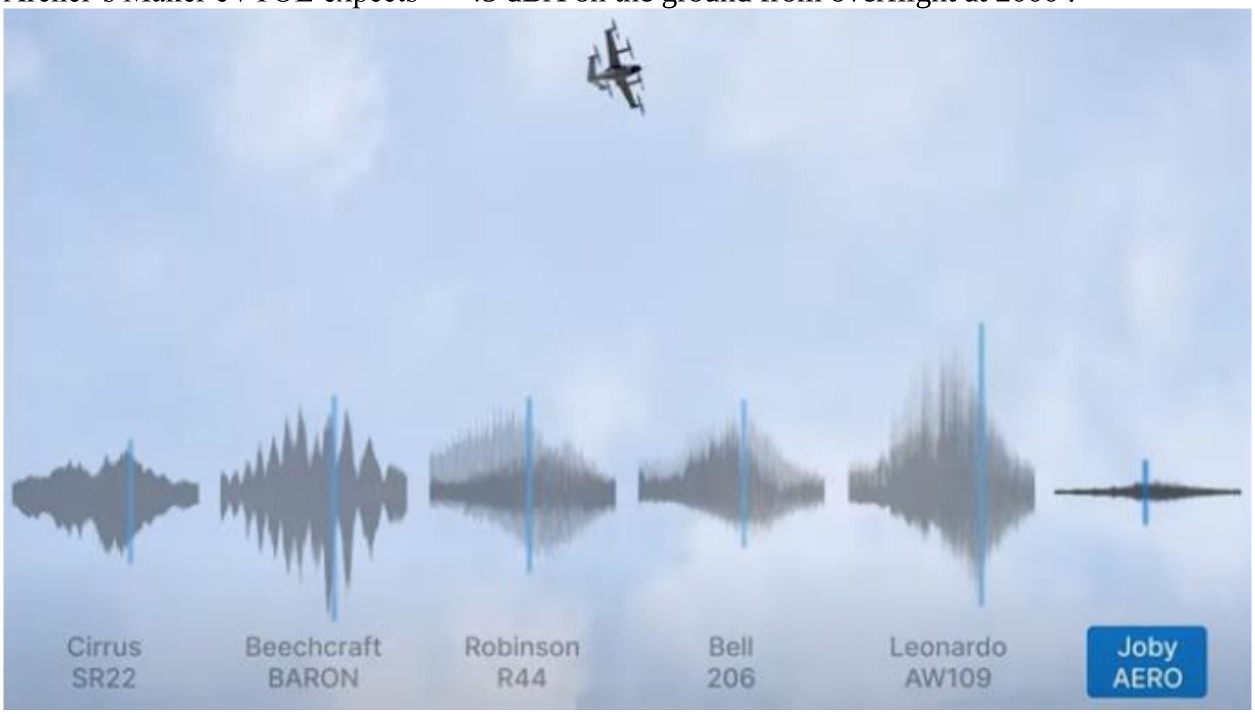


Fig. 1. Noise (dBA) traces as common fixed- or rotary-wing aircraft, or a Joby electric air taxi, overfly the listener under identical conditions. Graphic courtesy of Joby (see endnote reference).

Takeoff and landing profiles will also depend on detailed aircraft characteristics: some electric planes' takeoff might be slower, potentially lengthening noise exposure. Such details await detailed designs, testing, and refinement. But a recent thorough review[55] of electric planes' aeroacoustics confirms their "potential for ultra-quiet aircraft operation in and around the communities they serve." Combining that potential with the pace and ambition of commercialization described in our Essay #5, noise reduction at Aspen Airport should first capture the short-term opportunities described above—but over the next generation, should be essentially resolved by the revolution in ultraquiet aviation technology. For long-suffering residents, help is on the way. But if not preempted by the momentum of outdated information and obsolete plans, it will come far less from the bigger, heavier, fossil-fueled planes officially proposed and planned than from their far quieter, cleaner, carbon-free, and probably earlier replacements.

[1] Federal Aviation Administration, "Hearing and noise in aviation," undated, https://www.faa.gov/pilots/safety/pilotsafetybrochures/media/hearing.pdf.
[2] D. Gély & F. Márki, "Understanding the Basics of Aviation Noise," 2022, chapter in *Aviation Noise Impact Management*, https://link.springer.com/chapter/10.1007/978-3-030-91194-2_1. That's a good semitechnical introduction distinguishing sound pressure level, sound intensity, and perceived loudness.
[3] The A-weighted method is conservative because it underestimates the perceived loudness of low-frequency components and ignores its dependence on bandwidth (the range of frequencies included in the sound). See C. Mendonça *et al.*, "Noise perception, psychoacoustic indicators, and traffic noise," *Management of Speed and Traffic Noise*, Guimarães, 2012, ISBN 978-972-8692-70-4, https://www.researchgate.net/publication/235984861_Noise_perception_psychoacoustic_indicators_and_traffic_noise.
[4] Congressional Research Service, *Federal Airport Noise Regulations and Programs*, R46920, 27 Sep 2021, https://crsreports.congress.gov/product/pdf/R/R46920, summarizes in its abstract: "A recent FAA survey of approximately 10,000 people living near 20 representative airports showed that aircraft noise becomes a significant 'annoyance' at levels as low as DNL50 dB and DNL 55 dB. This suggests that the established DNL 65 dB threshold for identifying significant noise problems may no longer be an adequate guide for federal policymakers." That survey, required by the 2018 FAA Reauthorization Act, is at https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/ArtMID/3682/ArticleID/2845/Analysis-of-NES, and is further discussed at https://www.faa.gov/regulations_policies/policy_guidance/noise/survey/#results. The 2021 survey results invalidate the venerable 1978 Schultz Curve on which current FAA noise rules are based. FAA's current authorization from Congress expires 30 Sep 2023, so this issue looks set to come up again.
[5] FAA, "Community Response to Noise," 2022, https://www.faa.gov/regulations_policies/policy_guidance/noise/community.
[6] Ref. 4, p 2, says FAA's DNL metric adds 10 dB for nighttime noise—meaning 2200–0700 (p 4), thus overlapping ASE's curfew by 30–60 minutes. ASE's Fly Quiet assessments apparently don't follow this convention, which we have not seen described elsewhere—a discrepancy to be resolved.
[7] One of the more readable summaries is "Introduction to Noise" by the Chicago Department of Aviation, 2013, in the "Noise 101" link at https://www.flychicago.com/community/ORDnoise/Noise101/Pages/default.aspx.
[8] M. Basner *et al.*, "Aviation Noise Impacts: State of the Science," *Noise and Health* **19**(87):41–50 (2017), https://doi.org/10.4103/nah.NAH_104_16 or PMC5437751.
[9] Toronto Pearson Airport, "Environmental and perception factors," https://www.torontopearson.com/en/community/noise-management/understanding-airport-noise/environmental-perception-factors.
[10] Ref. 2.
[11] O. Zaporozhets, "Aircraft noise models for assessment of noise around airports—improvements and limitations," ICAO *Environmental Report*, 2016, pp 51–55, https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2016/ENVReport2016_pg50-55.pdf.
[12] D. Hauptvogel *et al.*, "Aircraft Noise Distribution as a Fairness Dilemma—A Review of Aircraft Noise through the Lens of Social Justice Research," *Int. J. Res. Public Health* **18**(14):7399, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8305156/.
[13] Ref. 1
[14] Mary Vigilante, Synergy Consultants, Inc., brief to ASE Vision Technical Working Group, Meeting #3, 2 Oct 2019, p 23, https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/Meeting-3-Technical-Working-Group-Presentation-–-October-2nd-PDF.pdf.
[15] ICAO, ***Noise**dB Noise Certification Database*, most recent version (2.34, 9 Sep 2022), https://noisedb.stac.aviation-civile.gouv.fr.
[16] 11 Sep 2019, https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/Meeting-1-Technical-Working-Group-Presentation-–-September-11th-PDF.pdf.
[17] The E175LR is findable by Commercial Name in ICAO's current noise database (ref. 15) under 36 weight and engine variants. This type has been announced as ASE's only current option to replace the supposedly retiring CRJ700s (cf. Aspen Fly Right, Essay #4, "The airlines' planes aren't vanishing," 5 Jan 2023, https://aspenflyright.org/wp-content/uploads/2023/01/ABL-essay_4.-Fleet_01Jan2023.pdf), but violates the BOCC's Resolution 105-2020 requirements (preface to Goals 12–15) to be quieter and significantly cleaner than the CRJ700 (though views differ on by how much), and would require more flights because of its summer performance limitations. The E175's proposed considerably quieter and more efficient E2 variant has been twice postponed—in

Feb 2022, until at least 2027 (https://simpleflying.com/embraer-e2-environmentally-friendly-jet/); it doesn't meet scope-clause requirements; and though it's popular, its ASE future seems at least as speculative as the resumed, and perhaps up-engined, CRJ700 production reported in the trade press as a logical development to expect. See our Essay #4, p 10, https://aspenflyright.org/wp-content/uploads/2023/01/ABL-essay_4.-Fleet_01Jan2023.pdf.

[18] This number, used in our Essay #7 at p 12, can now be confirmed as the 2017–22 average (59.1%), because the 2018–22 commercial/GA fuel-sale splits were posted 16 Feb 2022 at the bottom of the new Airport Dashboard from Pitkin County's Finance Department, https://stories.opengov.com/pitkincountyco/published/eEf-qrQ2P. The 2017 fuel split, 59.4% GA and 40.6% commercial, is on p 41 at https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/Work-Session-3-Appendix-F-from-the-City-of-Aspen-2017-Greenhouse-Gas-Inventory-PDF.pdf.

[19] A. Salvail, "Study says noise levels from Aspen airport in the acceptable range," *Aspen Daily News*, 20 Feb 2019, https://www.aspendailynews.com/news/study-says-noise-levels-from-aspen-airport-in-the-acceptable-range/article_51dd3f6a-34d0-11e9-92c5-37a250a5b25b.html. Actual noise measurements were very limited and heavily processed through indirect metrics, so the headline's logical linkages are tenous.

[20] ASE Vision, Technical Working Group #3 Presentation, 2 Oct 2019, pp 14–16, https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/Meeting-3-Technical-Working-Group-Presentation-–-October-2nd-PDF.pdf. We conservatively show here the "level" values, not the higher "limit" values.

[21] We were unable to find fuel kg/LTO cycle for the Dash 8–Q400, but according to datasheets at https://www.flyradius.com/bombardier-q400/fuel-burn-consumption and https://www.globalsecurity.org/military/world/canada/crj700-specs.htm, it uses ~10.2% less fuel *at cruise* (not per LTO) than the CRJ700 and carries 8.6% more passengers, for a 20.9% fuel and emissions advantage per passenger.

[22] EASA Type-Certificate Data Sheet for Noise, EASE.IM.A.070 Issue 10 (Gulfstream GII, GIII, GIV, GV), 28 Sep 2015, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwipkeKd7sD9AhU3LzQIHSqLDAUQFnoECBQQAQ&url=https%3A%2F%2Fwww.easa.europa.eu%2Fen%2Fdownloads%2F8277%2Fen&usg=AOvVaw1IasSH-IcMLaU9Y3I6RU5t.

[23] As the draft 2021 Fly Quiet report notes at p 9 and Fig. 1 (p 10), the Stage 3 noise classification has such a broad range that, for example, the Beech Jet beats it by 7.3 dB but the Cessna Citation X beats it by 35.5 dB.

[24] Ref. 11.

[25] https://www.aspenairport.com/operation/administration/reports/, "Fly Quiet Report." That name appears to have morphed into "Fly Green/Fly Clean" around 2010: J. Urquhart, "Aspen air tries to turn down the noise," *Vail Daily*, 26 Jan 2010, https://www.vaildaily.com/news/aspen-airport-tries-to-turn-down-the-noise/. The Fly Quiet program began in January 2009, but its original criteria and its 2005–07 baseline data do not seem to be posted.

[26] E. Stewart-Severy & S. Miller, "Airport expansion may not resolve pollution and noise problems," *Aspen Journalism*, 8 Apr 2020, https://aspenjournalism.org/airport-expansion-not-expected-to-fix-pollution-and-noise-problems/.

[27] Bridgenet International / Mead & Hunt, "Aspen Fly Quiet Program Draft Annual 2021 Report."

[28] This site began year-round measurements of High Noise Events apparently starting sometime in 2014 or 2015. The timing of installing the other monitors, and of whether and when they began year-round measurements, is unclear. It does appear from the draft 2021 report that its results use only the single Woody Creek monitor.

[29] Conversely, the 2020 report also notes five high noise events from Gulfstream 650s, which cannot legally land at ASE, but were temporarily said by the then Airport Director to qualify—until reversing himself in 2012, when the FAA clarified that winglets are indeed included in wingspan.

[30] Except rare emergencies, like the Flight for Life flight at 0041 26 Feb 2023, which are properly always permitted. When those occur, they should be posted on the Airport's website so citizens will know not to file a complaint.

[31] That is, nearly 50 out of more than 5,000, according to Boeing's comprehensive database at https://www.boeing.com/commercial/noise/list.page/. Fewer than a dozen US commercial airports, notably Long Beach and John Wayne (SNA), had and were allowed to keep mandatory curfews predating Congress's 1990 Aircraft Noise and Capacity Act (ANCA), which made it hard to add curfews or other noise and access restrictions. A useful short review of noise restriction options and examples is "Curfew Programs Nationwide Highlight & Recommendations," 1 Feb 2022, http://pepapurchaseny.com/index.php?p=169. A 30-year retrospective on ANCA is at https://www.aiationpros.com/airports/article/21126774/30-yes-after-anca-can-airports-live-with-new-communityimposed-noise-restrictions.

[32] That is, 206 divided by the 42,664 operations in 2020 as reported by month (annual totals would be helpful) at https://aspenairport.wpenginepowered.com/wp-content/uploads/2021/04/2020-Operational-Data.pdf.

[33] S. Condon, "Pitkin County faces challenge reducing airport emissions," *Aspen Daily News*, 8 Feb 2023, https://www.aspendailynews.com/news/pitkin-county-faces-challenge-reducing-airport-emissions/article_a799c84c-a763-11ed-9ec3-bf1bcddda09a.html.

[34] Ref. 11. Actually, noise contour maps under FAA's voluntary Part 150 program typically include continuous DNL noise contours at 65, 70, and 75 dB levels (Ref. 4, p 6).

[35] Ten Mead & Hunt billings for Fly Quiet Program from 15 April 2020 to 21 Feb 2022, obtained by Ellen Anderson's CORA request to Pitkin County, excluding a further $53,475 for "Air-Noise Monitoring" at the Airport.

[36] In 2018/19, a more serious United curfew violation, for which the then Airport Director granted successive long curfew extensions apparently contrary to County Code, was ignored, while two small American violations resulted in an Airport hearing and two $1,000 fines (A. Salvail, "American Airlines admits to airport curfew violations," *Aspen Daily News*, 8 Mar 2019, https://www.aspendailynews.com/news/american-airlines-admits-to-airport-curfew-violations/article_3823bd0a-4160-11e9-9ea2-33475c390e30.html; —, "Airline agrees to $2,000 in fines for curfew violations," *Aspen Daily News*, 27 Mar 2019, https://www.aspendailynews.com/news/airline-agrees-to-2-000-in-fines-for-curfew-violations/article_9de1f2d4-504b-11e9-ab6f-eb3f2ccd239c.html/. Another violation by a small-plane private pilot also resulted in a court summons and fine.

[37] See p 18 and n 97 of our essay #3 (29 Dec 2022), https://aspenflyright.org/wp-content/uploads/2023/01/ABL-essay_3.-FBO_dr21_29-Dec-2022rev5Jan2023.pdf.

[38] Ref. 25 (*Vail Daily* story).

[39] FAA *Finding of No Significant Impact / Record of Decision For the Runway & Terminal Area Improvement Projects At the Aspen/Pitkin County* Airport, July 2018, p 17, http://aspenairport.wpenginepowered.com/wp-content/uploads/2023/01/ASE-EA-Final-Document-and-Appendicies-min_Part1.pdf. However, a table presented to the ASE Vision Technical Working Group on 23 Oct 2019, "Options for Aligning ADG III Airfield with Community Values" (https://aspenairport.wpenginepowered.com/wp-content/uploads/2020/09/Meeting-5-Technical-Working-Group-Presentation-–-October-23-PDF.pdf), cryptically commented on "Increase Berm / Soundwalls along HWY 82 to reduce noise at ABC" as follows: "Potentially unsightly and conflicts with current standards." We're not aware of which "current standards" such sound attenuation would violate. It's stated to be a County decision and consistent with FAA rules and guidance.

[40] E.g. J. Kinsey *et al*., "Determination of the emissions from an aircraft auxiliary power unit (APU) during the Alternative Aviation Fuel Experiment (AAFEX)," *J. Air Waste Manag. Assoc.* **62**(4):420–430 (2012), https://doi.org/10.1080/10473289/2012.655884. That APU released from each kg of fuel 20–700 mg of fine particulates—0.5–5 quadrillion particles whose inhalation could raise health concerns.

[41] P 13 of Ref. 27 says the number of Runway 33 arrivals is reported but "not calculated in the overall score." This is hard to reconcile with Tables 3–7's apparently inclusion and description of explicit point penalties (e.g. §3.2.1) for Runway 33 landings. Either way, Fly Quiet clearly intends to discourage Runway 33 landings generically.

[42] Presentation by Alec Seybold to AAB Safety Task Force and an extensive and valuable discussion, 29 Jan 2023. Development by Mr. Seybolds's firm Flight Tech and FAA began in 2020; of the two approaches, Honeywell now owns the RNAV-N (RNP-AR) version, and the RNAV Mike 15 GPS version is potentially available to others. The underlying FAA effort, begun in 2018, aims to eliminate Opposite Direction Operations by creating divergent arrival and departure paths, offering new opportunities to improve safety while increasing airport access—all thanks to new technology and tied to equipage standards, crew training, and aircraft performance considerations.

[43] C. Page, "How pilots minimize noise and carbon emissions on descent," 25 Apr 2021, https://thepointsguy.com/news/continuous-descent-approaches/.

[44] Air Traffic Manager Keith Geirach's 18 Aug 2022 brief to the Airport Advisory Board (https://drive.google.com/file/d/1Jg4THrjD_dxmwOWatiHcBntTIdEYnYdc/view) left the impression that the only available holding patterns were over both towns, but at least one local pilot says his many holds en route into ASE have never been within ten miles of either community (often much farther out), and that holding patterns do not require a ground facility. This difference should be clarified.

[45] 49 USC §47524(c)(1)(A)–(F), governing restrictions imposed after 1 Oct 1990 on Stage 3 aircraft. This procedure under 14 CFR Part 161 has been repeatedly pointed out to the Board of County Commissioners over the past few years. It is summarized on pp 10–11 of Ref. 4.

[46] This often-forgotten but still-relevant history is recounted by L. Sahagun, "FAA and Aspen in Dogfight Over Airport Curfew: The county cites safety for banning private planes after sunset. Residents want quiet evenings. But the government wants equal access." *Los Angeles Times*, 25 Jan 1994, https://www.latimes.com/archives/la-xpm-1994-01-25-mn-15276-story.html.

[47] US General Accounting Office (now the Government Accountability Office), "Aviation Safety: FAA Can better Prepare General Aviation Pilots for Mountain Flying Risks," GAO/RCED-94-15, Dec 1993,

https://www.gao.gov/assets/rced-94-15.pdf. The Safety Task Force is reviewing this report. GAO specifically examined Aspen Airport's risks, found them greater than at comparable mountain airports, and found those airports had a 155% greater General Aviation accident rate in FY1992 than a group of similar-traffic non-mountain airports during FY1983–92 (when mountain airports suffered almost 11% of the nation's GA deaths). In a four-year period, NTSB staff cited inadequate pilot training or experience in mountain flying in nearly 60% of 11 Western states' fatal mountain flying accidents. GAO sided with Aspen's safety study over the FAA's. GAO's conclusions strikingly mirror our own in Essay #2 (22 Dec 2022). GAO also offers some interesting suggestions, such as "that FAA could encourage training by approving mountain flying courses and allowing pilots who complete such training to receive a 'mountain endorsement' that can be used in lieu of the biennial flight review requirement." GAO also noted that the written certification test included no questions referring, and <2% indirectly relevant, to mountain flying.

[48] L. Blain, "Toroidal propellers: A noise-killing game changer in air and water," 26 Jan 2023, https://newatlas.com/aircraft/toroidal-quiet-propellers/.

[49] E. Nesbitt, "Current engine noise and reduction technology," *CEAS Aeronautical J.* **10**:93–100 (2019), https://link.springer.com/article/10.1007/s13272-019-00381-6. A later innovation—an almost weightless graphene oxide/polyvinyl alcohol aerogel—is so good at absorbing noise that it quieted an engine by 15.8 dB: J. Dunhill, "Silencing Aircraft Engines; New Material Could Reduce Noise To That Of A Hairdryer," 22 Jun 2021, https://www.iflscience.com/silencing-aircraft-engines-new-material-could-reduce-noise-to-that-of-a-hairdryer-60117.

[50] See Fig. 4, T. Raef, A. Elzahaby, & M. Khalil, "Enhancement of Propulsion Performance Through Jet Noise Reduction Technologies: A Review," *Procs. 16th Int. Conf. Applied Mechanics & Mech. Eng.* (AMME), 27–29 May 2014, https://www.researchgate.net/publication/273060945_ENHANCEMENT_OF_PROPULSION_PERFORMANCE_THROUGH_JET_NOISE_REDUCTION_TECHNOLOGIES_A_REVIEW. Inlet and fan noise can be greatly reduced by sophisticated shapes and liners: e.g. A. Kempton, "Acoustic liners for modern aero-engines," Rolls-Royce plc, 2011, https://www.win.tue.nl/ceas-asc/Workshop15/CEAS-ASC_XNoise-EV_K1_Kempton.pdf. See also Ref. 49.

[51] At https://www.youtube.com/watch?v=0bTOdASL6J8.

[52] "Joby Confirms Revolutionary Low Noise Footprint Following NASA Testing," 10 May 2022, https://www.jobyaviation.com/news/joby-revolutionary-low-noise-footprint-nasa-testing/.

[53] General Aviation, "Flight testing reveals electric aircraft reduce noise pollution," 15 Apr 2021, https://generalaviationnews.com/2021/04/15/flight-testing-reveals-electric-aircraft-reduce-noise-pollution/.

[54] "How Loud Is An EVTOL?," 21 Oct 2021, https://archer.com/news/how-loud-is-an-evtol.

[55] E. Greenwood, K. Brentner, & T. Gan ZF, "Challenges and opportunities for low noise electric aircraft," *Intl. J. Aeroacoustics*, **21**(5–7):315–381, 2022, https://doi.org/10.1177/1475472X221107377.