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RUMBLE as a tool for community spaceport noise prediction

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Rocket launches generate acoustic environments that impact nearby communities, motivating the need for tools to predict launch noise at the community level. RUMBLE is a computational rocket noise prediction model that produces spatial predictions of acoustic metrics but offers limited temporal resolution, complicating direct comparison with field measurements. This paper tests whether RUMBLE-predicted unweighted maximum sound levels (Lmax) agree with community-level measurements from nine Falcon 9 Block 5 launch events recorded near Cape Canaveral, Florida. Field measurements were obtained using Larson–Davis sound level meters deployed at residential distances of approximately 20–25 km from active launch pads. Because RUMBLE outputs only scalar metrics without time histories, a rolling Lmax analysis using Z-weighting and slow exponential time weighting was developed to enable direct comparison. Across nine launch events, RUMBLE-predicted Lmax values agreed with measured community levels within 5 dB, with mean absolute differences of 3.5 dB for Space Launch Complex 40 operations and 2.8 dB for Launch Complex 39A operations. These results demonstrate that Lmax is an effective scalar metric for validation of RUMBLE predictions at community locations. While the absence of time-domain and spectral outputs limits more detailed comparisons, the results provide a foundation for future model development and monitoring efforts.

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1. INTRODUCTION

Rocket noise is among the most prominent environmental impacts of modern spaceflight. Acoustic loads generated during liftoff and early ascent can affect launch pad infrastructure, payloads, local ecosystems, and nearby communities.[1–4] Several recent studies have characterized the acoustic signatures of modern launch vehicles through field measurements. Far-field acoustic measurements of Falcon 9 launches have provided detailed characterization of launch noise spectra and time-domain behavior at community distances.[5] Additional work has examined acoustic events associated with launch operations, such as Falcon 9 reentry sonic booms, highlighting the broader acoustic environment produced by reusable launch systems.[6] Community-based measurement campaigns have also demonstrated the value of distributed sensor networks for capturing launch acoustics in populated areas, as illustrated by measurements of the Artemis I mission.[7]

With increasing launch frequencies at Cape Canaveral Space Force Station and Kennedy Space Center due to SpaceX's Falcon 9 and future Starship operations,[8,9] reliable prediction tools are needed to anticipate and mitigate noise impacts at the community level. Predicted launch noise levels play a central role in Environmental Impact Statements (EIS) and Environmental Assessments (EA), where modeled acoustic metrics are used to assess potential community impacts, guide mitigation strategies, and support regulatory decision-making.[8,9]

Several approaches to predicting environmental noise have been developed in related fields and adapted for rocket launch acoustics. Empirical and semi-empirical models have historically been used to estimate rocket noise source levels and near-field acoustic loads.[1,4] More recent work has explored computational and semi-empirical approaches for predicting launch acoustics and comparing model outputs with measured data.[10] However, these approaches are generally focused on source characterization or near-field conditions and are not well suited for predicting far-field community noise or accounting for site-specific propagation effects.

As a result, there are relatively few publicly available, end-to-end tools designed specifically for predicting rocket launch noise at community scales. RUMBLE was developed to address this gap by combining rocket-specific source modeling with atmospheric propagation and trajectory information in a user-accessible computational framework.[11]

RUMBLE, a computational rocket noise prediction model developed by Blue Ridge Research and Consulting, is a state-of-the-art tool for predicting launch noise.[11] RUMBLE accepts trajectory and atmospheric inputs. These inputs allow the user to produce contour maps of acoustic metrics, including the unweighted maximum level ($L_{\max}$) and A-weighted maximum level ($LA_{\max}$) (contour map displayed in Figure 1). RUMBLE offers time-integrated metrics like Sound Exposure Level (SEL) and Day-Night Level (DNL). However, these metrics are primarily used for noise produced by frequent events like aircraft operations.[12,13] By comparing measured $L_{\max}$ to RUMBLE predictions, we can identify discrepancies in maximum level predictions.

This paper compares RUMBLE-predicted unweighted maximum sound levels ($L_{\max}$) with community-level measurements from Falcon 9 Block 5 launches.

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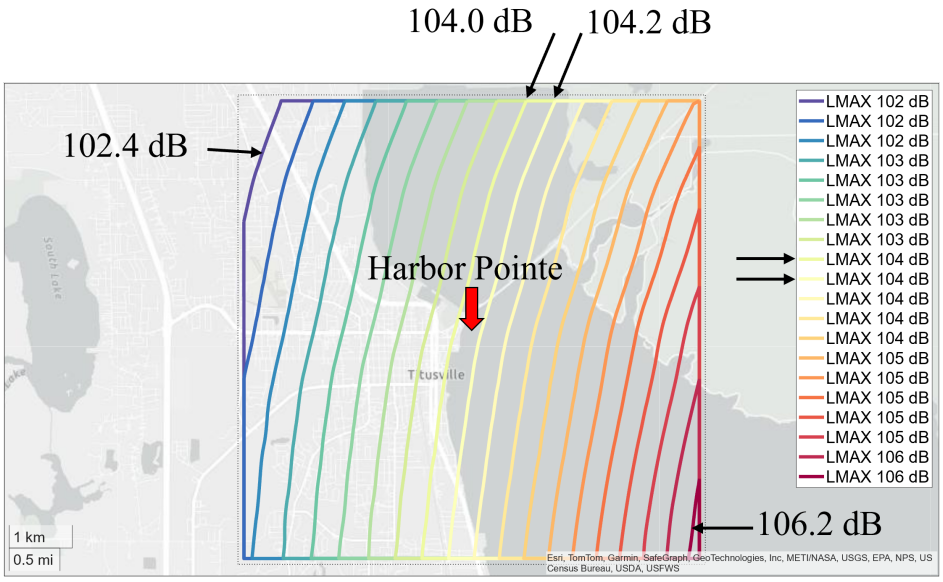


Figure 1: RUMBLE-generated contour plot of $L_{\max}$ for the SiriusXM SXM-10 Falcon 9 Block 5 launch event, launched from SLC-40. Predictions generated around the Harbor Pointe Condominium complex. Contour lines are separated by 0.2 dB. The predicted $L_{\max}$ for this event is 104.1 dB.

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2. METHODS

A. FIELD MEASUREMENTS

Community measurement sites were selected to represent typical residential distances from active launch pads. Two Larson–Davis 831C sound level meters (SLMs)[14] were deployed at Harbor Pointe Condominiums in Titusville, FL, located 19.4 km from Launch Complex 39A (LC-39A) and 22.8 km from Space Launch Complex 40 (SLC-40) for seven Falcon 9 Block 5 launch events. SLMs were deployed at Cape Canaveral City Hall in Cape Canaveral, FL, located 24.7 km from LC-39A and 19.8 km from SLC-40 for two Falcon 9 Block 5 launch events, for a total of nine recorded launch events (Figure 2). Falcon 9 Block 5 launches were targeted for launch frequency and consistency in vehicle type. These sites and distances were selected to represent typical residential communities located at tens-of-kilometers ranges from active launch pads at Cape Canaveral.

B. DATA PROCESSING

Waveform data were processed in MATLAB.[15] Scripts computed rolling Overall Sound Pressure Level (OASPL) and spectral analysis, consistent with prior studies of rocket acoustics.[16,17] OASPL is a single-number metric calculated as the Root Sum Square (RSS) of sound pressure.[18] Rolling OASPL is the decibel equivalent of the overall sound pressure level calculated in 1-second blocks of the waveform. Though rolling OASPL is a standard metric used for plotting rocket noise data in the time domain, RUMBLE does not offer scalar

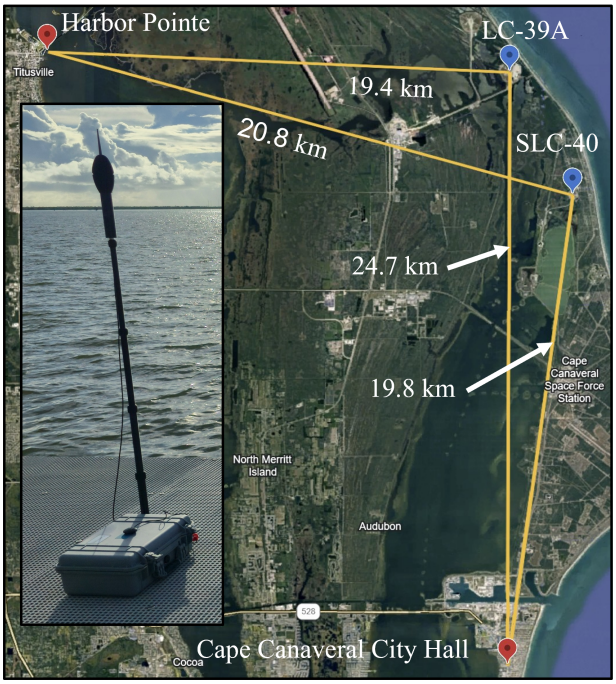


Figure 2: Map of community measurement locations relative to Falcon 9 Block 5 launch pads at Cape Canaveral Space Force Station and Kennedy Space Center. Launch pads (LC-39A and SLC-40) are marked with blue pins. Measurement locations (Harbor Pointe Condominiums and Cape Canaveral City Hall) are marked with red pins. Yellow lines indicate straight-line ground distances between pads and sites, labeled in kilometers. The inset shows a representative sound level meter deployment at a measurement location. This map includes data from: Google, AirbusData SIO, NOAA, U.S. Navy, NGA, GEBCO. Imagery from the dates: 1/21/2012–12/11/2025.[19]

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or time-domain predictions of OASPL. The closest metric offered by RUMBLE is $L_{\max}$, defined as the maximum unweighted sound level with slow-scale exponential time weighting.[11]

Building on this framework, we developed an original rolling $L_{\max}$ script that applies a 1-second exponential window (slow) to Z-weighted levels and reports the maximum within each window. The script identifies peak sound levels in one-second windows and complements OASPL analysis by highlighting short-duration maxima. Because RUMBLE outputs only scalar acoustic metrics without time histories, the rolling $L_{\max}$ analysis was developed to provide a visual aid for comparing rolling peak levels with RUMBLE's single output value. As displayed in Figure 3, rolling OASPL and rolling $L_{\max}$ largely agree on time of peak levels of the launch event, though rolling OASPL shows consistently higher peaks and lower troughs than rolling Lmax.

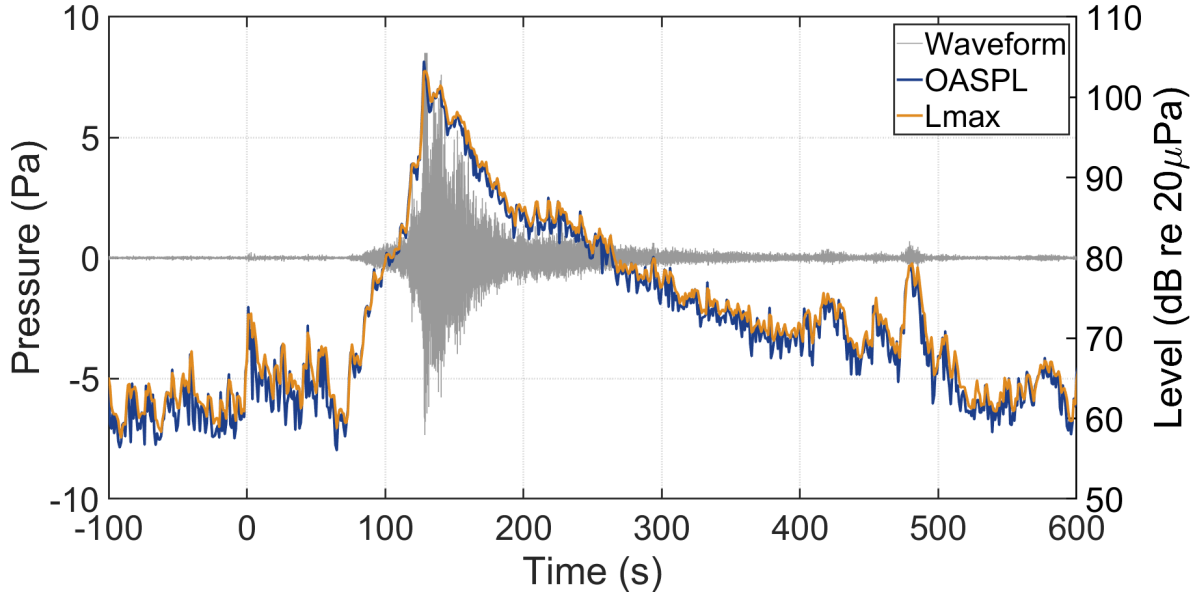


Figure 3: Rolling OASPL (blue) and $L_{\max}$ (orange) for SiriusXM SXM-10 Falcon 9 Block 5 launch mission (SLC-40) recorded from the Harbor Pointe Condominium complex. Both rolling OASPL and rolling $L_{\max}$ correspond to the rightmost y-axis. The gray trace shows the pressure waveform, corresponding to the leftmost y-axis. The x-axis displays time relative to engine ignition in seconds, where '0' refers to the time at which the Falcon 9 engines were ignited.

C. RUMBLE INPUT GENERATION

RUMBLE simulations require specification of the spaceport location, a defined receptor grid, launch vehicle parameters, and trajectory data. A square receptor grid spanning 4×4 nautical miles (nmi) with 81×81 receptor points was used for all simulations. Falcon 9 vehicle specifications are built into RUMBLE and trajectory inputs were derived from publicly available FlightClub.io data.[20] Atmospheric inputs used in this study are summarized in Table 1.

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Table 1: Atmospheric profile used as input to RUMBLE predictions for the SiriusXM SXM-10 launch event. Sea-level temperature, pressure, and relative humidity were recorded and used to construct vertical profiles as functions of altitude. These profiles define the propagation environment for all modeled launch events.

Altitude (m)	Temperature (°C)	Pressure (hPa)	Relative Humidity (%)
0	26.1	1016.9	92.0
500	22.9	941.4	71.6
1000	19.6	870.7	55.8
1500	16.4	804.6	43.5
2000	13.1	742.9	33.8
2500	9.9	685.3	26.4
3000	6.6	631.5	20.5

Atmospheric input is optional in RUMBLE. If no atmospheric profile is provided, the model assumes the 1976 U.S. Standard Atmosphere, a generalized representation of air temperature, pressure, and density as functions of geometric height up to 1000 km.[11,21]

In this study, measured sea-level temperature, pressure, and relative humidity were used to generate synthetic atmospheric profiles from 0 km to 3 km at 500 m intervals. Temperature was extrapolated using a constant tropospheric lapse rate of 6.5 K/km,[21] and pressure was computed from the resulting temperature profile using the barometric (hydrostatic) relation.[22,23,25] Relative humidity was prescribed to decay exponentially with altitude using a 2 km scale height.[22,25] At each altitude, saturation vapor pressure was calculated from temperature,[24] actual vapor pressure was obtained from relative humidity, and the water-vapor mole fraction was used to compute a humidity-corrected sound speed.[22,25–27] This vertical extent is consistent with lower-tropospheric propagation effects relevant to launch acoustics.

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3. RESULTS

Across all nine Falcon 9 Block 5 launch events, RUMBLE-predicted $L_{\max}$ values agreed with measured community levels within 5 dB. Table 2 presents RUMBLE-predicted and measured $L_{\max}$ values for Falcon 9 Block 5 launch events, separated by launch pad (SLC-40 and LC-39A). For each launch, the predicted $L_{\max}$, measured $L_{\max}$, and absolute difference are reported, along with summary statistics for each launch pad. Operations out of SLC-40 produced a mean absolute difference of 3.5 dB and a standard deviation of 1.5 dB, displayed in Table 2a. Operations out of LC-39A produced a mean absolute difference of 2.8 dB and a standard deviation of 0.7 dB, displayed in Table 2b. Rolling OASPL and $L_{\max}$ plots (Fig. 3) provide context for these scalars by showing how the peak relates to the surrounding acoustic environment.

Table 2: RUMBLE-predicted and measured L_{max} values (presented in dB re 20μPa) for Falcon 9 Block 5 launch events. Launch events are separated by launch pad (SLC-40 and LC-39A). Launch mission name in the first column, launch date in the second column, measurement distance from launch pad in the third column, RUMBLE-predicted L_{max} values in the fourth column, measured L_{max} values in the fifth column, and the absolute difference between the measured and predicted L_{max} value in the sixth column. Red for underpredictions and blue for overpredictions.

(a) SLC-40 operations

Mission Name	Date	Distance (km)	Predicted	Measured	Abs. Diff.
Starlink Group 10-12	2025-02-18	20.8	103.0	106.9	3.9
SiriusXM SXM-10	2025-06-07	20.8	104.1	103.3	0.8
Starlink Group 12-24	2025-06-10	20.8	100.3	104.7	4.4
Starlink Group 10-16	2025-06-25	20.8	104.3	108.6	4.3
Starlink Group 10-17	2025-10-19	19.8	105.7	103.3	2.4
Starlink Group 6-81	2025-11-06	19.8	105.8	100.7	5.1
SLC-40 Mean Abs. Diff.					3.5
SLC-40 St. Deviation					1.5

(b) LC-39A operations

Mission Name	Date	Distance (km)	Predicted	Measured	Abs. Diff.
Worldview Legion 5 & 6	2025-02-04	19.4	106.0	102.4	3.6
Nova-C IM-2	2025-02-27	19.4	101.4	98.5	2.9
Starlink Group 10-57	2025-09-05	19.4	106.1	104.2	1.9
LC-39A Mean Abs. Diff.					2.8
LC-39A St. Deviation					0.7

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4. DISCUSSION

These results demonstrate that RUMBLE accurately predicts community-level peak sound levels from Falcon 9 Block 5 launches. Across all nine launch events, RUMBLE-predicted L_{max} values agreed with measured community levels within 5 dB, with mean absolute differences of 2.8–3.5 dB depending on launch pad. This level of agreement supports the use of L_{max} as a practical scalar metric for first-order validation of rocket noise predictions at community locations.

Despite this agreement in peak levels, RUMBLE does not currently provide time-domain predictions, which limits more detailed comparisons such as identifying fine-scale temporal structure or secondary peaks in the acoustic signal. While using DNL or SEL could provide more context for launch event exposure levels, we avoid these metrics until a rocket-specific noise exposure metric is developed and integrated.[13] Incorporating time-dependent outputs into RUMBLE would substantially enhance its utility for field validation.

Another source of uncertainty arises from the atmospheric profiles used in the simulations. Because the profiles are constructed from sea-level measurements, higher-altitude conditions are not directly measured but instead estimated using standard atmospheric models. Consequently, deviations between modeled and actual upper-atmosphere conditions may contribute to discrepancies between predicted and measured sound levels.

In addition to time-domain predictions, RUMBLE does not calculate the frequency spectra of rocket launch events. Spectral analysis provides information about how acoustic energy is distributed across frequency, which can vary with both observer location and time as the sound propagates. Examining spectra at different locations, as well as time-evolving spectra at a fixed location, can reveal shifts in dominant frequency content that are not captured by scalar metrics such as $L_{\max}$. While incorporating spectral predictions into RUMBLE would add modeling complexity, such capability would enable more comprehensive evaluation of frequency-dependent community noise exposure.

5. FUTURE WORK

This project establishes a foundation for a multi-year effort to monitor and understand rocket noise at community locations in Florida. Future work will focus less on computational prediction and more on structural and community impacts, while continuing to use RUMBLE as a comparison tool for empirical data and to inform community members of expected noise levels from future launch events.

Plans are underway to deploy multiple long-term monitoring stations at community locations in Cape Canaveral, three equipped with SLMs and two with accelerometers, to capture acoustic and vibrational responses of structures to launch events. These long-term locations will be at distance ranges of 17.8–21.4 km from SLC-40 and 22.8–26.3 km from LC-39A. Expanding the number of long-term monitoring locations will increase the available dataset, enabling more robust comparisons with RUMBLE across a wider range of atmospheric conditions and times of day.

Future work will also focus on improving the atmospheric inputs to RUMBLE. Planned efforts include incorporating radiosonde (weather balloon) data to better constrain vertical temperature, pressure, and wind profiles at the time of launch. These measurements will enable refinement of the synthetic atmospheric profiles and improve consistency with the U.S. Standard Atmosphere where appropriate. By reducing uncertainty in upper-altitude conditions, these improvements are expected to enhance the accuracy and physical fidelity of predicted community sound levels.

The resulting measurements and predictions are intended to inform the City of Cape Canaveral and community stakeholders regarding long-term structural response and perceived annoyance associated with launch activities.

6. CONCLUSION

This study implemented rolling $L_{\max}$ analysis and validated RUMBLE predictions against measured community noise levels from Falcon 9 Block 5 launch events. RUMBLE predicted

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L_{max} within 5 dB of field observations across all nine Falcon 9 Block 5 launch events, supporting its use for estimating peak community noise levels. The lack of spectral or time-domain outputs is the greatest limitation and, of potential future additions, is the most desired. Expanded datasets and future long-term monitoring will be essential for further validating RUMBLE predictions, and for assessing the broader structural and community impacts of frequent rocket launches.

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REFERENCES

[1] S. A. McInerny, "Rocket Noise: A Review," *AIAA 13th Aeroacoustics Conference* (October 1990).

[2] S. A. McInerny, "Launch vehicle acoustics. I. Overall levels and spectral characteristics," *Journal of Aircraft* **33**(3), 511–517 (May 1996).

[3] S. A. McInerny, "Launch vehicle acoustics. II. Statistics of the time-domain data," *Journal of Aircraft* **33**(3), 518–523 (May 1996). https://doi.org/10.2514/3.46975

[4] S. A. McInerny and S. M. Ölçmen, "High-intensity rocket noise: Nonlinear propagation, atmospheric absorption, and characterization," *J. Acoust. Soc. Am.* **117**(2), 578–591 (January 2005). https://doi.org/10.1121/1.1841711

[5] L. T. Mathews, K. L. Gee, and G. W. Hart, "Characterization of Falcon 9 launch vehicle noise from far-field measurements," *J. Acoust. Soc. Am.* **150**, 620–633 (2021). https://doi.org/10.1121/10.0005658.

[6] J. T. Durrant, M. C. Anderson, K. L. Gee, L. T. Mathews, and G. W. Hart, "Initial comparison of a Falcon-9 reentry sonic boom with other launch-related noise," *Proc. Mtgs. Acoust.* **46**, 045002 (2022).

[7] M. S. Kellison, K. L. Gee, C. F. Cunningham, W. L. Coyle, T. R. Moore, and G. W. Hart, "Community-based noise measurements of the Artemis-I mission," *Proc. Mtgs. Acoust.* **51**, 040004 (2023).

[8] 2nd Lt. Sarah Meginnes, "Space Launch Delta 45 breaks records, remains world's busiest spaceport in 2024," *United States Space Force News* (2025). https://www.spaceforce.mil/News/Article-Display/Article/4020171/space-launch-delta-45-breaks-records-remains-worlds-busiest-spaceport-in-2024/

08 July 2026 20:55:53

[9] Federal Aviation Administration, *SpaceX Starship–Super Heavy Launch Vehicle at Launch Complex 39A at the Kennedy Space Center, Merritt Island, Florida: Draft Environmental Impact Statement, Volume I*, FAA-2024-1395, U.S. Department of Transportation, Washington, DC (2025).

[10] K. A. Logan, K. L. Gee, and G. W. Hart, "Prediction and characterization of rocket launch noise using semi-empirical modeling," *J. Acoust. Soc. Korea* **40**(3), 214–223 (2021). https://doi.org/10.7776/ASK.2021.40.3.214

[11] *User Guides for Noise Modeling of Commercial Space Operations—RUMBLE and PCBoom*, National Academies of Sciences, Engineering, and Medicine, Washington, DC (2018). https://doi.org/10.17226/25099

[12] S. R. More, "Aircraft noise characteristics and metrics," Ph.D. thesis, Purdue University (2010).

[13] W. L. Coyle and K. L. Gee, "An application of aircraft noise metrics to the Artemis-I launch," in *INTER-NOISE and NOISE-CON Congress and Conference Proceedings* **270**, 3712 (2024). https://doi.org/10.3397/IN_2024_3712

[14] *Model 831C SLM Reference Manual*, PCB Larson Davis, Provo, UT (2022).

[15] MathWorks, *MATLAB*, Version R2024b, MathWorks, Natick, Massachusetts (2024). https://www.mathworks.com/

[16] B. W. McLaughlin, "Comparing Sound Pressure Level Predictions Generated by RUMBLE to Field Measurements of Atlas V, Falcon 9, and Delta VI Heavy Rockets," B.S. thesis, Brigham Young University, Department of Physics and Astronomy (2024).

[17] C. P. Lubert, K. L. Gee, and S. Tsutsumi, "Supersonic jet noise from launch vehicles: 50 years since NASA SP-8072a," *J. Acoust. Soc. Am.* **151**(2), 752–791 (February 2022). https://doi.org/10.1121/10.0009160

[18] National Aeronautics and Space Administration, "Acoustic Noise Requirement," NASA Lessons Learned Information System (LLIS), Lesson #787 (2000). https://llis.nasa.gov/lesson/787

[19] Google, Airbus, SIO, NOAA, U.S. Navy, NGA, and GEBCO, Map imagery and geographic data (imagery dates: 21 January 2012–11 December 2025), provided through Google Earth.

[20] Flightclub.io, "ALT-AZ Generator" (2025). https://flightclub.io/path-tracker

[21] *U.S. Standard Atmosphere, 1976*, NOAA-S/T 76-1562, NOAA, NASA, and USAF, Washington, DC (1976).

[22] M. L. Salby, *Physics of the Atmosphere and Climate*, 2nd ed., Cambridge University Press, Cambridge (2012). https://doi.org/10.1017/CBO9781139005265

[23] J. R. Holton and G. J. Hakim, *An Introduction to Dynamic Meteorology*, 5th ed., Academic Press, Amsterdam (2013).

08 July 2026 20:55:53

[24] O. A. Alduchov and R. E. Eskridge, "Improved Magnus form approximation of saturation vapor pressure," *J. Appl. Meteorol.* **35**(4), 601–609 (1996). https://doi.org/10.1175/1520-0450(1996)035<0601:IMFAOS>2.0.CO;2

[25] J. M. Wallace and P. V. Hobbs, *Atmospheric Science: An Introductory Survey*, 2nd ed., Elsevier Academic Press, Amsterdam (2006).

[26] O. Cramer, "The variation of the specific heat ratio and the speed of sound in air with temperature, pressure, humidity, and CO_2 concentration," *J. Acoust. Soc. Am.* **93**(5), 2510–2516 (1993).

[27] *Acoustics—Attenuation of sound during propagation outdoors—Part 1: Calculation of the absorption of sound by the atmosphere*, ISO 9613-1:1993, International Organization for Standardization, Geneva (1993).

08 July 2026 20:55:53