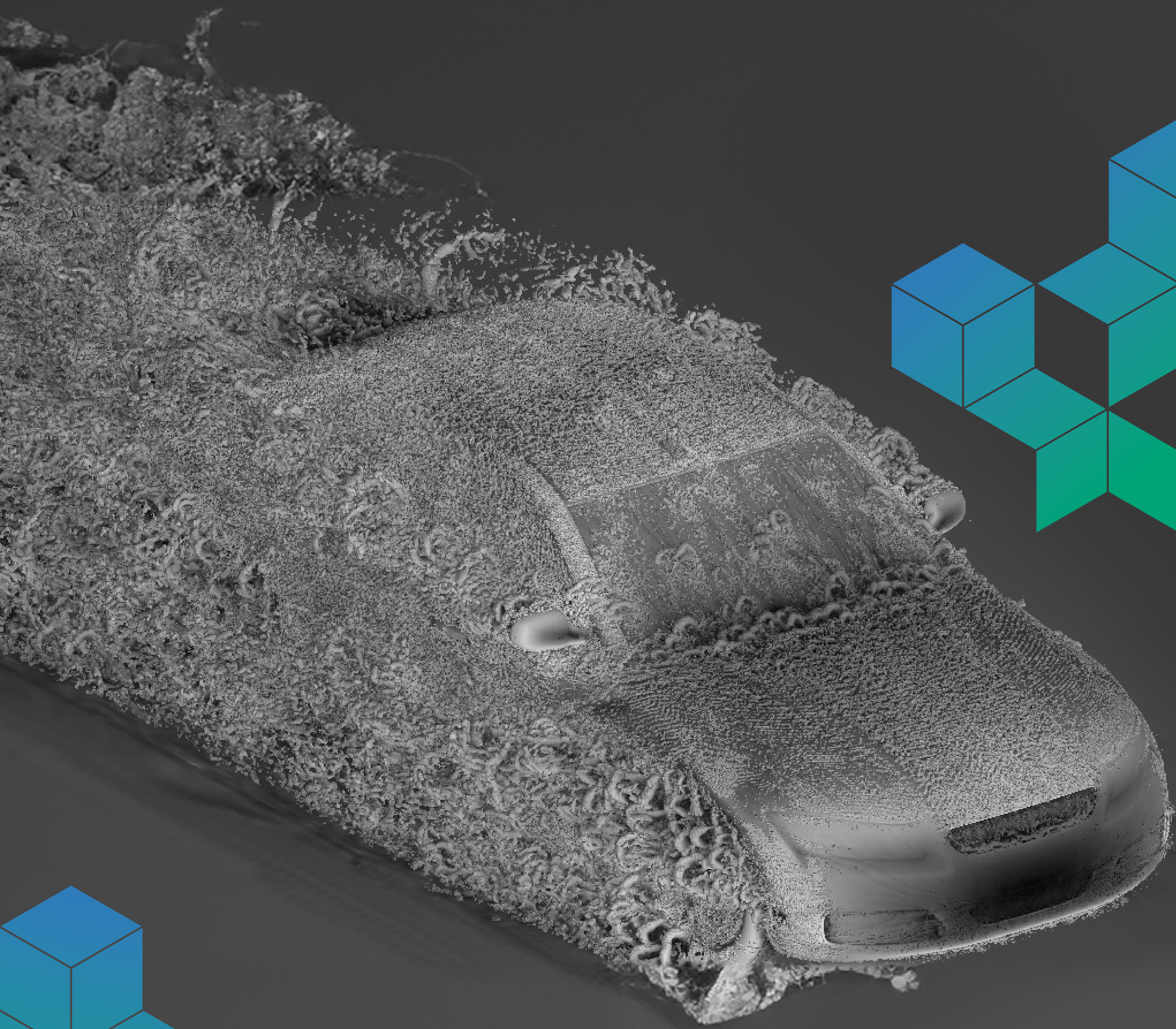
EBOOK

Engineer’s Guide to Simulating Aeroacoustics

by Cadence



Introduction

Aeroacoustics is the study of noise generation due to turbulent fluid motion or the interaction of aerodynamic forces with surfaces. This guide provides an in-depth exploration of the specific challenges and techniques associated with simulating aeroacoustics.

Predicting aeroacoustics is not just about pinpointing the origin of sound. It involves comprehending the complex mechanisms behind sound generation, propagation, and reception in various scenarios. From the high-frequency acoustic emissions of streamlined car designs to the low-frequency noise signatures of jet propulsion systems, each presents unique challenges and insights for engineers.

The significance of aeroacoustic simulations extends beyond design and optimization considerations. They are crucial for environmental compliance, ensuring user comfort, and adhering to industry-specific noise standards. With rapid advancements in sectors such as aerospace and automotive, the emphasis on accurate aeroacoustic predictions is increasingly paramount.

This guide offers a detailed overview of aeroacoustics, bridging foundational knowledge with advanced simulation methodologies. It is a valuable resource covering fundamental principles, aeroacoustic noise sources, modeling challenges, current tools and techniques, simulation setup guidelines, post-processing insights, as well as real-world case studies.

Fundamentals of Aeroacoustics

Embarking on our journey into aeroacoustics, we'll first investigate the basics of this intriguing subject. Aeroacoustics stands at the intersection of fluid dynamics and acoustics. To adeptly simulate its behaviors, it's imperative to ground ourselves in the fundamental principles most pertinent to the field.

Equations of Motion

Certain mathematical frameworks govern the behavior of sound generated by fluid motions. Central among them are the linearized Navier-Stokes equations. Although a full derivation is beyond our scope here, recognize that these equations capture the essence of how disturbances in a fluid can generate acoustic waves.

Wave Propagation

Sound waves propagate as compressions and rarefactions in a medium. Several factors influence this propagation. Properties such as the elasticity and density of a medium can affect sound speed and attenuation. Additionally, environmental factors like temperature, altitude, and humidity can variably affect sound wave propagation, altering its speed and direction.

Sound Interactions with Boundaries

When simulating environments, it's important to understand how sound waves interact with structures by way of reflection, diffraction, and absorption. As shown in Figure 1, reflection is when sound waves bounce back upon encountering a boundary, with the angle of reflection equaling the angle of incidence. As waves encounter obstacles, they can bend around them, especially when the wavelength is large compared to the obstacle size. This is defined as diffraction. Some materials can absorb sound energy, converting it to heat and thereby attenuating the sound, which is known as absorption.

NEED A HIGH-LEVEL OVERVIEW?

If you're looking for a more overarching perspective on aeroacoustics, particularly from a managerial or decision-making standpoint, consider checking out our complementary resource: Manager's Guide to Simulating Aeroacoustics. Although this engineer's guide explores the technical nuances, the manager's guide offers a broader overview, highlighting the strategic importance, cost implications, and other managerial aspects of aeroacoustic simulations.

Explore the Manager's Guide to Simulating Aeroacoustics here

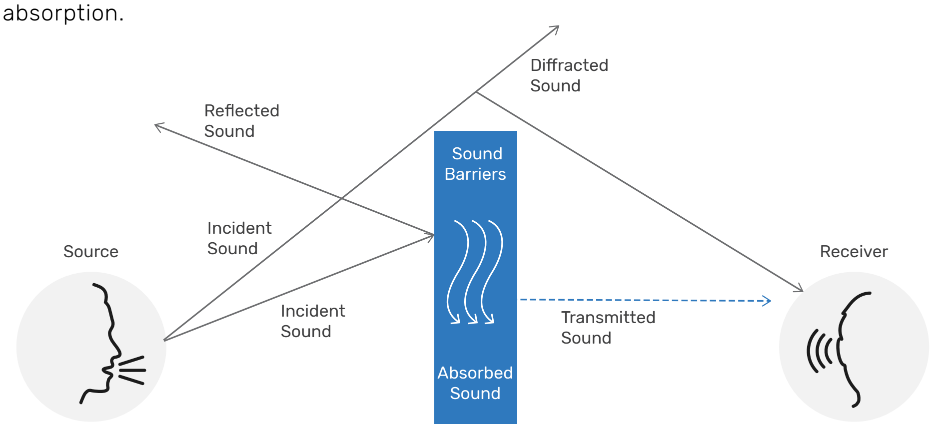


Figure 1: Incident sound is reflected, diffracted, or absorbed by a sound barrier.

Sources of Aeroacoustic Noise

Identifying the origin of aeroacoustic sound is central to its effective simulation. Many sources can be categorized based on how they radiate sound, either as first-order sources (i.e., monopoles, dipoles, and quadrupoles) or higher-order sources. Noises we perceive can also be categorized into two spectral types: tonal and broadband. Tonal noise is characterized by distinct peaks at specific frequencies in the noise spectrum, often linked to periodic events or resonances in the flow. Alternatively, broadband noise spans a wide range of frequencies and results from more random and turbulent processes, lacking the pronounced peaks seen in tonal noise. This section explores the primary sources of aeroacoustic noise and the spectral characteristics of the sound produced.

Monopole Sources

Monopole sources radiate uniformly in all directions, much like an inflating or deflating balloon. They are mainly associated with volume changes in the fluid. Combustion noise is an example of a monopole source.

- Combustion Noise: Rapid combustion events, such as in engines, can cause sudden volume changes that radiate as monopole sources.

Dipole Sources

Dipole sources arise from fluid flow interactions with solid boundaries. They produce sound primarily in two opposite directions and are stronger than monopole sources in many scenarios. Examples of dipole sources include boundary layer and blade noise, as well as flow-induced vibration.

- Boundary Layer Noise: As fluid flows over surfaces, boundary layer turbulence can exert fluctuating forces on the surface, leading to dipole noise radiation.
- Flow-Induced Vibrations: Interactions between the flow and structures, like aeroelastic flutter or cavity resonance, can lead to dipole sound radiation.
- Blade Noise: In rotating machinery, the interaction between turbulent inflow and the blade can produce dipole noise.

Quadrupole Sources

These sources are associated with turbulence-turbulence interactions and are typically weaker than both monopole and dipole sources but can be significant in high-speed, high-turbulence scenarios such as turbulent mixing noise.

- Turbulent Mixing Noise: In high-speed flows with intense turbulence, the interactions between different turbulent structures can lead to quadrupole sound radiation.

Shock Waves and Higher-Order Sources

In supersonic flows (Figure 2), the formation of shock waves can lead to complicated aeroacoustic behaviors like sonic booms and screech tones that don't neatly fit into monopole, dipole, or quadrupole categorizations. The complex nature of the flow and sound interactions means that higher-order source mechanisms are involved, which are a combination of multiple first-order sources.

- Sonic Boom: This loud, impulsive noise is produced when an object travels through the air faster than the speed of sound.
- Screech Tones: In supersonic jets, certain conditions can lead to the formation of screech tones, which are piercing, high-frequency noises.

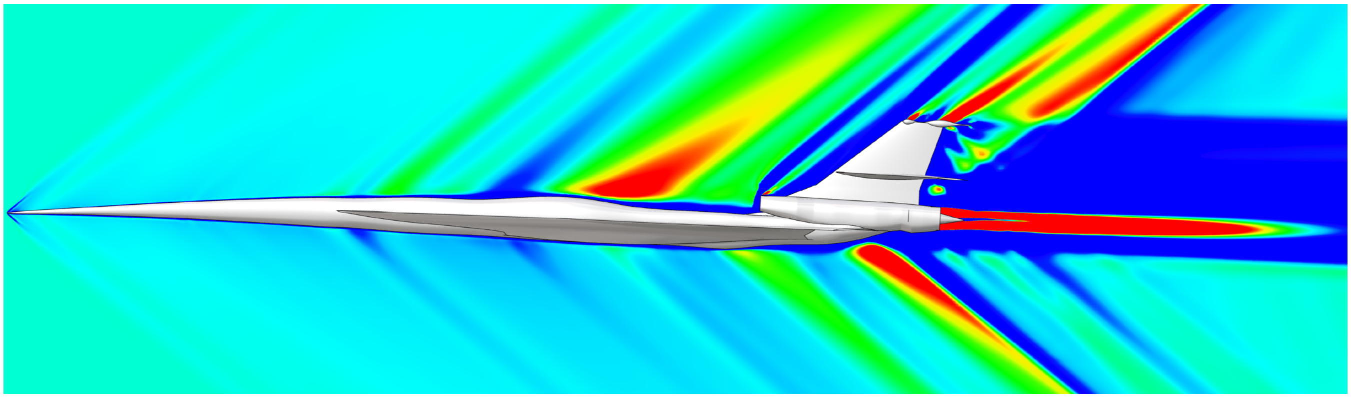


Figure 2: Simulation of a supersonic jet traveling faster than the speed of sound (Mach 1).

Basics of Simulating Aeroacoustics

Simulating aeroacoustic noise involves many steps, including noise source identification. It is a balance between accuracy and computational efficiency. As engineers and researchers, the goal is to capture the essential physics without investing substantial computational resources. This section presents the primary considerations when simulating aeroacoustics.

Time versus Frequency Domain

Simulations in the time domain directly capture the transient behavior of the flow and the resultant sound. They're particularly useful for non-stationary sources and when looking at the transient evolution of noise sources. In contrast, frequency-domain simulations focus on specific frequencies. They're typically faster than time-domain simulations and are suited for steady-state problems or when only specific tonal noises are of interest.

Grid and Source Considerations

Acoustic waves require finely resolved grids to be accurately captured, especially at higher frequencies. Reflective boundaries can distort acoustic simulations. Therefore, non-reflecting or absorbent boundaries are often used in aeroacoustic simulations to prevent artificial reflections. Additionally, understanding the type and nature of the aeroacoustic source is critical. Whether it's a monopole, dipole, or higher-order source can dictate the simulation strategy and required resources.

Simulation Strategies and Techniques

Simulating aeroacoustics effectively requires a choice between several methods and techniques, each with its strengths and applications. Recognizing these options aids in tailoring the simulations to the specific aeroacoustic problem at hand.

- Direct Methods: These techniques aim to capture both the flow and acoustic fields simultaneously without making assumptions about the relationship between them.
  - Direct Numerical Simulation (DNS): DNS resolves all scales of the turbulent flow. It offers unparalleled accuracy but is computationally intensive, making it often impractical for large or complex real-world scenarios. However, for fundamental studies or simpler geometries, DNS provides a wealth of detailed information.
- Indirect Methods: Here, the primary focus is on the flow field, with the acoustic field determined post-hoc, often using acoustic analogies, which are described later.
  - Reynolds-Averaged Navier Stokes (RANS): RANS averages the flow properties over time, capturing the mean behavior but not the instantaneous fluctuations, as shown in Figure 3. Although computationally less demanding than other methods, it will not capture all aeroacoustic sources, especially those tied to transient or fluctuating turbulent phenomena. The turbulent kinetic energy and related quantities are typically used to infer noise sources, and then statistical methods are applied for noise prediction.
  - Unsteady Reynolds-Averaged Navier Stokes (URANS): -An extension of RANS, URANS captures unsteady or fluctuating behaviors but with certain assumptions. It can detect some transient aeroacoustic sources but with lesser resolution than LES.
  - Nonlinear Harmonic (NLH) Method: This frequency-domain method is tailored for turbomachinery noise predictions, capturing the primary blade-passage frequency as well as its associated harmonics. The NLH method allows for efficient computational solutions by addressing only specific harmonics of interest.
  - Acoustic Perturbation Equations (APE): This method specifically focuses on the small perturbations (disturbances) in a fluid medium and their propagation as sound waves. It is a time-domain approach that captures the time-varying nature of sound waves and their interactions.
  - Large Eddy Simulation (LES): LES resolves the larger, energy-containing eddies while modeling the smaller scales. This offers a balance between DNS and RANS in terms of computational cost and accuracy. It's particularly useful for capturing transient aeroacoustic sources linked to turbulent flow structures.
- Hybrid Methods: These strategies combine different simulation methods to exploit the strengths of each, often coupling a flow-focused method with an acoustic analogy for noise prediction.
  - Detached-Eddy Simulation (DES): DES utilizes RANS in stable flow regions and LES in areas with significant turbulence. This approach is versatile and well-suited for complex scenarios where different flow behaviors coexist.

- Delayed Detached-Eddy Simulation (DDES): DDES is a modified form of the DES approach. The transition from RANS to LES is delayed until the flow has sufficiently moved away from the wall to avoid the premature engagement of LES mode in regions where RANS is more appropriate. DDES has found utility in scenarios where flow separation and vortex shedding are of interest.

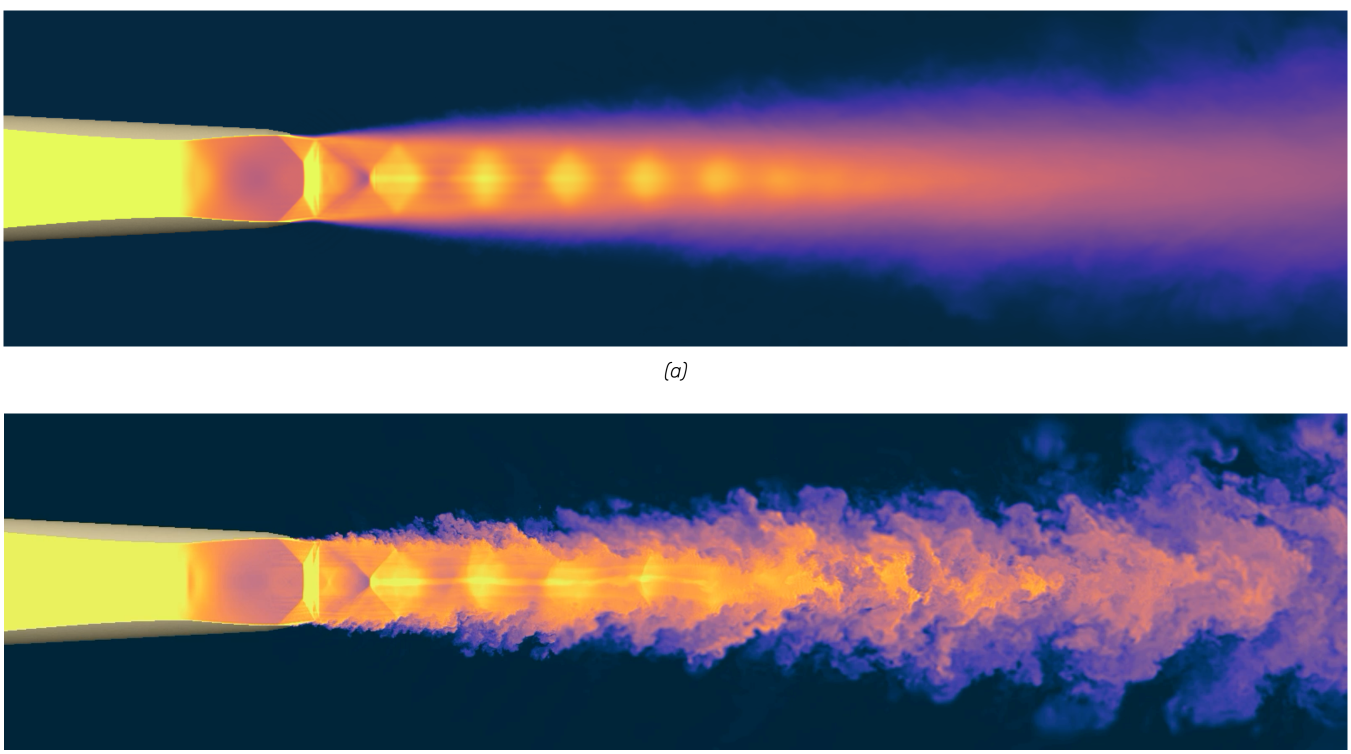
Aeroacoustics is a highly transient phenomenon driven by turbulence. Its accurate representation requires the use of transient methods. RANS offers an approximate solution, but DNS is impractical for most industrial applications. Although LES was once limited in its applicability, it has now become a more widely accepted method for detailed aeroacoustic simulations due to advances in efficiency.

Acoustic Analogies

The simulation strategies and techniques described above are based on the Navier-Stokes equations. These equations govern fluid motion and intertwine aerodynamic and acoustic information. However, in the field of fluid mechanics, only a small portion of information corresponds to sound. Separating the acoustically relevant information from the dominant aerodynamic effects can be a challenging endeavor. Acoustic analogies, like the ones listed below, reframe these equations to create a source term and wave propagation equation, making it more straightforward to identify and analyze the primary sources of sound in turbulent flows.

- Lighthill’s Analogy: Often considered the pioneering acoustic analogy, Lighthill’s theory focuses on turbulence as the primary noise source. It’s ideal for scenarios where turbulent flows are the dominant noise producers, like jet noise.
- Ffowcs Williams-Hawkings (FW-H) Equation: An extension of Lighthill’s analogy, the FW-H equation includes the effects of solid boundaries, making it suitable for situations involving moving surfaces, such as rotating blades.
- Kirchhoff’s Method: Useful for situations where the surface geometry and flow field are known, and the surface’s motion and pressure fluctuations are responsible for noise generation.

As a result, engineers can zero in on the mechanisms of sound generation and propagation using acoustic analogies without being overwhelmed by the broader complexities of fluid dynamics.



(a)

(b)

Figure 3: Comparison of (a) RANS and (b) LES of NASA THX-5 nozzle.

Validation and Verification

As with all simulations, validating and verifying your results against experimental data or analytical solutions is crucial. It ensures the accuracy and reliability of the simulation outcomes. Verification pertains to the process of determining whether the computational solution accurately represents the underlying mathematical model. On the other hand, validation assesses how well the mathematical model captures the physical reality. As listed below, the key aspects of verification are grid convergence, solution consistency, and code comparisons.

- Grid Convergence: By simulating on different grid resolutions (Figure 4), one can ascertain whether the solution is approaching a grid-independent state. This is essential to ensure that numerical errors due to grid discretization are minimized.
- Solution Consistency: Involves assessing whether the solution behaves as expected when parameters like time step, initial conditions, or boundary conditions are altered slightly.
- Code Comparisons: Evaluating results from different simulation codes (inter-code comparison) tackling the same problem can offer insights into the consistency and reliability of the solution.

In addition to verification, the main ways a simulation is validated are through physical experimentation, benchmark problems, and uncertainty quantification.

- Physical Experimentation: Comparing simulation results with experimental data allows researchers to gauge the fidelity of their computational model to real-world scenarios.
- Benchmark Problems: Benchmarking against standard problems for which analytical or widely accepted solutions exist, offers a means to measure the performance of a new or altered simulation setup.
- Uncertainty Quantification: Recognizing and quantifying uncertainties is important, whether they stem from measurement errors, model approximations, or boundary condition estimations. This provides a clearer picture of the confidence one can place in the simulation results.

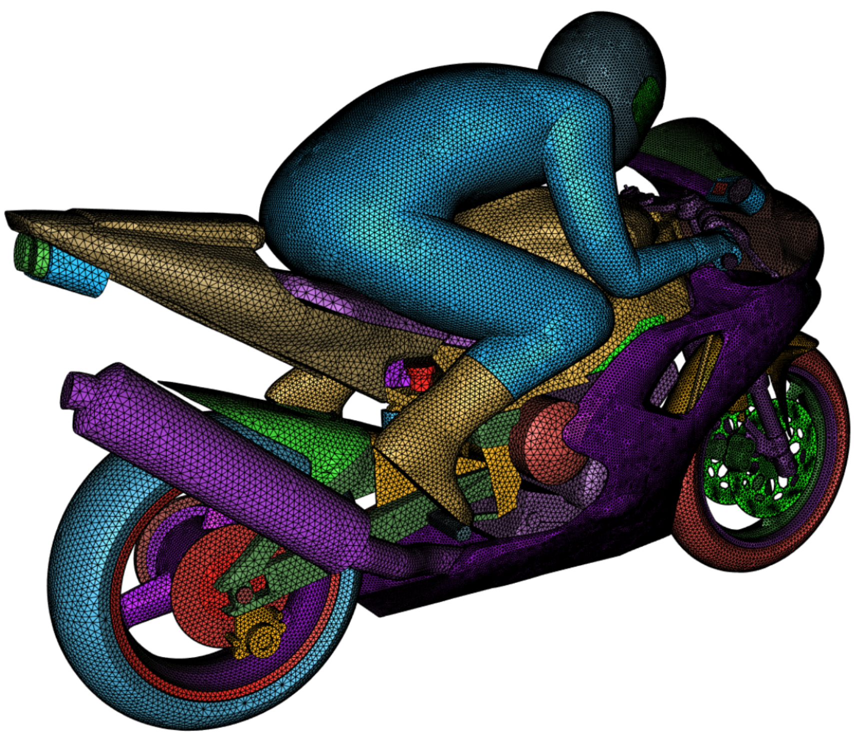


Figure 4: High-density motorcycle mesh.

Challenges in Simulating Aeroacoustics

Simulating aeroacoustics presents a myriad of challenges due to the difficulty in capturing fluid dynamics and acoustic phenomena. Here are some of the major challenges encountered:

- Wide Range of Scales: Aeroacoustic phenomena span a broad range of spatial and temporal scales. Sound waves can have wavelengths from millimeters to meters, and the turbulent structures producing the sound can vary substantially in size. Capturing all these scales demands very fine grid resolutions and long simulation times.
- Acoustic Wave Amplitudes: Aeroacoustic signals of interest often have much lower amplitudes than the hydrodynamic pressure fluctuations in turbulent flows. Distinguishing these subtle acoustic waves from the dominant flow structures is challenging.
- Far-Field Propagation: Sound generated by a local aerodynamic source can propagate over large distances. Simulating the entire domain, from the noise source to a distant observer, becomes computationally prohibitive.
- Complex Geometries: Real-world aeroacoustic problems often involve intricate geometries, like aircraft engines or vehicle exteriors. Modeling these geometries and their impact on fluid flow and sound propagation complicates the simulations.
- Boundary Conditions: The choice and implementation of appropriate boundary conditions is critical. Incorrect or overly simplistic boundaries can introduce spurious reflections or other non-physical behaviors.
- Transient Nature: Many aeroacoustic problems are inherently unsteady and require transient simulations (Figure 5). This increases computational effort and makes it challenging to obtain statistically meaningful results.
- Nonlinear Interactions: In many scenarios, especially at high sound levels, there are nonlinear aerodynamic and acoustic interactions. Simulating these nonlinearities requires additional attention to detail and computational resources.
- Multiphysics Interactions: In certain cases, aeroacoustic simulations might also need to account for other physical effects, like heat transfer or combustion, which further complicates the simulation setup.
- Numerical Dissipation: Numerical methods can introduce artificial dissipation, which can dampen or entirely suppress the very acoustic signals of interest.

All these challenges underscore the complexities involved in accurately and efficiently simulating aeroacoustics. The pursuit to tackle these challenges has driven continuous advancements in the field, pushing the boundaries of computational capabilities and methodologies.

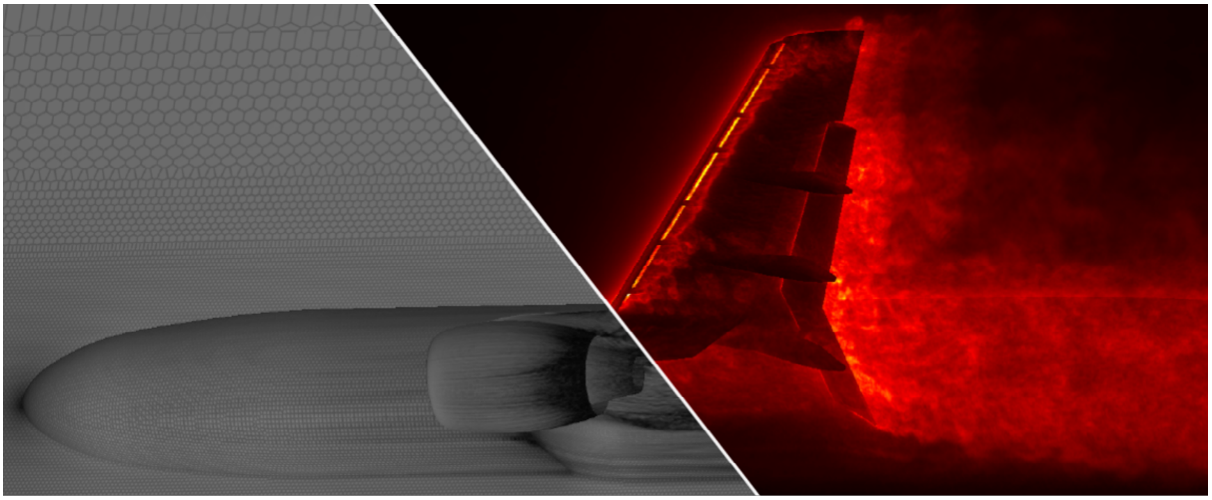


Figure 5: LES of aircraft in flight, highlighting its transient nature.

A Unique Solution for Simulating Aeroacoustics: Cadence Fidelity CharLES

Whether you're addressing real-world engineering challenges or venturing into fundamental research, choosing the right simulation software is vital. In the domain of aeroacoustics, a software tool has emerged that facilitates accurate and efficient simulations.

Cadence's premier flow simulation software, Fidelity CharLES, is specifically designed for high-fidelity flow analyses, including aeroacoustics. CharLES harnesses the potential of LES by integrating state-of-the-art numerical techniques and models that can simulate unsteady flows while minimizing dissipation and dispersion. Different solver formulations based on the finite volume method are used to capture various flow conditions, including low-speed, high-speed, and reacting flows, to ensure optimum performance. By integrating cutting-edge sub-grid and wall modeling, CharLES consistently performs well across various grid resolutions. Even on coarse grids, CharLES is still able to capture correct flow phenomena. Furthermore, it boasts impressive efficiency and scalability on CPUs and GPUs. For instance, one V100 GPU has the equivalent processing power of nearly 400 Intel Skylake 2018 CPUs for the implicit low-Mach CharLES solver, as presented in Figure 6.

Engineers can easily manage their entire simulation workflow with CharLES's user-friendly application. CharLES takes care of all steps in your simulation process, from preparing geometries and creating meshes to running the simulation and analyzing the results. Designed to work smoothly on both laptops and desktops, this application connects securely for remote file sharing. The strength of CharLES's solver is exploited to provide detailed 3D views of intricate engineering models. Besides offering visualization features, you can also adjust simulation settings on the go, benefit from a command glossary with automatic suggestions, and see graphs that track changes over time in key metrics.

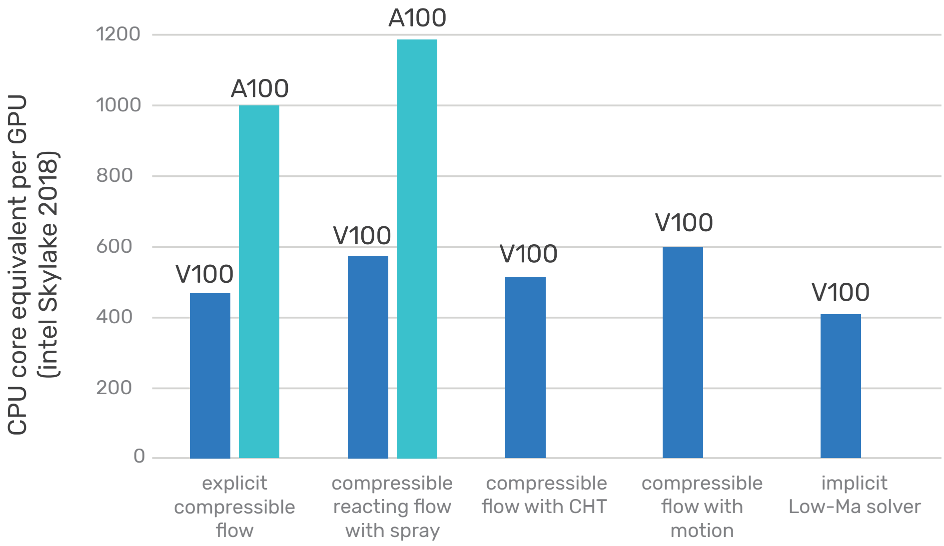


Figure 6: Intel Skylake 2018 CPU core equivalent per NVIDIA A100 and V100 GPUs for various flow scenarios using the CharLES solver.

Setting Up an Aeroacoustic Simulation

Executing an aeroacoustic simulation demands a systematic approach. From understanding the nature of the problem to selecting the right solver, each step influences the quality and accuracy of the results. Below is a guide to help you navigate this intricate process.

Understanding the Problem

Before getting started, pinpoint the primary sources of noise. Is it the turbulent boundary layer, vortex shedding, or something else? Additionally, define the frequency range of interest. Low-frequency sounds differ in their simulation requirements compared to high-frequency noises.

Geometry and Meshing

After defining the problem, the geometry and mesh are prepared for the analysis. The mesh quality is not just a detail but a pivotal factor that dictates the accuracy and efficiency of your simulation. Engineers normally must simplify the design while retaining critical features impacting the aerodynamic and acoustic fields. However, this is no longer necessary thanks to CharLES's advanced geometry preprocessing and meshing tools called Surfer and Stitch, which ensure high-quality results without wasting hours on manual geometry cleanup tasks.

Surfer

Creating a flawless and robust discretized geometry can pose challenges. Surfer serves as a geometry preprocessor, facilitating the manipulation of discretized geometry through several avenues, such as diagnosing and rectifying surface quality problems, merging multiple geometries through Boolean functions, and altering existing geometries. This tool ensures models transferred to Stitch are primed for meshing, as showcased in Figure 7, eliminating the necessity for alterations using CAD/CAE applications.

Stitch

Once the geometry is prepared via the Surfer feature, the Stitch tool is used to mesh the model. This feature employs Voronoi diagrams, a computational approach that ensures the mesh aligns perfectly with complex geometries. As displayed in Figure 8, the stitch tool allows the user to manipulate the local mesh resolution, which is vital for meticulously describing the flow features that come into play.

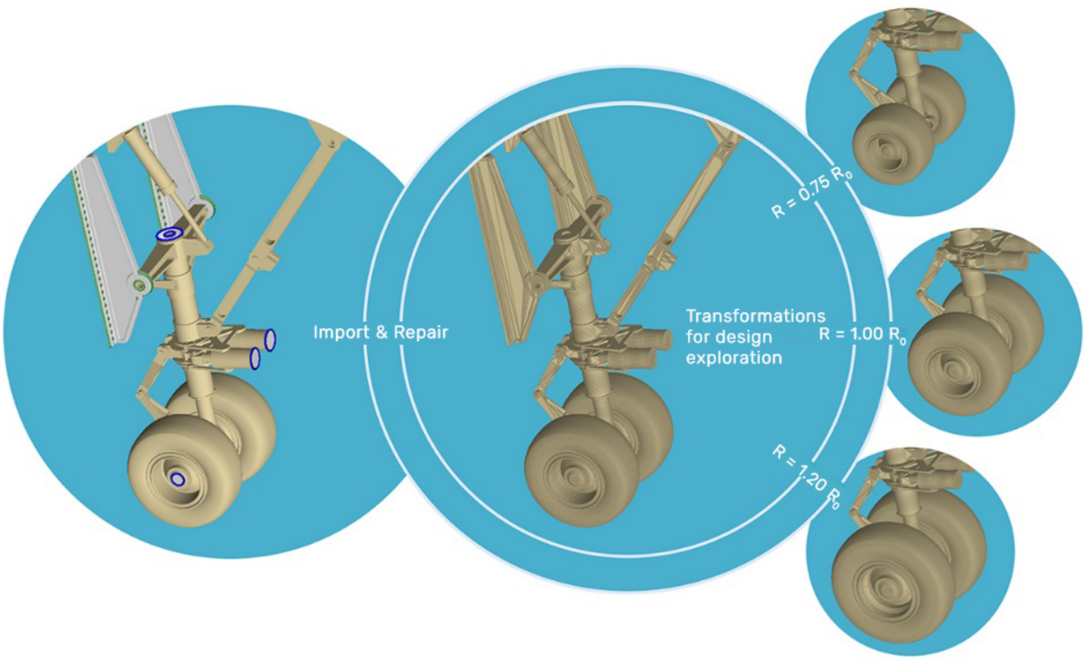


Figure 7: Sample geometry preprocessing via the Surfer feature.

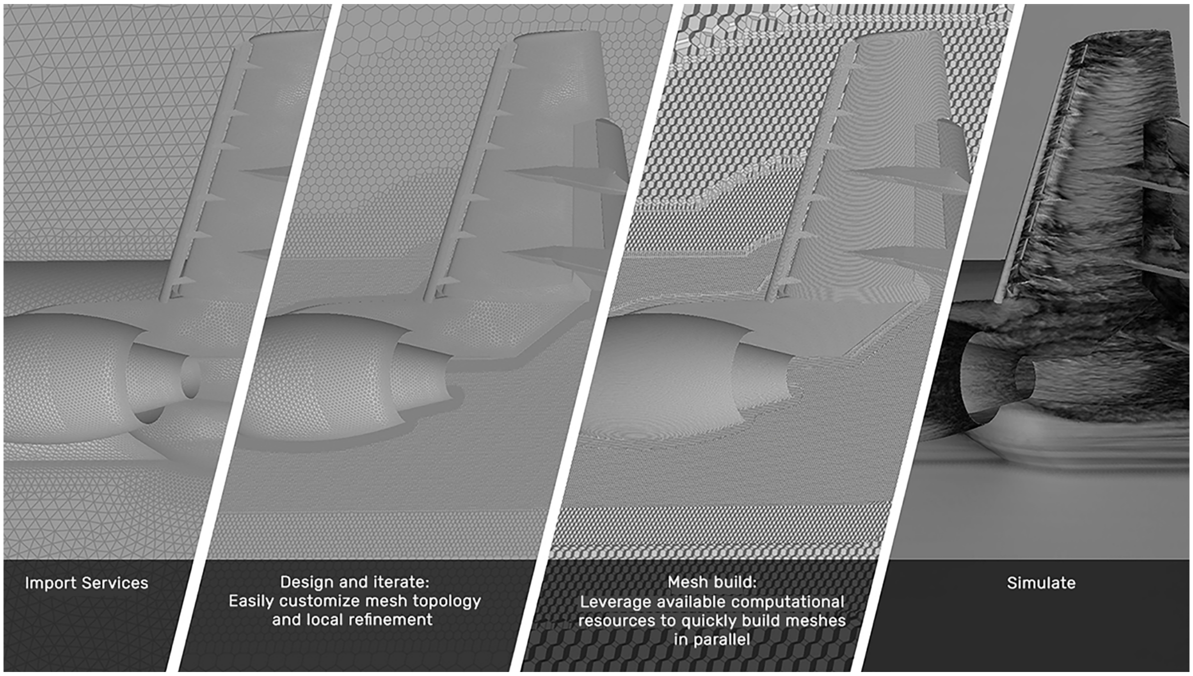


Figure 8: Sample mesh refinement via the Stitch feature.

CharLES doesn't stop there; it offers an adaptive meshing technique that dynamically tunes the mesh by zooming in on regions with high turbulence or acoustic sources. And for those dealing with rotating bodies, CharLES provides mesh motion methods optimized for the dynamic world of fans, turbines, and VTOL rotors, where the mesh moves and deforms in harmony with these bodies.

When it comes to aeroacoustics, CharLES goes the extra mile by resolving boundary layers with pinpoint accuracy, a crucial step in predicting noise sources bounded by walls. Additionally, parallel mesh generation features are available that distribute the meshing process across multiple processors to minimize the time needed to craft large, complex meshes. Users can also dictate the mesh parameters, tailoring every detail to meet the unique demands of your simulation, from mesh density to element type.

Boundary and Initial Conditions

Following geometry and meshing processes, designate boundaries that allow sound waves to exit without reflection. Common methods include sponge layers where variables are damped to prevent boundary reflections or perfectly matched layers (PMLs), which are non-reflecting layers that exponentially attenuate waves. Then set up inflow, outflow, wall, and other conditions as per the flow scenario. Depending on the simulation type, you may need to provide initial flow or noise fields.

Solver Selection

A solution strategy must be chosen based on the problem's complexity, desired accuracy, and available resources. CharLES leverages a time-dependent, indirect LES methodology. For such transient simulations, ensure the temporal resolution is sufficient by selecting a timestep that captures the highest frequencies of interest.

Acoustic Analogies and Sources

Employing the right acoustic models is fundamental to the accuracy and reliability of an aeroacoustic simulation. The appropriate acoustic analogy is often determined by the nature of the noise source and the problem's specific requirements. Therefore, incorporating the correct source terms in a simulation is vital, as these represent the physical phenomena leading to noise generation. In some simulations, especially with direct methods, it might be necessary to introduce explicit sources representing physical processes, such as vortex shedding or boundary layer interactions. In indirect methods, source terms are often derived from the computed flow field. For instance, turbulence statistics might be extracted from a RANS simulation and then used as source terms in an aeroacoustic analogy. It's critical to correctly define where these source terms act. In scenarios involving rotating machinery, the region close to the blades might be designated as the primary source region.

Post-Processing and Optimization

Performing aeroacoustic simulations is as much about the post-processing and optimization phases as it is about the pre-processing and simulation stages. Once the calculations are complete, an enormous dataset awaits. CharLES offers a robust arsenal of post-processing tools listed below, all designed with one goal in mind: to help you extract meaningful information hidden in the simulation data.

- Quantitative Imaging: Generate quantitative PNG images directly from simulations.
- Modal Decomposition: Break down the flow and acoustic fields into their individual modes.
- Ffowcs Williams-Hawkings Acoustic Predictions: Predict far-field noise from near-field data.

CharLES not only offers data analysis features, but it also provides advanced visualization tools like plots, contour maps, and graphical representations that breathe life into simulation data, as depicted in Figure 9. Through contour and surface plots, one can obtain insights into the pressure and velocity fields in order to pinpoint flow features and noise sources. The use of spectrograms and frequency plots can help you distinguish between resonant tonal sounds and chaotic broadband noises. Adding another layer of depth are particle tracing and streamline plots that paint a picture of turbulent structures, vortex shedding, and other noise-generating phenomena.

As we dig deeper, we find a Python API and built-in expression evaluator for customizing and automating specific tasks or processes as well as quantifying visual insights through the creation of variables and equations to calculate derived quantities, such as sound pressure level (SPL) or turbulence intensity. Metrics such as SPL highlight acoustic hotspots, while the overall sound pressure level (OASPL) is a measure of the total SPL over a specified frequency range.

Furthermore, optimization methods for aeroacoustics are available with algorithms that minimize acoustic emissions from aerodynamic sources through the modification of design variables. These methods can include gradient-based techniques, where sensitivity information is used to iteratively improve the design, and global optimization techniques like genetic algorithms, which search for solutions across a broad design space without relying on gradient information. The goal is to find design configurations that lead to the lowest possible noise levels while still meeting performance and operational requirements.

After post-processing and optimization, documentation becomes vital. Engineers must demonstrate their findings clearly and comprehensively. Summarized data, distilled into easily digestible formats, coupled with actionable recommendations, can guide subsequent engineering decisions. And for the sake of reproducibility and future reference, archiving every bit of information—from simulation setups to conclusive insights—ensures that the wisdom acquired from today's analyses benefits tomorrow's endeavors.

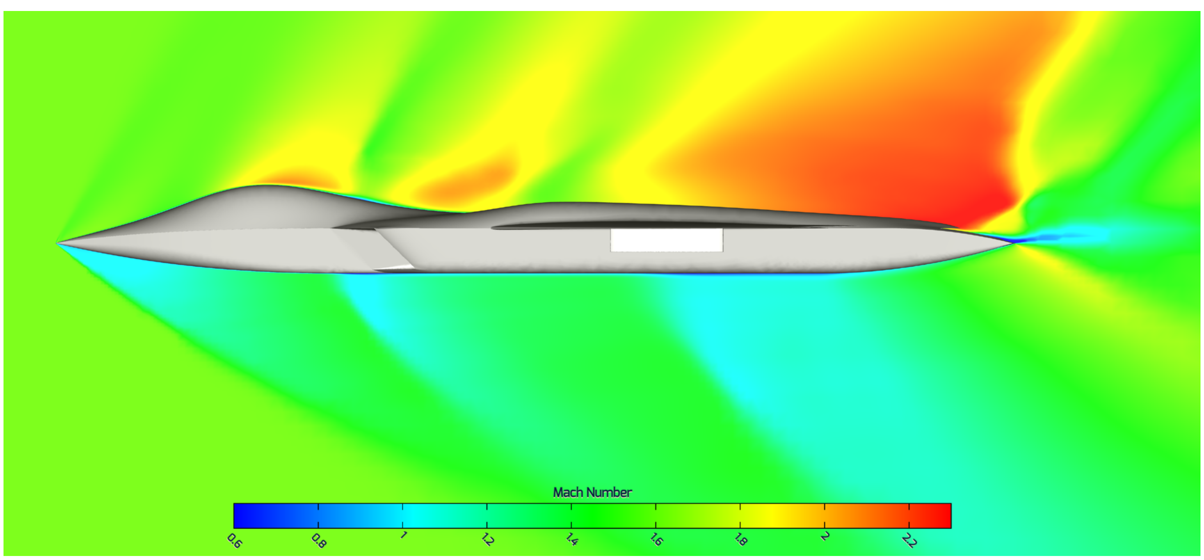


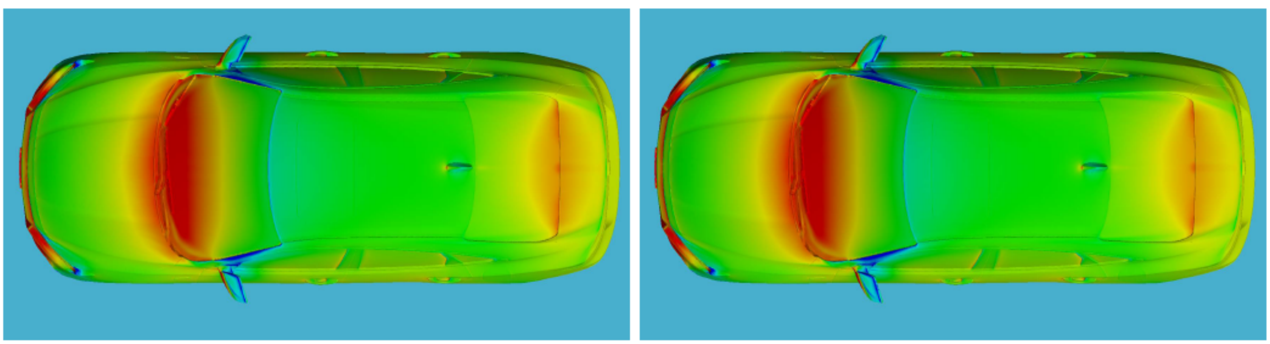
Figure 9: Mach number contour plot of an efficient supersonic air vehicle (ESAV).

Real-World Case Studies

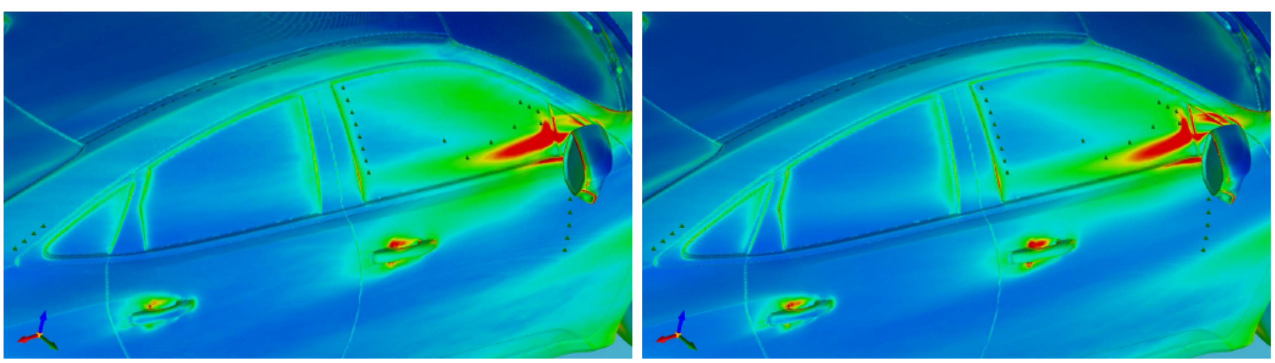
Now we find ourselves at the juncture where theory meets practice, where we explore real-world applications that have leveraged CharLES's capabilities to address pressing aeroacoustic challenges. Let's take a closer look at some notable endeavors where CharLES has proven its mettle.

Noise Predictions for a Full-Scale Car with Honda R&D

Honda R&D employed CharLES to simulate the aeroacoustic profile of a standard sedan traveling at 120 kph. Figure 10 presents the 2 mm (Acs118M) and 1 mm (Acs253M) surface mesh resolutions of the sedan that were compared to evaluate grid convergence. Notably, the 1 mm resolution revealed intricate turbulent structures, particularly around the car's A-pillar. This zone emerged as a hotspot for pronounced vortex shedding, which can considerably impact aerodynamic behavior and noise generation. To ensure the validity of the simulations, the findings were compared to wind tunnel measurements. This involved assessing surface pressure variations at critical locations, such as the hood, front windshield, and side windows. Consequently, the LES data corresponded closely with empirical observations. Additionally, the performance metrics of CharLES on traditional CPU platforms versus GPU configurations were evaluated. Harnessing 32 Nvidia V100 GPUs expedited the simulation, which concluded in a mere 1.5 hours. In contrast, the simulation lasted around 6 hours when deploying 2560 AMD EPYC CPUs. This efficiency leap is instrumental, especially when considering the broader applications in contemporary vehicle design, including the burgeoning electric vertical take-off and landing (eVTOL) aircraft sector.



(a) $p_{avg} - p_0$, LES case Acs118M *(b) $p_{avg} - p_0$, LES case Acs253M*



(c) p_{rms}, LES case Acs118M *(d) p_{rms}, LES case Acs253M*

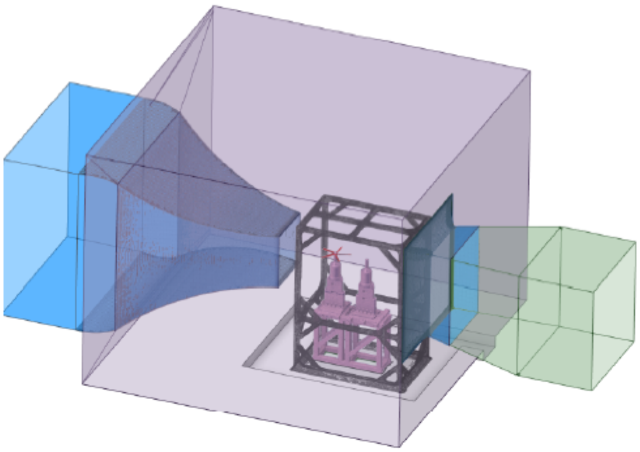
Figure 10: Time average (top images) and rms (bottom images) of the surface pressure on the top and right-hand side of the full-scale sedan car for the LES cases Acs118M and Acs253M. The color ranges are (blue) $-800 \le p_{avg} - p_0 \le 250\ P_a$ (red) and (blue) $0 \le p_{rms} \le 100\ P_a$ (red).

Harnessing 32 Nvidia V100 GPUs expedited the simulation, which concluded in a mere 1.5 hours. In contrast, the simulation lasted around 6 hours when deploying 2560 AMD EPYC CPUs

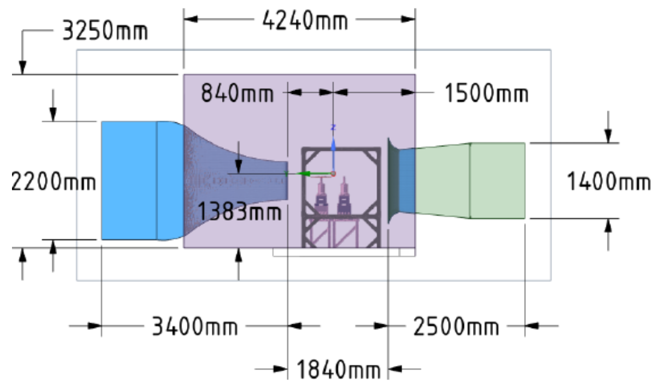
Read the AIAA Conference Paper

Noise Analysis of Multiple Blade VTOL Rotors with Honda R&D

Researchers used CharLES to examine the aeroacoustic performance of VTOL rotors—those used in drones and urban air mobility vehicles. Their primary objectives were to evaluate the accuracy and efficiency of high-frequency aeroacoustic simulations. The study simulated rotors ranging from 2 to 5 blades and then compared the results with experimental data from Honda's wind tunnel facility, as visualized in Figure 11. Consequently, as the blade count increased on the rotor, it directly correlated with amplified noise—a trend consistent with the empirical data. The results resonated well in terms of various noise benchmarks. To further demonstrate the potential of CharLES, a comprehensive simulation of a full-scale eVTOL aircraft (Figure 12) equipped with eight rotors and two propellers was carried out. This also served to highlight the advantages of GPU acceleration in computational throughput. Through CharLES, the future looks bright for engineering quieter and more efficient aerial vehicles for urban environments.



(a) Overview of domain



(b) Representative dimensions

Figure 11: Computational domain highlighting the wind tunnel walls (in purple), the inlet nozzle (in blue), and the outlet duct (in green), as well as the rig installed in the tunnel.

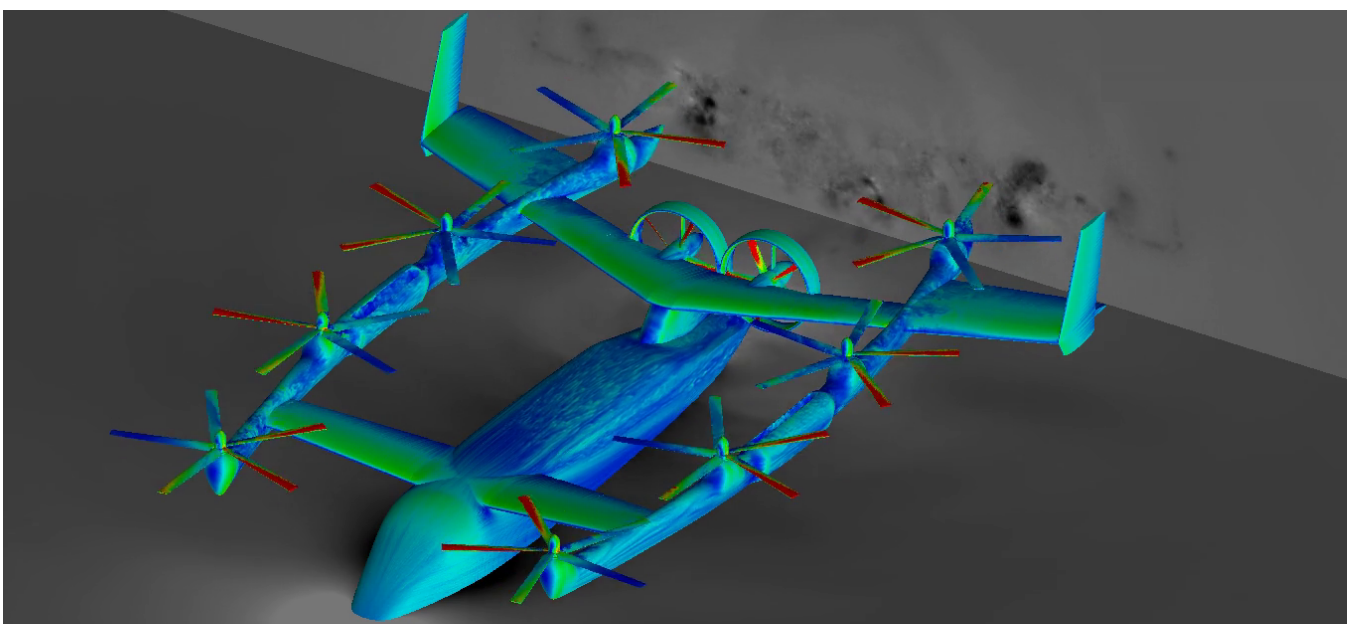


Figure 12: Surface shear stress on Honda's full-scale eVTOL vehicle (color scale) and instantaneous pressure in two horizontal and vertical planes (grey scale).

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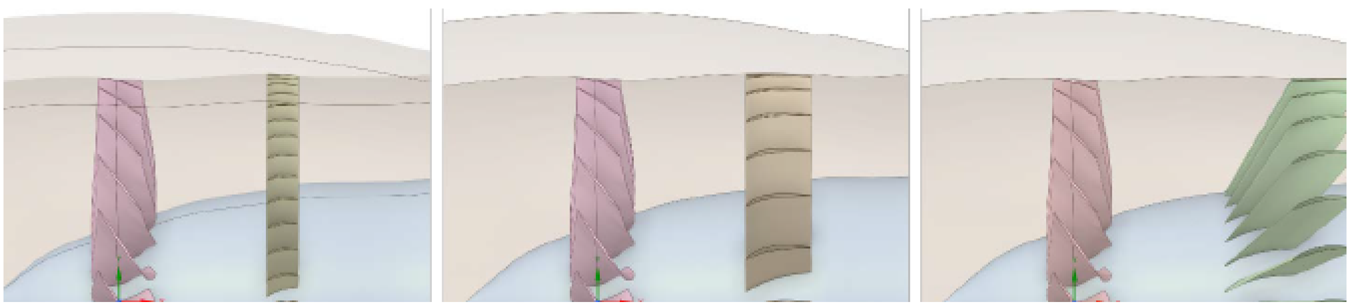
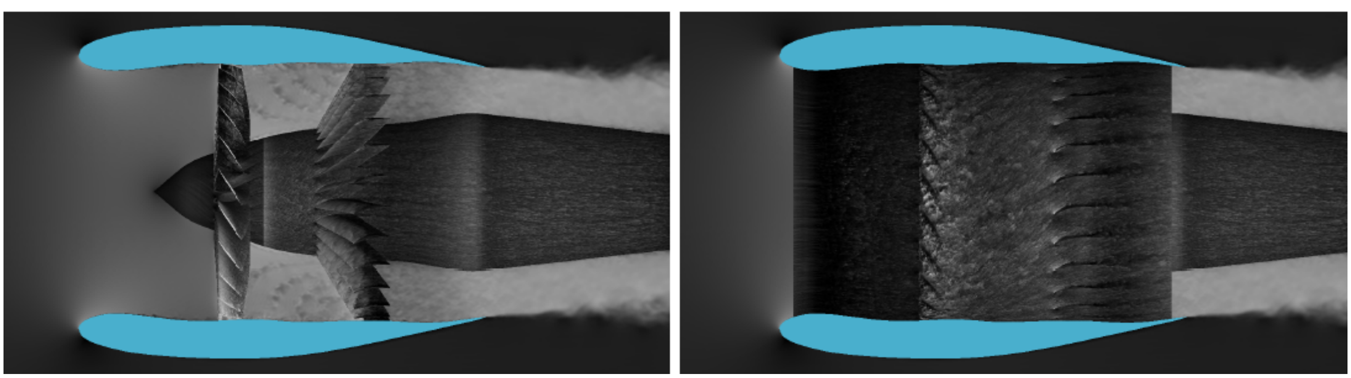
NASA's Fan Noise Source Diagnostic Test

A wall-modeled LES of NASA's fan noise SDT was performed using CharLES. Engineers discerned the impact of varying outlet guide vane (OGV) setups on the aerodynamics and acoustic profile of the fan. Figure 13 exhibits the computational setup, which incorporated the entire fan and OGVs, the nacelle, and the full test section. This comprehensive model led to a reduction in numerical inaccuracies. The fan was set to a reduced rotational speed of 7,809 rpm, amounting to roughly 61.7% of its design speed. One of the key takeaways was the efficacy of the low noise OGV design (Figure 14), which managed to cut down the noise level by approximately 2 dB compared to the standard and low count OGV configurations. This outcome was supported by real-world tests. Despite certain mesh resolutions being less than optimal (especially around the fan blade and OGV surfaces, as well as the tip gap), the simulations closely mirrored experimental measurements. CharLES exhibited impressive accuracy, with errors as low as 0.5% in certain aerodynamic efficiencies. This study has reinforced CharLES's predictive capabilities, setting the stage for its heightened involvement in future aeroacoustic research.



(a) Baseline OGV *(b) Low count OGV* *(c) Low noise OGV*

Figure 13: SDT fan with three different OGV configurations.



(a) Internal flow and blade surfaces *(b) Nacelle interior surface*

Figure 14: Flow Mach number and surface shear stress for the NASA fan SDT with low noise OGV configuration at approach condition (61.7% design speed) from the GPU-accelerated CharLES simulation on a 142 million control volume mesh.

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Conclusion

The dynamic interplay of aerodynamics and acoustics is a domain teeming with challenges and opportunities. As this guide has elucidated, simulating aeroacoustics is not merely about understanding the noise generated from fluid flows but is a key component in designing quieter, more efficient, and environmentally friendly technologies for the future.

From the foundational principles of aeroacoustics to the intricacies of simulation setup and post-processing, our journey through this guide underscores the importance of accurate, high-fidelity simulations in pushing the boundaries of what's achievable. With rapid advancements in computational methods, software tools, and high-performance computing platforms, the field of aeroacoustic simulation is set for transformative changes.

Moreover, as industries worldwide grapple with the challenges of sustainability, noise pollution, and efficiency, the role of engineers and the simulations they conduct will only grow in significance. Addressing the challenges, such as accurate validation and verification or the balance between computational cost and resolution, ensures that these simulations remain relevant and accurate.

On the horizon, we foresee a world where the insights realized from aeroacoustic simulations directly inform design choices, policy decisions, and urban planning. A world where technology harmoniously coexists with the environment, ensuring progress without compromise. Thank you for embarking on this journey with us. As you delve deeper into the world of aeroacoustics, may this guide serve as a compass, helping you navigate the complexities and marvel at the possibilities.

Want to Learn More?

Are you considering utilizing CharLES for your aeroacoustic simulations? We welcome you to reach out to Cadence for any additional information you may need. Don't hesitate to explore our product demo through the link below for firsthand experience and insights. Our experts are also ready to assist you with detailed answers to all your queries.

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